# SMART MONITORING OF SEWAGE INFRASTRUCTURE TO ALLEVIATE ENVIRONMENTAL POLLUTION

**by**

**MUSAWENKOSI NDLOVU**

**Thesis submitted in fulfilment of the requirements for the degree**

**Master of Engineering: Electrical Engineering**

**in the Faculty of Engineering and the Built Environment**

**at the Cape Peninsula University of Technology**

**Supervisor: Dr. C Kriger**

**Bellville**

**22 February 2024**

## DECLARATION

I, Musawenkosi Ndlovu, declare that the contents of this thesis represent my own unaided work, and that the thesis has not previously been submitted for academic examination towards any qualification. Furthermore, it represents my own opinions and not necessarily those of the Cape Peninsula University of Technology.

**Signed** **Date** 22 February 2024

## ABSTRACT

The problem of environmental pollution resulting from sewage spillage is a significant concern in South Africa, a country with aging infrastructure. Municipalities, particularly local municipalities located in rural and semi-rural areas, are tasked with the collection and treatment of household sewage. Manual monitoring methods currently in use are labour-intensive, prone to inaccuracies, and lack real-time data capabilities. This study investigates the feasibility of deploying intelligent monitoring technology to address sewage-related pollution issues. The proposed intelligence involves the utilization of sensors capable of real-time data collection and feedback, aimed at preventing sewage spillage and addressing it promptly. The research is conducted within a local municipality in semi-rural South Africa, serving as a worst-case scenario with findings applicable to more developed regions within the country. The envisioned system leverages advanced technologies and adheres to IEEE standards such as IEEE 1451 for sensor interoperability and IEEE 802.11 for wireless communication. Its primary objectives are real-time monitoring, early pollution detection, and rapid intervention to prevent sewage spillage. A comprehensive literature review highlights the shortcomings of manual sewage monitoring and explores the potential of smart sensors and data-driven solutions in mitigating sewage pollution. The research involves the development of monitoring models and data analytics using MATLAB, with a specific focus on the pump station and sump section of the sewer network. The implementation of this smart sensor and data-driven sewage monitoring system enhances resource allocation efficiency, enables targeted maintenance, and ensures timely responses. The integration of electrical and automation technologies further enhances the reliability, accuracy, and scalability of sewage monitoring operations. The study's findings contribute to the formulation of effective pollution management strategies, inform policy-making decisions, and provide guidance for the implementation of smart monitoring systems in municipalities. These outcomes contribute to sustainable development efforts and a cleaner, healthier environment in South Africa, offering a transferable solution applicable to regions worldwide facing similar challenges.



Keywords: Environmental pollution, Sewer spillage, Smart sensors, monitoring data, IEEE standards, Real-time monitoring, Early pollution detection, Ndlambe Local Municipality

## ACKNOWLEDGEMENT

I wish to thank:

- My Lord Jesus Christ, my Saviour and King, for granting me the invaluable opportunity to embark on my academic journey in a world where such privileges are not accessible to all. It is through His boundless grace that I have reached this significant milestone.
- My husband, Mholi, whose unwavering encouragement and inspiration compelled me to elevate my qualifications and pursue this research. His prayers and unwavering support have been instrumental in carrying me through this arduous journey. I am also grateful to my two boys and baby girl, whose unwavering cheers and understanding during times when I was unable to devote time to them due to the demands of work and research, have meant the world to me.
- My parents whose diligent efforts in shaping my academic foundation and nurturing my career aspirations have been invaluable.
- My siblings and my in-laws for the moral support.
- Ndlambe Local Municipality Management, particularly the Municipal Manager, Adv. R Dumezweni, the CFO, Mr. M Klaas, and the Director of Infrastructure, Dr. N Vithi-Masiza, for granting me access to their intellectual property and data for the purpose of my research.
- Herman Smit, my former business partner, for introducing me to the water industry and empowering me to grow. It is through his exceptional leadership that I have found inspiration for my academic and career endeavors. This research stands as a testament to the seeds he planted.
- My mentor, Mr. Ayodele, I am profoundly grateful for your unwavering support and invaluable guidance. Your mentorship has kept me grounded and focused throughout this journey.
- My industry mentors, Mr. L.v.Z Smit and Oom Koos, for their patience in mentoring me and providing invaluable insights into the water and wastewater industry. Your contributions have been instrumental in shaping my understanding and growth.
- Blessing, Skhu and Dr. S Mabusa-Ndlovu, I celebrate and express deep gratitude for your unwavering support and contributions throughout this journey.

- My Supervisor, Dr. Kriger. This thesis would not have reached its current state without the unwavering support of his constant availability and exceptional commitment to assisting me have surpassed all expectations. His professionalism and expertise have left an indelible positive impact on my life.

## ABBREVIATIONS AND ACRONYMS

Supervisory Control and Data Acquisition: A process control system that enables a system operator to monitor and control processes distributed among various remote sites.

SCADA A process control system that enables a system operator to monitor and control processes distributed along various remote sites.

| | | |
|---|---|---|
| SCADA | - | Supervisory Control and Data Acquisition |
| VT | - | Voltage Transformer |
| A/D | - | Analogue to Digital |
| HMI | - | Human Machine Interface |
| WTW | - | Water Treatment Works |
| WWTW | - | Wastewater Treatment Works |
| PLC | - | Programmable Logic Controller |
| IEEE | - | Institute of Electrical and Electronics Engineers |
| FC | - | Function Call |
| FB | - | Function Block |
| DB | - | Data Block |
| PID | - | Proportional Integral Derivative |
| WISA | - | Water Institute of Southern Africa |

**CONTENTS**

## Table of Figures

## Tables

# CHAPTER 1

## 1. BACKGROUND OF THE STUDY

### 1.1. Introduction

Sewer environmental pollution is a major global challenge that affects the health and well-being of both human populations and wildlife. In South Africa, environmental pollution is a major concern, with sewage infrastructure being one of the primary sources of water pollution. Poorly maintained sewage infrastructure, inadequate treatment facilities, and limited monitoring systems have resulted in severe environmental pollution in many parts of the country.

The lack of efficient and effective monitoring systems for sewage infrastructure in South Africa has contributed to the ongoing problem of environmental pollution. The current manual methods of monitoring are time-consuming, prone to errors, and do not provide real-time information. As a result, it is difficult to identify and mitigate sources of pollution in a timely and efficient manner. According to National Library of Medicine in 2001 close to 14000 people contracted cholera and more than 50 have died in the South African province of KwaZulu-Natal (Sidley, 2001). In 2023 UNICEF and UN in South Africa scaled-up health, water and sanitation and lifesaving communication on cholera outbreak response in most affected areas. The South African Department of Health confirmed on 26 June 2023 that the number of cholera-related deaths sat at 43 since the 2023 Gauteng cholera outbreak. According to the department, South Africa recorded 1 045 suspected cases of cholera in 15 out of 52 districts across five provinces, 197 of which were laboratory-confirmed. In all recorded cases, the spillage of raw wastewater resulted in people contracting cholera.

In South Africa, the National Water Act of 1998 and the Water Services Act of 1997 stipulates the legal mandate for municipalities for the removal and sanitation of wastewater. These acts provide the legislative framework for water and sanitation services in the country.

- National Water Act of 1998: This act is the overarching legislation that governs water resources management in South Africa. Section 9 of the National Water Act stipulates that the Minister of Water and Sanitation may assign the responsibility for water services, including sanitation, to water service authorities, which are typically municipalities.
- Water Services Act of 1997: This act specifically deals with water services and sanitation. It establishes the legal framework for the provision of water services by municipalities and other service providers. Section 10 of the Water Services Act designates municipalities as water services authorities responsible for ensuring the

provision of water and sanitation services within their areas of jurisdiction.

Most municipalities in South Africa are local municipalities. There were 205 local municipalities, and they are responsible for providing basic municipal services and functions to their communities. There are eight metropolitan municipalities in South Africa. These are large urban areas that have both municipal and provincial functions. They include cities like Johannesburg, Cape Town, Durban, and others. In turn, there are 44 district municipalities. District municipalities are responsible for providing certain services and coordinating local municipalities within their geographic areas.

Water plays an integral part in the ecosystem. Consistent and pro-active monitoring of wastewater is critical to alleviate contamination of clean water and the environment. Pollution of natural water sources has become prevalent. The physical and chemical composition of natural water sources has deteriorated over the years. Access to clean drinking water and sanitation is a basic human right according to Office of the High Commissioner for Human Rights, (OHCHR, 2010) and there must be smarter ways to monitor sewage infrastructure to alleviate environmental pollution.

One of the most alarming challenges surfaced because of a flaw in the treatment system design coupled with Combined Sewage Overflow (CSO). During periods of heavy rainfall, storm water and wastewater flow through the same pipe due to the design of the citywide systems. The bypass of the filthy water then overwhelms the plant of the sewage treatment and partially treated sewage, or raw sewage end up in oceans, lakes and rivers, (Mowbray, 2022).

A data-driven preventative maintenance and monitoring of these pumps and the network using smart means is proposed in this research work to ensure a pro-active approach is implemented. Studies in the Netherlands, Japan and the United States measure the extent and impact of sewage contamination in the environment. Further studies use artificial intelligence methods to test water quality in the sewer network, (United States Environmental Protection Agency, 2013).

There are however still many problems that are associated with sewage infrastructure. The use of smart technologies may assist to alleviate the environmental pollution. The use of automatic water quality-monitoring devices still support a reactive approach instead of a proactive approach. Furthermore, these studies do not focus on digging deeper to assist the maintenance teams in identifying the root cause for the spillage. They further lack the ability to assist the maintenance team to fault-find and give a precise location of where the potential sewage spillage is.

There seems to be a global crisis with sewage infrastructure globally. (River keeper, 2022) indicates that there is more than 27 billion gallons which equate to more than 102 million cubic meters of raw sewage and polluted storm water discharged out of 460 CSOs into New York Harbour annually. Also, there are about 860 United States municipalities including urban areas like Chicago and St. Louis where CSOs are of great concern. Where CSOs are counted in the tens of thousands, this problem of sewer infrastructure and environmental pollution is also felt in the European Union and Great Britain, (Mowbray, 2022).

Traditional means of monitoring sewage networks are based on physically visiting pump stations and physically locating burst pipes. The supplier of sewage pumps provide maintenance guideline schedules, which municipalities generally adopt. This approach has proven to be ineffective as these pumps operate in environments that are different to the test environment. This leads to premature pump failures and eventually overflowing of sumps causing environmental pollution. A data-driven sewage spillage preventative approach would be preferred noting the consequences because of sewage spillage to the environment and water sources.

Section 1.1 gave an overview of status of monitoring sewage pollution and gave insight into levels of contamination. Section 1.2 presents an awareness of the research problem, while Section 1.3 provides a statement of the research problem. Section 1. 4 details the research aim and objectives. This section is split into two with the Theoretical and Practical objectives stated. The research questions are contained in Section 1.5. Section 1.6 gives the hypothesis, and the delineation of research is contained in Section 1.7. The motivation for the research is presented in Section 1.8, while Section 1.9 shows the assumptions, and Section 1.10 presents the research methodology. Section 1.11 details a summary of the thesis chapters and Section 1.12 concludes this chapter.

### 1.2. Awareness of the research problem

With industrialisation hitting most part of the world, migration of people to big or small cities has increased exponentially over the years. This rapid growth has led to wastewater infrastructure straining coupled with aging. In addition, this infrastructure in most cased is not properly designed to meet the expanding urban population and is generally poorly maintained.

Despite acknowledging that investing may come in as a handy solution to address these challenges, an integrated and comprehensive water and wastewater management at municipal and national level with good sewage infrastructure may assist to alleviate the challenge of environmental pollution. This may cover water supply, disposal, treatment of wastewater as well as urban planning, (Corcoran et al., 2010).

The Department of Water and Sanitation of South Africa gazetted an incentive based system to rate the performance of Wastewater Management in Municipalities. This program is called Green Drop. Based on the Green Drop report released by the Department of Water and Sanitation, South Africa, 2022 only 2% of municipalities are compliant in terms of wastewater monitoring. Coupled with the dilapidating infrastructure and inadequate monitoring, sewage from South African cities is flowing to natural water sources including the ocean, (Water Institute of Southern Africa (WISA, 2022).

The Green Drop Progress Assessment Tool released by the Department of Water and Sanitation in 2023 highlighted a near collapse of the South African Wastewater System (Sanitation, 2023). This crisis has a direct impact on the natural water sources.

There are a variety of solutions to the environmental pollution. The environmental pollution also entails sewage and wastewater and from the various experts that were interviewed, two solutions stood out. These solutions are technology and changing the perceptions of the public (Mowbray, 2022).

This section detailed the awareness of the research problem. Based on this awareness the next section details the statement of the research problem. The statement of the research problem details a concise and clear description of the gap in knowledge regarding the employment of artificial intelligence and methods to monitor sewage infrastructure to alleviate environmental pollution.

### 1.3. Statement of the Research Problem

There is a challenge with conventional wastewater treatment systems as they are highly priced and centralised. These systems are also inadequate in addressing the urban growth pattern (Mowbray, 2022).

The problem of environmental pollution in South Africa is a major concern, and inadequate monitoring systems for sewage infrastructure are a significant contributor to this problem (Smith, 2018). The manual methods of monitoring sewage infrastructure that are currently used in South Africa are time-consuming and prone to human error, making it difficult to identify and mitigate sources of pollution in a timely and efficient manner (Chen and Zhang, 2019). This leads to several problems, including inadequate treatment facilities, a lack of real-time information, increased health risks, and economic costs associated with environmental pollution (Smith, 2018).

The implementation of smart monitoring technologies offers a promising solution to these issues, as they provide real-time information, that allow for early detection of potential sources of pollution and can help to reduce the risk of environmental pollution (Jain and Bhatia, 2017; Chatterjee and Mukherjee, 2019). Smart monitoring systems use advanced technologies, such as smart sensors to gather and analyse data, providing a more efficient and effective way of monitoring sewage infrastructure (Khandelwal and Agarwal, 2020).

The National Water and Sanitation Master Plan for South Africa was developed by the Department of Environmental Affairs (DEA) in recognition of the need for efficient and effective monitoring systems for sewage infrastructure (DEA, 2021). The United Nations Environment Programme (UNEP) and World Health Organization (WHO) have also noted the health impacts of environmental pollution in South Africa and the need for action to address this issue (UNEP, 2018; WHO, 2019).

This study aims to provide a framework for the implementation of effective and efficient monitoring systems for sewage infrastructure in South Africa, by investigating the potential of smart sensors and databased monitoring technologies. The results of this research work will contribute to the development of effective methods for monitoring sewage infrastructure, thus reducing the risk of environmental pollution, and improving the overall health and well-being of the South African population.

This section outlined the statement of the research problem. The next section details the research aim and objectives. In this section a broad statement is made describing the overall goal or purpose of this research study. It typically outlines the general intention of the research and the primary outcome that the study aims to achieve. On the other hand, the research objectives section outlines specific, measurable, and achievable goals that serve as steps towards achieving the research aim. These objectives are derived from the research question.

The researcher believes that a study on smart sewage monitoring system to alleviate environmental pollution and possibly implementing the smart sewage monitoring system may prove to be a permanent solution and that is a pro-active approach to prevent sewage spillage. Should spillage occur; a fault-finding option is to be investigated to improve corrective action response time.

## 1.4. Research Aim and Objectives

### 1.4.1. Research Aim

The purpose of this research is to use smart sensors to monitor sewage infrastructure to alleviate environmental pollution through sewage spillage with the sewer pump station as the focal point.

### 1.4.2. Objectives of the Research

#### 1.4.2.1. Theoretical Analysis

The objective of the theoretical study is to identify gaps in the existing monitoring technologies and suggest technology-based solutions to alleviate environmental pollution in South Africa with the sewer pump station as the focal point. The specific objectives of the theoretical objectives research are:

- To perform a thorough literature review in wastewater treatment reticulation systems to determine the current state.
- To identify how smart sensor technologies can assist to alleviate environmental pollution in the literature.
- To ascertain the measures that are in place with regards to monitoring of sewer infrastructure in the literature.
- To propose feasible strategies that help alleviate environmental pollution.
- To identify how sewer pump station level monitoring can assist alleviate environmental pollution.
- To identify how sewer infrastructure network pressure can be used to alleviate environmental pollution.

#### 1.4.2.2. Practical Real-Time Implementation

- To develop sensor based methods and software data analyses to monitor sewage pumps motor current and vibration.
- To validate and test the implemented solution by correlating the qualitative data

collected from a pump station, quantitative data and the theoretical findings.

- To develop a SCADA system for real-time system monitoring with alarm notification for the dispatch of maintenance teams.
- To implement a cloud-based database for storage of data, analysis and preventative maintenance scheduling.
- To implement the complete system in a pilot case study with one pumping stations at the Ndlambe Municipality.
- To design a smart sewer diversion pit for cases of pump failure and resultant sewage overflow, thus preventing environmental pollution.

Having established the research aim and objectives, the next section addresses the research questions. These research questions are specific, focused, and concise questions derived from the research objectives and aim to provide a clear and specific direction for this research study.

## 1.5. Research Questions

- What measures are in place with regards to monitoring of sewer infrastructure in municipalities?
- How can smart sensor monitoring of the pump motor current contribute to alleviating environmental pollution?
- How can smart sensor monitoring of the pump motor vibration contribute to alleviating environmental pollution?
- How can smart sensor monitoring of the sewer sump levels contribute to alleviating environmental pollution?
- How can monitoring the sewer network pressure alleviate environmental pollution?
- Can an automated system be designed to act as contingency during pump station downtime?

Having established the research questions, the next section is the hypothesis. In this study, the hypothesis is developed based on the research problem and the aim and objectives of the research.

## 1.6. Hypothesis

The following assumptions are considered during the conception, design and implementation of this project, and are based on the current state of research in this field.

- The hardware and software used to collect data is available in the market and complies with the relevant IEEE standards.
- The proposed system is used to monitor the pump motor vibration and current levels.
- The existing monitoring system uses the Global Positioning System (GPS) to locate each pump station and manholes to be used for this study.
- Only one pump station and adjacent network lines and manholes are to be monitored for the practical implementation.
- Siemens WinCC Supervisory Control and Data Acquisition System (SCADA) System to be used to display the data.
- The Municipality being studied has a functional and active incident management protocol and maintenance team.
- The Municipality being studied represents the typical local Municipalities in South Africa.
- Sewer pump stations have upstream solid waste screens.

With the hypothesis established in this section, the next section details the delineation of the research. This section refers to the boundaries or limitations of the study. In this section the researcher defines the scope of the research by specifying what is included and excluded, and by identifying any constraints or assumptions that impacts the study.

## 1.7. Delineation of Research

### 1.7.1. Within Scope

- Practical Implementation of sewer pump station motor current in one of the three pump stations studied
- Practical Implementation of sewer pump station motor vibration in one of the three pump stations studied
- Implementation of Data collection and feedback from the Ndlambe Local Municipality in South Africa
- Theoretical Analysis of vibration and current monitoring of the sewer sump of three

pump stations studied

- Theoretical Analysis of the sewer pump station network pressure monitoring
- Theoretical Analysis of the contingency smart sensor based solution for sewer spillage
- Theoretical Analysis of the sewer sump pressure monitoring

#### 1.7.2. Outside Scope

- Practical Implementation of the sewer pump station network pressure monitoring
- Practical Implementation of the temperature monitoring
- Practical Implementation of vibration and current monitoring in the two of three pump stations studied

Having delineated the research, the next section addresses the motivation of the research project. In this section the driving force behind the research is discussed while further providing a clear rationale for the study.

### 1.8. Motivation for the Research Project

In 2018 the researcher owned a business that used advanced technology water treatment systems (membrane technology). Emergency desalination plants had to be implemented in Cape Town in 2018 to alleviate day zero and the researcher's company was procured to design, install, commission, operate and maintain a 2 million litres a day desalination plant at the V&A Waterfront in Cape Town. The project ended up in court.( (News, 2018) In 2020, the researcher's company also got involved in an emergency 2 million litres a day desalination contract in the Eastern Cape, South Africa (Mavericks, 2023). The project also ended up in court (Thomson & Fenger, 2001). The golden thread in both projects was that during the commissioning and operation phase, huge volumes of raw sewage changed the design raw water quality by more than 400%. In both instances it was evident that the spillage of raw sewage to the Ocean had changed the ocean's typical seawater quality to 'soup' that is difficult to treat. The increased cost of producing water because of seawater contaminated by raw sewage became a bone of contention. Both cases have not been finalised nor resolved as at October 2023.

Desalination is an excellent method of augmenting traditional water sources; however, the rate at which the natural water sources are being contaminated with sewage has had a direct impact on the success of implementing desalination in South Africa. The sewage spillage over the years causes a complex water quality which is expensive to treat due to the chemically intensive means that is required. This research aims to assist municipalities to prevent this disaster by closely monitoring their systems to alleviate this contamination which has a direct impact on the availability of affordable drinking water for communities.

Having established the motivation for the research, the next section details the significance of the study. This section discusses the importance and relevance of the research being conducted. It further highlights the potential contributions that the research may make to the field, and the impact that it may have on theoretical studies at tertiary educational institutions, industrial practices, governmental policy and the health and wellness of people in society.

### 1.9. Significance of the study

The findings of this study have important implications for the South African government and other stakeholders responsible for monitoring and managing sewage infrastructure. By investigating the potential of smart monitoring technologies, this study aims to provide a framework for the implementation of effective and efficient monitoring systems for sewage infrastructure in South Africa. These systems would provide real-time information on the status of sewage infrastructure, allowing for timely identification and mitigation of sources of pollution. This study has the potential to significantly reduce environmental pollution in South Africa and improve the health and well-being of its population and wildlife.

With global warming, desalination is meant to play a critical role in building water resilient coastal towns. This research aims to establish a permanent solution for the government and the contractors by improving the quality of seawater making it treatable at affordable prices for drinking purposes. This study will further contribute to the existing body of published research on environmental pollution, sewer infrastructure and alleviation of environmental pollution in South Africa. The smart technologies to be implemented will benefit different municipalities and alleviate environmental pollution. Recommendations will make valuable contributions to sewer infrastructure and in the formulation of policies related to environmental pollution. The study also seeks to contribute to postgraduate students at universities identifying possible further research opportunities in this very important field.

This section discussed the significance of the study. The next section addresses assumptions made by the researcher. This section includes any assumptions or limitations that are relevant to the research design, data collection, and analysis.

### 1.10. Assumptions

The following assumptions are assumed in this research:

- That all municipalities have systems in place to monitor and control environmental pollution that is sewer related.

- That there are reticulated sewer systems
- That local municipalities rely on conventional ways of monitoring sewage infrastructure
- That local municipalities have waterborne sewer systems
- Sewer pump stations do not have duty/standby pumps (worst case scenario)

## 1.11. Thesis Chapters

There are seven chapters in this document as follows:

### 1.11.1. Chapter 1

The thesis begins with Chapter 1, where the reader is introduced to the research problem of environmental pollution caused by sewer spillage. The chapter provides an overview of the problem and highlights its significance in terms of environmental and health hazards in the Global and South African context. It also introduces the concept of smart sewage infrastructure monitoring as a potential solution to alleviate pollution. The research objectives, research questions, and the motivation behind the study are presented. The chapter also details the hypothesis, research questions and assumptions The chapter concludes by outlining the structure and organization of the thesis.

### 1.11.2. Chapter 2

In Chapter 2, an extensive literature review is conducted to explore current sewage infrastructure monitoring systems and their effectiveness in mitigating environmental pollution globally and in the South African context. The chapter examines various studies and research papers related to the topic, analysing the strengths and limitations of existing methods. Additionally, the review focuses on the incorporation of sewage infrastructure monitoring, highlighting the potential advantages and challenges associated with technology based systems. Relevant standards and research that incorporate smart monitoring of monitoring sewer network infrastructure are discussed to provide a comprehensive understanding of the field.

### 1.11.3. Chapter 3

Chapter 3 details the research methodology employed in the thesis. It describes the quantitative and qualitative data collection methods used to gather information on the current state of sewage infrastructure and pollution. The chapter elaborates on the electrical, electronic, and automation equipment utilized to collect data, ensuring the accuracy and reliability of the measurements. The research methodology establishes a solid foundation for analysing the collected data and drawing meaningful conclusions.

### 1.11.4. Chapter 4

Chapter 4 focuses on sewer pump station monitoring with smart sensors to prevent sewer spillage. It covers motor vibration, current, and sump level monitoring, bridging traditional and smart sensor-based methods. The chapter highlights the potential for data-driven decision-making in sewer infrastructure monitoring, emphasizing real-time analysis and anomaly detection. Smart sensors can predict motor failure, identify clogs, monitor environmental impacts, and estimate repair costs. Data analysis, using tools like MATLAB, informs the design of a smart diversion pit. The chapter concludes with a comprehensive one-month data analysis, enhancing our understanding of system behaviour.

### 1.11.5. Chapter 5

Chapter 5 offers a detailed exploration of the programming aspects using Siemens TIA Portal V16. This program is used for the practical implementation of motor vibration and motor current monitoring.

### 1.11.6. Chapter 6

In Chapter 6, the qualitative data collected from the community and the municipal staff is presented and analysed. The chapter explores the extent of the sewer spillage problem, assessing its impact on the environment and the effectiveness of current monitoring methods. The data collected through interviews, surveys, or observations is carefully examined to identify common themes, challenges, and opportunities for improvement. The integration of qualitative and quantitative data in this chapter enables a holistic view of the problem and its implications. This section further illustrates the comparison between existing sewer infrastructure monitoring compared to smart monitoring.

### 1.11.7. Chapter 7

The thesis concludes with Chapter 7, summarizing the key findings and contributions of the research. It highlights the implications of the study for future research and provides recommendations based on the research findings. Chapter 7 addresses sewage spillage pollution in South Africa and proposes using smart sensors for real-time monitoring in sewer pump stations. The study sets objectives, answers research questions, and validates hypotheses. It focuses on Ndlambe Municipality and offers significant recommendations for the government, emphasizing the importance of smart monitoring for pollution reduction and public health improvement.

### 1.12. Chapter summary

In conclusion, this chapter has provided a comprehensive introduction to the research, laying the foundation for the subsequent chapters. The chapter began by raising awareness of the research problem surrounding environmental pollution caused by sewer spillage. It then proceeded to articulate the statement of the research problem, establish the research aim and objectives, formulate research questions, and present the research hypothesis. Furthermore, the chapter delved into the delineation of the research, discussing its scope and boundaries, and explored the motivation behind undertaking this study. Assumptions are identified, and the chosen research methodology, encompassing both qualitative and quantitative approaches, is elucidated. Finally, the chapter concluded by providing a summary of the subsequent chapters, offering readers an overview of the document's content.

Chapter 2 delves into an extensive literature review, exploring current sewage infrastructure monitoring systems and their effectiveness in mitigating environmental pollution. The analysis of various studies examines strengths, limitations, and the integration of smart sensor monitoring. Emphasis is placed on the potential advantages and challenges of smart sensor-based systems, highlighting their role in enhancing monitoring capabilities. The incorporation of relevant IEEE standards and examination of research integrating smart sensor monitoring contribute to a comprehensive understanding. Serving as a critical foundation, Chapter 2 lays the groundwork for subsequent chapters, guiding the research methodology and the development of an advanced sewage infrastructure monitoring system to mitigate environmental pollution.

**CHAPTER 2**

# 2. LITERATURE REVIEW

## 2.1. Introduction

This chapter reviews and analyses the existing research, advancements, and knowledge on smart monitoring of sewage infrastructure. The various types of monitoring mechanisms are discussed. This chapter further describes the traditional and current methods employed by municipalities to monitor sewer infrastructure. These entail level, flow, pressure and water quality instruments amongst other methods.

This chapter is organised as follows:

- Sewer Infrastructure Overview (Section 2.2): Explore monitoring methods, address the impact of population growth on sewage systems, and highlight global challenges and solutions, including wastewater monitoring and the need for smarter infrastructure in the face of environmental issues and municipal challenges. This section further explores the benefits and elements of closed-loop systems for sewer infrastructure.
- Communication and Analytics (Section 2.3): Covers data communication through telemetry, real-time analysis via SCADA, and underscores the significance of data-supported infrastructure monitoring.
- Literature Review (Section 2.4): Focuses on monitoring components like pumps, sump levels, and sewer pipes, along with considerations of communication systems, system integration, user interfaces, and a graphical representation of research paper publications over time.
- Section 2.5 reviews smart monitoring for sewer systems, proposing solutions like IoT-enabled sensor networks and machine learning. The system architecture emphasizes real-time decision-making through sensors, telemetry, SCADA, and an HMI.
- Section 2.6 gives the Chapter Summary

## 2.2. Monitoring of Sewer Infrastructure

The Researcher further studies the effectiveness of the traditional methods without intelligence (open-loop) compared to the effectiveness when intelligence is added (closed-loop). Different analysers, controllers, meters, SCADA systems and sensors are studied and the role they play in improving effective monitoring of sewage systems. Findings from understanding the existing literature will assist the research formulation and conclusion. A review of work by other scholars assists in describing concepts with which the study engages and methods that have previously been used to study issues. The literature review assists in denoting the gaps in the field of study.

According to a study by (Zié Adama Ouattara, 2023) the degradation of urban sewage systems is acknowledged as a highly concerning issue in sub-Saharan Africa. Findings from this study reveal that various socio-environmental factors contribute to the increasing dysfunction of these urban sewage and drainage systems. Moreover, it has been noted that the adverse effects linked to the sewage overflow manifest in four aspects: air quality, water quality, soil, and business and infrastructure. Among these, the majority of research studies have predominantly addressed the influence of sewage overflow on groundwater quality (Titilayo A. Owolabi, 2022). The findings of this advanced review offer researchers and environmental engineers comprehensive insights for addressing this significant issue, ultimately leading to a substantial enhancement of both the environment and human well-being

Population growth is exponential, and its growth corresponds to the production of sewer waste. There is an urgent need for monitoring of the pumping stations and the sewage network as the sewer spillage pollutes the environment. The pressure on the sewage network and spillage in municipalities has exacerbated land contamination and even natural water sources like rivers and seas. This has presented problems of fresh water not being accessible, resources end up being unevenly distributed leading to a mismatched pattern on the human development. Scarcity of water results due to the environmental pollution challenges and that limits social and economic growth, (Narasimhan, 2008).

(Abdulrahman et al. 2012) also contends that population growth has spiked as city dwellers comprise of 50% of the world population. It is also projected that by 2050 there will be an increase of 70% of the current population and this translates to pressure on the sewage infrastructure as a basic urban area service. It is therefore of great importance that there be monitoring of the sewage systems to alleviate environmental pollution. Several scholars have echoed their sentiments on the issue of population growth which puts pressure on the sewage infrastructure. Population may result in wastewater which may contaminate streams, fresh water and even ponds. Without a proper monitoring system there could be ripple effects due to the strain on the ecology and reservoirs may deteriorate leading to an effect that is detrimental, (Mortazavi-Naeini et al., 2019).

Wastewater is transported in the sewage infrastructure. Wastewater refers to a mixture of any of the following: storm water usually from runways, grey water that consists of bathing and kitchen wastewater, water that is from establishments that are commercial like hospitals and industry sites. In addition to the list is black water which is effluent from faecal sludge, urine and excreta. This wastewater must be monitored using the sewage infrastructure so that it does not contaminate the environment like rivers, seas and reservoirs, (Raschid-Sally and Jayakody, 2008).

(Mowbray, 2022) asserts that the waste challenge is affecting the globe, and this impacts ecosystems, the climate, the coastal ecosystem and the health of humans. To combat this challenge aging sewer infrastructure must be replaced with smarter systems in the changing world with the advent of new technology. Communities may also be conscientised on the issue and technical experts need to be proactive in bringing solutions.

In low-income countries there is a concern of wastewater being released into the environment as they only treat 8% of industrial and domestic wastewater as compared to high income countries who treat about 70%. There are looming concerns that in many parts of the world contaminated water ends up in rivers, oceans and lakes thereby causing environmental pollution. It is projected that the volume of wastewater to be treated will rise greatly in the developing world, (UN World Water Development Report, 2017). In a report for the Municipal strategic self-assessment for 2019, it is stated that municipalities are having a crisis of wastewater and how to manage them, more so smaller municipalities. Some of these challenges are because of limited finances in the municipality, inexperienced technical staff which results in a water quality that is poor discharged into the environment. This has resulted in sewage contamination that is deadly in smaller towns and lately even in bigger towns and rural areas. The effects are devastating and are hazardous to human health as a result (Water Institute of Southern Africa, 2022).

A detailed literature review is conducted using the following keywords: Sewage infrastructure, Environmental pollution, Smart monitoring, Alleviation of Environmental pollution. The focus is on:

- Hardware devices including devices that measure and collect data, such as level sensors, flow monitors, pressure monitors, pump-run monitors and many more.
- Communications is another focal point that refers to networks which include wireless communications that migrate data from the hardware to the systems that perform the

analysis of the data.

- The data management is another aspect focused on and these include software tools and analytical solutions that provide information and data visualization to provide users with real-time information for decision-making (United States environmental protection Agency, 2021).

According to (Adnan Khalid, 2021), in modern municipalities, the underground sewerage system is vital, but continuous usage causes gradual deterioration, posing a risk of financial and environmental disasters. Early detection is crucial, and despite the effectiveness of CCTV inspection, it proves time-consuming for extensive networks.

The focus in this project is to consider ways of using smart sensors to existing sewer monitoring systems to ensure that a pro-active approach rather than a reactive approach is employed through using closed-loop systems. Sewer network infrastructure is monitored by Water Services Authorities (WSA) and Water Services Providers (WSP) to ensure that spillage does not occur which may pollute the environment. Information is gathered using different methods from physically walking the sewer network lines to using sensors, to start and stop pumps. Intelligent ways of collecting data includes the employment of Programmable Logic Controllers (PLCs) to collect data from sensors and present it in real-time for users to implement corrective action.

To achieve this the combination of the physical equipment (hardware), communication layer (automation and control), software and analytics make it convenient for end-users to act on information before spillage occurs. Smart infrastructure monitoring can be used to inform operational decisions that ultimately improve the efficiency, reliability and lifespan of physical assets (EPA guidance documents, 2022).


**Figure 2.1. Data Analytics (© Bentek Systems,2022)**

The infrastructure monitoring system depicted in Figure 2.1 consists of three essential layers: the management layer, the communication layer, and the physical layer. Each layer plays a crucial role in ensuring the efficient and effective operation of the monitoring system. The management layer serves as the central control unit of the infrastructure monitoring system. It is responsible for overseeing and coordinating the overall monitoring process. Within the management layer, data collected from various sensors and devices is analysed and processed to derive meaningful insights. This data analysis involves applying algorithms and statistical techniques to identify patterns, anomalies, and trends in the infrastructure's status. By utilizing advanced data visualization techniques, the management layer presents the analysed data in a pictorial or graphical format, making it easily interpretable for users and stakeholders. This visual representation allows users to quickly assess the current state of the infrastructure and identify any potential issues or areas requiring attention.

The communication layer facilitates the transmission of data and information between different components of the infrastructure monitoring system. It establishes the connectivity and communication channels that enable seamless data exchange. This layer employs various communication protocols and technologies to ensure reliable and secure transmission of data. It enables real-time feedback, allowing users to receive timely updates on the infrastructure's status. By providing instant notifications and alerts, the communication layer empowers users to take immediate corrective actions before a potential spillage incident occurs. This layer also supports bidirectional communication, enabling users to interact with the monitoring system, access historical data, and configure system settings.

The physical layer comprises the physical components and devices that are deployed within the infrastructure to collect data and monitor its condition. This layer includes sensors, actuators, data loggers, and other physical devices that are strategically installed to capture relevant information. Sensors measure various parameters such as water levels, flow rates, pressure, and temperature, providing real-time data on the infrastructure's performance. The physical layer ensures accurate and reliable data collection, forming the foundation for effective monitoring and analysis within the management layer.

Together, these three layers - the management layer, the communication layer, and the physical layer - form a cohesive infrastructure monitoring system. By integrating data analysis, visualization, real-time communication, and physical data collection, this system enables proactive management and decision-making, ultimately preventing spillage incidents and ensuring the efficient operation of the monitored infrastructure.

Figure 2.2 gives typical results of operational processes supported by information inputs. This figure illustrates the central role of data in enabling efficient and effective monitoring of infrastructure.


**Figure 2.2. Data supported infrastructure monitoring (Bentek Systems,2022)**

Data-supported infrastructure monitoring encompasses the collection, analysis, and utilization of various data sources to gain insights into the condition, performance, and behaviour of the monitored infrastructure. These data sources can include sensor measurements, historical records, real-time feeds, and external data feeds. By harnessing the power of data, stakeholders can obtain a comprehensive understanding of the infrastructure's status and make informed decisions.

Figure 2.2. showcases the flow of data within the infrastructure monitoring system. It begins with the collection of raw data from sensors deployed throughout the infrastructure. These sensors capture important parameters such as temperature, pressure, flow rates, vibrations, or other relevant variables. The collected data is then processed and analysed using advanced techniques such as statistical analysis, machine learning algorithms, or data fusion methods. Through this analysis, valuable insights are extracted from the data. These insights provide a deeper understanding of the infrastructure's behaviour, identify potential anomalies or issues, and enable predictive capabilities. With the aid of data-supported monitoring, stakeholders can anticipate and proactively address challenges, minimizing disruptions and optimizing maintenance efforts.

The utilization of data infrastructure monitoring leads to informed decision-making. Figure 2.2 illustrates how insights gained from data analysis inform stakeholders about the status of the infrastructure, highlight trends or patterns, and support decision-making processes. By leveraging data, stakeholders can make data-driven decisions to allocate resources effectively, optimize operational strategies, and implement preventive or corrective actions. Notifications also play a crucial role in data-supported infrastructure monitoring. Figure 2.2 shows how notifications are generated based on data analysis outcomes, signalling important events, abnormal conditions, or potential risks. These notifications are delivered through various communication channels, ensuring that stakeholders are promptly informed and can take immediate action if necessary.

Building on this notion, recent studies have explored innovative approaches to intelligent infrastructure solutions. For instance, Kumar et al. (2023) proposed a sewage cleaning and monitoring robot using IoT technology, showcasing the evolving landscape of advanced monitoring systems [1]. Additionally, H. S et al.'s (2023) work on an efficient sensory monitoring and bacteria detection system for contaminated water adds further depth to the integration of cutting-edge technologies in infrastructure monitoring [2]. These studies collectively contribute to the broader understanding of leveraging technology for enhanced infrastructure management.

### 2.2.1. Traditional Monitoring Methods (Open- loop)

Infrastructure monitoring has evolved over the years. Traditional ways of monitoring sewer network infrastructure are mainly open-loop systems. This method is used to start and stop the pumps and does not store or generate data to analyse should there be a fault condition arising (Fecarotta, Martino and Morani, 2019).

A typical open-loop schematic is presented in Figure 2.3. This method does not have an active and real-time user interface.

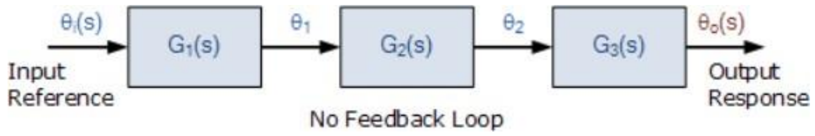



**Figure 2.3 Open-loop System. (Toulson and Wilmshurst, 2012)**

### 2.2.2. Sewer Pipe Monitoring

WSP and WSA rely on inspections and include man entry, flow isolation and use of closed-circuit television (CCTV). It should be noted that most inspection techniques depend on visual observation and subjective judgments. The location of potential defects may be missed or misinterpreted if the evaluator has not had adequate training (Stephenson and Barta, 2005). Today's drainage systems are not high-tech. Early alerts of the blockage are not received which makes detection and repairing of the blockage time consuming. Routine checking of sewer pipelines is not as effective as blockages usually happen on an emergency basis (Stephenson and Barta, 2005).

Figure 2.4 is a representation of a typical schematic view of current visual sewer inspection. This method is limited to the diameter of the sewer, type of pipe material used, and odd shapes and sumps built into the collection system.

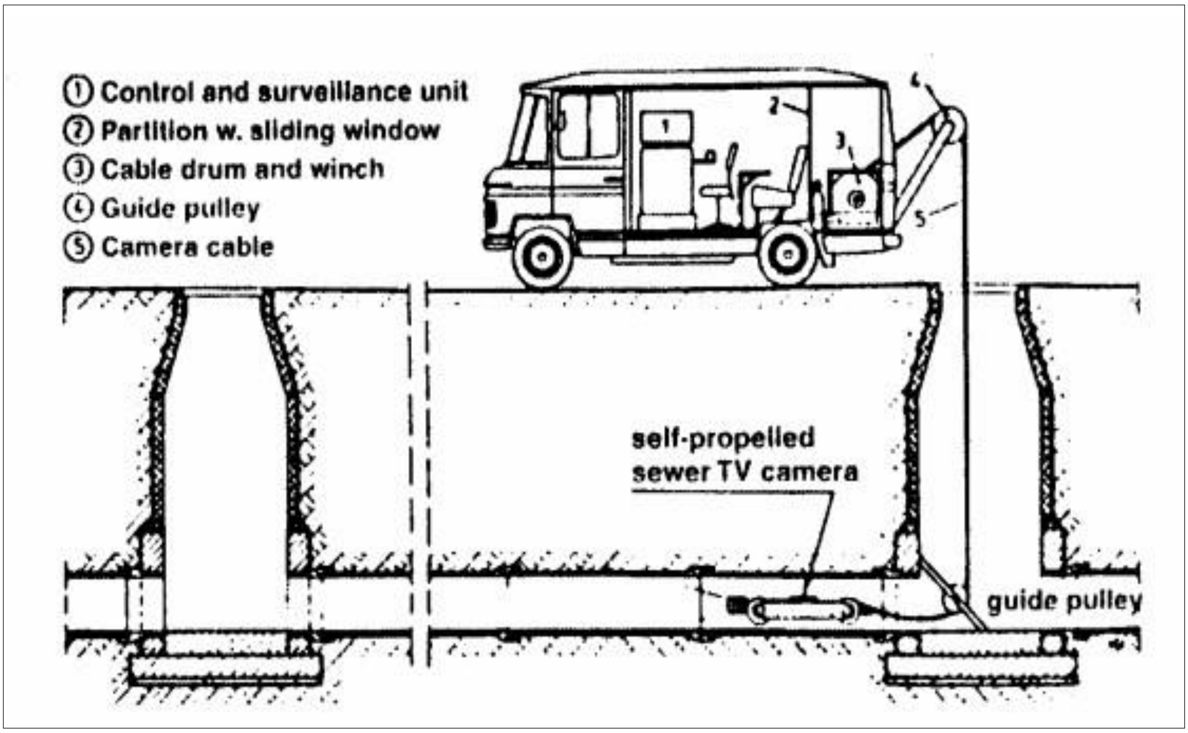



**Figure 2.4 Typical visual sewer inspection (Stephenson and Barta, 2005)**

Figure 2.4 provides a schematic view illustrating the current visual sewer inspection method commonly employed in sewer infrastructure assessment. This method relies on the use of specialized equipment and vehicles to visually inspect the condition of sewer pipes and identify potential issues or areas of concern. The image showcases a vehicle control and surveillance unit, which serves as the central hub for operating and controlling the inspection process. This unit is equipped with various components to facilitate the inspection, including a partition with a sliding door that separates the control area from the equipment area.

The inspection equipment consists of a cable drum and winch system, which is responsible for deploying and retracting the camera cable into the sewer pipes. The winch system ensures controlled movement and precise positioning of the camera within the sewer infrastructure. A guide pulley is integrated into the setup to guide the camera cable along the desired path within the sewer pipes, ensuring smooth and accurate navigation through the network. This pulley assists in manoeuvring the camera around bends, junctions, and obstacles encountered during the inspection process.

The camera cable, connected to the winch system, carries a self-propelled sewer TV camera. This camera is designed to capture high-resolution video footage and images of the interior of the sewer pipes. It is equipped with lights to illuminate the surroundings, allowing for clear visibility and detailed inspection of the pipe condition. Through the combination of the camera cable and the self-propelled sewer TV camera, operators can remotely visualize the interior of the sewer pipes in real-time. This visual inspection enables the identification of various issues such as cracks, leaks, blockages, or corrosion within the pipe network. It is important to note that this visual sewer inspection method has certain limitations. The effectiveness of the inspection is influenced by factors such as the diameter of the sewer pipes, the type of pipe material used, and the presence of irregular shapes or sumps in the collection system. These factors may impact the ability to thoroughly assess the entire sewer network using this visual method alone.

Figure 2.4 provides a representation of the key components involved in the visual sewer inspection process. This method serves as a valuable tool for conducting initial assessments, identifying potential problem areas, and gathering visual evidence to aid in maintenance and repair decisions for sewer infrastructure.

### 2.2.3. Sewer Pumps Monitoring

Many WSAs/WSPs in South Africa do not have a formal method for determining or predicting maintenance on infrastructure. Due to a lack of predictability infrastructure, maintenance costs increase exponentially over time. (Stephenson and Barta, 2005). This ultimately leads to a failure of infrastructure which result in sewage spilling over to the environment.

In Figure 2.5, the table illustrates the principle of regular maintenance against a no maintenance approach. This graph illustrates the comparison between a regular maintenance approach and a no maintenance approach in relation to the failure rate of infrastructure. This study, conducted by the Water Resource Commission in 2018, aimed to explore the benefits of adopting a predictive or data-driven maintenance strategy for infrastructure, with the goal of reducing infrastructure failures and minimizing maintenance costs over time.

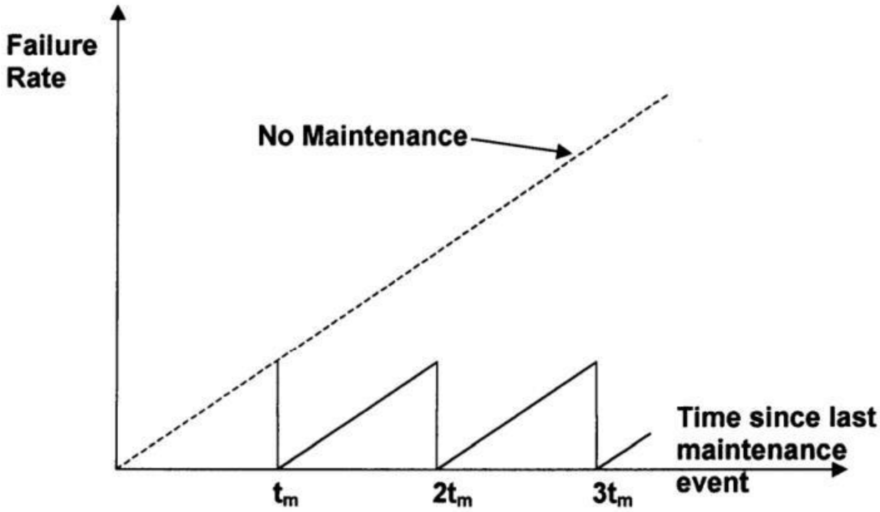



**Figure 2.5. Principle of No Maintenance Vs Regular Maintenance Approach (Water resource commission, 2018)**

The graph depicts the failure rate of the infrastructure on the vertical axis, while the horizontal axis represents the time since the last maintenance event. This study was done by the Water Research Commission, (2018). One of the outcomes of the study is to determine how predictive or data-driven maintenance of the infrastructure can assist in alleviating infrastructure failure and decrease maintenance costs over a period. Results are plotted against the graph below to determine the effect of adding intelligence to traditional ways of maintaining infrastructure. The graph follows a zigzag pattern along the horizontal line, indicating the fluctuating failure rate over time under different maintenance approaches. The principle of the no maintenance approach, represented by the lower line on the graph, suggests that without regular maintenance, the failure rate of the infrastructure gradually increases over time. This is depicted by the upward trend of the line as time progresses. Without proactive maintenance interventions, infrastructure components are more prone to wear and deterioration, leading to a higher probability of failures occurring.

In contrast, the principle of the regular maintenance approach, represented by the upper line on the graph, demonstrates that by implementing scheduled and proactive maintenance activities, the failure rate of the infrastructure are effectively managed. This is evident from the relatively flat or downward trend of the line, indicating a lower failure rate over time. The graph serves to highlight the significance of regular maintenance in preventing infrastructure failures and minimizing associated risks and costs. It showcases the advantages of adopting a data-driven or predictive maintenance approach, where maintenance activities are strategically planned based on real-time data and insights. By leveraging intelligence and advanced analytics, maintenance activities are targeted to address specific areas of concern, preventing potential failures and optimizing the lifespan of the infrastructure.

The study conducted by the Water Research Commission aims to emphasize the importance of incorporating intelligence and data-driven decision-making into traditional maintenance practices. By doing so, infrastructure owners and operators can make informed decisions regarding maintenance intervals, prioritize critical assets, and allocate resources effectively. Ultimately, the goal is to reduce infrastructure failures, enhance operational efficiency, and achieve long-term cost savings.

### 2.2.4. Closed-loop based sewer infrastructure monitoring

Closed-loop systems have feedback that is presented to the user interface. The user interface informs the user when there is a malfunction or potential malfunction in real time. The feedback signal is compared with the required input reference and allows the system to adjust itself (with a controller providing corrective action) in such a way that the desired output follows the required input. Figure 2.6 is a schematic of a typical closed-loop system. The explanation on what is contained in the figure is elaborated on below the figure.

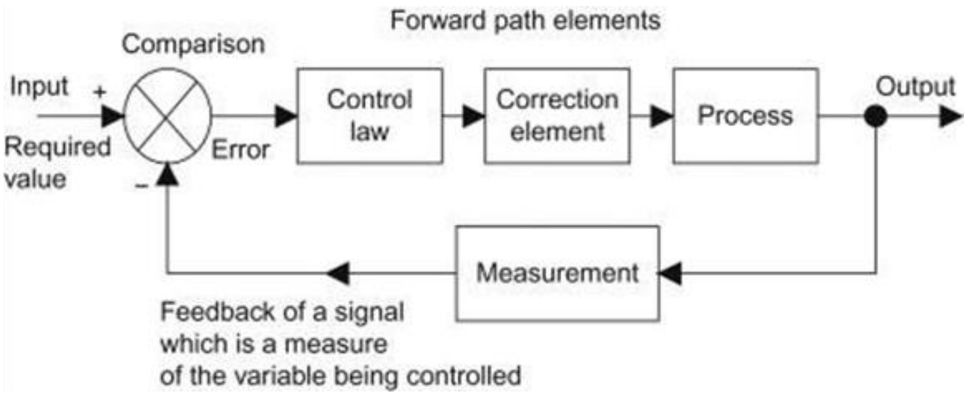



**Figure 2.6. User Feedback System Architecture (Chandrakana et al, 2015)**

Computer vision algorithms with on-board processing are not efficiently utilized. There are no robust algorithms and robotic systems available for real-time detection to date. This finding bares testament to the fact that intelligent ways of monitoring sewer systems through data-driven prediction could be a possible solution to the challenge of reactive responses to sewer spillage ( Ravindra, Saniya, Rajnish and Mohamad, 2021). The basic elements of a closed-loop control system are:

Comparison element: This element produces an error signal by comparing the required value of the variable being controlled with the measured value.

$$Error = Required\,Value\,Signal - Measured\,Actual\,Value\,Signal$$

When there is a difference between the actual value and the required value, an error signal is generated, and a control action is initiated. However, when the output is the same as the required value, there is no error signal generated.

- Control law implementation element: This determines the corrective action to be taken when an error signal is received. This may be to supply a signal that switches on or off when there is an error based on the size of the error.
- Correction element (Actuator): This is also called the final control element. It produces a change in the process which aims to correct or change the controlled condition. This element provides the power to carry out the control action.
- Process: This is the system in which there is a variable that is being controlled.
- Measurement element: This element produces a signal related to the variable condition of the process that is being controlled.

Terms used to describe the various signal paths through the system:

- Feedback path- When a signal related to the actual condition being achieved is fed back to modify the input signal to a process.
- Forward path- Used for the path from the error signal to the output through the process element.

### 2.3. Communication and Data Analytics

Data collected by the hardware is communicated via the telemetry system. This data gets processed at the SCADA system via the human interface. The Supervisory Control and Data Acquisition gathers data in real-time from remote locations to control equipment and conditions. The data is then analysed and displayed on the Human Machine Interface as a graph, image, alarm, etc. triggering real time decision-making for process operators. The image below shows a typical remote monitoring system based on smart technology.

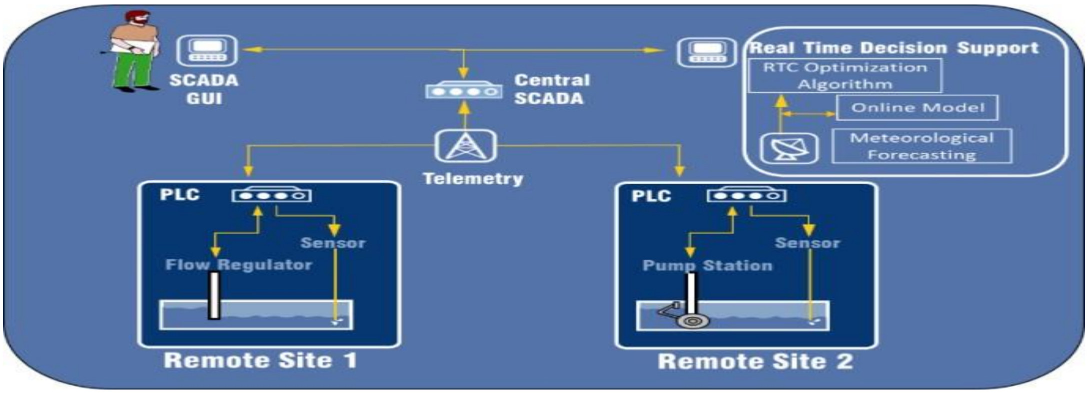



**Figure 2.7. Typical smart infrastructure monitoring system (Bentek Systems,2022)**

Figure 2.7 provides an overview of a typical remote monitoring system that utilizes smart technology. The system consists of various components that work together to collect, process, and analyse data for real-time decision-making and control. At the core of the system are the sensors, which are responsible for capturing data from the monitored environment. These sensors could measure various parameters such as temperature, pressure, flow rate, or any other relevant variables depending on the specific application.

The data collected by the sensors is then transmitted to the central SCADA (Supervisory Control and Data Acquisition) system through the telemetry system. Telemetry enables the wireless or remote transmission of data from the field to the central monitoring system. This ensures that data is acquired from remote locations and sent to the SCADA system for further processing. Once the data reaches the central SCADA system, it undergoes processing and analysis. The SCADA system's human interface, also known as the SCADA GUI (Graphical User Interface), allows operators to interact with the system and visualize the data in various formats such as graphs, images, or alarms. The SCADA GUI provides a user-friendly interface for operators to monitor the system's status, identify anomalies, and make real-time decisions based on the available data.

To enhance the decision-making process, the SCADA system may incorporate real-time decision support tools. These tools can include RTC (Real-Time Control) optimization algorithms or online models that leverage the collected data to provide insights and recommendations for optimizing system performance. These decision support tools can assist operators in adjusting process parameters, implementing control strategies, or initiating appropriate actions based on the real-time data and system conditions. This system enables the collection, transmission, processing, and analysis of data from various sensors in real-time. The system's central SCADA system acts as a central hub for data management, visualization, and decision-making, providing operators with the necessary tools and information to monitor and control the monitored processes effectively. The combination of smart technology, sensors, telemetry, and the SCADA GUI facilitates efficient and proactive monitoring and control of systems, contributing to improved operational performance and decision-making in various industrial applications.

This section provides a comprehensive review and analysis of existing research on smart monitoring of sewage infrastructure. It discusses various types of monitoring mechanisms and traditional methods used by municipalities. The section also includes a literature review, a discussion of closed-loop sewer systems, a comparative analysis of existing literature, and an outline of the system architecture. It emphasizes the need for monitoring due to the environmental pollution caused by sewer spillage and the pressure on sewage infrastructure due to population growth. The section also highlights the importance of data-supported infrastructure monitoring and the role of hardware devices, communications, and data management in effective monitoring. Additionally, it explores traditional monitoring methods without feedback, sewer pipe monitoring, and sewer pump monitoring. The section concludes by highlighting the limitations of visual inspection methods and the lack of predictability in infrastructure maintenance. Overall, the section provides a comprehensive overview of the current state of research on smart monitoring of sewage infrastructure and identifies gaps in knowledge and areas for further investigation. Section 2.4 is next and shall give a literature review of existing papers on sewer infrastructure monitoring.

### 2.4. Literature Review of existing papers on sewer infrastructure monitoring

The literature review on sewer network infrastructure monitoring focuses on three key aspects: monitoring pumps, sump levels, and sewer pipes. This indicates a comprehensive investigation into different components of the sewer system to ensure efficient and reliable operation. By examining these specific areas, researchers aim to develop better monitoring methods that can enhance the overall performance and management of sewer networks.

Additionally, the literature review extends beyond the technical aspects of monitoring to explore other critical considerations. It includes a review of available communications, system integration, and user interfaces for real-time decision-making. This broader perspective highlights the importance of not only collecting data but also effectively communicating and utilizing that data to make informed decisions in real-time. By examining the communication systems, system integration approaches, and user interfaces, researchers seek to create a holistic framework for efficient monitoring and decision-making processes in sewer infrastructure management.

Figure 2.8 presents a graphical representation of the number of research papers published each year on smart infrastructure monitoring. The selected papers are chosen to demonstrate the evolution and progress of infrastructure monitoring technology over a span of 21 years, from 2000 to 2021. These papers are categorized into three specific groups: sewer pump infrastructure monitoring, sewer sump levels monitoring, and sewer pipeline monitoring. By grouping the papers based on these categories, the authors provide a structured analysis of the research landscape in sewer infrastructure monitoring, allowing for a deeper understanding of the advancements in each specific area.

To generate the graph, the researchers compiled a dataset of relevant papers by conducting a systematic search using keywords such as "sewage infrastructure," "environmental pollution," "smart monitoring," and "alleviation of environmental pollution." This approach ensures that the dataset encompasses papers that directly relate to sewer network infrastructure monitoring and its environmental implications.

The analysis of the graph reveals an interesting trend. From 2004 to 2022, there has been a consistent and gradual increase in the number of published research papers. This gradual growth indicates a sustained interest and ongoing research efforts in the field of sewer network infrastructure monitoring. However, what stands out is the abnormal spike observed in 2006. This sudden surge in research activity suggests a distinct turning point or catalyst that sparked an increased interest in sewer infrastructure monitoring during that year. The researcher speculates that the abnormal spike in 2006 could be attributed to a sudden interest in infrastructure. This speculation implies that there might have been a specific event, technological breakthrough, policy change, or influential research paper that triggered a notable surge in research activity. Further investigation and analysis would be necessary to identify the precise reasons behind this anomaly and determine the factors that contributed to the sudden surge in research publications during that particular year.

Overall, the combination of focused research areas, consideration of communication and decision-making aspects, and the graphical representation of publication trends provides valuable insights into the field of sewer network infrastructure monitoring and its evolution over time.

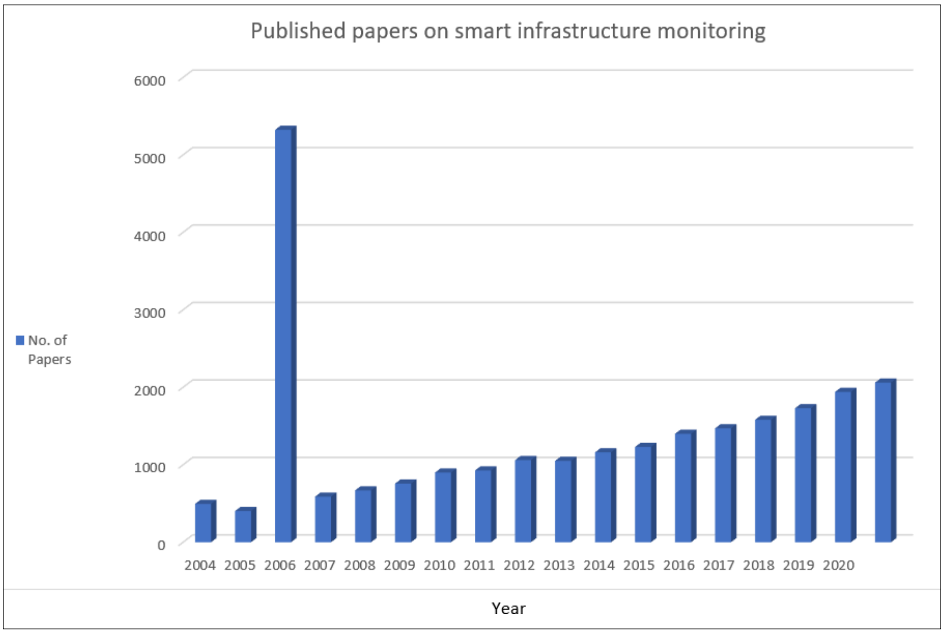



**Figure 2.8 Published papers on smart infrastructure monitoring**

**Table 2.1 Reviewed Papers on Smart Monitoring of Sewage Infrastructure**

| Paper (Reference) | Aim of the project | System Overview | Hardware/Software Required | Author's Conclusions |
|---|---|---|---|---|
| Review of the State-of-the-art Sewer Monitoring and Maintenance Systems Pune Municipal Corporation - A Case Study. (Ravindra et al., 2021) | The review highlights the available methodologies that is utilized in developing sewer inspection and cleaning robotic systems.<br>This paper reviews the existing robotic systems and various platforms and algorithms along with their capabilities and limitations being discussed. | Use of smart technology in sewer pipeline inspection. | Robotic systems and various platforms and algorithms | Results from this review revealed that computer vision algorithms with on-board processing are not efficiently utilized. It further pointed out that smart technologies are not effectively used to monitor sewer pipelines thus leaving a gap for studies |
| Smart Data Infrastructure for Wet Weather Control and Decision Support<br>(US environmental Protection Agency, 2021) | This document was originally developed in August 2018 to share how municipalities, utilities, and related organizations can use advanced technologies and monitoring data to support both wet weather control and decision-making in real time or near real time | Remote monitoring of sewer overflows, sanitary sewer overflows, sewer backups, street flooding, and stormwater discharges. | RTC Systems, SCADA and RTDSS systems including pressure, flow and level sensors | Results revealed that using smart technologies to monitor sewer infrastructure made a positive contribution to the operational team and assisted with decision-making systems. |
| Stochastic Contracts for Runtime Checking of Component-based Real-time Systems(Chandrakana et al., 2015) | This paper presents a technique for dynamic verification of component-based real-time systems based on statistical inference. | Statistical inference based approach for computing real-time contracts for component-based real-time control applications | C++ programming language | It was established that a data- based real-time control is possible. |

| Paper (Reference) | Aim of the project | System Overview | Hardware/Software Required | Author's Conclusions |
|---|---|---|---|---|
| Manhole Detection and Monitoring System (Ruheena et al, 2021). | Establishing and implementing IoT based real time system that alerts management when manhole movement is detected. An underground drainage monitoring system was designed to curb slow handling of problems in drainage and improve corrective action turnaround time | Design space of wireless sensor networks, Wireless Communications towards the Implementation of IoT for Environmental Condition Monitoring in homes | Arduino Uno: ATmega328P powered by the USB.<br>DHT 11 (temperature and humidity sensor).<br>LCD (liquid crystal display). | Real time update on the Internet helps in maintaining the regularity in drainage check thus avoiding the hazards.<br>This empowers the user to take appropriate action. |
| Wastewater Pump Control under Mechanical Wear (Fecarotta et al, 2021). | This paper aims to evaluate the time decay of pump performances to determine mechanical wear and energy savings. | The pump test was carried out according to the ISO9906 standard regulation which describes the methodology to lead a lab test for the measurement of the steady performance of a pump | Mathematical model has been solved by the Basic Open-Source Nonlinear Mixed Integer Programming (BONMIN) | Results show that plant efficiency is strongly affected by mechanical wear. An accurate pump maintenance was recommended to prevent the reduction of machine efficiency. |
| Guidelines on reduction of the impact of water infiltration into sewers (Stephenson and Barta, 2005). | To build an awareness and insight into the issues inherent to municipal waterborne sanitation systems with specific emphasis on extraneous flows (i.e., inflow and infiltration events)<br><br>To consolidate past and present South African design standards and criteria in respect to the changes in recently promulgated water legislation and environmental conservation laws. | Quantitative risk analysis<br>Risk assessment for a sewer system<br>Estimation of probability and frequency in qualitative risk analysis<br>Quantifying the risk costs of sewer pipe failure. | N/A | To evaluate and predict future reliability of a water services system (or its subsystems) requires investigating the system complexity, management practices, maintenance programme and costs. |

| Paper (Reference) | Aim of the project | System Overview | Hardware/Software Required | Author's Conclusions |
|---|---|---|---|---|
| Monitoring the Hydraulic Performance of Sewers Using Fibre Optic Distributed Temperature Sensing (Kechavarzi, et al., 2020). | Fibre optic distributed temperature sensing (DTS) is used to monitor the discharge of wastewater for three months to assess the performance of a long underground foul sewer. | This paper presents the monitoring results of a DTS study carried out in a foul sewer in the UK during a period of over three months, from 23 March 2015 until to 1 July 2015. | DTS cables for data collection.<br>The analyser used in this study was a Halo DTS manufactured by Sensornet Ltd | The need for better monitoring methods in the sewer system is evident from the literature.<br>DTS captures temperature abnormality very well and is capable of being a standalone surveying system in future installation. |
| An Acoustic Sensor for Combined Sewer Overflow (CSO) Screen Condition Monitoring in a Drainage Infrastructure (Horoshenkov et al., 2021). | This paper presents the results of a feasibility study using low-cost, low-energy acoustic sensors to remotely assess the condition of CSO screens to move to cost-effective reactive maintenance visits.<br>To monitor the conditions of the inlet and outlet pipes of the CSO, several pipe inspection methods have had either destructive or non-destructive testing approaches | -The ultrasonic water level sensor monitors the water levels to inform the operator of the frequency of spill incidents.<br>-The fibre optic sensor is used to detect the changes of humidity and temperature.<br>-Acoustic measurement system | ATEX-certified explosion- proof box (EExd) manufactured by JCE Europe (EJB3A certification number CESIATEX004U)<br>Microphones, speaker, temperature sensor and data acquisition unit.<br>The speaker is connected to a power amplifier and a low-pass filter (LPF) with a cut-off frequency of 1000 Hz.<br>Zener diode barriers are used for safety | The speed of the acoustic measurements (a few seconds) and sensor's ability to quantify the screen condition remotely have the potential to be at least two orders of magnitude less costly than traditional site visit and visual inspection methods. |
| A large-scale experimentation of the smart sewage system<br>(Rjeily et al., 2017). | The paper shows how the smart technology could be implemented and used to enhance our understanding of the sewage system and to improve its management | Data collection and analysis:<br>-Turbidity sensor<br>-Wastewater flow pattern<br>-Detection of abnormal events. | Sensors Data logger Radio Communication System | Access to data concerning both the sewage and drinking water systems allows the use of numerical modelling and the detection of operating faults. Analysis of this data allowed an enhanced understanding of the wastewater system |

| Paper (Reference) | Aim of the project | System Overview | Hardware/Software are Required | Author's Conclusions |
|---|---|---|---|---|
| Innovative sewage solutions: Tackling the global human waste problem (Mowbray, 2022). | Tackling the global human waste problem | A combination of green and grey infrastructure is required to tackle the global human waste problem. | N/A (Information Purposes) | Decentralized nature-based solutions can greatly reduce wastewater pollution, effectively removing pollutants including nitrogen and phosphorus, pathogens, and pesticides, and can complement existing treatment infrastructure. |
| Smart Cities: Survey (Alkandari,et al., 2012). | Establish availability of smart cities that link infrastructure, water, people together | To establish availability of smart cities which are mainly identified by the presence of Communication Technology (ICT) and Wireless Sensor Networks (WSNs) | N/A | The result of this research shows that the Information Communication Technology (ICT) covers all areas of smart cities such as government facilities, buildings, traffic, electricity, health, water, and transport. Until now there is no unique definition for smart cities, as most researchers define the smart city from their needs or personal perspective. |
| Internet of things for secure surveillance for sewage wastewater treatment systems (Kumar and Hong, 2022). | Monitoring the disposal of sewage in the treatment plants. | Use of Surveillance-based Sewage Wastewater Monitoring System (SSWMS) with IoT for monitoring wastewater treatment and improving water quality | Smart water sensor<br>IoT monitors water quality, water pressure water temperature sensor | The experimental results show feedback raised wastewater levels to 97.98%, enhancing secure communication and less moisture content when compared to other methods. |

| Paper (Reference) | Aim of the project | System Overview | Hardware/Software Required | Author’s Conclusions |
|---|---|---|---|---|
| Waterborne Sanitation Design Guide. Water Research Commission South Africa. (Van Vuuren et al., 2011). | This report emanates from a project entitled: Development of a South African Guide for the Design and Operation of Waterborne Sewerage Systems (WRC Project No. K5/1744).<br>The objective of the report is to provide a concise guide for the analysis and design of waterborne sanitation systems. | Conventional gravity sewer<br>Vacuum sewer systems<br>Small-bore sewer<br>Simplified sewerage | SewerAID | To streamline the planning and design process in South Africa a three- tier philosophy is proposed for sewage collection system planning and design. As described by Jacobs and Van Dijk (2009) the philosophy used originates from the field of transport engineering where three different ‘solution levels for design procedures’ are documented in the South African Code of Practice for the Design of Highway Bridges and Culverts (Department of Transport, TMH 7). Adopting this concept for the planning and design of sewage collection systems leads to three technical tiers. This three-tiered philosophy could be used as a basis to derive a best management practice for sewer system planning and design. |
| Green Drop National Report 2022 (Department of Water and Sanitation South Africa, 2022) | The Green Drop programme seeks to induce changes in behaviour of individuals and institutions to facilitate continuous improvement and adoption of best practice management of wastewater networks and treatment systems | The Green Drop 2022 report provides comparative analyses and diagnostics to assist Water Services Institutions (WSIs) to focus on specific areas for improvement and restoring functionality of wastewater infrastructure. | N/A | 2% of municipalities in South Africa are Green Drop compliant. Sewage spillages and failing wastewater treatment works are detrimentally impacting our environment as well as the livelihood and health of many of our communities daily in the year 2022 |

| Paper (Reference) | Aim of the project | System Overview | Hardware/ Software Required | Author's Conclusions |
|---|---|---|---|---|
| Identifying locations of sewage pollution within a Hawaiian watershed for coastal water quality management actions (Wiegner, et al., 2021) | identify the location within the Puako ̄ watershed where sewage was entering into the groundwater using biological and chemical sewage indicators<br>Determine the source of faecal indicator bacteria (FIB) and nitrate (NO3) through microbial source tracking (MST) and stable isotopes of nitrate using mixing models, respectively<br>quantify water quality impairment caused by homes with OSDS through dye tracer studies and measurements of sewage indicators<br>assess whether proposed sewage treatment upgrades are sufficient for meeting state water quality standards. | Statistical analyses based on water samples.<br><br>Quantifying water quality impairment from OSDS. | N/A | This study successfully used a variety of biological and chemical sewage indicators to determine locations in Puako ̄'s watershed where sewage was entering into groundwater. This information is critical for appropriate management actions to be determined and implemented in targeted locations. Use of multiple biological and chemical sewage indicators allowed for the successful identification of where sewage was entering into Puako ̄'s watershed groundwater. |
| Research Progress on Integrated Treatment Technologies of Rural Domestic Sewage: A Review (Chen et al., 2022). | Development proposals for further optimization and improvement of the integrated rural sewage treatment process in developing countries. | MBR | N/A | Given the existing problems in integrated sewage treatment, the optimization and assembly of process modules, energy conservation and consumption reduction, the creation of intelligent management methods, and the formulation of standards and regulations are proposed as the key points of the integrated improvement in the future |

| Paper (Reference) | Aim of the project | System Overview | Hardware/Software Required | Author's Conclusions |
|---|---|---|---|---|
| Monitoring Pumping Station Performance for Maintenance Optimisation (Tarrant,et al.,2019) | This short paper describes the Environment Agency's ambition to develop a new condition-based monitoring system (CBMS) for their Mechanical, Electrical, Instrumented and Automatic (MEICA) flood defense assets. | Review and proof-of-concept of CBMS.<br>Proto-type design and specification of CBMS.<br>Deployment and pilot testing of prototype.<br>Development of deployment strategy | current (amps) sensor<br>noise sensor<br>flow sensor<br>pressure sensor<br>level sensor | The research team seeks to use both pragmatic changes to operational rules to generate performance data allied with new advance in predictive analytical techniques and sensors. |
| A Case Study on Condition Assessment of Water and Sanitation Infrastructure (Von Holdt et al., 2009) | This paper extrapolates from our review of methods, tools and techniques that are available for use in infrastructure condition assessment and risk management. Based on observed cases of water and sanitation providers in South Africa, a summary of the extent to which available condition monitoring, information and communication technologies influence asset management activities like condition assessment, risk analysis and predictive modelling is made. | Provide a rating of the asset condition "as found".<br>Indicate the risks associated with allowing the asset to remain in the "as found" condition; and<br>Identify the scope of work that may be necessary to restore to, and/or sustain the asset at desired condition. | N/A (Case Study) | Whereas the respondents' feedback suggests visual inspections as the prevailing common method for condition assessments.<br>However, visual inspections can encompass a rather broad definition of activities ranging from cursory inspections to highly detailed technical examinations utilising sophisticated instrumentation. The same applies for 'direct assessment' as the measure of reliability and the use of 'monetary value' as the basis for risk ranking. |

| Paper (Reference) | Aim of the project | System Overview | Hardware/Software Required | Author’s Conclusions |
|---|---|---|---|---|
| Monitoring and Predictive Maintenance of Centrifugal Pumps Based on Smart Sensors (Chen, et al. , 2022). | Use of smart sensors and the Digital Internet-of-Things (IoT) systems to monitor the real-time operating status of pumps and predict potential failures for achieving predictive maintenance of pumps and improving the intelligence level of machine health management. | Real-time monitoring of the running status of centrifugal pumps and intelligent diagnosis of centrifugal pump faults | Microelectromechanical system (MEMS) chip (Wireless vibration temperature integrated sensor)<br><br>Wired vibration temperature integrated sensor (IEPE (Integrated Electronics Piezo-Electric)<br>Data collector uses 220 V AC power supply, has 4G, WIFI, RJ45, RS485, LINUX operating system<br>Narrow Band Internet of Things (NB-IoT)0020RF4W 4G communication. | The research on the sensors and pump monitoring system provides feasible methods and an effective means for the application of centrifugal pump health management and predictive maintenance. |
| Development Of Acoustic Condition Monitoring for Pump Predictive Maintenance (Sudarno, et al., 2016). | Utilization of the sound card on the computer (PC) as a data acquisition system. This shows how the technology is a low cost solution. | Acoustic condition monitoring for predictive pump maintenance. | LabVIEW | The test results showed that the spectrum of the acoustic signal is influenced by the operating frequency of the pump. It is used as a comparison to determine whether there are changes in the frequency response of the pump caused by the degradation of the performance of the pump. |

| Paper (Reference) | Aim of the project | System Overview | Hardware/Software Required | Author's Conclusions |
|---|---|---|---|---|
| A multi-criteria analysis of sewer monitoring methods for locating pipe blockages and manhole overflows (Utepov, Kazkeyev, and Aniskin, 2021). | This article is devoted to the aggregation of existing methods for monitoring sewage systems into a single symbiosis; methods for identifying the locations of clogged pipes and manhole overflows. | To aggregate existing methods for monitoring sewage systems into a single symbiosis. | Applied devices, sensors and technologies<br>-Acoustic method Sonars, ultrasonic level meters<br>-Laser Method<br>RedZone Robotics, Sima Environmental, CUES, Envirosight, R&R Visual | In some conditions, one method of monitoring is not enough to determine an accurate picture of the internal condition of the pipeline, so it is recommended to use a symbiosis of several devices, combined into a single system suitable for a particular case. |

## 2.5. Existing Literature Comparative analysis and discussion

The above-mentioned challenges of mainly population increase, wastewater, environmental pollution and aging sewage infrastructure may be addressed by the introduction of smart monitoring infrastructures. These smart monitoring infrastructures may be a solution to alleviate environmental pollution by wastewater and specifically sewage spills. Smart technology will enable real-time supervision of the sewage infrastructure.

It must be noted that according to Abbas, et al., (2017) even though smart technology is still new in the market there seems to be a concern that it may suffer from a lack of field feedback. To address this uncertainty in the construction of such infrastructure there are several issues to be taken into consideration. These issues are data transfer, data storage, analysis and visualisation, smart sensors, interaction with the end-users, cyber security, the economic return of the technology and engineering exploitation.

Some researchers have come up with smart monitoring structures to address the issue of environmental pollution. Xiaoyan Song et al. (2020) developed the Management Mode Construction (MMC), and this is implemented to monitor and solve the operation of rural sewage treatment systems. Its focus is enabled by a framework of smart administration which with smart data gathering monitoring structures. The MMC is proving to be more effective than the traditional methods. It is efficient as it labour-saving, efficiency-improving and application-enhancing. This was implemented in Jiaxing City, Zhejiang Province in China. There was the construction of a set of systems which integrated functions like data collection and management of the whole process, data value analysis, and standardized process management. Operators and supervisors can master the related operation information.

Technology is advancing and evolving. With the population growing exponentially, sewer systems have come under strain and infrastructure maintenance thereof. Table 2.1 illustrates several different methods and technologies researched over an 18-year period from 2004 up to 2022 to effectively monitor sewage infrastructure. The review done by (Patil et al., 2021) highlights the available methodologies that are utilized in developing sewer inspection and cleaning robotic systems. From this study it is revealed that computer vision algorithms with on-board processing are not efficiently utilized. It further pointed out that smart technologies are not effectively used to monitor sewer pipelines thus leaving a gap for research studies.

It is noted that over the years there have been studies focusing on smart monitoring of pumps with communication; however, the effectiveness of this has not been researched in comparison to the traditional ways of monitoring sewer infrastructure.

Van Vuuren, et al., (2011) provided a concise guide for the analysis and design of waterborne sanitation systems on their research to the Water Commission. Software like Sewer Aid are used to process data. Since 2011 there has been a vast interest in using technology to monitor sewer infrastructure and incorporates a user interface for decision-making. With technology advancing in 2017 a large-scale experimentation of the smart sewage system was done (Abbas et al., 2017). The paper showed how the smart technology is implemented and used to enhance the understanding of the sewage system and to improve its management. Intelligent mechanical and electronic equipment (transducers) are employed to collect data from water infrastructure. The downside of this study is that a real- time user interface is not established which left the gap of data analysis and interpretation in real time for decision-making and corrective action implementation.

From the year 2015 to 2022 several articles have been published which seek to address human feedback interface and predictive infrastructure monitoring. According to the reviewed papers it is established that predictive monitoring of sewer network still has gaps as data collected must be in real-time and must be used for operational decision-making. (Sudarno et al., 2016) conducted a study on acoustic condition monitoring of pumps as part of predictive maintenance. The results of this study showed that the spectrum of the acoustic signal is influenced by the operating frequency of the pump. Pump degradation could be predicted, but the information was not based on real-time feedback.

Among other studies done between 2016 and 2022 researchers have published articles on smart monitoring of sewer infrastructure for predictive maintenance. (Chen, et al., 2022) published an article on Monitoring and Predictive Maintenance of Centrifugal Pumps Based on Smart Sensors. In this article the researcher focused on the use of smart sensors and the Digital Internet-of-Things (IoT) systems for the real-time monitoring of the operating status of pumps and the predicting potential failures to achieve a predictive maintenance system for the pumps. Findings from this research revealed that sensors and pump monitoring systems provide suitable methods for effectively monitoring and ensuring the pump health using predictive maintenance.

According to the papers reviewed it is established that sewer contamination of the environment is a global crisis. Studies have been done on how smart technologies is used to alleviate spillage. The following key smart technologies have been identified and are integral to the research:

- IoT-Enabled Sensor Networks: Studies have explored the deployment of IoT-based sensor networks in sewage systems to monitor key parameters such as flow rates, pressure, and water quality. These sensors provide real-time data for early detection of leaks and spillage events. (Abdullah I. A. Alzahrani, 2023)
- Machine Learning Algorithms: Research indicates the application of machine learning algorithms to analyse sensor data and predict potential spillage incidents. These algorithms enhance the accuracy and responsiveness of the monitoring system. (Przybyś-Małaczek, 2023)
- Smart Sewer Inspection Robots: Emerging technologies involving autonomous inspection robots equipped with sensors have been investigated. These robots can navigate sewage infrastructure autonomously, identifying blockages and structural weaknesses to prevent spills. (Binil John, 2016)
- Advanced Data Visualization and Analysis Tools: Studies highlight the importance of user-friendly interfaces and data visualization tools that enable operators to interpret complex data effectively. These tools assist in early identification of issues and proactive spillage prevention. (Srivastava, 2023)
- Remote Monitoring and Control Systems: Research has explored the integration of remote monitoring and control systems that enable real-time adjustments to sewage infrastructure operations. This approach helps in optimizing system performance and reducing spillage risks. (Congcong Sun, 2020)

The research approach is centred on the systematic evaluation and integration of these smart technologies into sewage infrastructure. The choice of these technologies is motivated by their potential to enhance environmental sustainability by preventing sewage spills and mitigating pollution risks. The selection of specific technologies align with the objectives of the research, considering factors such as their compatibility with sewage infrastructure, cost-effectiveness, and their ability to provide actionable insights for proactive maintenance and spillage prevention. The research aims to contribute to the field of electrical engineering by advancing the application of smart technologies in sewage infrastructure monitoring, thereby reducing environmental pollution and improving system efficiency.

Current open-loop systems are used to communicate corrective action through implementing closed-loop systems. There is still a gap or rather slow transition between data collection and data analysis for decision-making with an open-loop system. The quicker the data gets collected and analysed for decision-making the more effective the alleviation of sewer spillage achieved. The Researcher will use this gap to establish possible smart means to be added to the infrastructure monitoring to alleviate pollution. The Researcher will further monitor existing pumps using smart sensors and identify the effectiveness of the use of smart technology in alleviating environmental pollution.

### 2.5.1. System Architecture

The literature review has provided valuable insights into sewer network infrastructure monitoring, and based on the findings, a basic proposed system architecture is modelled, as depicted in Figure 2.9. This proposed architecture considers the existing work in the field and aims to address the challenges and requirements identified in the literature review. One of the key focal points of this proposed system architecture is the effective collection, analysis, and conversion of data to facilitate real-time decision-making. To achieve this, the architecture incorporates various components and processes (Chandrakana et al, 2015).

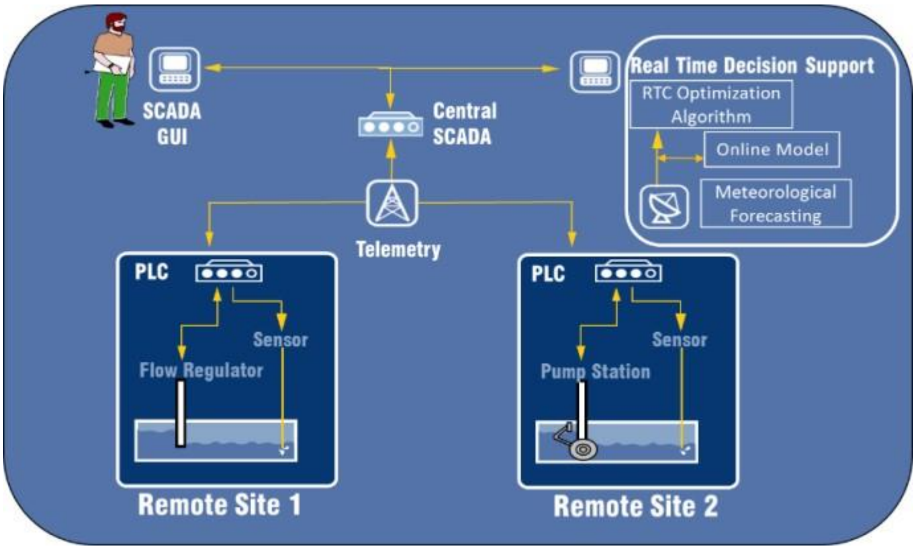



**Figure 2.9 User Feedback System Architecture (Chandrakana et al, 2015)**

Firstly, the system utilizes sensors deployed throughout the sewer network to collect relevant data on parameters such as pump performance, sump levels, and pipeline conditions. These sensors play a crucial role in gathering real-time information about the infrastructure. The collected data is then transmitted through telemetry systems to a central supervisory control and data acquisition (SCADA) system. The SCADA system acts as the central hub for data processing and management. It receives the data from the sensors and performs analysis using real-time decision support tools and algorithms.

The analysis of the data involves several steps, including data cleansing, aggregation, and contextualization. This process aims to eliminate noise and inconsistencies in the data, aggregate it into meaningful units, and provide the necessary context for accurate interpretation. The analysis may also involve the use of advanced techniques, such as machine learning algorithms, to detect patterns, anomalies, and potential issues in the infrastructure.

Once the data is analysed, it is displayed on a Human Machine Interface (HMI), which serves as the user interface for process operators. The HMI presents the analysed data in various formats, such as graphs, images, alarms, and other visual representations. These visualizations provide operators with a clear and intuitive understanding of the current state of the sewer network. The real-time decision-making process is facilitated through the HMI. Operators can interpret the displayed data and make informed decisions promptly.

The HMI may also incorporate features such as real-time control optimization algorithms and online models to assist operators in identifying the most optimal actions to be taken based on the current conditions. The proposed system architecture also includes the integration of a SCADA graphical user interface (GUI), which provides a user-friendly interface for configuring and monitoring the SCADA system. The GUI allows operators to interact with the system, set up monitoring parameters, define thresholds, and access historical data (Chandrakana et al, 2015).

In summary, the basic researcher’s proposed system architecture leverages sensors, telemetry, central SCADA, and a user-friendly HMI to enable effective data collection, analysis, and conversion for real-time decision-making in sewer network infrastructure monitoring. By combining these components, the architecture provides a comprehensive framework for monitoring, analysing, and visualizing data, empowering process operators with the tools and information necessary for efficient and informed decision-making. Considering the architecture in Figure 2.9 it is proposed that this be streamlined to focus on elements to be monitored for this research. Figure 2.10 is an illustration of further data analysis to be done to communicate potential pump failure to managers and technical operators.

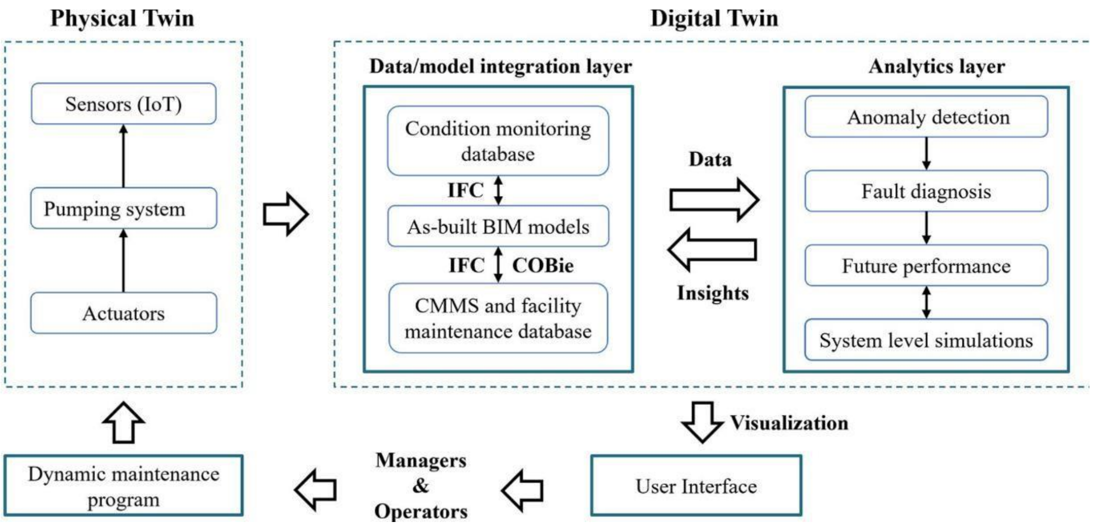



**Figure 2.10 Typical pump predictive maintenance ( (Seyed Mostafa Hallaji, 2022)**

The proposed system for this research work to be designed focuses on:

- Manhole monitoring using pressure sensors (Theoretical analysis and practical implementation)
- Sump level monitor control (Theoretical analysis and practical implementation)
- Pump health monitor using current and vibration monitors. (Practical Implementation)

## 2.6. Chapter summary

Chapter 2 offers a thorough exploration of smart sewerage infrastructure monitoring, conducting a comprehensive literature review. It traces the evolution of monitoring methods, control types, and communication systems between 2004 and 2022, identifying knowledge gaps. The chapter highlights the environmental impact of sewer spillage and the strain on sewage infrastructure due to population growth. Existing research on smart sewage infrastructure monitoring is reviewed, emphasizing the necessity for effective monitoring to mitigate pollution and address infrastructure challenges. The section underscores the importance of data-supported monitoring, hardware devices, communications, and data management. It discusses traditional monitoring methods and their limitations, leading to a comparative analysis with smart predictive monitoring methods.

The proposed system architecture model emphasizes the pivotal role of sensors, central SCADA, telemetry, and SCADA GUI in providing real-time decision support. However, identified gaps in the current state of knowledge include the need for smart monitoring of sewer pipelines, a gap in real-time data analysis and interpretation for decision-making, and the slow transition between data collection and analysis in open-loop systems. Additionally, the section addresses the challenge of spillage containment while awaiting pump station repairs. In conclusion, Chapter 2 advocates for a shift towards predictive-based approaches in sewage infrastructure monitoring to bridge these identified gaps.

Chapter Three of this study delves into the researcher's contribution, unveiling the critical research methodology used to achieve the research objective of alleviating sewer environmental pollution through smart sewer infrastructure monitoring technology. This chapter provides in-depth insights into the methods employed for data collection and the specialized equipment used to ensure accurate and reliable measurements. By understanding the research methodology, readers gain a clearer picture of how the information studied aligns with the overarching goal of the research: improving environmental conditions through the implementation of smart sewer infrastructure monitoring technology.

# CHAPTER 3:

# 3. RESEARCH METHODOLOGY

## 3.1. Introduction

Chapter 3 details the research methodology adopted. A mixed-methods approach is adopted in this study. Methods used are a mixture of the quantitative and the qualitative research methods. This chapter illustrates the smart sensor monitoring of the sewer pump station pump motor vibration, current and sump level. This is followed by the illustration of the fundamentals of each monitored data and presents the electrical, communication and smart sensors used.

This chapter is organised as follows:
Section 3.2. discusses smart sensor monitoring of a sewer pumpstations. Section 3.3 investigates sewer spillage in Ndlambe, focusing on Mbabela station data for infrastructure monitoring using smart sensors. Sections 3.4 cover electrical connections, smart sensor monitoring, and data communication, emphasizing efficient wastewater management. Section 3.5 discuses the fundamentals of infrastructure monitoring using smart sensors. Section 3.6 describes the qualitative methodology, mentioning the use of questionnaires, case studies, and interviews for data collection, focusing on the Ndlambe Local Municipality's perspective and the factors related to sewer spillage. Section 3.5 provides the conclusion to this chapter and introduces Chapter Four.

## 3.2. Smart Sensor Monitoring of Sewer Pump station

Quantitative research approach entails the collection and analysis of numerical data, and it may incorporate the use of test casual relationships, predictions, averages and patterns and is the process of collecting and analysing numerical data. It is used to find patterns and averages, make predictions, test causal relationships, and generalize results to wider populations, (Flick, 2015).

The top two largest provinces in South Africa are Northern Cape and Eastern Cape. Ndlambe Local Municipality is a rural Municipality in the Sarah Baartman Region of the Eastern Cape. Eastern Cape is predominantly non-urban (65%) while Northern Cape which has the highest proportion of people living in non-urban areas in the country (89%). Figure 3.1 indicates the location of Ndlambe Local Municipality in the context of South Africa.

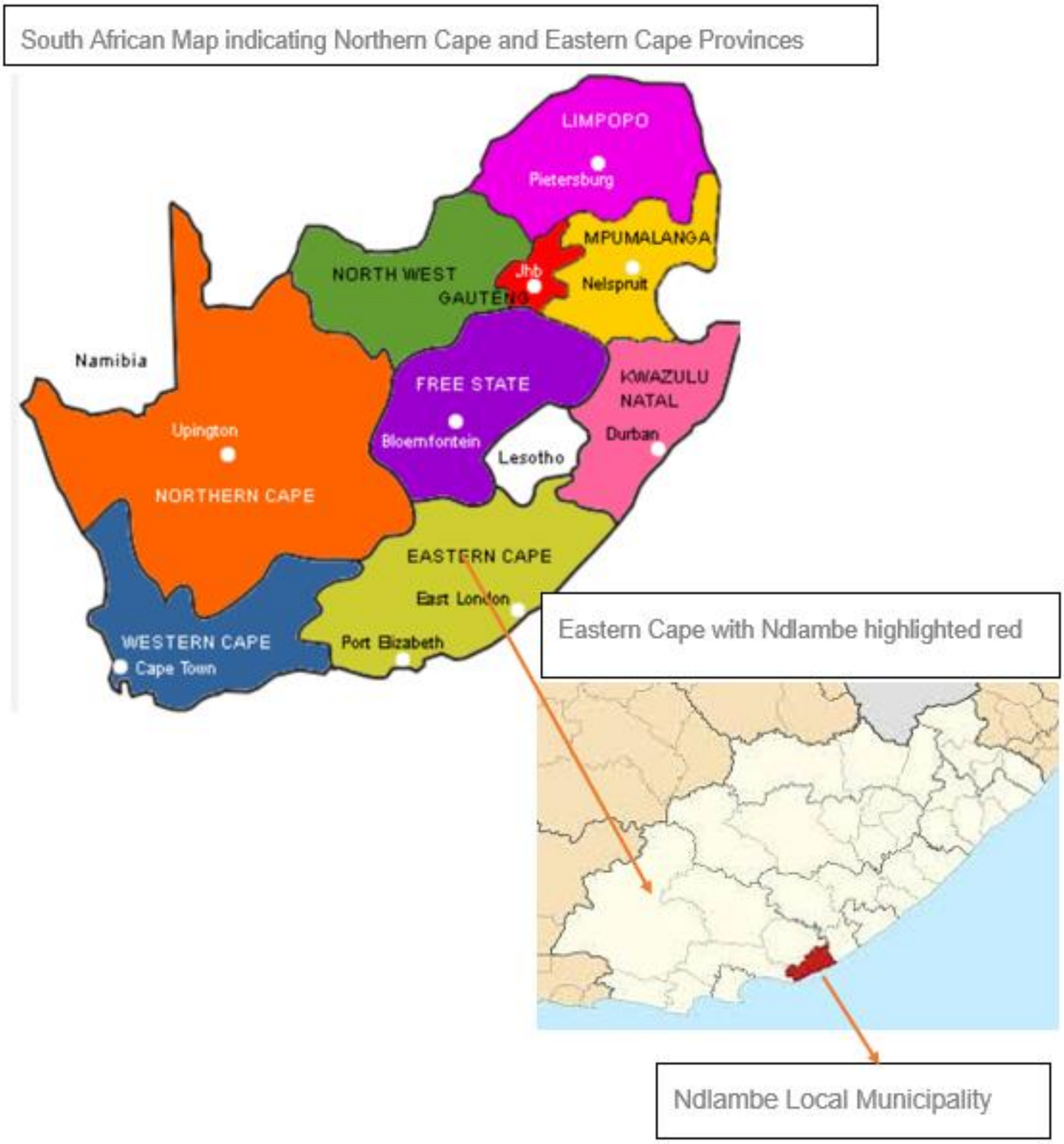



**Figure 3.1 Location of Ndlambe Local Municipality in South Africa**

## 3.3. Sewer Pump Stations

According to Ndlambe Local Municipality, records and data collected from the residents as detailed under the qualitative research section of this thesis it is established that most of the sewer spillage occurs at the pump stations. This survey suggests that sewer sumps fill up and spillage occurs with manual ways of reporting incidents being employed.

The quantitative data entails information on the frequency of sewer spillage incidents and relevant causes. The following sensors are employed to collect data:

- Pump motor vibration sensors
- Pump motor current sensors
- Sump level monitor

Figure 3.2 gives an overview of Ndlambe Local Municipality Pump Stations being studied with the main focus being on the Mbabela pumping station as a starting point for the implementation of this work.

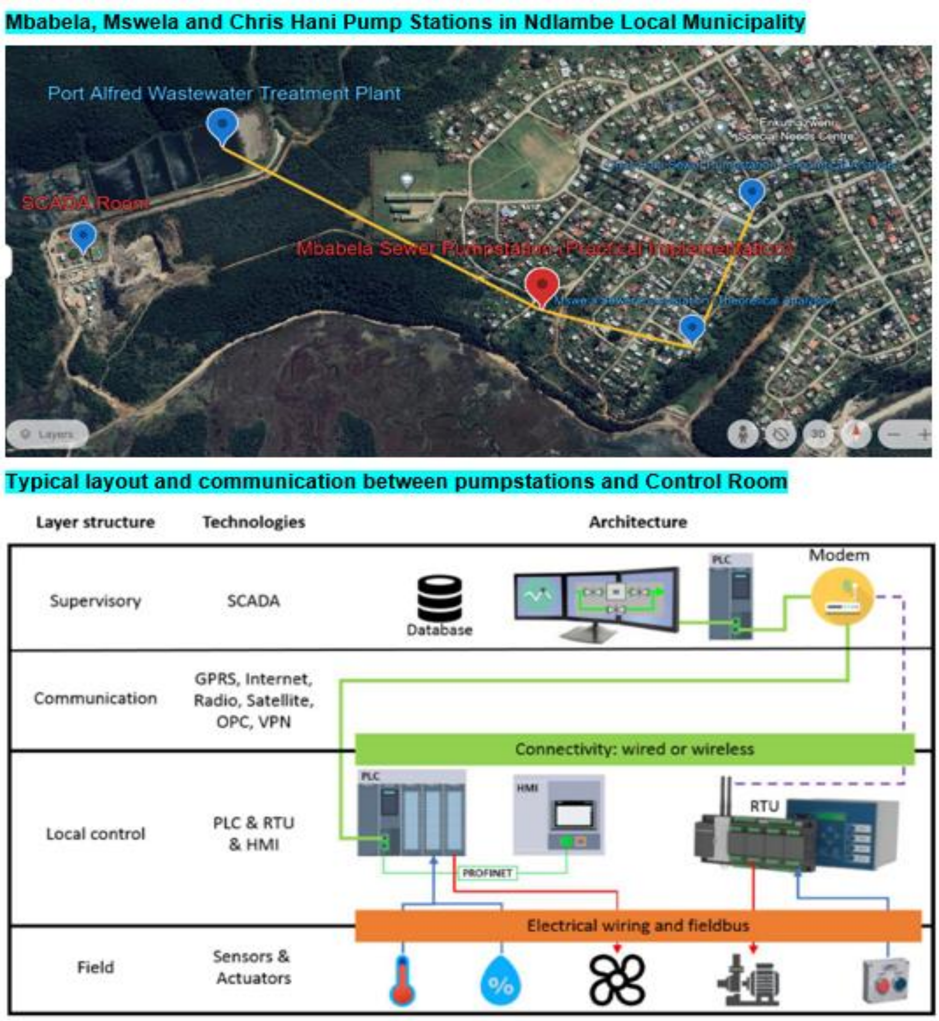



**Figure 3.2 Practical Implementation System Overview**

A typical sewer pump station has two positive displacement pumps which pump sewage collected in the sump to the wastewater treatment plant. At the wastewater treatment plant, the sewage is treated to acceptable recreational standards before being released to the environment or rivers (Jacobs, 2015).  The focus for this research work is on three pump stations being operated by the Ndlambe Local Municipality. The pump stations are approximately 5km apart in the informal settlement section of the Ndlambe Local Municipality. Initially these pump stations were operated by the researcher’s company.

While the focus is on three adjacent pump stations, access to one of the three pump stations located at Nemato informal settlement was granted. This pump station is named Mbabela. Mbabela’s system architecture is like the other two pump stations. The main setup of these pump stations are:

- Two above ground Gorman Rupp pumps
- Concrete sewer sump
- Local Motor Control Centre (MCC)
- Palisade fencing security around the pump station.

Figure 3.3 and Figure 3.34 shows images of Mbabela pump station and sump being studied to get the analytical data. This data is  processed and used to alleviate sewer contamination due to sewer spillage.  The intention is to prove that the use of smart sensors are used to alleviate sewer spillage at this pump station.


**Figure 3.3 Sewer Pump station**

Figure 3.4 shows the motor being monitored. This image was taken during the refurbishment of the pump station before the testing period commenced

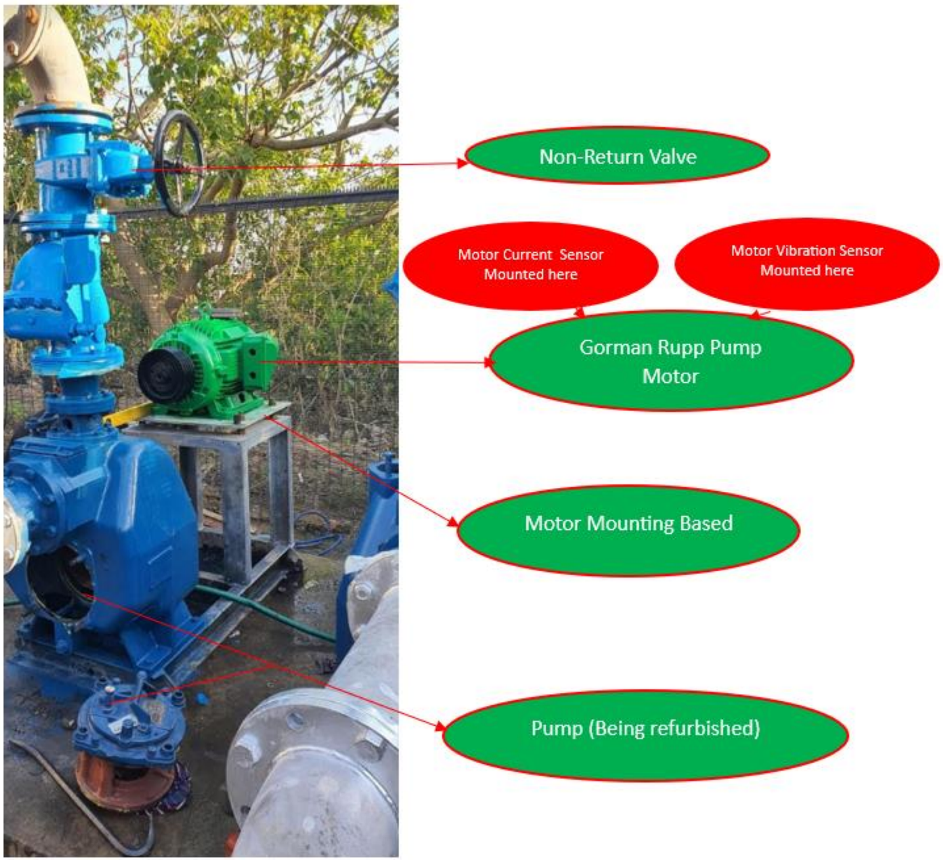



**Figure 3.4. Sewer Sump Pump Overview**

### 3.4. System Electrical Connection and Communication Overview

A single-line diagram illustration of the vibration and current sensors monitoring of the sewer pump motor as well as the communications from the sensors to the PLC is indicated below with the following components.

1- Power Supply Unit (PSU): The PSU complies with IEEE guidelines for voltage and current ratings to provide a stable power source for the system.
2- Key Terminals (L1, N, PE): These terminals (Phase, Neutral, Protective Earth) are accurately depicted to ensure compliance with IEEE regulations related to grounding and safety.
3- Contactors: Strategically placed in the diagram according to IEEE 1451 and IEEE 1547 Standards, contactors control electrical current, ensuring safe and efficient system operation.

4- Specialized Components (PLC Analogue Card, Current Sensor, Vibration Sensor): These components are designed to meet IEEE specifications, guaranteeing precise measurements and reliable signal conversion for data collection purposes.
5- Voltage Levels (0-24V): Specified within the diagram in alignment with IEEE recommendations for low-voltage systems, the 0-24V range ensures proper operation and compatibility of interconnected devices and sensors.
6- Standardized Symbols: The use of standardized symbols in the diagram represents electrical connections, both for analogue and digital signals, ensuring compatibility and consistency in the system design.

The layout for all three pump stations is the same as per Figure 3.5 . The data collected in this specific research is for one of the pump stations with future studies encouraged to focus on the other two pump stations and compare results. The temperature sensor is included in the drawing as a recommendation to be used in future to ascertain the impact of change in temperature relative to pump failure to alleviate failure.

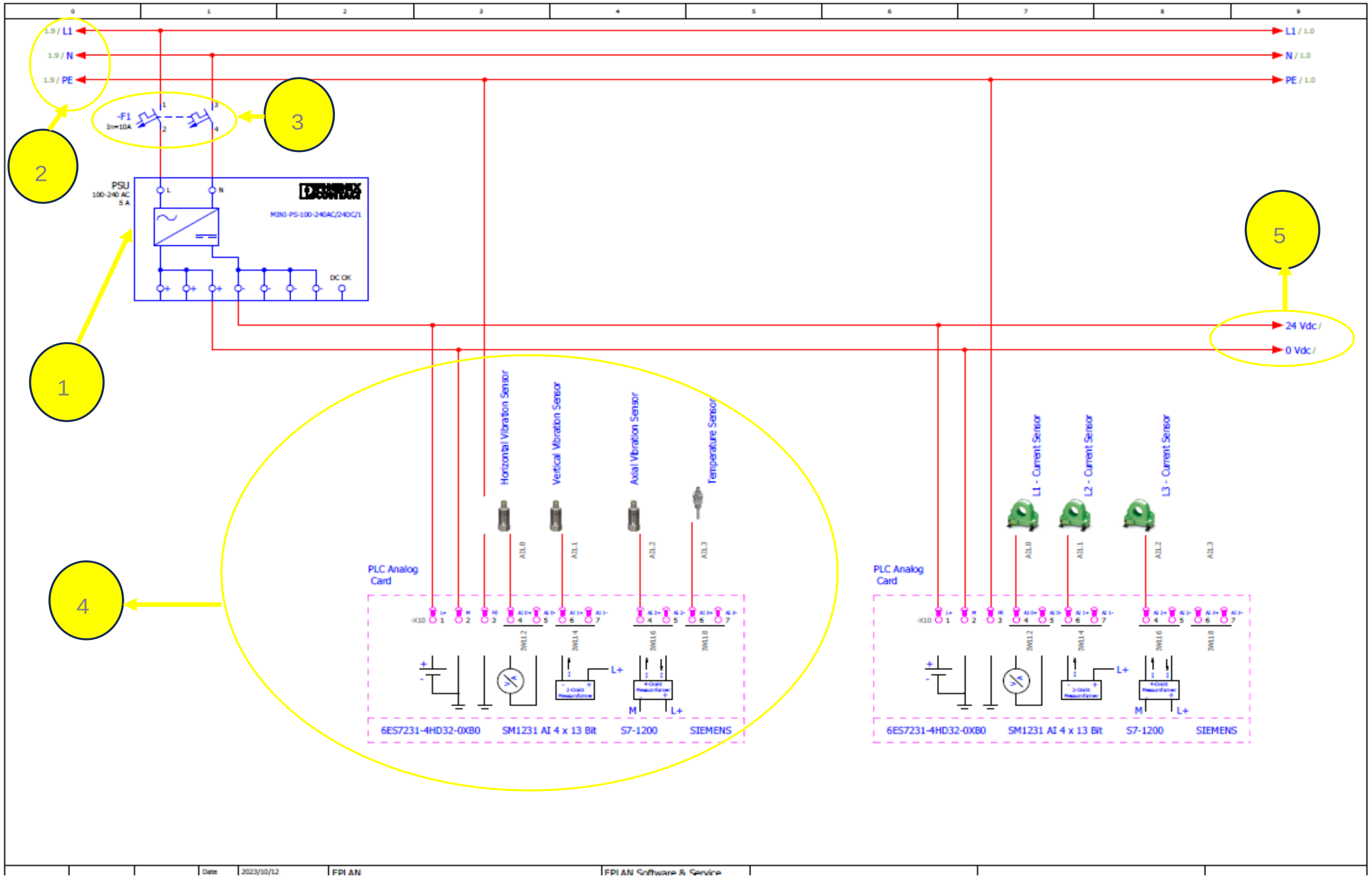



**Figure 3.5 Electrical and Control Line Diagram**

### 3.5. Fundamentals of smart sensor monitoring

The smart sensor monitoring is based on the fundamentals of a closed loop system referred to as the smart sensor system is to be adopted. Below is a typical closed-loop method as per Figure 3.6.

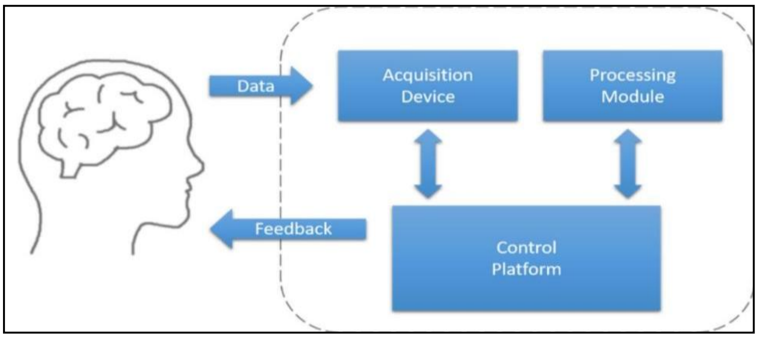



**Figure 3.6 Closed Loop System 1(© Jinyoung Choi, 2022)**

A closed loop system, also known as a feedback control system, is a system that utilizes feedback from its output to regulate or adjust its behaviour. In such a system, the output of the system is measured and compared to a desired or reference value. The difference between the actual output and the desired value, known as the error signal, is used to adjust the system's inputs or parameters to minimize the error and bring the system closer to the desired state.

A closed loop system typically consists of four main components:

- Input: The input to the system represents the desired goal or setpoint. It could be a specific value, a reference signal, or a sequence of commands.
- Plant or Process: This component represents the system or process being controlled. It can be a physical system, such as a mechanical or electrical system, or an abstract system, such as an algorithm or software.
- Controller: The controller receives the error signal, which is the difference between the desired input and the actual output and generates a control signal based on that error. The control signal is then applied to the plant or process to influence its behaviour.
- Feedback: The output of the system is measured and fed back to the controller, allowing it to continuously monitor the system's performance. The feedback signal is compared to the desired input, and any deviation or error is used to adjust the control signal.

By continuously monitoring the output and adjusting the input based on the feedback, a closed loop system can maintain stability, track desired setpoints, reject disturbances, and improve the overall performance and accuracy of the system. This feedback mechanism enables the system to adapt and self-correct in real-time, making closed loop systems widely used in various applications, such as industrial control systems, robotics, process control, and automation as part of Internet of Things. (TarekAbdelzaher1, 2020)

The Internet of Things (IoT) is defined as a network of interconnected devices and sensors that collect, transmit, and analyse data related to these parameters. Specifically:

- Motor Current Monitoring within IoT: Motor current monitoring in the IoT context involves using sensors to measure the electrical current drawn by the wastewater pump motor. These sensors collect real-time current data and transmit it to a central IoT platform or cloud-based system. IoT analytics then process this data to assess the operating condition of motors, detect irregularities or faults, and optimize energy usage.
- Vibration Monitoring within IoT: Vibration monitoring in IoT entails the deployment of sensors that measure mechanical vibrations in machinery, equipment, or structures. In this instance the wastewater pump motor vibration is monitored. These sensors capture vibration patterns and transmit the data to an IoT hub for analysis. IoT algorithms can assess vibration data to identify signs of wear and tear, misalignment, imbalance, or impending equipment failures, allowing for predictive maintenance and improved operational reliability.
- Sewerage Sump Level Monitoring within IoT: Monitoring sewerage sump levels through IoT involves utilizing sensors placed within sewerage or wastewater collection systems to measure the depth or volume of sewage or wastewater. These sensors send real-time sump level data to an IoT platform, typically in a centralized location. IoT systems can use this data to optimize pump operations, prevent overflows or underflows, and provide early warnings of potential issues, contributing to efficient sewage management.

In essence, IoT in this context facilitates the collection and integration of data from these critical parameters into a unified digital ecosystem. The IoT infrastructure enables remote monitoring, data analysis, and intelligent decision-making to enhance the efficiency, reliability, and sustainability of systems involving motor current, vibration, and sewerage sump levels (Xin Li, 2019).

### 3.5.1. Fundamentals of Monitoring of sewage pump motor current and vibration

In wastewater management systems, the monitoring of sewage pump motor current plays a crucial role in ensuring the efficient operation of pump stations. The current drawn by the pump motor provides valuable insights into the performance and health of the pump system. By establishing set-points and implementing a feedback mechanism based on the monitored current, it becomes possible to detect anomalies and take appropriate actions to address them.

Set points are established as predetermined values that represent the desired current range for normal motor operation. These set-points are determined based on design specifications, operational requirements, and expected conditions. The set-points serve as reference values against which the monitored current is compared. If the monitored motor current deviates below the established set-point, it indicates potential issues with the motor or the system. A lower-than-expected current reading may suggest motor failure, mechanical faults, or obstructions. This information triggers feedback actions, such as generating alerts or initiating maintenance procedures, to address the underlying problem and restore normal operation. Conversely, if the monitored current exceeds the set-point, it can signify higher-than-anticipated motor current draw, indicating problems like mechanical overload or motor jamming. The feedback mechanism, triggered by the higher current readings, promptly communicates the motor's condition to the control system or operators. This immediate notification enables timely responses, such as activating safety measures, shutting down the motor to prevent damage, or deploying maintenance personnel to resolve the issue.

Similarly, monitoring motor vibration involves using vibration sensors to measure the mechanical oscillations produced by the motor during its operation. Just like motor current monitoring, set points are established for vibration levels, representing acceptable thresholds for normal motor behaviour. If the monitored vibration exceeds the set-point, it indicates abnormal conditions such as misalignment, bearing wear, or unbalanced loads. The feedback mechanism in this case initiates actions to prevent further damage, mitigate risks, and schedule maintenance (Ashnibha, 2012).

Figures 3.7  shows a typical hardware setup for motor current monitoring.

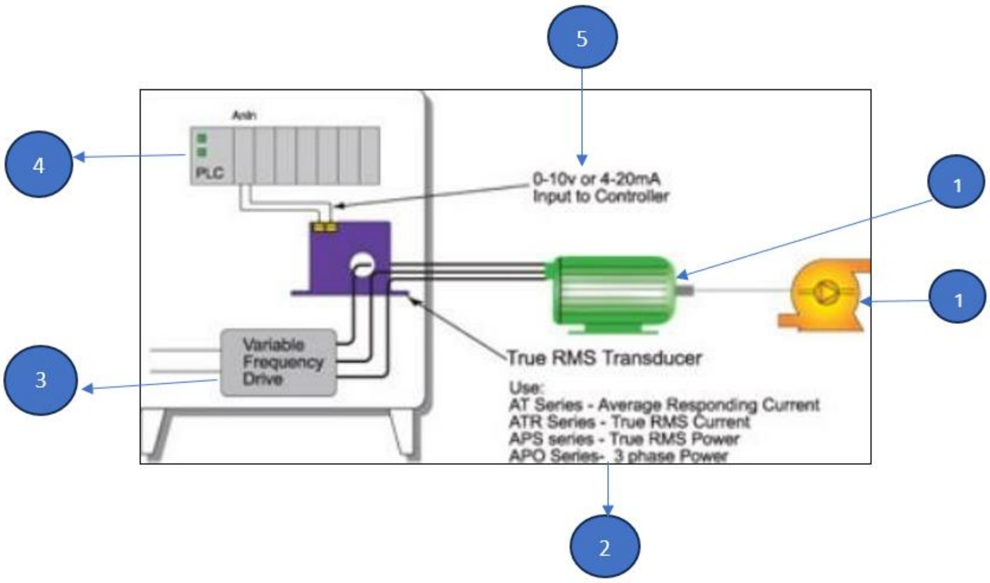



**Figure 3.7 Current Monitoring Hardware (©NK Technologies,2022)**

Each hardware unit and function is detailed in the text below relative to each number.

1- Motor and Pump: The motor and pump form the core components of the system. The motor drives the pump to move fluids or perform mechanical work. The motor current is a key parameter that needs to be monitored to ensure proper operation and identify any abnormal conditions.

2- Current Measurement: The current measurement unit consists of a current sensor, signal conditioning circuitry, and an RMS measurement module. The current sensor, such as a current transformer (CT) or a Hall-effect sensor, is installed in the motor's circuit to measure the current. The measured current signal is conditioned to ensure accurate and reliable measurements. The RMS measurement module calculates the root mean square value of the current, which provides an indication of the average current magnitude over time.

3- Variable Frequency Drive (VFD): A VFD is often used to control the speed and torque of the motor. It converts the incoming AC power supply into a variable frequency and voltage output to regulate the motor's speed. The VFD can provide valuable data on motor operating conditions, including current, voltage, and frequency.

4- Programmable Logic Controller (PLC): The PLC serves as the central control unit of the system. It is responsible for coordinating and controlling various components, including the motor, VFD, and current monitoring. The PLC receives input signals, executes control logic, and provides output signals to drive the system. It acts as the interface between the monitoring hardware and the control system.

5- Input to the Controller: The current measurement unit provides the measured and processed current signal as an input to the PLC. This input serves as feedback to the controller, allowing it to monitor the motor's performance and make control decisions based on the current readings. The PLC can compare the measured current with predefined set-points and trigger appropriate actions based on the deviation. The PLC uses the current measurements and control logic to perform various control and monitoring actions. For example, if the measured current exceeds a set-point, indicating an abnormal condition such as a jammed pump, the PLC can trigger an alarm, activate safety measures, and initiate corrective actions such as shutting down the motor or notifying maintenance personnel. The PLC can also adjust the VFD parameters to optimize motor performance based on the current readings (M.Chakravarthy, 2016).

### 3.5.2. Vibration sensor

The vibration transmitter is mounted with a magnetic base onto the bearing housing of the motor. The sensor is mounted on the thick housing wall and the signal direction is verified to be correct. Checks are done to ensure a safe vibration transmission and allowed no elastic intermediate layers. The transmitter detects the vibration on the motor and converts it into an analogue current signal that is relayed to a PLC. The formula for vibration velocity is:

$$measured\ /\ evaluated\ physical\ unit\ =\ vibration\ velocity$$

Figure 3.8 shows the electrical connections of the sensor. Three sensors are installed to measure vibration. Measuring vibrations in multiple directions allows for a more accurate assessment of the dynamic forces and movements affecting the system. It helps in detecting abnormalities, such as excessive vibrations, imbalances, misalignments, or wear in machinery. By monitoring vibrations in specific orientations, engineers can identify potential issues, diagnose problems, and implement appropriate maintenance or corrective measures to ensure optimal performance, reliability, and safety of the monitored equipment or structure.

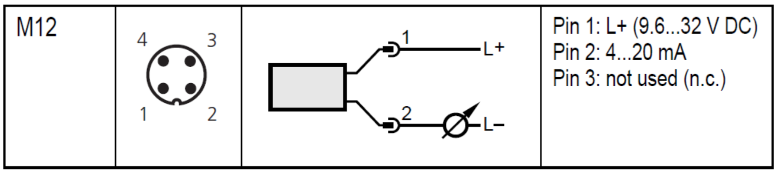



**Figure 3.8 Electrical diagram of the installation.**

Figure 3.9 shows the installation of the axial, horizontal and vertical vibration sensors.

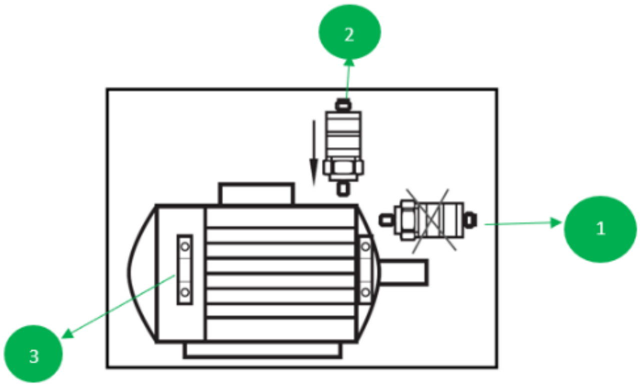



**Figure 3.9 Vibration sensor installation**

For vibration monitoring, three sensors are installed as described below:

1- Horizontal Vibration Sensor Installation: A horizontal vibration sensor is installed with its sensitive axis parallel to the horizontal plane. It measures vibrations that occur along the x-axis or y-axis, typically in the horizontal direction. This type of installation is suitable for monitoring vibrations caused by lateral movements or forces acting horizontally, such as machine vibrations or movements of structures in the horizontal plane.

2- Vertical Vibration Sensor Installation: A vertical vibration sensor is installed with its sensitive axis perpendicular to the horizontal plane, measuring vibrations that occur in the vertical direction along the z-axis. This type of installation is used to monitor vibrations caused by vertical movements or forces, such as vibrations in buildings, seismic activity, or vertical motions of machinery.

3- Axial Vibration Sensor Installation: An axial vibration sensor is installed with its sensitive axis aligned with the axis of the equipment or structure being monitored. It measures vibrations along the axial direction, which is typically the direction of rotation or movement of the equipment. This type of installation is commonly used to monitor vibrations in rotating machinery, such as motors, pumps, or turbines. By measuring vibrations along the axial direction, it can provide insights into the condition and performance of rotating components.

Previous studies on 3-phase motor vibration monitoring were conducted. Findings from these studies influence part of this research. The following literature was relevant is cementing the fundamentals of this research:

- Analysis of Combined Motor Current Signature and Vibration-Monitoring Techniques in the Study of Broken Bars in Three-Phase High-Performance Induction Motors (Ronaldo et al.,2017).
- Vibration analysis of an induction motor (Wang and Joseph,19999).
- Vibration analysis of reconditioned high-speed electric motors (Pawel,2019).
- Noise and vibration analysis of an inverter-fed three-phase induction motor (Yassine et al,2020).
- Vibration and motor current analysis of induction motors to diagnose mechanical faults (Hakin,2014)
- Electromagnetically Excited Vibration Calculation for a Three-phase Asynchronous Motor with Finite Element Method (Yan et al ,2015).
- Real time condition monitoring system for industrial motors (Kabir, Ravin and Islam, 2015).
- Online Current and Vibration Signal Monitoring Based Fault Detection of Bowed
- Rotor Induction Motor (Uddih and Rahman,2015)

### 3.5.3. Current sensors

The load current of the motor is measured by a current transducer illustrated in Figure 3.10.

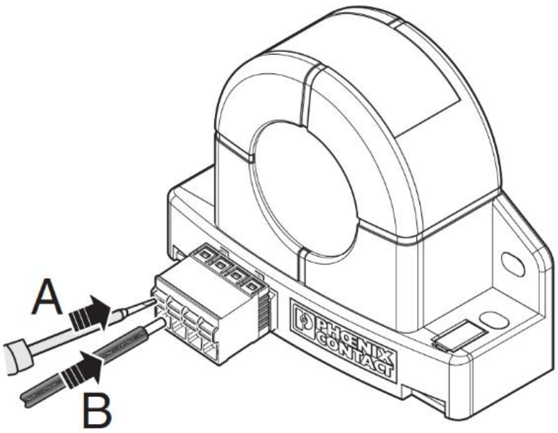



**Figure 3.10 Current sensors**

The advantages of using this sensor which has variable mounting on DIN rail and mounting plate is that its compact dimensions also enable distributed use and has simple connection technology. It further has 3-way isolation and universal current measurement, and no shunt resistor is required.

Figure 3.11 is the application drawing of the current sensor.

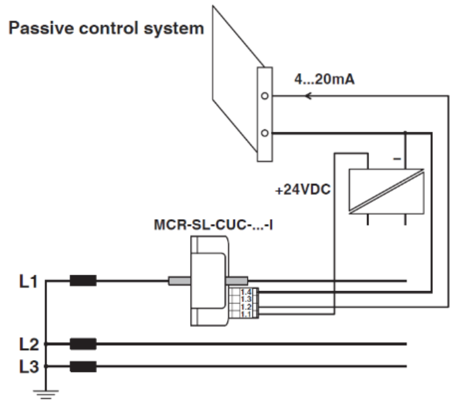



**Figure 3.11 Application drawing of the current sensor**

This transducer is universal and can measure AC, DC, and distorted currents, 0 ... 100 A input current, 4 ... 20 mA output. Figure 3.12 is the circuit diagram of the sensor. It shows the input current signal being passed though the transformer, amplified and the Analog-to Digital Converter (ADC) of the microcontroller before being transformed by the Digital-to-Analog Converter (DAC) into the output signal.

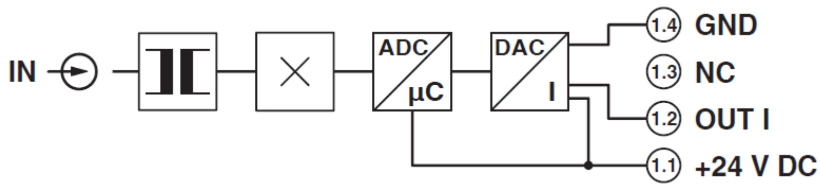



**Figure 3.12 Circuit diagram of the sensor**

The electrical properties of the installed current sensor are detailed in Figure 3.13.

| | |
|---|---|
| Linearity error | <± 1 % (From the range end value) |
| Maximum power dissipation for nominal condition | 1 W |
| Step response (10-90%) | 150 ms |
| Temperature coefficient, typical | 0.02 %/K (0 °C ... 60 °C) |
| | 0.04 %/K (-40 °C ... 65 °C) |
| Maximum transmission error | <± 1 % (of final value) |
| Rated insulation voltage | 300 V AC |
| **Electrical isolation Input/output** | |
| Test voltage | 3.5 kV AC (50 Hz, 60 s) |
| **Electrical isolation Input/power supply** | |
| Test voltage | 3.5 kV AC (50 Hz, 60 s) |
| **General** | |
| Accuracy class | 1 |
| **Supply** | |
| Nominal supply voltage | 24 V DC |
| Supply voltage range | 20 V DC ... 30 V DC |
| Max. current consumption | $(30 + I_{OUT})$ mA |
| Power consumption | 1.65 W |

**Figure 3.13 Electrical properties of the installed current sensor**

By employing a closed loop feedback system for both motor current and vibration monitoring, industrial systems can proactively detect deviations from normal operating conditions. This approach enhances system reliability, efficiency, and longevity while minimizing the risk of failures and disruptions. Efficient motor current and vibration monitoring contribute significantly to the overall productivity and safety of industrial processes, ultimately leading to improved environmental and operational outcomes.

### 3.5.4. Fundamentals of communication from motor current or vibration data collection to the file manager for analysis

The typical communication path from motor current data collection to the file manager for analysis can involve the use of an IoT gateway, cloud services, and a field manager.

The function of each unit is detailed in the text below relative to each number. Figure 3.14 shows typical communication from motor current or vibration data collection to the file manager for analysis.

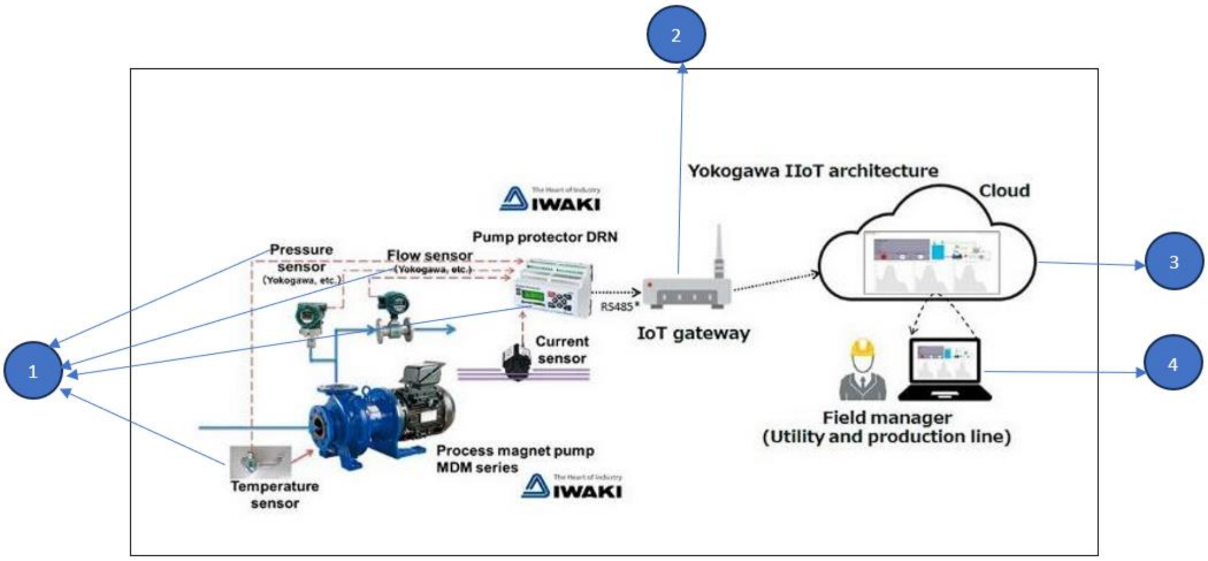



**Figure 3.14 Pump motor current communicate 1 (Seewater Inc CA, 2020)**

Data Collection Sensors (Temperature, Pressure, Current and flow): These sensors collet data and the PLC processes and acquires the data. Vibration sensors are also connected in a similar manner.

- IoT Gateway: An IoT gateway serves as a bridge between the local network where the sensors are located and the cloud services. The IoT gateway receives the data from the PLC and acts as a communication interface to transmit the data to the cloud for further analysis. The gateway may also provide data pre-processing or filtering capabilities to optimize data transmission.
- Cloud Services: The IoT gateway communicates with cloud services, which provide a scalable and flexible infrastructure for data storage, processing, and analysis. The motor current data is securely transmitted to the cloud using protocols such as MQTT (Message Queuing Telemetry Transport) or HTTPS (Hypertext Transfer Protocol Secure). In this instance, the motor current data is stored in a cloud-based database or data storage service. This allows for efficient storage, retrieval, and management of large volumes of data. The cloud storage ensures data integrity, availability, and provides backup capabilities. The cloud services offer various tools and technologies for data analysis and processing. This can include real-time analytics, machine learning algorithms, or custom data analysis workflows. The motor current data is analysed to detect patterns, anomalies, or performance trends that can provide insights into the

motor's behaviour and identify potential issues.

- Field Manager: The field manager, who may be an engineer, technician, or maintenance personnel, accesses the cloud-based platform or application to retrieve the motor current data and perform analysis. The field manager can visualize the data, generate reports, and gain actionable insights to optimize maintenance schedules, troubleshoot problems, or make informed decisions about the motor and pump system. The field manager may export the motor current data or analysis results from the cloud platform to a file manager or data analysis software for further processing or integration with other data sources. The file manager allows for in-depth analysis, visualization, and correlation with other relevant data, facilitating comprehensive diagnostics and performance optimization.

By integrating these components and establishing a feedback loop between the current and vibration monitoring units, the PLC, and the control system, the hardware setup enables real-time monitoring and control of both motor current and vibration. This integration contributes to the efficient and safe operation of the motor and pump system, preventing pump damage, elongated downtime, and sewage overflow from the sump.

In the context of this research, the combined current and vibration monitoring assist maintenance managers in detecting and addressing potential issues before they escalate. The integration of these monitoring parameters allows for a comprehensive view of the motor's health and performance, enabling proactive maintenance and minimizing the risk of failures. Furthermore, the design of a smart diversion pit creates room for alleviating environmental pollution while corrective measures are being implemented when a fault has been identified. By leveraging the IoT gateway, cloud services, and field manager, the data collected from the hardware setup, encompassing both motor current and vibration measurements, is efficiently transmitted, stored, analysed, and accessed for analysis and decision-making. This integrated approach facilitates remote monitoring, centralized data management, and advanced analytics, leading to improved overall efficiency, reliability, and maintenance of the motor and pump system.

The following publications indicate some studies that have been done covering 3-phase induction motors and some of the fundamentals have been used in this research:

- SVPWM for 3-phase 3-level Neutral Point Clamped Inverter fed Induction Motor Control (Palanisamy and Vijayakumar,2018).
- Performance assessment of a solar powered rice husking system with a VFD controlled

high capacity 3-phase inverter (Uddih et al, 2016).

- Operation of Single-Phase to Three-Phase VSI-PWM Rectifier-Inverter System with Reduced Switch Count (Gamel,2008).
- ANN Assisted Multi Sensor Information Fusion for BLDC Motor Fault Diagnosis (Tanvir and Jang wook,2021).
- Brief Review of Motor Current Signature Analysis (Dubravko,2015)
- Rotor Broken Bar Detection and Diagnosis in Induction Motors Using Stator Current Signature Analysis and Fuzzy Logic (Luis and Gazzana,2004).
- A Method for Broken Rotor Bars Diagnosis Based on Sum-Of-Squares of Current Signals (Jiageng et al, 2020).
- Detecting industrial motor faults with current signatures (Shashikumar and Vijayakumar, 2021).

### 3.5.5. Fundamentals of Monitoring of sewage sump levels

The monitoring of sewer sump levels plays a crucial role in ensuring the effective management of wastewater systems.

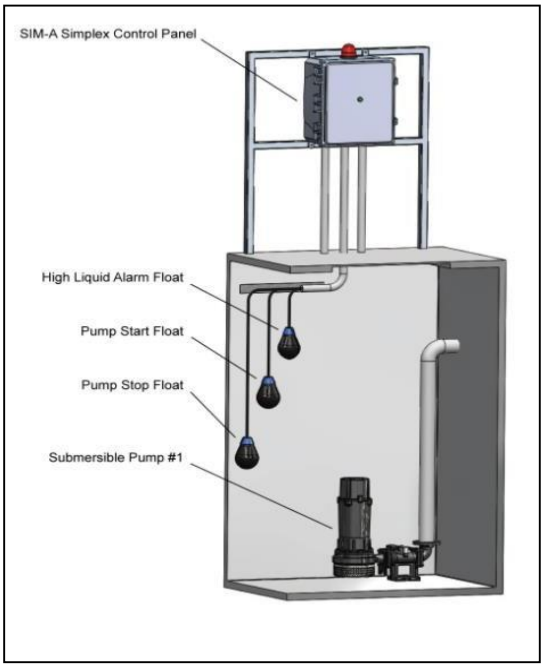



**Figure 3.15 Sewage Sump Level Monitor 1 (Seewater Inc CA, 2020)**

Sewage sump levels are monitored and set-points are established which triggers an alarm should levels go outside established set-points and a corrective action alarm is triggered. Figure 3.15 shows a typical sump level monitor using float switches. In the context of wastewater management, Figure 3.15 illustrates the utilization of various components such as a simplex control panel, pump stop float switch, pump start float switch, high liquid alarm, and a submersible pump. This hardware setup enables the continuous monitoring and control of sump levels, contributing to the efficient and reliable operation of the wastewater system. Acting as the central control unit, the simplex control panel receives inputs from different sensors and switches, providing the necessary control signals to regulate the pump operation based on the sump level.

The pump stop float switch is responsible for detecting high water levels in the sump. When the wastewater reaches a predetermined level, the float switch sends a signal to the simplex control panel, initiating the pump stop sequence to prevent sump overflow. On the other hand, the pump start float switch detects low water levels in the sump. When the water level drops below a specific threshold, the float switch signals the control panel to activate the submersible pump, effectively pumping the wastewater from the sump into the sewage system. Additionally, the system incorporates a high liquid alarm, which is triggered when the sump reaches a critical high level. This alarm provides an audible or visual alert, notifying operators or maintenance personnel of the potential risk of overflow or system malfunction. The submersible pump, a crucial component of the setup, is responsible for efficiently pumping the wastewater from the sump to the sewage system. Its activation is controlled by the simplex control panel, considering the input signals received from the float switches.

By integrating these components into the hardware setup, the sump levels in the wastewater system are continuously monitored and controlled. The simplex control panel, with inputs from the pump stop float switch, pump start float switch, and high liquid alarm, enables real-time monitoring of sump levels. It effectively regulates the operation of the submersible pump, ensuring the proper functioning of the wastewater system by preventing sump overflow and maintaining efficient wastewater transfer.

### 3.5.6. Fundamentals of Monitoring of sewage network manholes

In the monitoring of sewer manholes, several components are employed to ensure efficient and effective operation. These components include a manhole lid, high level alarm, notifications, low power data logger, critical level, sewer depth sensor, mobile app, external antenna, and third-party platform. Figure 3.16 shows a typical manhole with installed monitoring sensors. The sewage manhole pressure levels are monitored. Set points are established and should levels fall outside parameters a corrective action alarm is triggered

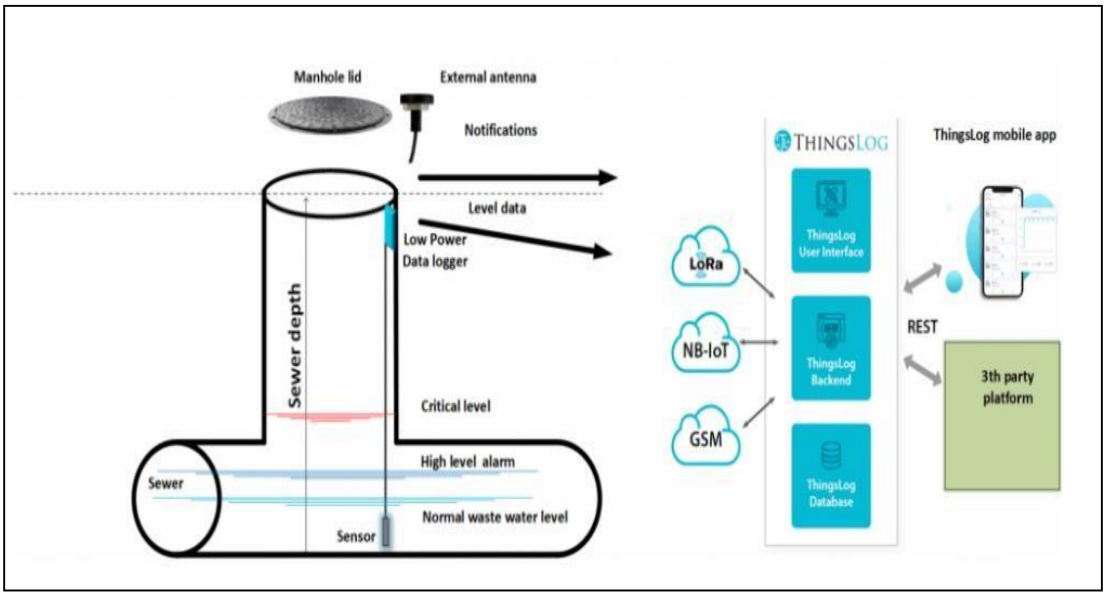



**Figure 3.16 Sewage Network manhole monitor ( Bentek Systems,2022)**

.

The manhole lid serves as the access point to the sewer system, providing a secure and easily accessible entry for maintenance and inspection activities. It also helps to prevent unauthorized access and ensure safety. To monitor the sewer levels within the manhole, a sewer depth sensor is installed. This sensor measures the depth of the wastewater within the manhole and provides real-time data on the sewer level. It acts as a key component in the monitoring system, enabling continuous and accurate measurement of the sewer depth.

If the sewer level reaches a critical point, a high-level alarm is triggered. This alarm is designed to alert operators or maintenance personnel when the wastewater level exceeds the predetermined threshold. It is in the form of an audible alarm, visual indicator, or both, depending on the specific implementation. To enhance the functionality of the monitoring system, notifications can be set up. These notifications are configured to send alerts or messages to designated personnel or stakeholders when certain conditions are met, such as when the sewer level exceeds the critical level. These notifications enable timely responses and actions to address potential issues or emergencies. It enhances the understanding of sewer levels, facilitates timely responses to critical events, and enables effective management of the sewer system. Data is collected remotely and stored within the cloud. This data is collected over a period. Figure 3.17 below is a typical data collection layout. It is made of different components.

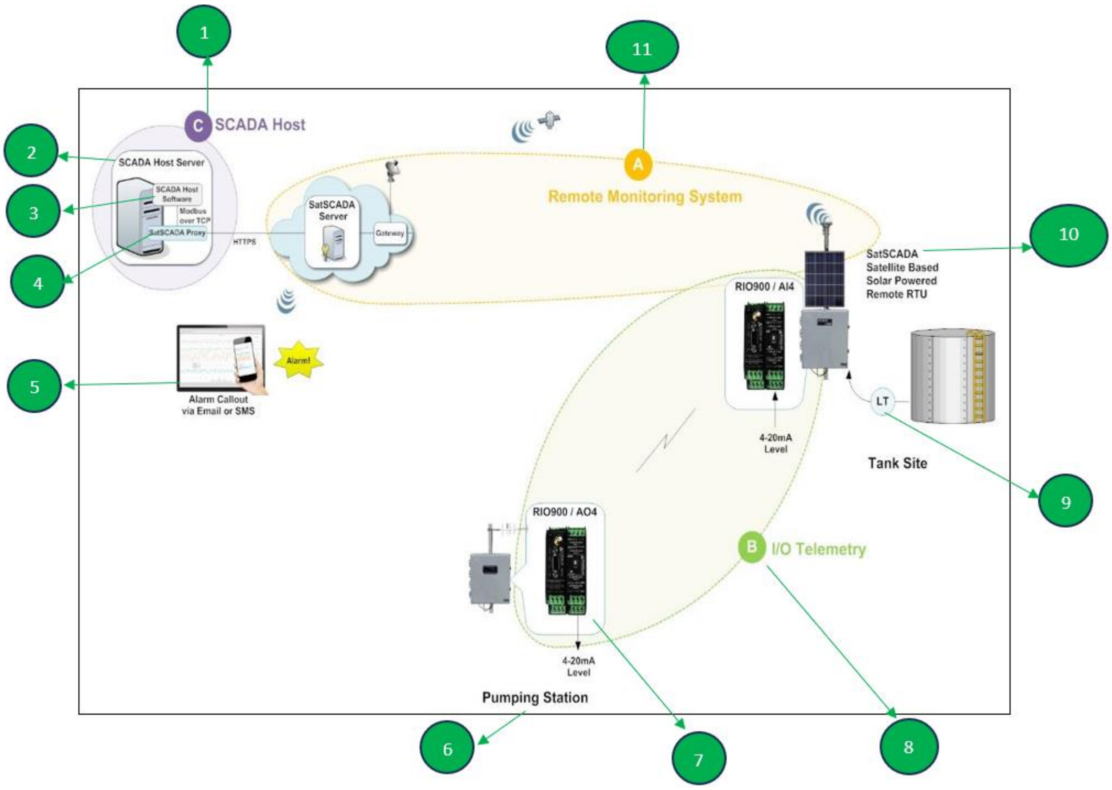



**Figure 3.17 Data collection SCADA 1( Bentek Systems,2022)**

These components work together to collect data from various sources within the closed-loop wastewater monitoring system, enabling real-time monitoring, analysis, and control to ensure the efficient and reliable operation of the wastewater infrastructure.

Each component and function is discussed below.

1- SCADA: Supervisory Control and Data Acquisition, is a system that collects real-time data from various sensors, instruments, and control devices in an industrial or infrastructure setting. In the context of wastewater monitoring, SCADA plays a crucial role in collecting data from different components of the system, such as pumps, sensors, and telemetry units.

2- SCADA Host Server: The SCADA (Supervisory Control and Data Acquisition) host server is the central computer or system that collects and manages data from various sources within the wastewater monitoring system. It serves as the hub for data storage, processing, and visualization.

3- SCADA Host Software: The SCADA host software is the application installed on the SCADA host server that enables the configuration, monitoring, and control of the wastewater monitoring system. It provides a user interface for system operators or administrators to interact with the system, view real-time data, and set up alarms or notifications.

4- SCADA Proxy: The SCADA proxy acts as an intermediary between remote devices and the SCADA host server. It facilitates secure communication and data exchange between the remote devices and the central server, ensuring reliable and efficient data transmission.

5- Alarm Callout via Email or SMS: The alarm callout feature is an essential part of the wastewater monitoring system that sends notifications or alerts to designated personnel in the event of abnormal conditions or system failures. These notifications are sent via email or SMS, ensuring that responsible individuals are promptly informed of any critical situations.

6- Pump Station: The pump station is a critical component of the wastewater monitoring system responsible for pumping wastewater from one location to another. Data collection from the pump station allows for monitoring the pump's performance, including factors such as power consumption, flow rates, and operating conditions.

7- RIO900/AI4: The RIO900/AI4 is a specific type of Remote Input/Output (RIO) device used for acquiring analog input data in the wastewater monitoring system. It allows for the collection of various analog signals, such as level measurements from level transmitters, providing valuable data for system analysis and control.

8- I/O Telemetry: Input/output (I/O) telemetry devices are used to interface with sensors and control devices within the wastewater monitoring system. They facilitate the transfer of data between the sensors, control devices, and the central monitoring system, providing real-time information about the system's status.

9- Level Transmitter: Level transmitters are sensors designed to measure the liquid level in tanks, sumps, or pipes. In the context of wastewater monitoring, level transmitters are used to measure the level of wastewater in various parts of the system, providing real-time data on the liquid levels and facilitating efficient monitoring and control.

10- Satellite-Based Solar-Powered Remote RTU: Remote Terminal Units (RTUs) are devices used to monitor and control remote equipment or systems. In a closed-loop wastewater monitoring system, a satellite-based solar-powered remote RTU enables data collection and transmission from remote locations that may not have access to wired communication infrastructure. The solar power ensures continuous operation, and the satellite-based communication enables remote data transfer.

11- Remote Monitoring System: The remote monitoring system allows for the monitoring and control of the wastewater system from a remote location. It enables operators or maintenance personnel to access real-time data, receive alarms or alerts, and make necessary adjustments to ensure optimal system performance.

To ensure seamless data collection and management, a low power data logger is employed. This device records and stores the sewer depth data over time, providing a historical record of the sewer levels. It operates with low power consumption to optimize battery life and reduce maintenance requirements. The collected data is accessed and analysed through a mobile app or a dedicated platform. These interfaces allow authorized users to view the sewer depth information, monitor trends, and generate reports for further analysis or decision-making. The mobile app provides real-time updates and access to historical data, while the platform offers a more comprehensive and centralized data management solution.

For reliable communication and data transmission, an external antenna is used to ensure strong signal strength and connectivity between the monitoring system and the mobile app or platform. This helps to ensure uninterrupted data transfer and seamless integration with the monitoring infrastructure. In some cases, the monitoring system may be integrated with a third-party platform. This platform provides additional functionalities, such as advanced analytics, data visualization, and integration with other systems or services. It enables a comprehensive and holistic approach to sewer manhole monitoring, facilitating better decision-making and system management. The monitoring of sewer manholes with the integration of components like the manhole lid, high level alarm, notifications, low power data logger, sewer depth sensor, mobile app, external antenna, and third-party platform allows for continuous monitoring and data collection.

### 3.5.7. Fundamentals of data logging and analysis

The monitoring system is designed to collect data in real-time on the operating conditions of the motors, including vibration, and power consumption variables. For this work smart monitoring motor current, vibration, and sewerage sump levels is employed.

The quantitative data collection is done to monitor:

- Wastewater pump motor current
- Wastewater pump motor vibration
- Wastewater sump level

To validate the quantitative results, the qualitative results are used to correlate the findings to establish the impact and effect of using smart technology to alleviate environmental pollution. The qualitative data collection is done through a questionnaire discussed in Chapter 5 and it is done to ascertain:

- Whether sewer spillage does occur within the vicinity of the pump station being studied and the frequency
- The turnaround time for attending to the spillage
- The available technology to predict spillage

Findings would influence the implementation of contingency plans to alleviate environmental pollution through sewer spillage.

#### 3.5.2.1. PLC selection

For quantitative data collection a Programmable Logic Controller (PLC) is employed. A PLC is a specialized computer system used to control and automate industrial processes. It is a ruggedized device designed to withstand harsh environments commonly found in factories, plants, and manufacturing facilities. The Siemens S71200 PLC is selected as it is more robust and user friendly than most other PLC's on the market. The PLC is programmed with a software called TIA portal to enable communication and data capturing of field instrumentation. The Figure 3.18 shows an S7 1200 PLC and the TIA portal software.

Data logging refers to the process of recording and storing data over time. It involves capturing and saving measurements, observations, or events from various sources such as sensors, instruments, or systems. The collected data is typically stored in a structured format for later analysis and reference.

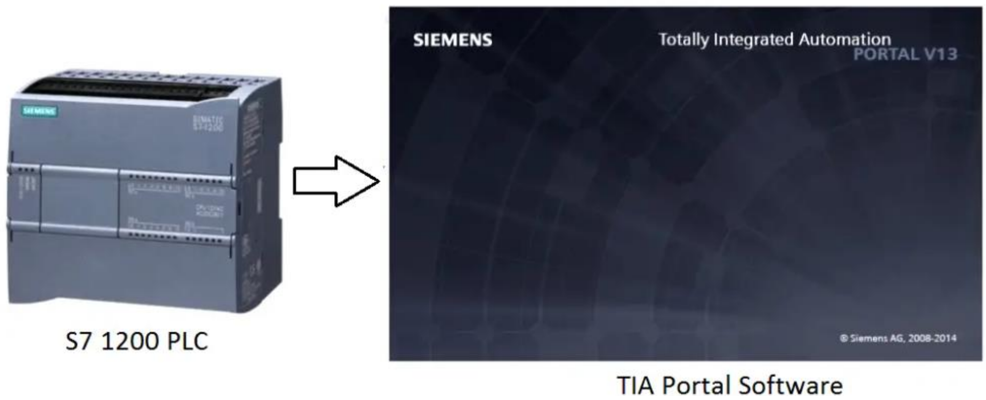



**Figure 3.18 S7 1200 PLC and the TIA portal software**

Trending, in the context of data logging, involves analysing the collected data to identify patterns, relationships, or changes over time. It enables the examination of data trends, fluctuations, or anomalies to gain insights into the behaviour or performance of a system or process. Trending helps in understanding the historical patterns and making informed decisions based on the observed trends in the data.

Data logging involves the collection and storage of data, while trending involves analysing and interpreting the collected data to identify patterns or changes over time. Both processes are valuable in various fields, including scientific research, industrial monitoring, and system analysis, as they provide valuable information for understanding and optimizing processes.

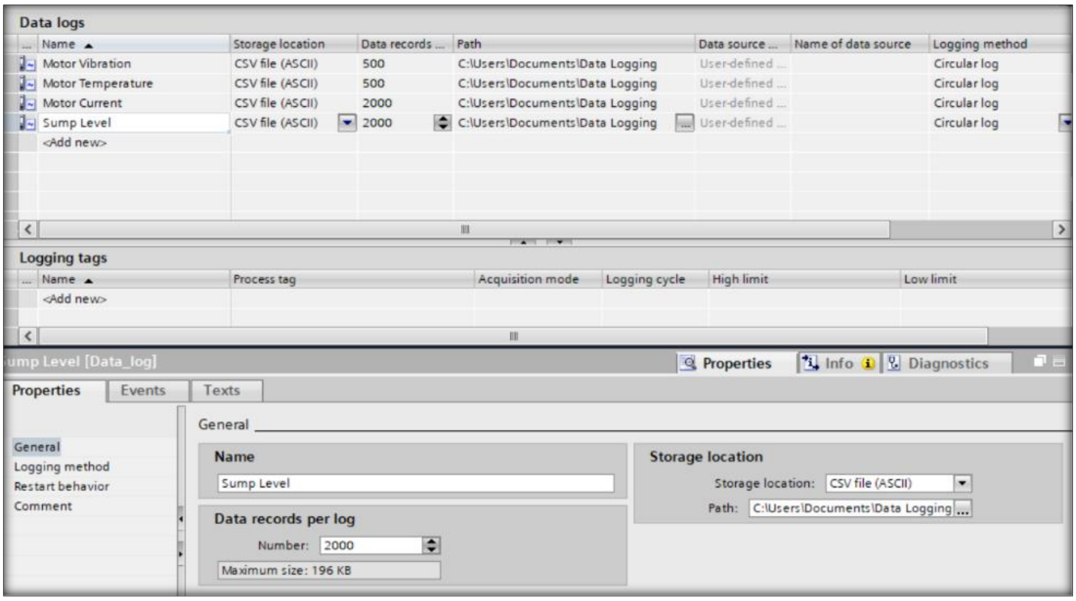



**Figure 3.19 Data logging setup with PLC software**

Figure 3.19 shows a setup of the data logging using the Siemens software TIA Portal. The data is saved on a computer hard drive accessible in a CSV or text file.

### 3.5.2.2. PC selection

A PC (Personal Computer) refers to a type of computer that is designed for individual use. It is a general-purpose computing device that performs a wide range of tasks, such as word processing, web browsing, multimedia playback, gaming, and much more. A PC typically consists of several hardware components, including a central processing unit (CPU), memory (RAM), storage devices (such as a hard drive or solid-state drive), input/output devices (keyboard, mouse, monitor), and various peripheral devices (printers, scanners, speakers, etc.). It runs an operating system (such as Windows, MacOS, or Linux) that provides a user interface and manages the computer's resources.

PCs are highly versatile and customizable, allowing users to install software applications, upgrade hardware components, and connect to external devices. They are widely used in homes, offices, educational institutions, and many other environments for personal and professional tasks. A mini-PC shown in the Figure 3.19 and Figure 3.20 is used for storage of the data and live monitoring. This mini-PC is portable, highly customizable, and affordable compared to traditional desktop computers. Furthermore, because of their size, mini-PCs do not take up much space.

**Figure 3.20 Mini-PC**

Figure 3.21 is an image showing the dimensions of the PC used.  As shown, there are various inputs and outputs of the PC.

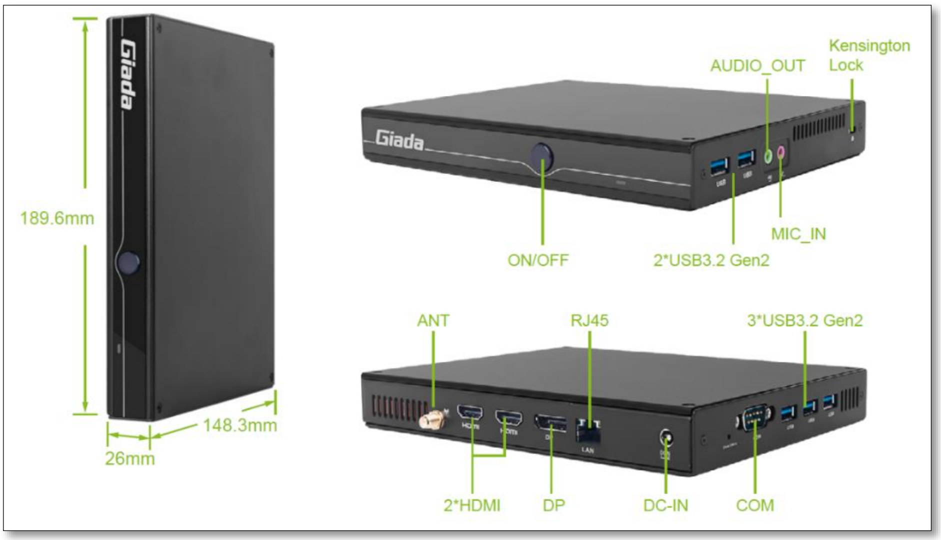


**Figure 3.21 Dimension of the PC used with various inputs and outputs.**

The displayed inputs and outputs are:

- ON/OFF: This is the power button used to turn the PC on and off.
- 2x USB 3.2 Gen2: These USB ports are used for connecting various external devices such as flash drives, external hard drives, or peripherals like keyboards and mice. USB 3.2 Gen2 provides faster data transfer speeds compared to older USB standards.
- MIC_IN: This is an input for connecting a microphone, commonly used for voice input and communication applications.
- Audio Out: This is an audio output for connecting speakers, headphones, or other audio devices to play sound from the PC.
- ANT: This term is not a standard PC input/output abbreviation. It could refer to an antenna port or connector, typically used for Wi-Fi or other wireless communication connections.
- 2x HDMI: HDMI ports are used to connect the PC to external displays such as monitors or TVs. They transmit audio and video signals.
- DP (DisplayPort): DisplayPort is another video output option for connecting the PC to external displays. It is commonly used for high-resolution monitors.
- RJ45: This is an Ethernet port used for wired network connections. It allows the PC to connect to a local area network (LAN) or the internet using an Ethernet cable.
- COM: The COM port, or serial port, is used for connecting older peripherals and equipment like serial mice, barcode scanners, or industrial devices.
- 3x USB 3.2 Gen2: Like the previous USB ports mentioned, these are used for connecting external devices with high-speed data transfer capabilities.

Each of these inputs and outputs serves specific purposes in enabling connectivity and functionality for the PC and its associated peripherals and devices.

## 3.6. Qualitative Methodology

A qualitative approach is an approach which studies the phenomena of nature, and it answers complex situations, the why factor and its aim is also to improve the natural setting by providing an intervention. One of the advantages of the qualitative approach is that probing questions may be asked from the respondents (Busetto, Wick and Gumbinger, 2020). Information is gathered using a questionnaire on the municipality's perspective; Information on existing sewer pump station monitoring; Information on the number of pump stations in Ndlambe Local

Municipality and the frequency of raw sewer spillage. Information on the causes of spillage per case reported (mechanical fault, electrical, maintenance, for instance) are also asked for.

A case study is incorporated in this study as a research design. A case study is a research design method that conducts research in its natural setting within a stipulated time frame, (Bhattaderjee, 2012). A descriptive Case Study of Ndlambe Local Municipality is used in this study. A research design is a method that is applied to collect data and analyse data. According to (Gray, 2014) the procedure displays how the research questions are responded to. The data collection techniques in qualitative approach include observation, document study, and interviews. Questions and interviews are channelled to the Water Reticulation Manager and collection is after two weeks with community feedback data collection also done via Google Forms.

### 3.7. Chapter Summary

Chapter 3 investigates the smart sensor monitoring system within sewer pump stations using a mixed-methods approach. This Chapter details the implemented work. It further underscores the importance of smart sensor applications in ensuring efficient and reliable sewer systems, ultimately reducing environmental pollution while highlighting the critical need for monitoring and managing sewer spillage, especially in informal settlements. The chapter details the sewer pump station components, emphasizing their role in wastewater treatment. It covers the electrical and communication infrastructure, stressing the importance of system architecture. The focus is on sewage pump motor current and vibration monitoring, emphasizing set-points and feedback mechanisms for system reliability. Vibration sensors detect mechanical issues, while current sensors offer practicality and effectiveness. The communication path for data collection and analysis enhances overall efficiency and maintenance.

Chapter Four presents the use of smart sensors to monitor sewer infrastructure to alleviate environmental pollution. The sewer pump station is the specific point of monitoring where the pump motor vibration, current and sump levels are monitored.

# CHAPTER 4:
# SEWER PUMP STATION SMART SENSOR MONITORING
## 4.1 Introduction

Chapter Four introduces the monitoring of Mbabela Pump Station using smart sensors to address sewer spillage. The Smart Sewer Infrastructure Monitoring Prototype aims to mitigate environmental pollution by enhancing monitoring and response mechanisms. This chapter further proposes a Smart Sewer Diversion pit as part of the solution to alleviate environmental pollution due to sewer spillage.

Section 4.2 presents the theoretical analysis and contribution of a smart sensor system aimed at averting sewer spills through a smart sump. Section 4.3 presents "Smart Control Program Flow Charts," the core of our research methodology for sewer infrastructure management and environmental protection. Section 4.4 details the System Design and Monitoring. Section 4.5 presents the practical implementation of the motor current and vibration sensors. Section 4.6 discusses the analytical insights and validation of the results. Section 4.7 provides the conclusion to this chapter.

## 4.2. Theoretical: Smart Sewer Infrastructure Monitoring System Overview And Control Architecture

Incorporating insights from both the literature review and a survey outlined in Chapter 6, a smart sensor monitoring system is designed and implemented. Beyond utilizing standard off-the-shelf smart sensors, a specialized smart sewer diversion pit is designed as the researcher’s contribution to the solution. The primary goal of this system is to employ intelligent sewer infrastructure monitoring to mitigate environmental pollution.

The key objectives of this smart sensor solution have an influence on whether smart sensors can contribute towards alleviation of sewer spillage. The key objectives are listed below:

- Building Redundancy/Contingency for Fault Resolution (Theoretical and Practical Implementation)
- Real-Time Communication of Failures (Implemented)
- Design of a Smart Sewer Diversion Pit for Environmental Protection (Implemented)

### 4.2.1. System Overview Above Ground

Figure 4.1 shows the overview of the system above ground. It further gives a bit of detailed information of the monitoring equipment installed underground.

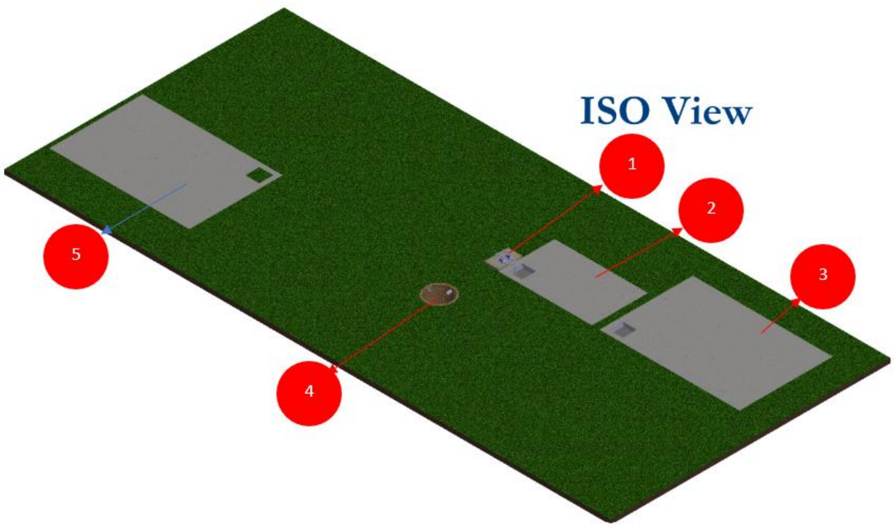



**Figure 4.1 Smart Sewer Infrastructure Monitor Overview-Above Ground**

Legend:

1- Above ground wastewater pumps: The wastewater abstraction system incorporates above-ground wastewater pumps, which are strategically located near the raw water sumps. These pumps are responsible for extracting screened wastewater and transporting it to the wastewater treatment facility tank through a manhole. To ensure spillage-free operation, the pumps are equipped with smart control capabilities. In a duty/standby configuration, the standby pump is activated in the event of a failure or scheduled rest period every 24 hours, effectively preventing any disruption in wastewater flow and minimizing the risk of environmental contamination.

2- Wastewater sump: The sump collects raw wastewater from the community through gravity feedlines. Waste from this sump is conveyed to the wastewater treatment plant using the above ground wastewater pumps.

3 & 5- Smart Diversion Pit: The implementation of a Smart Diversion Pit is proposed to enhance redundancy and prevent immediate sewer spillage when the main sump or manhole reaches capacity. Equipped with smart technology, the diversion pit utilizes signals from sewer infrastructure monitoring equipment to intelligently open and close,

diverting the flow of sewage as needed. This innovative solution ensures effective management of wastewater levels and minimizes the risk of environmental contamination.

4-Wastewater Manhole: Cylindrical structure that provides access to an underground sewer system. It is made of durable materials like concrete or brick and has a cover at the top for entry and inspection. Manholes allow maintenance, repair, and monitoring of the sewer system and may contain equipment for flow control and monitoring.

### 4.2.2. System Overview Below Ground

Figure 4.2 gave the design overview from above ground. A transparent view of what is underground is shown in Figure 4.3. The key smart control components are numbered with the legend clarifying the components.

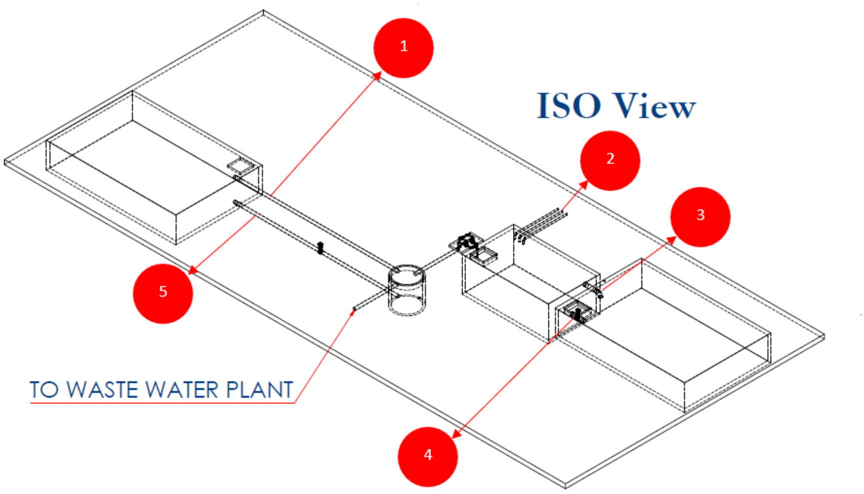



**Figure 4.2 Smart Sewer Infrastructure Monitor Overview-Below Ground**

Legend:

1- Sewer manhole overflow pipe (from manhole to smart diversion pit)
   - Sewage overflows using gravity when the manhole fills up
   - Sewer pipes from the community feeding into the local sewer sump
   - Gravity fed

2- Sewer sump overflow pipe (from the sump to the smart diversion pit)
   - Sewage overflows using gravity when the main sump fills up

3- Sewer sump overflow pipe (from the smart diversion pit to the sump)
   - An actuated valve is used to control the opening and closing of this overflow pipe

4- Sewer sump overflow pipe (from the smart diversion pit to the manhole)

- An actuated valve is used to control the opening and closing of this overflow pipe

### 4.2.3. System Overview Dimensions and Smart Sewer Diversion Pit

Figure 4.3 and Figure 4.4, below give the dimensions of the proposed system. An explanation on the design of the unit is given to justify the indicated sizes and dimensions.

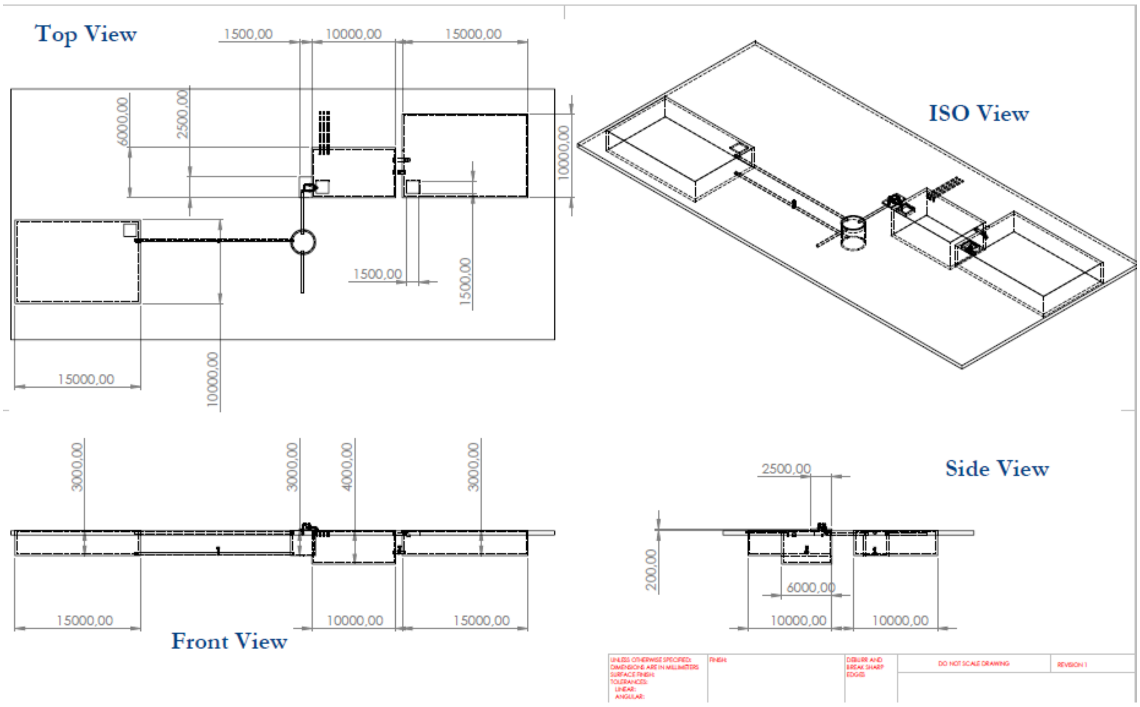



**Figure 4.3 System Overview Dimensions**

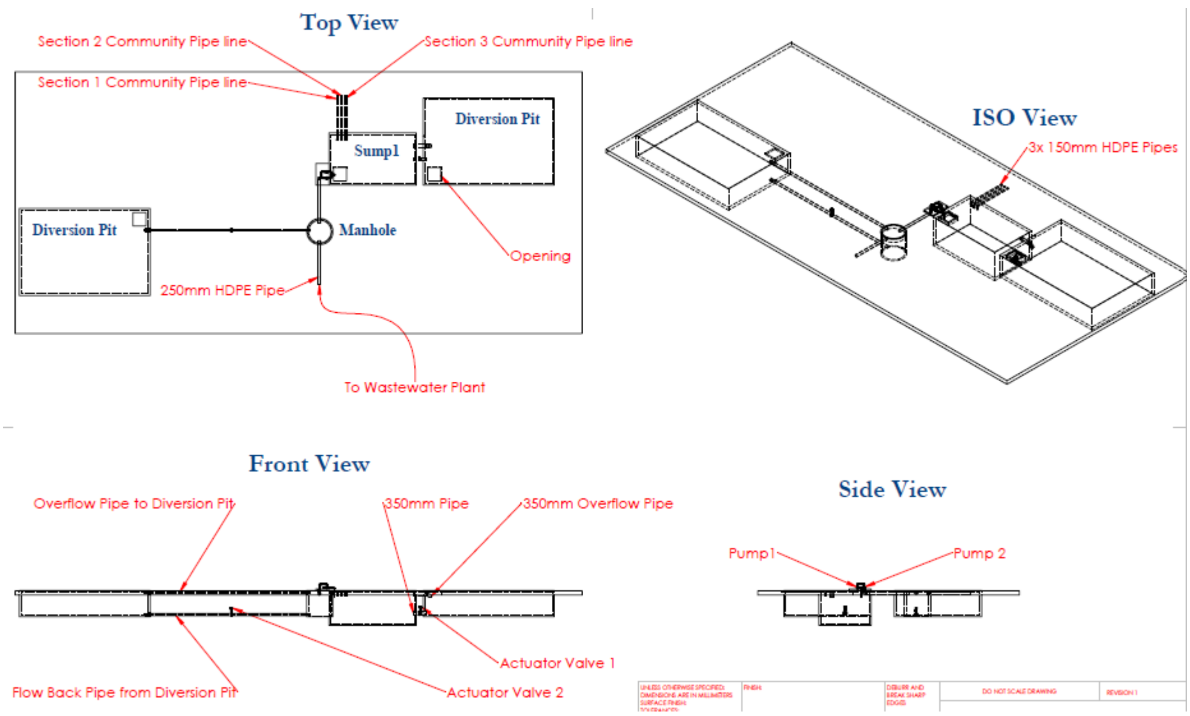



**Figure 4.4 System Overview Pipe Dimensions**

To enhance redundancy and prevent environmental pollution during pump failures or near-spillage scenarios, the prototype incorporates a smart sewer diversion pit. In instances where the pump trips or the manhole levels reach a critical point, threatening to spill sewage, the diversion pit automatically activates. The sewage is redirected to the diversion pit, effectively preventing environmental contamination. This smart feature buys time for resolving the underlying issue while ensuring the sewage is contained and safely managed within the diversion pit.

The integration of the smart sewer diversion pit adds an additional layer of environmental protection and operational efficiency to the Smart Sewer Infrastructure Monitoring Prototype. Together with the standby pump system, real-time communication, and GIS capabilities, it forms a comprehensive solution for minimizing sewage spillage, reducing response times, and enhancing the overall management of sewer infrastructure.

In the design of the smart diversion pit, the following assumptions are made:

- Feed lines into the sump bring a combined flow of approximately 150m3/hr maximum
- The material used for the smart diversion sump is compliant to the Civil Requirements as per existing sump

- The flow to the manhole is the same as the sump flowrate
- Smart solution must be able to hold sewage for a period of 4 hours before spillage occurs
- The problem will get resolved within 4 hours
- Inflow into sump 1: 150 $m^3$/hr
- Inflow into the diversion pit: 150 $m^3$/hr
- Sump 1 capacity: 180 $m^3$
- Desired duration for both sump 1 and the diversion pit to hold overflow: 4 hours
- Manhole fill-up flowrate same as sump fill up flowrate
-

Figure 4.5 shows the smart pit overview. The purpose of the smart pit is to employ smart sensors to contain sewer spillage in a pit automatically while the pump station is being fixed. The smart pit aims to alleviate sewer spillage to the environment through the implementation of smart sensors to auto-divert overflow sewage to a pit.

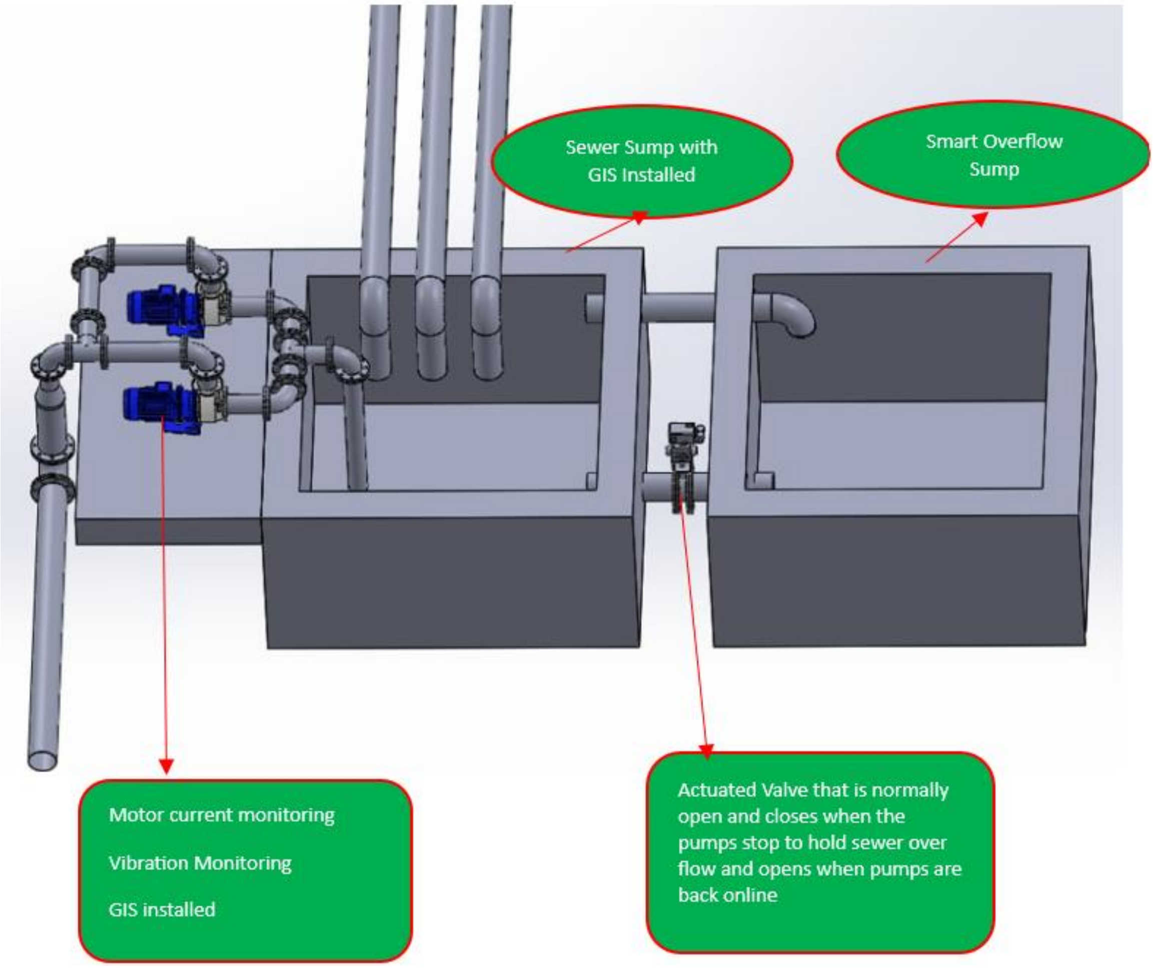



**Figure 4.5 Smart Pit Overview**

To calculate the time, it will take for the existing sump to fill up.

- $Time\ to\ fill\ up = Sump\ volume\ /\ Inflow\ rate$
- $Time\ to\ fill\ up = 180\ m^3\ /\ 150\ m^3/hr$
- $Time\ to\ fill\ up \approx 1.2\ hours$

Therefore, it will take approximately 1.2 hours for the sump to fill up completely with an inflow rate of 150 m³/hr. To calculate redundancy a diversion pit that can hold additional overflow for approximately 3 hours is to be designed. This pit size is designed based on the assumptions above and the calculations below.

- $Required\ pit\ volume\ =\ Inflow\ rate\ *\ Holding\ time$
- $Required\ pit\ volume\ =\ 150\ m^3/hr\ *\ 3\ hr$
- $Required\ pit\ volume\ =\ 450\ m^3$

Therefore, a pit volume of 450 m³ to hold the incoming flowrate of 150 m³/hr for a period of 3 hours is required. Considering the above, the smart diversion dimensions are established as 3m depth (considering the existing sump depth and the need for flow back to the existing sump using gravity), width of 10m and length of 15m.

In case of an emergency both sumps are designed to hold sewage for a period of 4 hours and 20 minutes while the matter is being resolved if the inflow into the sump is 150m3/hr. The integration of the smart sewer diversion pit in the prototype showcases the significance of redundancy and environmental protection. This intelligent solution plays a vital role in preventing pollution and ensuring the immediate containment of sewage during pump failures or critical manhole levels that could lead to spillage. Through real-time communication and Geographic Information System (GIS) capabilities, the smart diversion pit can promptly activate, redirecting the sewage flow to prevent environmental contamination.

Figure 4.6 and Figure 4.7 give further views on the Smart Diversion Pit.

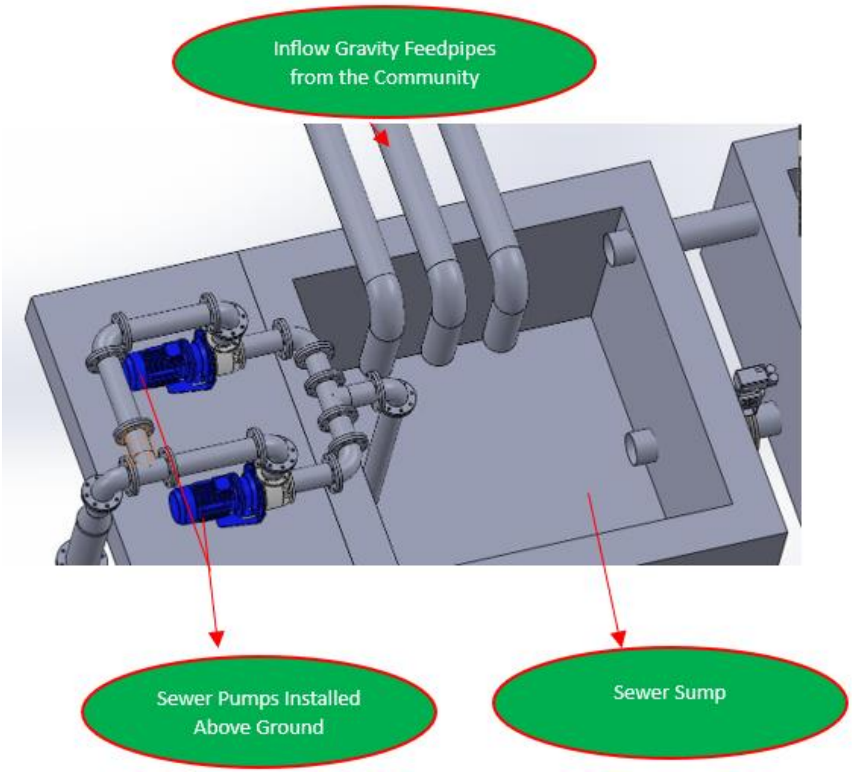



**Figure 4.6 Sewer Sump View**

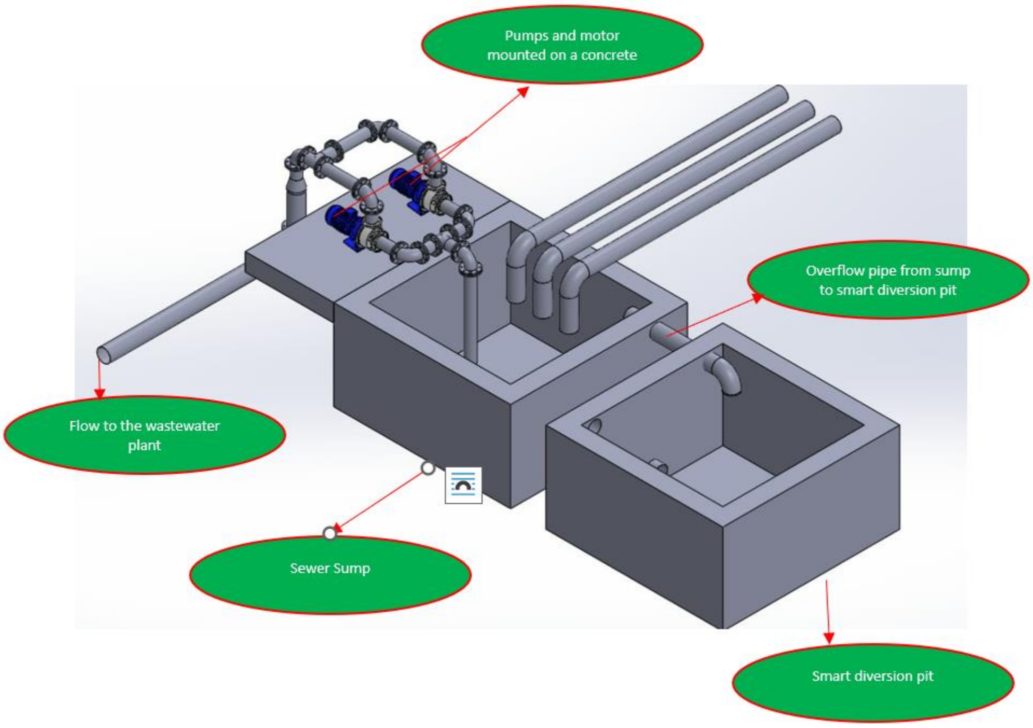



**Figure 4.7 Smart Diversion Pit Top View**

In summary, Figure 4.1 provides an overview of the above-ground system, offering detailed information on the installed monitoring equipment underground. The legend explains various components, such as above-ground wastewater pumps, wastewater sump, and Smart Diversion Pit, outlining their roles in the sewage infrastructure. The legend for Figure 4.2.2 illustrates the underground system, detailing components like sewer manhole overflow pipes, sewer pipes from the community, and sewer sump overflow pipes. Figure 4.2.3 presents dimensions and features of the proposed system, emphasizing the importance of a smart sewer diversion pit to prevent environmental contamination during pump failures or near-spillage scenarios.

The smart sewer diversion pit is a critical addition to the prototype, automatically activating when issues arise, redirecting sewage flow to prevent environmental harm. Assumptions about flow rates, materials, and problem resolution within four hours guide the design considerations. Calculations determine the required pit volume for holding overflow, establishing dimensions of 3m depth, 10m width, and 15m length. Figure 4.5 demonstrates the overview of the smart pit, including calculations for sump fill-up time and required pit volume for redundancy. The smart diversion pit, integral to the prototype, plays a crucial role in preventing pollution during emergencies, showcasing the significance of redundancy and environmental protection.

The integration of the smart sewer diversion pit, standby pump system, real-time communication, and GIS capabilities collectively fortifies the Smart Sewer Infrastructure Monitoring Prototype. This comprehensive approach not only minimizes sewage spillage risks but also enhances response times and overall sewer infrastructure management. Figures 4.6 and 4.7 provide additional perspectives on the Smart Diversion Pit, reinforcing its role in environmental protection and operational efficiency.

The next section focuses on the smart sensor flow charts and control.

## 4.3. Smart Sensor Flowcharts and Control

With the system overview established, Figure 4.8 zooms a bit into the overview of the smart monitoring instruments employed in this system

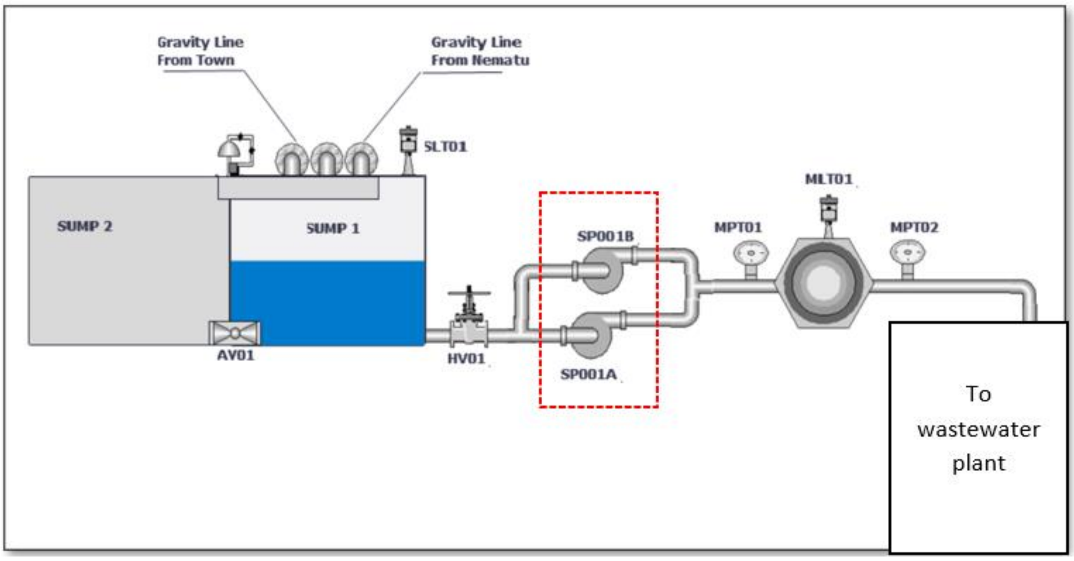



**Figure 4.8 Overview of analytical equipment**

Legend:

- AV101- This is a pneumatic actuated valve that controls the flow of sewage between sump 1 and the smart diversion sump labelled as Sump 2
- SLT01- Sewer sump continuous level transmitter: This device continuously measures and monitors the sewage level. In this specific instance it utilizes vibration, current, and pressure as triggers to measure and monitor the sewage level. The transmitter employs these technologies to provide real-time and accurate data, enabling proactive measures to prevent overflow and enhance the management of the sewer system.
- SP001A- Sewer sump pressure indicating transmitter: This is a device used to measure and display the pressure this one is specifically measuring pump 1. It uses a pressure sensor to detect the fluid pressure and converts it into an electrical signal. This signal is then displayed on a digital indicator or transmitted to a control system for monitoring and control purposes.
- SP001B- Sewer sump pressure indicating transmitter: This is a device used to measure and display the pressure this one is specifically measuring pump 2.
- MPT01- Manhole pressure indicating transmitter This is a device used to measure and display the pressure this one is specifically measuring manhole pressure at point 1.

- MPT02- Manhole pressure indicating transmitter: This is a device used to measure and display the pressure this one is specifically measuring manhole pressure at point 2.

- MLT01- Manhole continuous level transmitter: This device that continuously measures and monitors the sewage level. In this specific instance it utilizes pressure as a trigger to measure and monitor the sewage level.

Having established the system overview, the System Control Program Flow Chart clearly describes how the smart monitoring is done. The following sections paint a clear picture on the program flow chart for each intelligent and smart point to validate its relevance in the alleviation of sewer overflow into the environment. The key features used communicate the following:

- Use of smart vibration, level and current sensors to pick an error in the system
- Sensors immediately shutdown the pumps as per programmed thresholds to protect them
- The shutdown of the sewer pumps automatically gets communicated to the maintenance manager
- The communication is via SMS and provide the specific location of the pump station or manhole that is faulty using GIS
- The smart diversion pit opens and closes as required to ensure there is no sewer spillage for a period of at least 4 hours

### 4.3.1. Sump Level Program Flowchart: Smart Monitoring

The flowchart outlines a program that scales a 4-20 mA measured value from the Sump Level Transducer (SLT01) to obtain a real number value that is utilized within the program. The first step is to check if the scaled measured value falls within the sensor's measuring range. If it does not, the program stops scaling and sets a fault bit to indicate that the "SLT01 Sump level sensor" is faulty. This fault message is displayed on the HMI screen, and a fault message text is sent to the operator's phone via GSM.

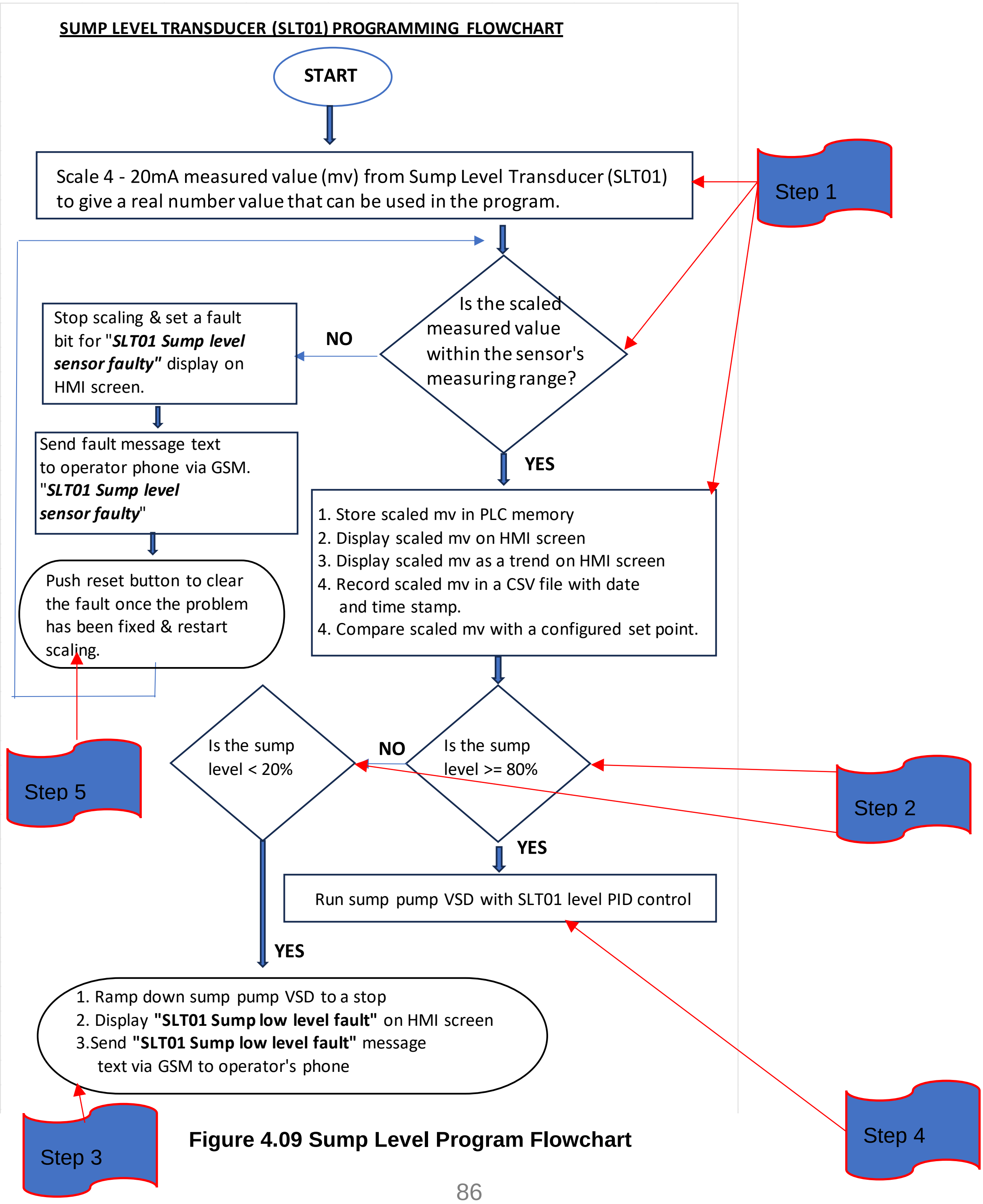



**Figure 4.09 Sump Level Program Flowchart**

Step 1: Start. If the scaled measured value is within the measuring range, the program proceeds to store the scaled value in the PLC memory with Cloud backup and displays it on the HMI screen. Additionally, the scaled value is shown as a trend on the HMI screen and recorded in a CSV file with a date and time stamp.

Step 2: The program also compares the scaled value with a configured set point. If the sump level is less than 20%, or if it is equal to or greater than 80%, specific actions are taken.

Step 3: If the sump level is less than 20%, the program activates the sump pump Variable Speed Drive (VSD) with SLT01 level PID control.

Step 4: If the sump level is equal to or greater than 80%, the program ramps down the sump pump VSD to a stop. In both cases, a "SLT01 Sump low level fault" message is displayed on the HMI screen, and a corresponding fault message text is sent via GSM to the operator's phone.

Step 5: To clear the fault once the problem is resolved, the operator needs to push the reset button, which restarts the scaling process.

Overall, the flowchart illustrates a program that scales the measured value from the SLT01 sump level sensor, performs various actions based on the scaled value, and provides fault notifications and communication to the operator for prompt response and troubleshooting.

### 4.4. Impact of smart sump monitoring in alleviating sewer spillage

The impact of implementing the flowchart in the research context is substantial, as it directly addresses the goals of alleviating sewage overflow to the environment and incorporating smart functionalities into the system. The following points highlight the impact of the flowchart:

Efficient error detection and prevention: By utilizing intelligent sensors and programmed thresholds, the flowchart effectively detects errors in the system. Immediate shutdown of pumps based on these thresholds prevents further damage, safeguards the infrastructure, and minimizes the risk of sewage overflow. This proactive approach significantly reduces the environmental impact of sewage spills.

- Timely communication and maintenance response: The flowchart's automatic communication feature ensures prompt notification to the maintenance manager via SMS. The inclusion of location details using GIS technology further enhances the response by providing precise information about the faulty pump station or manhole. This enables swift intervention and targeted maintenance actions, minimizing downtime and potential environmental risks.

- Enhanced control and containment through the smart diversion pit: The integration of a smart diversion pit in the flowchart adds an extra layer of protection against sewage spillage. By opening and closing as required, the diversion pit effectively contains the overflow and prevents environmental pollution. This feature ensures that the system can maintain uninterrupted operation for at least 4 hours, mitigating the impact of potential pump failures or critical conditions.
- Improved environmental sustainability: The overall impact of implementing the flowchart is a significant reduction in environmental harm caused by sewage overflow. By promptly detecting errors, initiating pump shutdowns, and diverting the sewage to a designated pit, the flowchart minimizes the risk of contamination to nearby water bodies and ecosystems. This contributes to the preservation and sustainability of the environment.

The implementation of the smart sump monitoring within the research context has a profound impact on mitigating sewage overflow to the environment. The efficient error detection, timely communication, utilization of smart diversion techniques, and overall focus on environmental sustainability collectively contribute to reducing the ecological footprint and ensuring the long-term viability of the wastewater system.

### 4.4.1. Sewer Pumps Smart Monitoring Program Flowchart

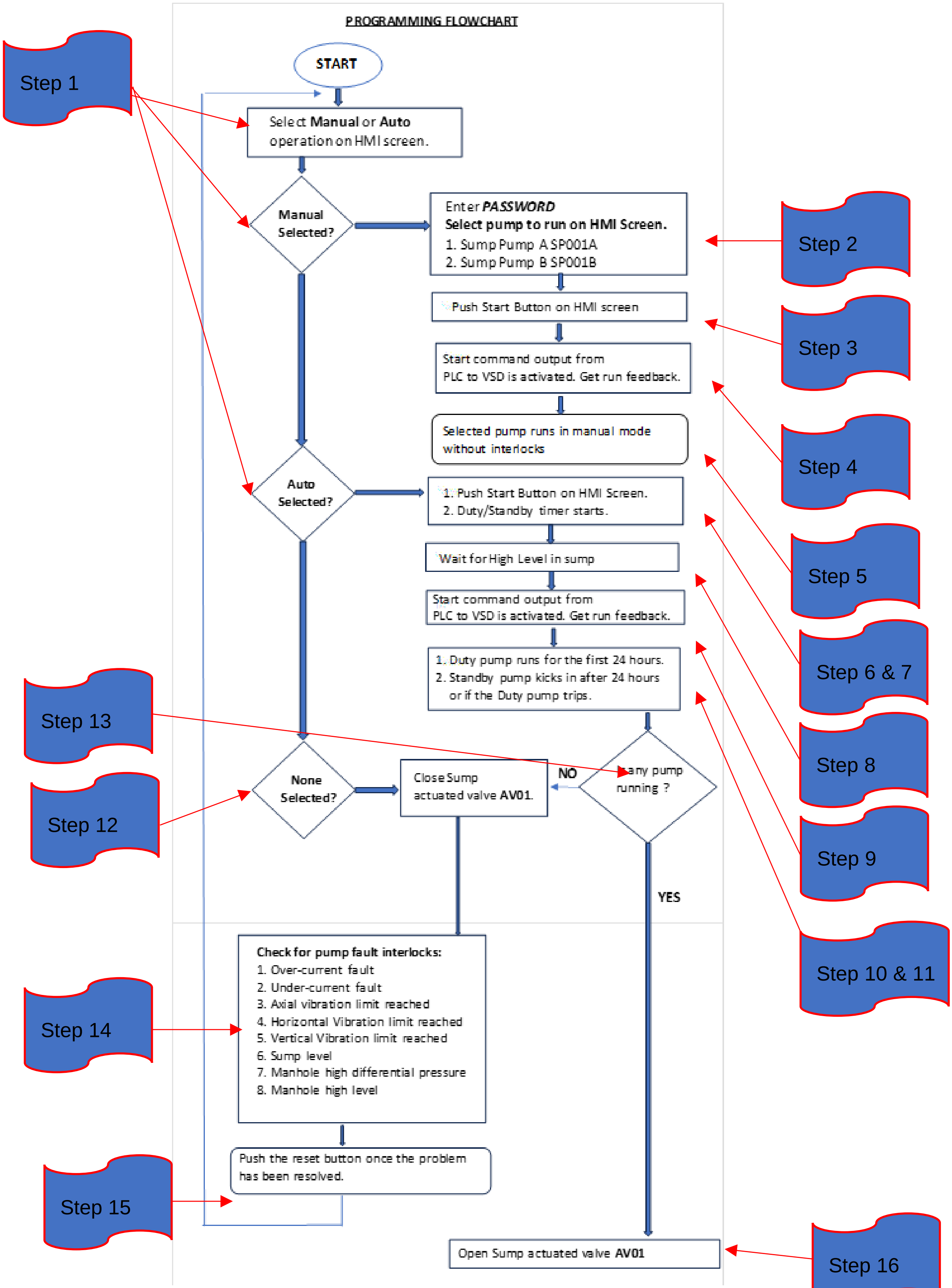



**Figure 4.10 Sewer Pumps Smart Monitoring Program Flowchart**

The steps for Figure 4.10 are detailed below:

START:

Step 1: Select Manual or Auto operation on HMI screen.

Step 2: Is the selected pump running in Auto mode? (YES/NO)

- If YES:
    - Enter PASSWORD and select the pump to run on the HMI Screen.
- If NO, proceed to Step 3.

Step 3: Push Start Button on HMI screen.

Step 4: Start command output from PLC to VSD is activated. Get run feedback.

Step 5: Is the selected pump running in manual mode without interlocks? (YES/NO)

- If YES, go to "Start command output from PLC to VSD is activated. Get run feedback."
- If NO, proceed to Step 6.

Step 6: Duty/Standby timer starts.

Step 7: Push Start Button on HMI Screen.

Step 8: Wait for High Level in the sump.

Step 9: Start command output from PLC to VSD is activated. Get run feedback.

Step 10: Standby pump kicks in after 24 hours or if the Duty pump trips.

Step 11: Duty pump runs for the first 24 hours.

Step 12: None selected? - If NONE, go back to check for pump fault interlocks. - If SELECTED, proceed to Step 13.

Step 13: Is any pump running? (YES/NO) - If YES, close Sump actuated valve AV01. - If NO, continue to Step 14.

Step 14: Check for pump fault interlocks: - Over-current fault - Under-current fault - Axial vibration limit reached - Horizontal Vibration limit reached - Vertical Vibration limit reached - Sump level - Manhole high differential pressure - Manhole high level

Step 15: Push the reset button once the problem has been resolved.

Step 16: Open Sump actuated valve AV01.

### 4.4.2. Sewer Pump Motor Axial, Horizontal and Vertical Vibration Monitoring Program Flowchart

The figure below illustrates the flowchart of the overall motor vibration monitoring system.

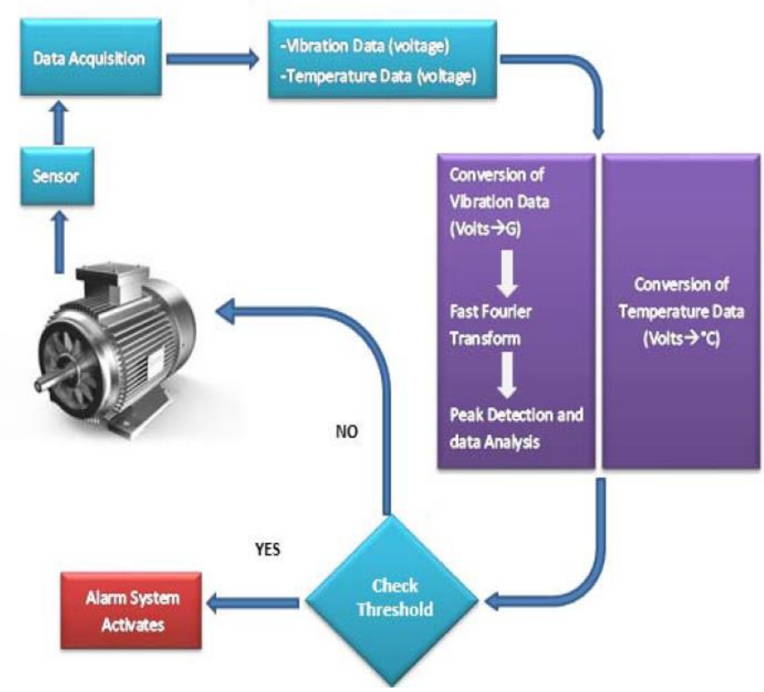



**Figure 4.11 Flowchart of the vibration monitoring system (S. S Goundar;2015)**

Figure 4.12, Figure 4.13 and Figure 4.14 shows flowcharts indicating how the monitoring of motor vibration is used to alleviate sewer spillage. The sensors employed in this control philosophy, namely the axial vibration transducer (AVT01), horizontal vibration transducer (HVT01), and vertical vibration transducer (VVT01), share a common control approach. These sensors provide a 4-20mA measured value (mv) that is scaled to a real number value, enabling its utilization within the program.

Step 1: The control philosophy encompasses various actions such as storing the scaled mv in PLC memory, displaying it on the HMI screen, recording it in a CSV file with a timestamp, and comparing it with a configured set point.

Step 2: Fault detection and communication are integral parts of this philosophy, where fault messages are sent via GSM to the operator's phone when sensor malfunctions occur.

Step 3: Additionally, interlocks are set and displayed on the HMI screen to initiate appropriate responses, including ramping down the sump pump Variable Speed Drive (VSD) to a stop in the event of high axial, horizontal, or vertical vibration.

This control philosophy not only facilitates real-time monitoring and analysis but also enables efficient maintenance and timely response to sensor faults. By incorporating these intelligent sensing and control mechanisms, the system ensures the reliable and safe operation of the sump pumps while actively addressing potential issues related to axial, horizontal, and vertical vibrations. The flowcharts are discussed at the bottom to shed light on the proposed system.

### 4.4.3. Sewer Pump Motor Horizontal Vibration Monitoring Program Flowchart

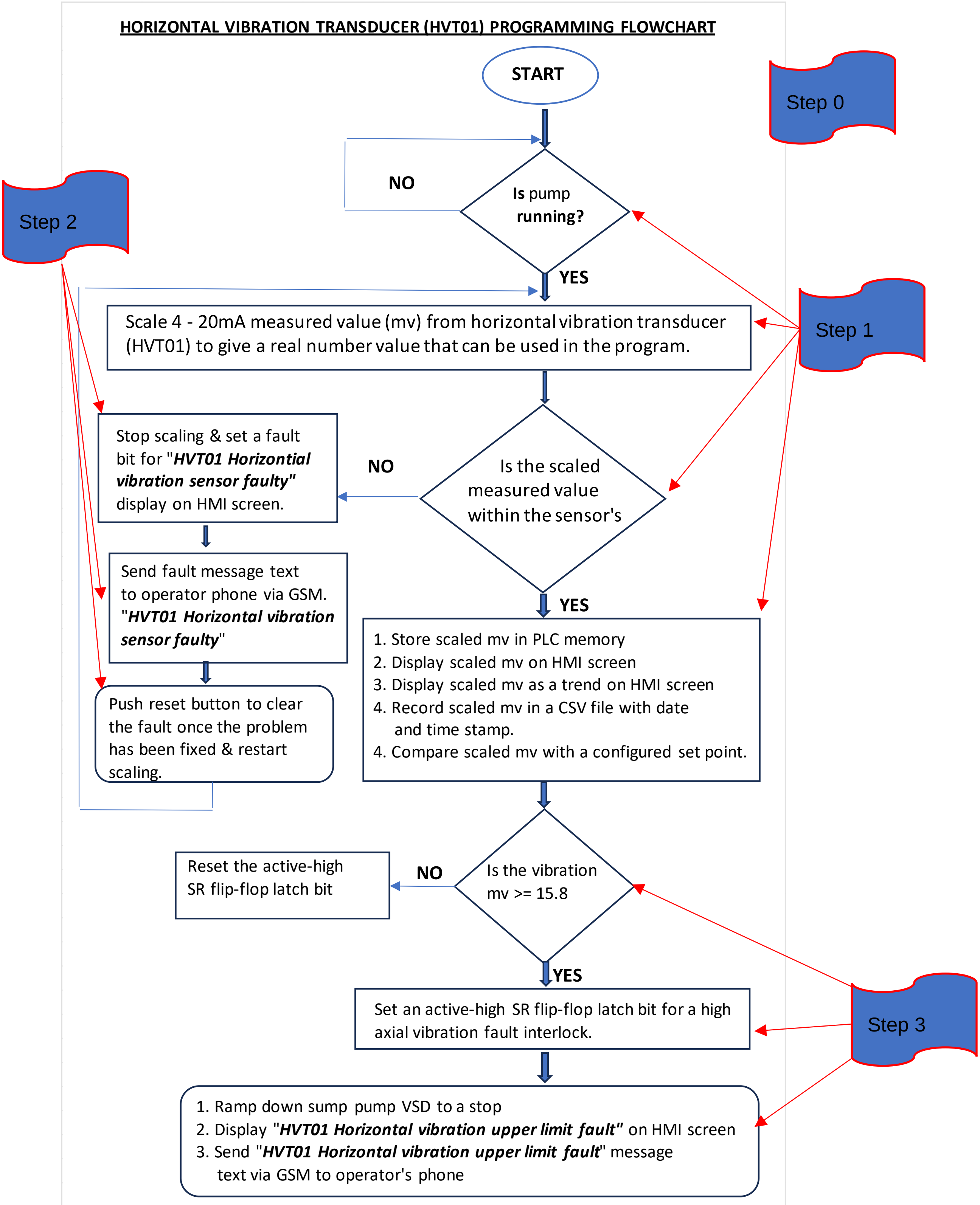



**Figure 4.12 Sewer Pump Motor Horizontal Vibration Monitoring Program Flowchart**

### 4.4.4. Sewer Pump Motor Axial Vibration Monitoring Program Flowchart

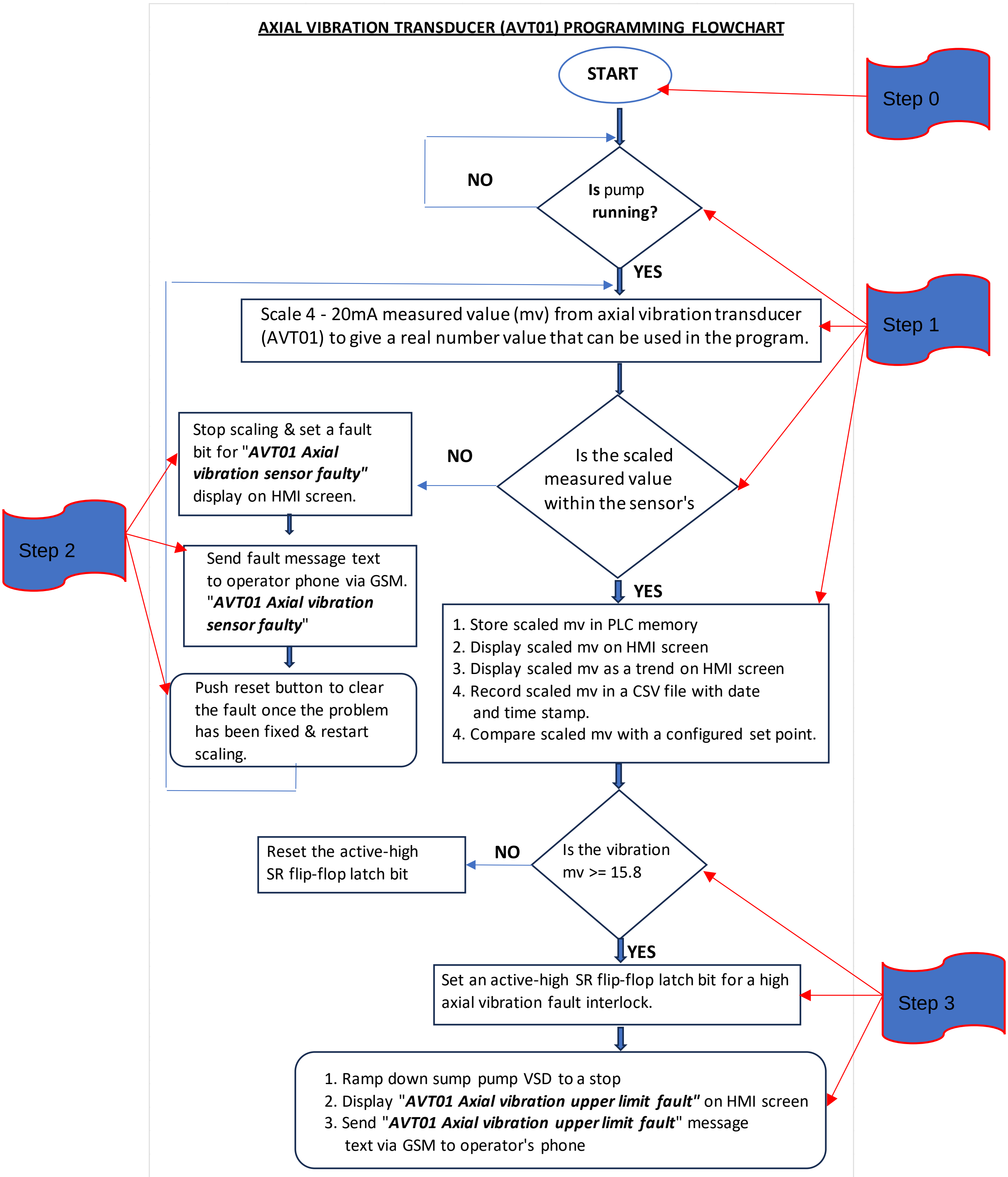



**Figure 4.13 Sewer Pump Motor Axial Vibration Monitoring Program Flowchart**

### 4.4.5. Sewer Pump Motor Vertical Vibration Monitoring Program Flowchart

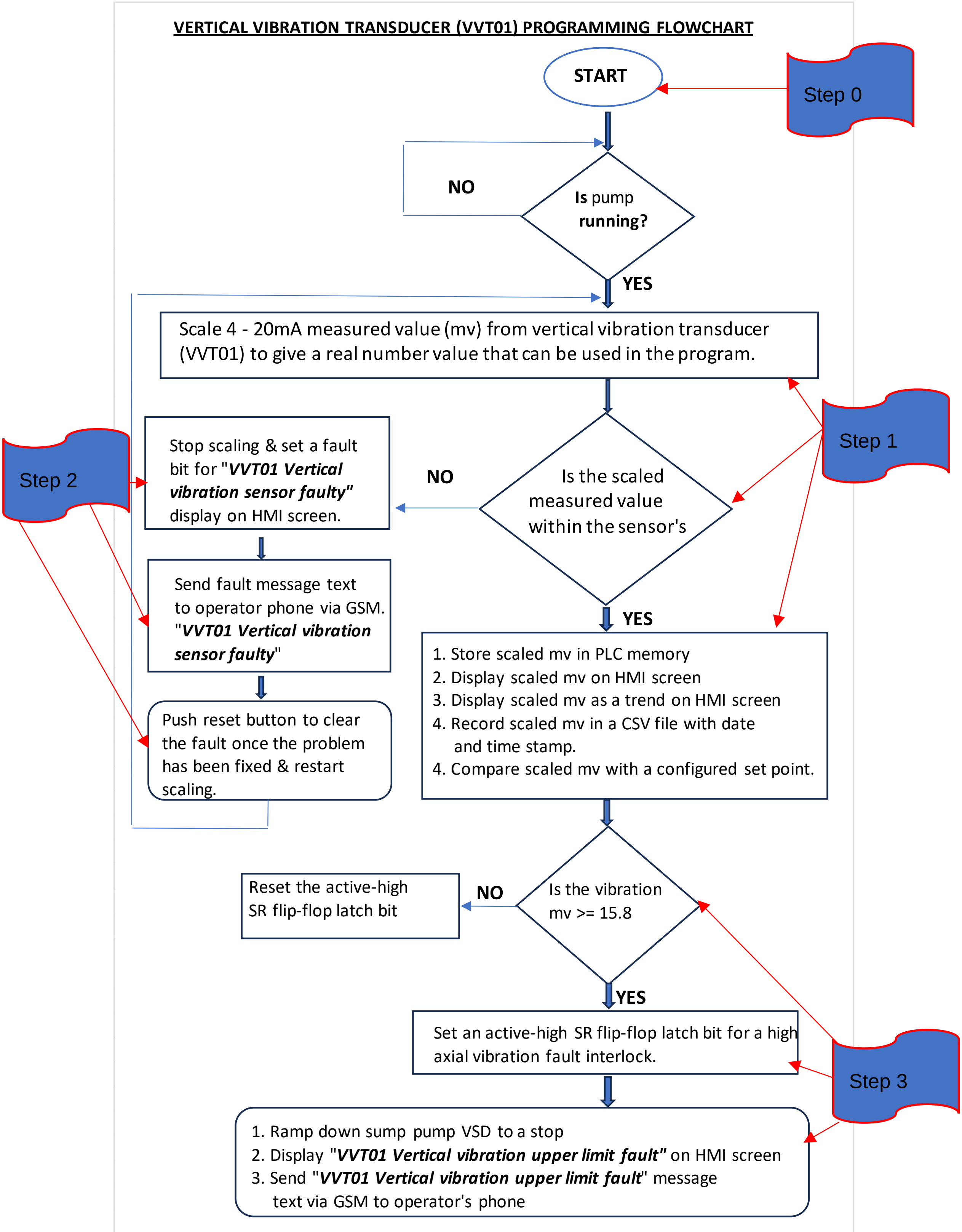



**Figure 4.14 Sewer Pump Motor Vertical Vibration Monitoring Program Flowchart**

### 4.4.6. Sewer Pump Motor Current Monitoring Program Flowchart

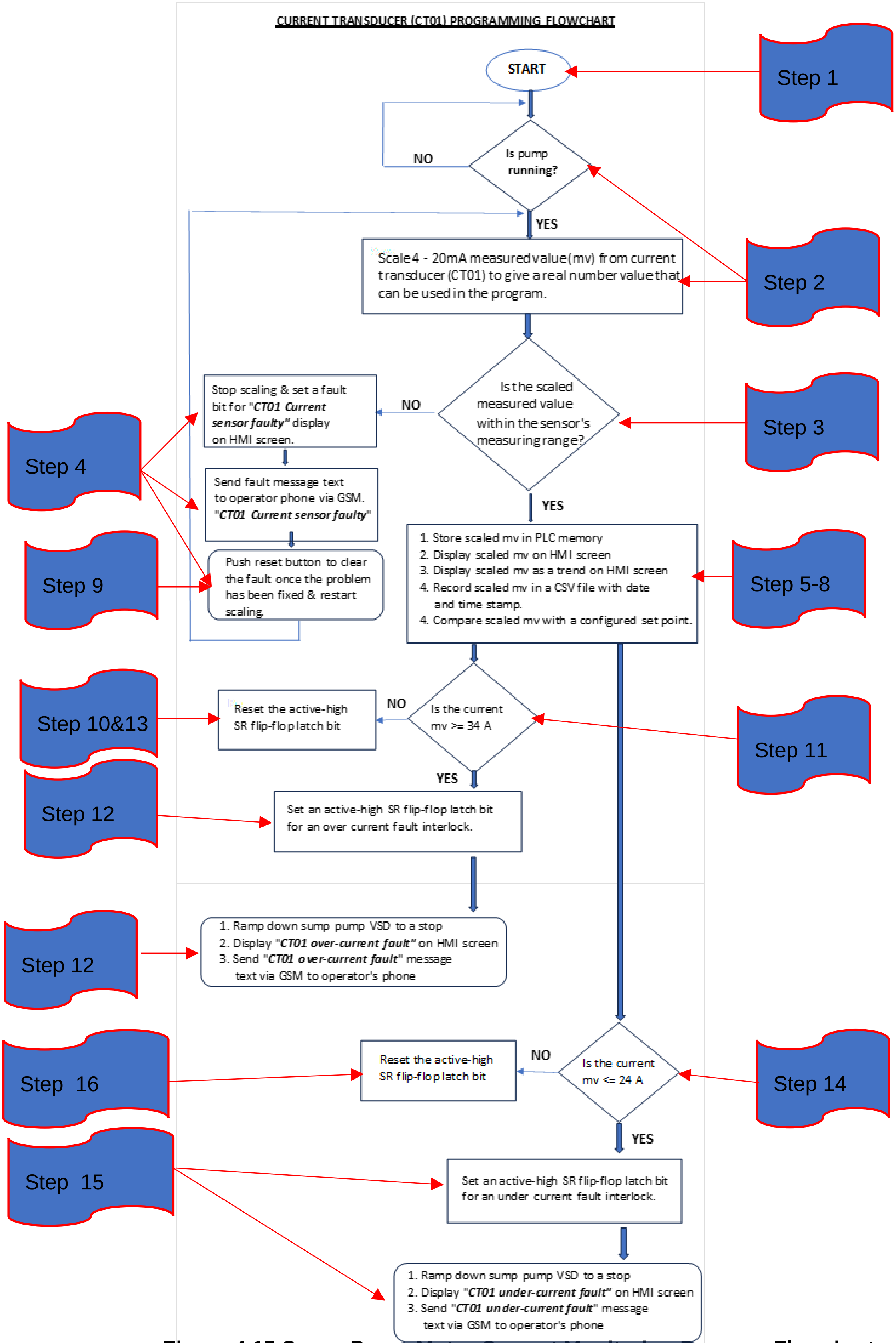



**Figure 4.15 Sewer Pump Motor Current Monitoring Program Flowchart**

The Control in Figure 4.15 is described below:

Step 1: Start: The control system begins.

Step 2: Scale 4 - 20mA measured value (mv) from the current transducer (CT01): The current transducer provides a measured value in the range of 4 - 20mA, which is then scaled to obtain a real number value suitable for use in the program.

Step 3: Check if the scaled measured value is within the sensor's range: The control system verifies if the scaled measured value falls within the operating range of the current transducer.

Step 4: If the scaled measured value is not within the sensor's range: The control system stops scaling and sets a fault bit, indicating that the "CT01 Current sensor" is faulty. A fault message is displayed on the HMI (Human-Machine Interface) screen, and a fault message text is sent to the operator's phone via GSM (Global System for Mobile Communications).

Step 4: Store scaled mv in PLC memory: The control system stores the scaled measured value in the PLC (Programmable Logic Controller) memory for further processing or analysis.

Step 5: Display scaled mv on HMI screen: The scaled measured value is displayed on the HMI screen, providing real-time information to the operator.

Step 6: Display scaled mv as a trend on HMI screen: The control system presents the scaled measured value as a trend on the HMI screen, allowing the operator to monitor the current behaviour over time.

Step 7: Record scaled mv in a CSV file with date and time stamp: The control system records the scaled measured value along with the corresponding date and time stamp in a CSV (Comma-Separated Values) file, enabling data logging and analysis.

Step 8: Compare scaled mv with a configured set point: The control system compares the scaled measured value with a preconfigured set point, which serves as a reference for determining normal or abnormal operation.

Step 9: Push reset button to clear the fault once the problem has been fixed & restart scaling: Once the issue with the current sensor is resolved, the operator can reset the system by pushing the reset button. This action clears the fault, allowing the control system to resume normal operation.

Step 10: Reset the active-high SR flip-flop latch bit: The control system resets the active-high SR flip-flop latch bit, ensuring proper functioning of the fault interlock.

Step 11: Check if the current mv is above a certain threshold (over current fault): The control system verifies if the current measured value exceeds a predefined threshold indicating an over current condition.

Step 12: If the current mv is above the threshold (over current fault): The control system triggers an appropriate response, such as ramping down the sump pump Variable Speed Drive (VSD) to a stop. It displays the "CT01 over-current fault" message on the HMI screen and sends a corresponding fault message text via GSM to the operator's phone.

Step 13: Reset the active-high SR flip-flop latch bit: Once the over current condition is resolved, the control system resets the active-high SR flip-flop latch bit associated with the fault interlock.

Step 14: Check if the current mv is below a certain threshold (under current fault): The control system checks if the current measured value falls below a predefined threshold indicating an under current condition.

Step 15: If the current mv is below the threshold (under current fault): The control system initiates an appropriate response, such as ramping down the sump pump VSD to a stop. It displays the "CT01 under-current fault" message on the HMI screen and sends a corresponding fault message text via GSM to the operator's phone.

Step 16: Reset the active-high SR flip-flop latch bit: After resolving the under current condition, the control system resets the active-high SR flip-flop latch bit associated with the fault interlock.

The integration of the current control system within smart monitoring of sewer network infrastructure proves highly valuable in the mitigation of sewer spillage. By continuously monitoring pump current levels, promptly detecting faults, and initiating appropriate responses, the system ensures the reliable operation of the sewer network. This proactive approach minimizes the risk of spills, enhances environmental protection, and supports efficient management of the sewer system.

In conjunction with the smart monitoring of the sump, the monitoring of other infrastructure within the reticulation network is also profound. Below is the smart monitoring of the sewer manhole which could come up as a weak spot in the reticulation network.

#### 4.4.7. Sewer Manhole Level Monitoring Program Flowchart

As defined before, a sewer manhole is an underground structure designed to provide access to a sewer system for maintenance, inspection, and repair purposes. It serves as an entry point to the sewer network and facilitates the flow of wastewater and sewage. While sewer manholes can come in various shapes and sizes, this specific manhole is cylindrical in shape. However, it is important to note that sewer manholes can also be found in other shapes, such as rectangular or square, depending on the specific design and requirements of the sewer system. Figure 4.16 further gives a picture of the sewer manhole structure in the context of this prototype.

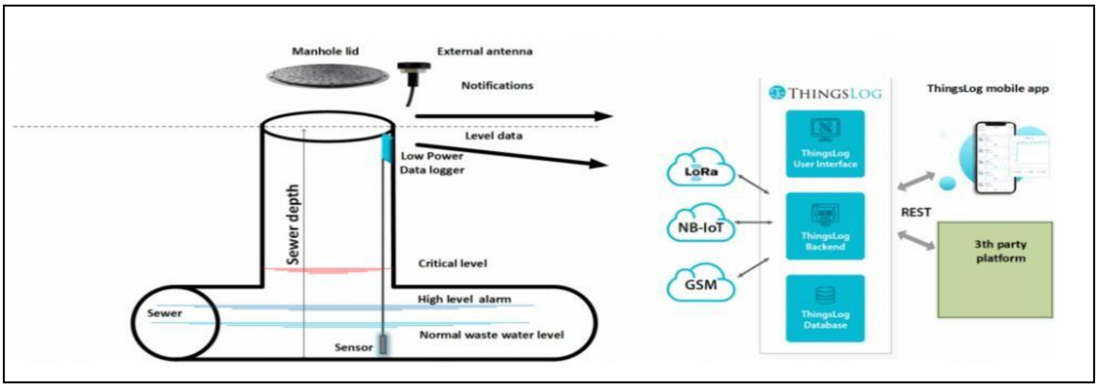



**Figure 4.16 Sewage Network manhole monitor (Bentek Systems,2022)**

The integration of the diversion pit acts as a barrier against environmental pollution through sewer spillage. By effectively managing the manhole levels and diverting the sewage to the pit when necessary, the control system minimizes the risk of sewage overflow into the environment. This proactive approach showcases the smartness of the system, as it employs real-time monitoring, fault detection, and immediate responses to ensure environmental protection and the efficient operation of the sewer infrastructure.

The flowchart below describes the program flowchart for the prototype to be used to monitor sump levels.

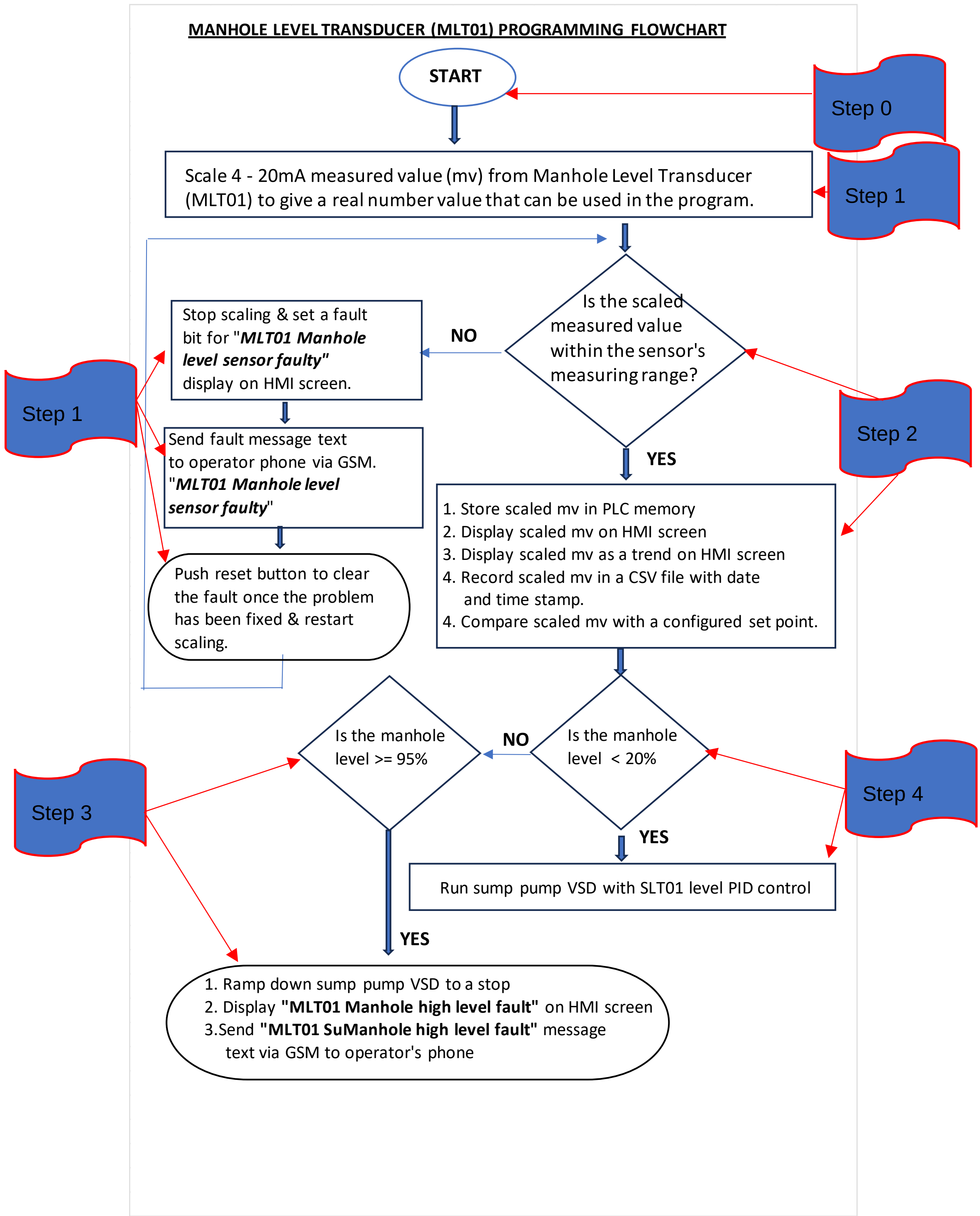



**Figure 4.17 Sewer Manhole Level Monitoring Program Flowchart**

The flowchart presented depicts a control system for monitoring sewer manhole levels and the utilization of a diversion pit to mitigate environmental pollution through sewer spillage. The system exemplifies the smart monitoring of sewage infrastructure, aligning with the thesis title "Smart monitoring of sewage infrastructure to alleviate environmental pollution."

The brief description is given below:

Step 1: The control system starts by scaling the measured value from the Manhole Level Transducer (MLT01) to obtain a real number value suitable for program usage. If the scaled measured value falls outside the sensor's measuring range, the system sets a fault bit and displays a fault message on the HMI (Human-Machine Interface) screen, indicating the "MLT01 Manhole level sensor" is faulty. This immediate fault notification is also sent via GSM (Global System for Mobile Communications) to the operator's phone.

Step 2: Assuming the scaled measured value is within the sensor's range, the system stores the value in the PLC (Programmable Logic Controller) memory and displays it on the HMI screen. Additionally, the scaled measured value is recorded in a CSV (Comma-Separated Values) file with a timestamp, allowing for data tracking and analysis. The system compares the scaled measured value with a configured set point to assess the manhole level's condition.

Step 3: In terms of managing the manhole levels, the control system incorporates specific thresholds. If the manhole level exceeds or equals 95%, indicating a high level, the system initiates the sump pump Variable Speed Drive (VSD) with SLT01 level PID (Proportional-Integral-Derivative) control. This action efficiently manages the pump operation to address the high level and prevent potential overflow. On the HMI screen, the system displays the "MLT01 Manhole high level fault" message, and a corresponding fault message text is sent via GSM to the operator's phone.

Step 4: Conversely, if the manhole level falls below 20%, the control system ramps down the sump pump VSD to a stop. This ensures the pump is not operating unnecessarily and conserves energy. The system displays the "MLT01 Manhole low level fault" message on the HMI screen and sends the fault message text to the operator's phone via GSM.

The presented flowchart demonstrates a control system that combines monitoring of manhole levels and the use of a diversion pit as a smart solution to alleviate environmental pollution caused by sewer spillage. By integrating intelligent monitoring techniques and efficient responses, the system upholds the principles of smart monitoring of sewage infrastructure, ensuring environmental sustainability and effective management of the sewer system.

### 4.4.8. Manhole Differential Pressure Monitoring Program Flowchart

In a similar manner, the sewer manhole differential pressure is monitored. As previously stated the monitoring of sump levels and the presence of a diversion pit act as crucial barriers in reducing environmental pollution through sewer spillage. By effectively monitoring the differential pressure and implementing appropriate control actions, the control system ensures the proper functioning of the sewer system. It actively mitigates the risk of sewer overflow and pollution by regulating the sump pump operation and diverting excess sewage to the diversion pit when necessary.

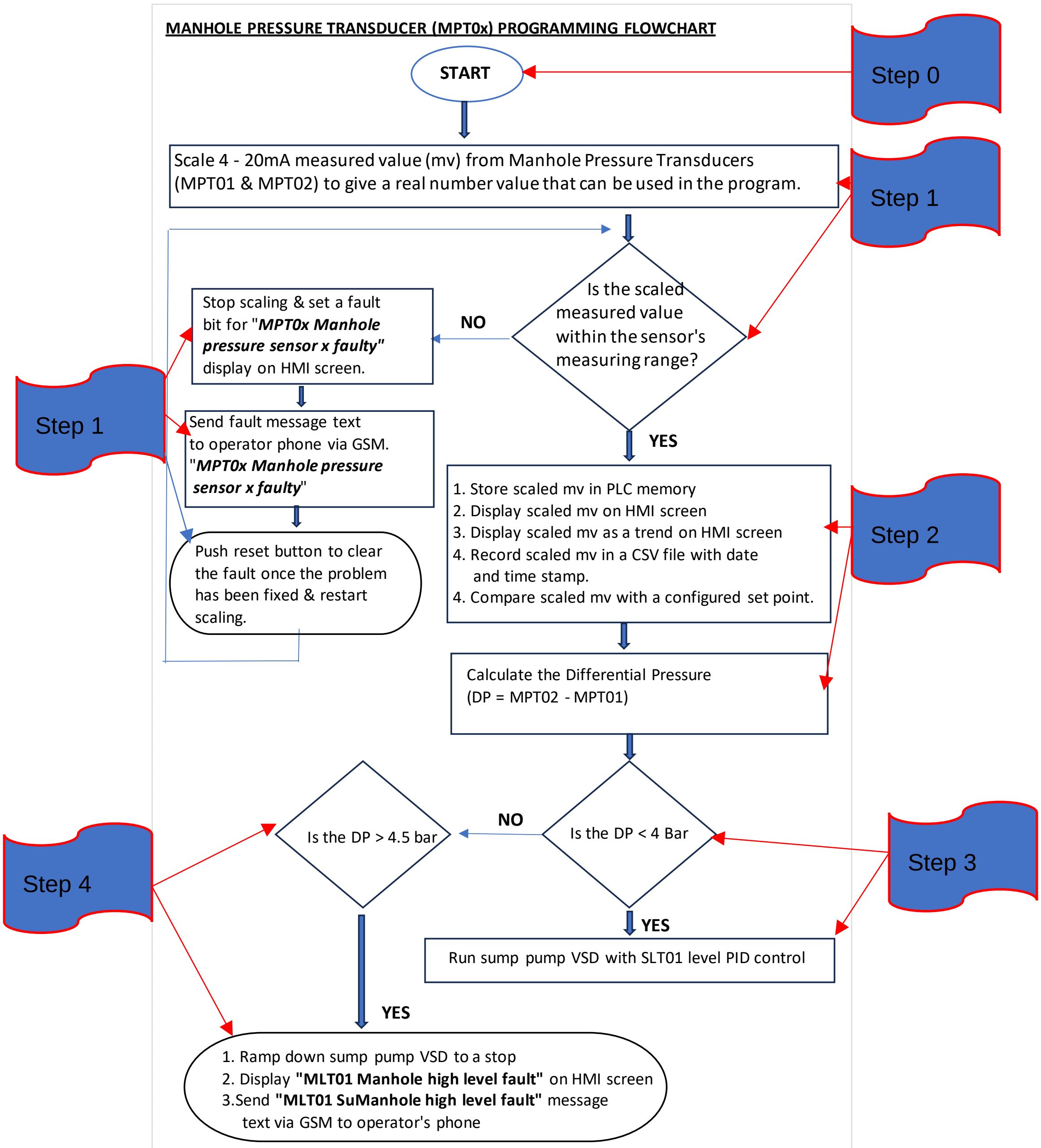



**Figure 4.18 Sewer Manhole Differential Pressure Monitoring Program Flowchart**

The flowchart presented below demonstrates a control system that incorporates the monitoring of sewer manhole differential pressure. Through real-time monitoring, fault detection, and appropriate responses, the control system leverages sump level monitoring and the presence of a diversion pit to reduce environmental pollution caused by sewer spillage. This proactive approach aligns with the principles of smart monitoring and sustainable management of sewage infrastructure. Below is the brief description:

Step 1: The control system begins by scaling the measured values from the Manhole Pressure Transducers (MPT01 and MPT02) to obtain real number values suitable for program usage. If the scaled measured value falls outside the sensor's measuring range, the system stops scaling and sets a fault bit. A fault message is displayed on the HMI (Human-Machine Interface) screen and sent via GSM to the operator's phone, indicating the faulty Manhole Pressure Sensor (MPT0x).

Step 2: Assuming the scaled measured value is within the sensor's range, the system stores the values in the PLC (Programmable Logic Controller) memory, displays them on the HMI screen, and records them in a CSV (Comma-Separated Values) file with a timestamp. The system then compares the scaled measured values with a configured set point to determine the differential pressure (DP) between the two transducers (DP = MPT02 - MPT01).

Step 3: Based on the calculated differential pressure, the control system determines the appropriate response. If the DP is less than 4 Bar, indicating a low differential pressure, the system ramps down the sump pump Variable Speed Drive (VSD) to a stop. This action helps prevent unnecessary pump operation and conserves energy. The control system displays the "Manhole low differential pressure fault" on the HMI screen.

Step 4: On the other hand, if the DP exceeds 4.5 Bar, indicating a high differential pressure, the control system initiates the sump pump VSD with SLT01 level PID (Proportional-Integral-Derivative) control. This action enables efficient control of the pump operation to address the high differential pressure and prevent potential overflow. The system displays the "Manhole high differential pressure fault" on the HMI screen and sends a corresponding fault message text via GSM to the operator's phone.

The combined flowcharts for smart monitoring of sewer networks showcase several key achievements that highlight their smartness and importance in achieving effective sewer network management and environmental protection. The flowcharts demonstrate the implementation of redundancy measures, ensuring fault resolution and system reliability. By utilizing multiple sensors and control systems, the flowcharts depict the ability to seamlessly switch to alternative components in the event of failures, reducing downtime and the risk of sewer spillage.

Real-time communication of failures is a key aspect highlighted in the flowcharts. They depict fault detection mechanisms that immediately communicate failures through various channels, including HMI screens, SMS messages via GSM, and operator phone notifications. This real-time communication enables swift response and resolution, minimizing the potential for environmental pollution. The integration of GSM for location tracking is another significant achievement demonstrated in the flowcharts. They depict the use of GSM technology to communicate fault messages along with precise location information. This capability allows operators to quickly identify the exact pump station or manhole experiencing a fault, enabling targeted maintenance and reducing response times.

In summary, the combined flowcharts exemplify the smartness and significance of the monitoring system in sewer network management. They illustrate achievements such as redundancy for fault resolution, real-time communication of failures, integration of GSM for location tracking, utilization of GIS for fault messaging, and the implementation of a smart sewer diversion pit. Together, these flowcharts provide a comprehensive framework for efficient monitoring, quick response, and environmental protection within the sewer network.

The next section provides the control philosophy of this Smart Sewer Infrastructure Monitoring Prototype.

### 4.4.9. Control and Monitoring Mechanisms

#### 4.4.9.1. Pump Design Parameters

The pump design parameters for the smart prototype system are specified in Table 4.1. The system includes two pumps, SP001A and SP001B, operating in a duty/standby configuration, where each pump alternates after a 24-hour period.

SP001A operates as the duty pump for the initial 24-hour period, handling a flow rate of 150 m3/hr at a pressure of 1.2 bar. After this period, SP001B, the standby pump, takes over as the duty pump for the next 24 hours, while SP001A becomes the standby pump. This duty/standby arrangement ensures that each pump is utilized and tested regularly, minimizing the risk of equipment degradation and ensuring their readiness in case of pump failure or maintenance needs. By taking turns, the pumps evenly distribute the operational load and extend their overall lifespan.

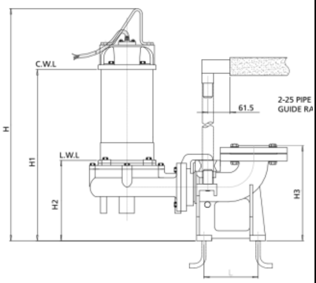
**Table 4.1 Pumps Design Parameters**

| Equipment Tag | Duty point |
|---|---|
| SP001A | 150 m3/hr @ 1.2 bar |
| SP001B | 150 m3/hr @ 1.2 bar |

### 4.4.9.2. Process Interlocks

The system has several interlocks in place to ensure proper operation and prevent potential issues.

**Table 4.2 Process Interlocks**

| Interlock No. | Description | Instrument Tag. | Value | Actions when interlock active |
|---|---|---|---|---|
| CP-I-1 | Collection Sump low level.<br><br>Below 20% of sump | SLT01 | 470mm (H1) from bottom of Immersible pump duck foot pedestal:<br><br> | Immersible pumps SP001A & SP001B to enter standby mode.<br>Actuated Valve AV01 to remain closed |
| CP-I-2 | Collection Sump high level. | SLT01 | 80% Level | Actuated Valve AV01 to open.<br>Duty pump to run, PID controlled by sump level ST01 |

| | | | | |
|---|---|---|---|---|
| MH-I-1 | Manhole High Level | MLT01 | 95% Level | Pumps SP001A & SP001B to enter standby mode, until level drops to 20%.<br>Actuated Valve AV01 to remain closed |
| MH-I-2 | Manhole Differential Pressure | MPT02 – MPT01 | Above 4 Bar | Pumps SP001A & SP001B to enter standby mode.<br>Actuated Valve AV01 to remain closed |

- Interlock CP-I-1 activates when the collection sump's level drops below 20%. In response, the immersible pumps SP001A and SP001B enter standby mode, and the actuated valve AV01 remains closed.
- Interlock CP-I-2 triggers when the collection sump's level reaches 80%. This causes the actuated valve AV01 to open, and the duty pump runs with PID control based on the sump level ST01.
- The Manhole High Level interlock (MH-I-1) is activated when the manhole's level reaches 95%. This prompts pumps SP001A and SP001B to enter standby mode until the level drops back to 20%. Additionally, the actuated valve AV01 remains closed.
- The Manhole Differential Pressure interlock (MH-I-2) is activated when the differential pressure between MPT02 and MPT01 exceeds 4 bar. This causes pumps SP001A and SP001B to enter standby mode, and the actuated valve AV01 remains closed.

These interlocks play a crucial role in maintaining proper system functioning, protecting equipment, and ensuring optimal performance. They provide safeguards against low and high sump levels, as well as excessive differential pressure in the manhole.

#### 4.4.9.3. Smart Prototype Monitoring values

For this smart prototype, the monitoring values are defined below.

**Table 4.3 Smart Prototype Monitoring values**

| Monitoring Value No. | Description | Value/Range | Unit |
|---|---|---|---|
| CP-M-1 | Collection Sump Level | 0 - 100 | % |

| | | | |
|---|---|---|---|
| MH-M-1 | Manhole Level | 0 - 100 | % |
| MH-M-2 | Manhole Differential Pressure | 0 – 6 | bar |

These monitoring values represent the ranges within which specific parameters are measured and monitored in the smart prototype system.

- CP-M-1 indicates the Collection Sump Level, which is measured on a scale of 0 to 100% to determine the level of sewage in the collection sump.
- MH-M-1 represents the Manhole Level, also measured on a scale of 0 to 100%, to assess the level of sewage in the manhole.
- MH-M-2 denotes the Manhole Differential Pressure, measured in bars, with a range of 0 to 6 bar. This value indicates the difference in pressure between two points in the manhole and helps identify any abnormal pressure differentials.

These defined monitoring values serve as important parameters for assessing the status and conditions within the smart prototype system. By continuously monitoring these values, operators can ensure efficient management of the sewage infrastructure, early detection of anomalies, and timely response to maintain optimal performance and prevent environmental pollution.

#### 4.4.9.4. Smart Prototype Alarm and SMS notifications

For this prototype, the alarm and SMS notifications are defined below.

**Table: Smart Prototype Alarm and SMS notifications**

| Alarm No. | Alarm Condition | Alarm Outcome | Alarm priority |
|---|---|---|---|
| CP-A-1 | Low level in collection sump | Alarm notification on HMI & SMS.<br>Strobe in control room active | 1 |
| MH-A-1 | High differential pressure across manhole | Alarm notification on HMI & SMS. | 1 |
| MH-A-2 | High level in manhole | Alarm notification on HMI & SMS. | 1 |
| CP-A-3 | High level in collection sump | Alarm notification on HMI. | 2 |

These defined alarms and SMS notifications are triggered based on specific conditions or events within the smart prototype system.

- CP-A-1 alarm activates when there is a low level in the collection sump. This triggers an alarm notification on the Human-Machine Interface (HMI) as well as an SMS notification. Additionally, a strobe in the control room is activated. This alarm has a priority level of 1, indicating its significance and immediate attention requirement.
- MH-A-1 alarm is triggered by a high differential pressure across the manhole. It results in an alarm notification displayed on the HMI and an SMS notification to relevant personnel. This alarm is also assigned a priority level of 1.
- Similarly, MH-A-2 alarm is activated when the level in the manhole exceeds a predefined threshold. It generates an alarm notification on the HMI and sends an SMS notification. Like the previous alarms, it holds a priority level of 1.
- CP-A-3 alarm is associated with a high level in the collection sump. It triggers an alarm notification on the HMI without an SMS notification. This alarm has a lower priority level of 2.

These alarm and SMS notifications play a critical role in promptly alerting operators to potential issues or abnormal conditions within the smart prototype system. By receiving real-time notifications, operators can take immediate actions to prevent system failures, address alarm conditions, and ensure the proper functioning of the sewer network.

#### 4.4.9.5. Smart Sewer monitoring Control Set-points

Pumps are PID tuned to maintain a level of 40% in the sump. To achieve this, the pumps are tuned using a PID (Proportional-Integral-Derivative) control algorithm. The PID controller continuously monitors the sump level and adjusts the pump speed accordingly to maintain it at the desired set-point of 40%. The controller calculates the appropriate control action based on the error between the desired level and the actual level.

The Proportional term in the PID controller responds to the present error, the Integral term addresses past errors, and the Derivative term anticipates future trends. By combining these three components, the PID controller dynamically adjusts the pump speed to ensure precise and stable control of the sump level. Maintaining the sump level at 40% offers several benefits. It provides sufficient buffer capacity in the sump to handle fluctuating inflow rates and prevents overflow or underflow conditions. Additionally, operating the sump at this optimal level helps ensure efficient pump performance, minimizes energy consumption, and extends the equipment's lifespan.

The set-point of 40% for the sump level in the smart prototype control system demonstrates the precision and intelligence of the system. By continuously monitoring and adjusting the pump operation to maintain the desired level, the control system optimizes the performance of the sewer infrastructure and contributes to efficient and reliable sewage management.

### 4.5. Practical Implementation: Smart Prototype Motor Interlocks

The smart prototype system includes motor interlocks to safeguard the pump operation. These interlocks are triggered based on specific conditions, such as overcurrent, undercurrent, and excessive vibrations. When an interlock is active, the duty running pump's Variable Speed Drive (VSD) is ramped down to a stop, the actuated valve closes, and the system waits for the standby pump to take over. These interlocks ensure the pumps operate within safe parameters, protecting the equipment and maintaining the system's integrity.

The smart motor interlocks defined for this specific prototype are given in the table below.

**Table 4.4 Smart Prototype Motor Interlocks**

| Interlock No. | Description | Instrument Tag. | Value | Actions when interlock active |
|---|---|---|---|---|
| M-I-1 | Pump over current | CT01 | Above 34 Amps | Duty running pump VSD to ramp down to a stop.<br>Actuated Valve AV01 to close.<br>Wait for standby pump to kick in. |
| M-I-2 | Pump undercurrent | CT01 | Below 24 Amps | Duty running pump VSD to ramp down to a stop.<br>Actuated Valve AV01 to close.<br>Wait for standby pump to kick in. |
| M-I-3 | High Axial Vibration | AVT01 | Above 15.8 | Duty running pump VSD to ramp down to a stop.<br>Actuated Valve AV01 to close.<br>Wait for standby pump to kick in. |
| M-I-4 | High Horizontal Vibration | HVT01 | Above 15.8 | Duty running pump VSD to ramp down to a stop.<br>Actuated Valve AV01 to close.<br>Wait for standby pump to kick in. |
| M-I-5 | High Vertical Vibration | VT01 | Above 15.8 | Duty running pump VSD to ramp down to a stop.<br>Actuated Valve AV01 to close.<br>Wait for standby pump to kick in. |

#### 4.5.1. Practical Implementation: Current and Vibration Monitoring Values

The defined monitoring values for this prototype and indicated below.

**Table 4.5 Current and Vibration Monitoring Values**

| Monitoring Value No. | Description | Value/Range | Unit |
|---|---|---|---|
| CT-M-1 | Motor Current | 0 – 40 | A |
| AV-M-1 | Axial Vibration | 0 – 20 | mm/sec |
| HV-M-1 | Horizontal Vibration | 0 – 20 | mm/sec |
| VV-M-1 | Vertical Vibration | 0 – 20 | mm/sec |

These monitoring values represent the ranges within which specific parameters related to motor current and vibration are measured and monitored in the prototype system.

- CT-M-1 indicates the Motor Current, which is measured in amperes (A) and has a range from 0 to 40 A. This value represents the electrical current flowing through the motor, providing insights into the motor's operating conditions.
- AV-M-1, HV-M-1, and VV-M-1 represent the Axial, Horizontal, and Vertical Vibration, respectively. These values are measured in millimeters per second (mm/sec) and have a range from 0 to 20 mm/sec. These measurements help assess the levels of vibration experienced by the system, which can indicate potential issues or anomalies in the motor's performance.

By monitoring these values within their specified ranges, the system can track and analyse the current and vibration patterns, ensuring the motors operate within safe limits. Deviations from the expected ranges can trigger alarms or interlocks, enabling timely actions to maintain motor health and prevent potential failures.

### 4.5.2. Theoretical: Current and Vibration Notifications

The current and vibration notifications for the smart prototype are designed below.

Table 4.6 Current and Vibration Notifications

| Alarm No. | Alarm Condition | Alarm Outcome | Alarm priority |
|---|---|---|---|
| CT-A-1 | Pump overcurrent | Alarm notification on HMI & SMS.<br>Strobe in control room active | 1 |
| CT-A-2 | Pump undercurrent | Alarm notification on HMI & SMS.<br>Strobe in control room active | 1 |
| AV-A-1 | High Axial Vibration | Alarm notification on HMI & SMS. | 1 |
| HV-A-1 | High Horizontal Vibration | Alarm notification on HMI & SMS. | 1 |

| | | | |
|---|---|---|---|
| VV-A-1 | High Vertical Vibration | Alarm notification on HMI & SMS. | 1 |

These defined notifications are triggered based on specific conditions related to motor current and vibration in the smart prototype system.

- CT-A-1 alarm is activated when there is overcurrent in the pump. This triggers an alarm notification on the Human-Machine Interface (HMI) as well as an SMS notification. Additionally, a strobe in the control room is activated. This alarm has a priority level of 1, indicating its significance and immediate attention requirement.
- Similarly, CT-A-2 alarm is triggered by undercurrent in the pump. It results in an alarm notification displayed on the HMI and an SMS notification to relevant personnel. The strobe in the control room is also activated. This alarm holds a priority level of 1.
- AV-A-1, HV-A-1, and VV-A-1 alarms are activated when there are high levels of axial, horizontal, and vertical vibrations, respectively. Each of these alarms generates an alarm notification on the HMI and sends an SMS notification. They all have a priority level of 1.

These notifications play a crucial role in alerting operators to potential issues with motor current and vibration. By receiving real-time notifications, operators can take immediate actions to address alarm conditions, prevent motor damage, and ensure the smooth operation of the smart prototype system.

### 4.5.3. Practical Implementation: SCADA

The SCADA (Supervisory Control and Data Acquisition) system is set out to show a high-resolution overview of the plant and allows users to interface with the controlled motor. This is illustrated in Figure 4.4.1.

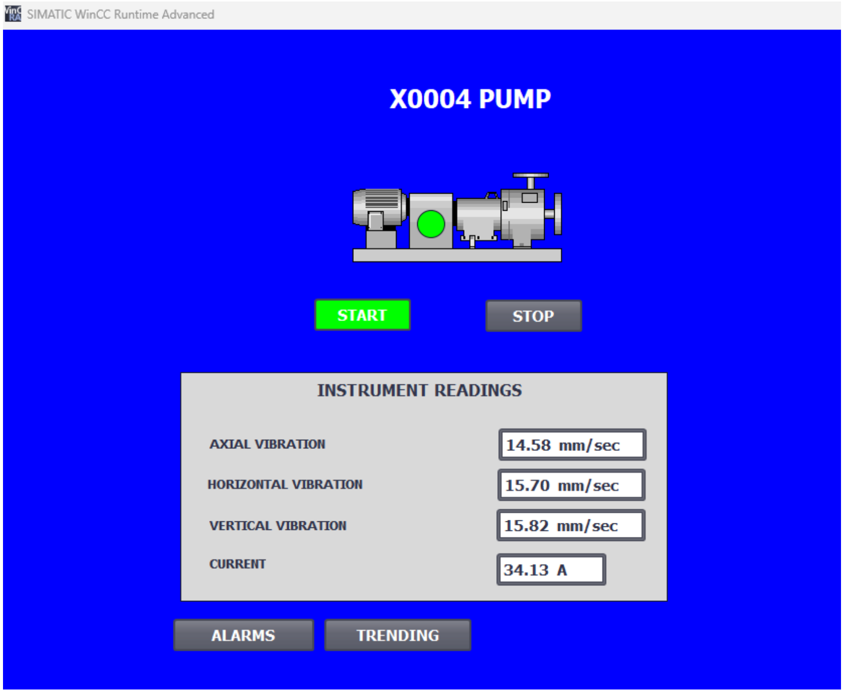



**Figure 4.19 SCADA Overview Screen Pump X0004**

The pump is started and stopped using the push buttons on the screen. The start button goes green once the button has been clicked and a green icon pops up to indicate pump run feedback when the pump starts running. The instrument readings from the sensors are monitored on the screen. The image below shows the SCADA overview screen.

#### 4.5.4. Practical Implementation: Control architecture

The control architecture implemented for this study involves the use of a programmable logic controller (PLC) to capture and monitor the measured values from the field. The PLC serves as the central control unit responsible for data acquisition. Additionally, a small Personal Computer (PC) is utilized to store the captured data in a spreadsheet format, enabling efficient data management and analysis.

After collecting motor vibration and current data using smart sensors, the PLC (Programmable Logic Controller) programming, incorporating upper and lower limits is leveraged to make real-time decisions. This approach allows for the continuous monitoring of the the pump motor performance and swiftly detect operational issues. The PLC-based system assessed the data in conjunction with predefined thresholds, triggering actions when conditions fell outside the specified limits. This proactive approach to data analysis and decision-making ensured the motors operated optimally and reduced the risk of unforeseen issues.

In summary, the implemented control architecture integrates a PLC for data capture and a PC for data storage and analysis. The combination of statistical analysis and machine learning algorithms facilitates a detailed examination of the collected data, providing valuable insights for optimizing motor performance and ensuring the efficient operation of the sewage infrastructure.

### 4.6. Analytical Insights and Validation

Section 4.5 details flowcharts relevant to the smart monitoring of the Gorman Rupp wastewater pumps at Mbabela wastewater pump station. Section 4.6 details data logging and further detail on data trending and analysis.

#### 4.6.1. Practical Implementation: Data logging

Data logging refers to the process of capturing and recording data over a period for analysis, monitoring, or archival purposes. A sample reading of each instrument is recorded and stored as a CSV file on the PC hard drive every hour for 24 hours. Figure 4.20 shows the settings in TIA Portal. The raw data trended on this chapter is appended in this document.

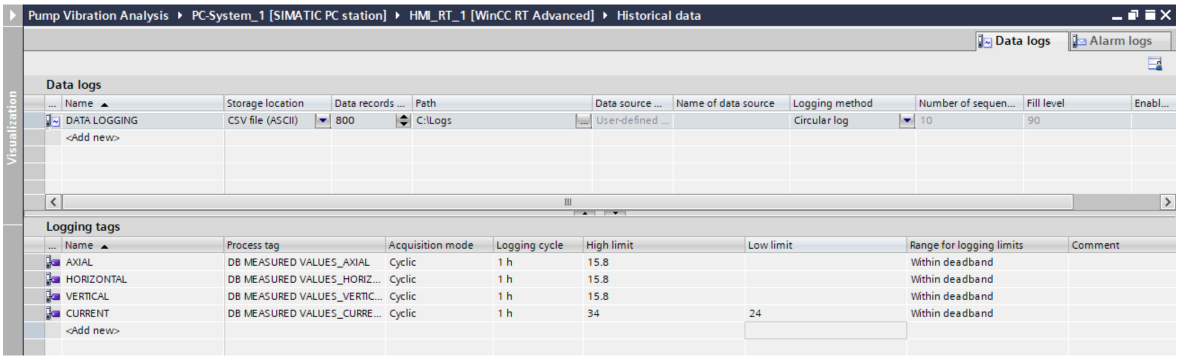



**Figure 4.20 Data Logging Settings**

### 4.6.2. Practical Implementation: Alarms Feedback

The Alarm page displays feedback if any of the instrument readings are out of the set range. The PLC is programmed to display fault feedback if the measured vibration value is above 15.8 mm/sec and if the current sensor is measuring current over 34 A or below 24 A. For vibration the table below indicates upper and lower limit parameters used to trigger the alarm. This information is based on ISO 10816-7, titled "Mechanical vibration – Evaluation of machine vibration by measurements on non-rotating parts – Part 7: Rotodynamic pumps for industrial applications. This information is used in conjunction with the Gorman Rupp pump's technical data with a safety margin of 10% on both thresholds.

| Vibration Limits as per ISO Standards | | |
|---|---|---|
| Good (mm/sec) | Fair (mm/sec) | Bad (mm/sec) |
| <6,58 | > 6,58-15,8 < | >15,8 |

**Figure 4.21 Pump Vibration Limits as per ISO Standards**

Based on data collected during the monitoring period, the screen in Figure 4.5.3 shows feedback displayed on the HMI indicating an abnormal pump operation.

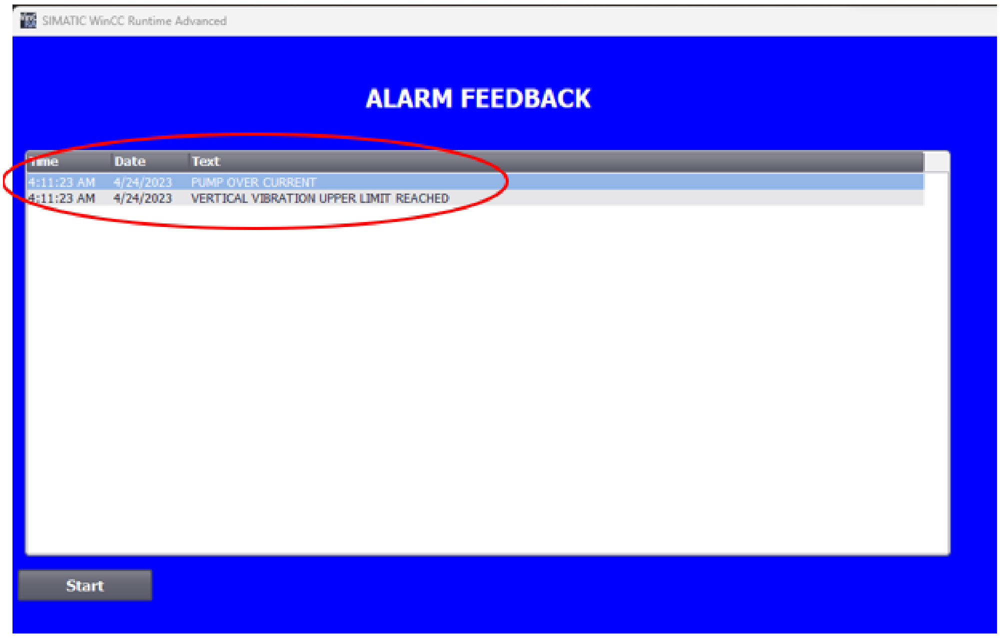



**Figure 4.22 Pump malfunction feedback display**

The occurrence of simultaneous abnormal current and vibration indications on the 24th of April 2023 within the monitored Gorman Rupp pump system holds significant technical importance. This synchronization strongly implies a potential correlation between observed current abnormalities and vibration irregularities. The simultaneous triggering of these alarms provides compelling evidence to support the hypothesis that variations in current consumption directly affect the vibration characteristics of the pump motor, indicating a direct influence of electrical performance on mechanical behaviour.

The abnormal current alarm signals an irregularity in the electrical power supplied to the pump motor, potentially indicating suboptimal operating conditions, excessive loads, or electrical faults. Similarly, the abnormal vibration alarm highlights deviations from expected vibration levels, which may suggest mechanical stress, misalignment, or other mechanical anomalies in the pump system. This correlation suggests a cause-and-effect relationship, where abnormal current consumption can lead to increased mechanical vibrations in the pump motor. This underscores the interdependence of electrical and mechanical aspects in the system's performance, necessitating further investigation to understand the underlying factors driving these anomalies.

To validate and complement the quantitative data, qualitative information is collected through manual recording of spillage incidents by the community and feedback from Municipal staff. The community's recorded incidents during the monitoring period, coupled with the insights provided by Municipal staff regarding the causes of pump failure and reaction time, serve as valuable validation. This combined information is critical in assessing how the manual process of identifying sewage spillage can be improved through the implementation of smart monitoring of sewer infrastructure. By employing such technology, the aim is to mitigate sewage spillage, reduce environmental pollution, and enhance the overall effectiveness of sewage management.

### 4.6.3. Vibration Data Trending and Analysis

The collected vibration data was analysed using the MATLAB software environment. The MATLAB script developed to analyse the motor vibration data is based on the stated thresholds is given in Appendix C together with an explanation of the script.

### 4.6.4. Motor Vibration Data Analysis Findings

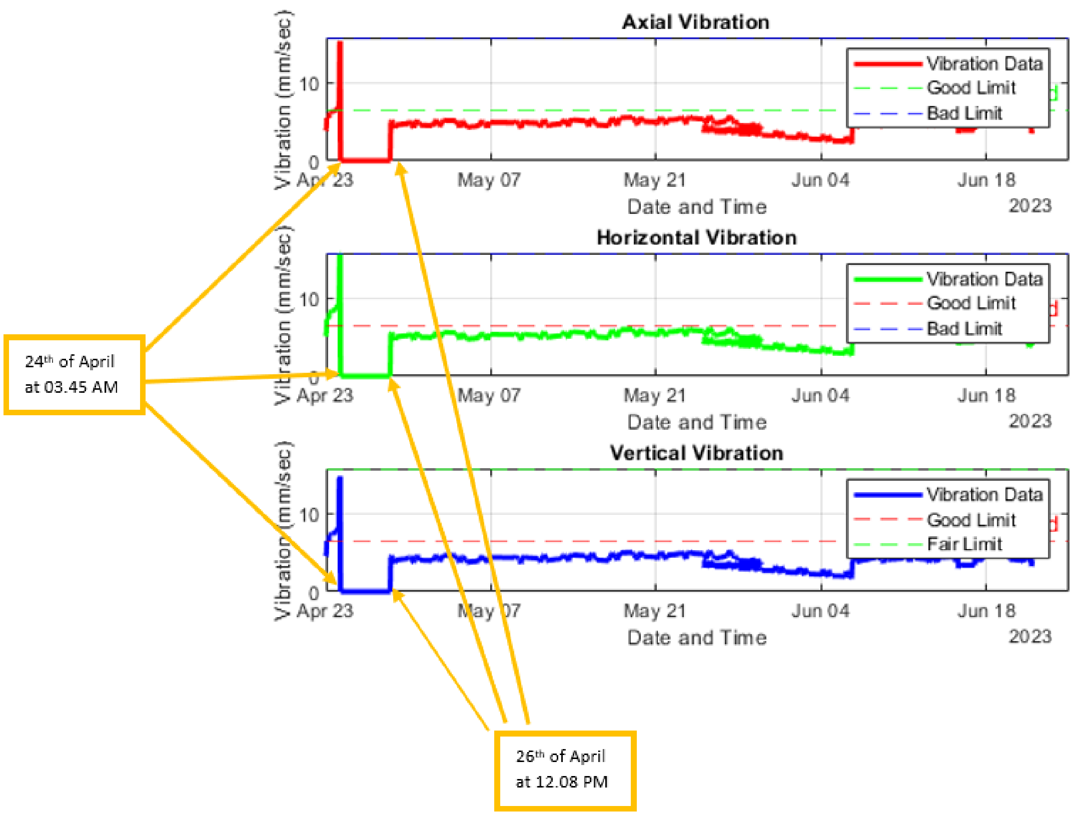



**Figure 4.23 Motor Vibration Graph**

Figure 4.23 illustrates the outcome from trending of vibration motor data. The graph shows results from the horizontal, vertical and axial smart sensors. As per Figure 4.23 and specifics from raw data, data trending shows that vibration is normal trending below 6.58mm/sec till the 24th of April at 03.45 AM where a steady vibration increase is observed. The vibration peaked abnormally high at 04.07am on the 24th of April. The pump vibration eventually indicated zero on the same day at 04.11am. Figure 4.49 and specific raw data indicates that the pump came back online on the 26th at 12.08pm.

### 4.6.5. Motor Current Data Analysis Findings

Typical motor current graph of a pump is presented below.

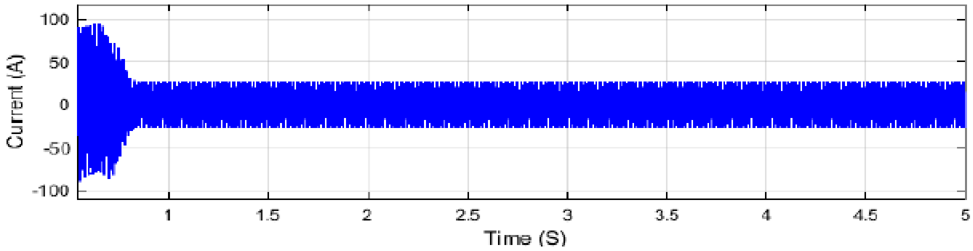



**Figure 4.24. Balanced Current (R. Palanisamy;2018)**

Figure 4.24 illustrates balanced current with maintained magnitude. Figure 4.25 illustrates the results from the current data collected.

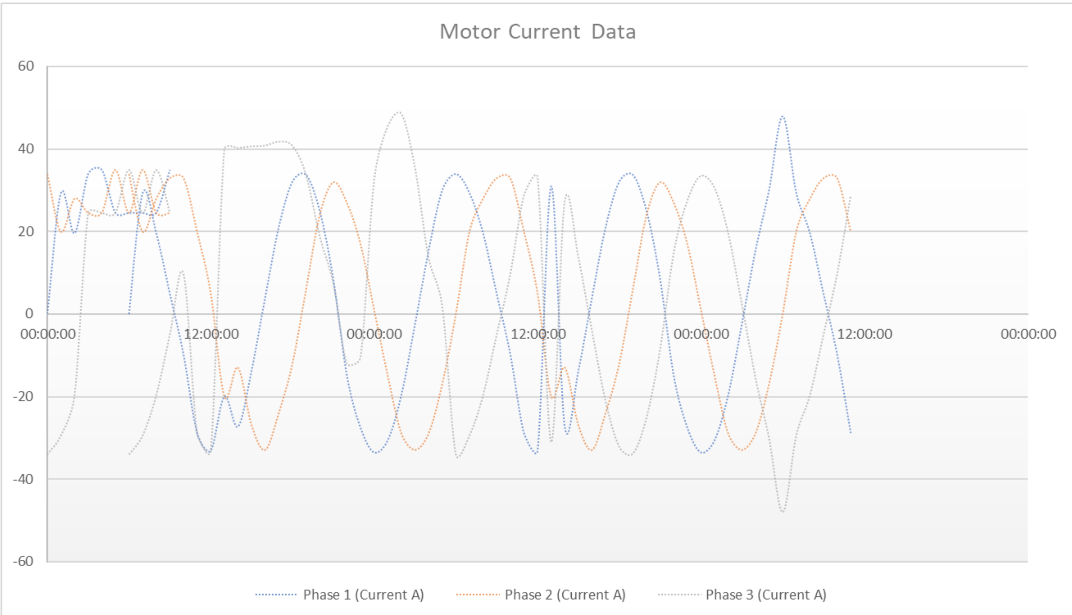



**Figure 4.25 Pump Motor Current Graph**

Having established the typical current graph and based on logged data, zooming in on the failure alarm as per Figure 4.25 it is noted that the pump had a few spikes in motor current operation. From the data collected it is evident that from the 24th of April around 4am the current started rising almost sharply till zero current was logged. The simultaneous occurrence of the alarm indicating vibration malfunction and current malfunction is an important observation that warrants further investigation. To gain a deeper understanding of the pump's behaviour during this specific period, the data for current is trended and analysed.

By trend analysis, it is possible to identify any anomalies, fluctuations, or patterns in the current readings during the time when the alarm is raised. The trended data provides valuable insights into the electrical performance of the pump motor and helps in understanding the potential factors contributing to the current malfunction. Any notable deviations from the expected current levels is detected and analysed for their correlation with the observed vibration malfunction. Section 4.25 also considers the vibration graph, which provides a graphical representation of the vibration levels experienced by the pump motor during the same period. By comparing the trended current data with the vibration graph, it becomes possible to establish correlations and draw meaningful conclusions about the relationship between the current malfunction and the vibration malfunction.

The combined analysis of the trended current data and the vibration graph enables a comprehensive understanding of the pump's behaviour and the interplay between electrical and mechanical aspects. By examining the data in conjunction, it becomes possible to identify any potential cause-and-effect relationships between the observed current malfunction and vibration malfunction. This holistic approach ensures a thorough investigation and supports the generation of accurate conclusions regarding the pump's performance during the specific period under scrutiny.

Figure 4.26 illustrates the total pump downtime which gives a reaction time. Use of smart monitoring of sewer infrastructure is essential through employing the smart sewer diversion pit while improving the reaction time compared to the conventional email and manual phone call methods.

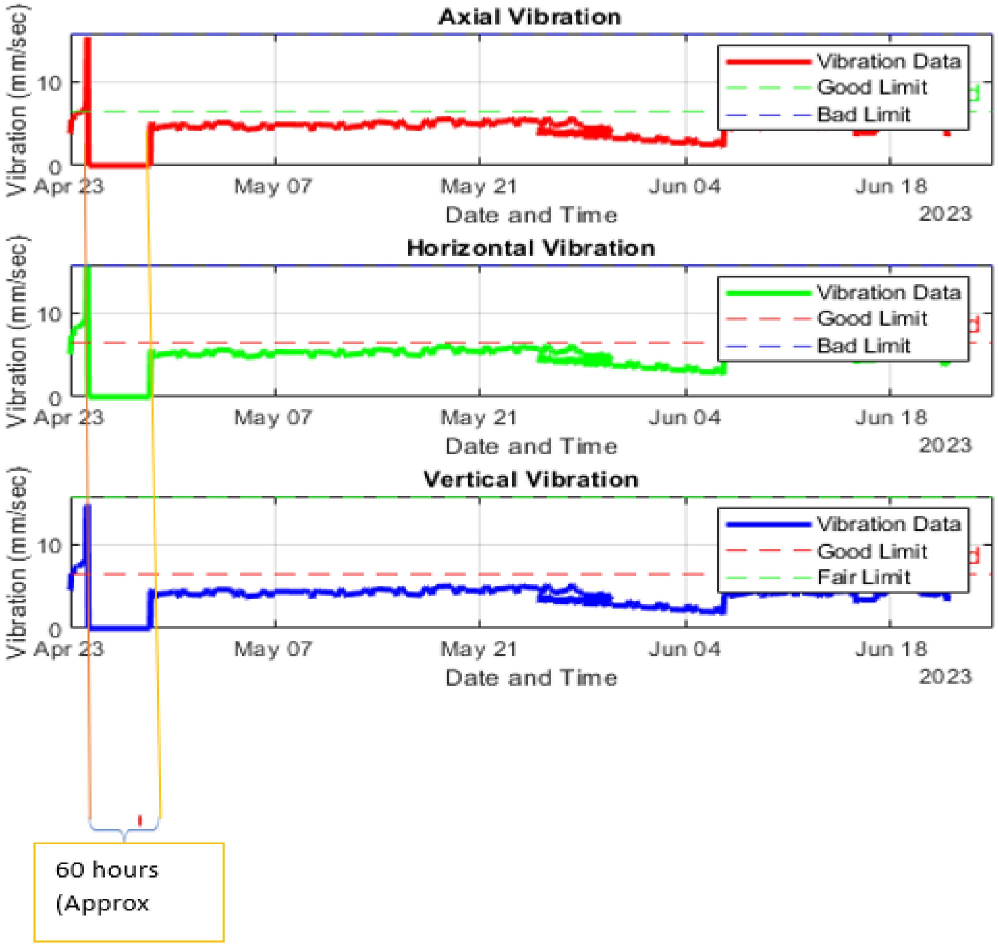



**Figure 4.26 Pump Downtime Graph**

It is essential to acknowledge the significant downtime experienced by the pump, which lasted approximately 60 hours. This extended period of inactivity had implications for the sump and its capacity to handle inflow. Considering a worst-case scenario with three feed pipes of 150mm diameter, each supplying the sump at a rate of 110m3/hr individually:

Let:

- $R\ be\ the\ rate\ of\ each\ feed\ pipe\ (110\ m^3/hr)$.
- $N\ be\ the\ number\ of\ feed\ pipes\ (3\ pipes)$.
- $C\ be\ the\ sump\ capacity\ (180\ m^3)$.
- $T\ fill\ be\ the\ time\ it\ takes\ to\ fill\ the\ sump\ to\ its\ capacity\ (in\ hours)$.

The equation to calculate the time it takes to fill the sump to its capacity is:

- $T\_fill\ =\ C\ /\ (R\ *\ N)$

Substitute the values:

  - $T\_fill\ =\ 180\ m^3\ /\ (110\ m^3/hr\ *\ 3)$
  - $T\_fill\ =\ 180\ m^3\ /\ 330\ m^3/hr$

- $T\_fill = 0.5455\ hours$

Converting to minutes:

- $T\_fill = 0.5455\ hours * 60\ minutes/hour$
- $T\_fill \approx 32.73\ minutes$

During the 56 hours and 24 minutes of downtime, a substantial volume of sewage is released into the environment, leading to environmental pollution assuming a continuous pumping rate of 370m3/hr (for the three pipes) over this period:

Let:

- $T_{downtime} be\ the\ downtime\ duration\ in\ hours\ (56\ hours\ and\ 24\ minutes, which\ is\ equivalent\ to$
- $P\_rate\ be\ the\ continuous\ pumping\ rate\ in\ m^3/hr\ (370\ m^3/hr).$
- $V\_contamination\ be\ the\ volume\ of\ sewage\ that\ contaminated\ the\ surroundings.$
- $The\ formula\ to\ calculate\ the\ volume\ of\ sewage\ that\ contaminated\ the\ surroundings\ is:$
- $V\_contamination = P\_rate * T\_downtime$
- $Substitute\ the\ values:$
- $V\_contamination = 370\ m^3/hr * 56.4\ hours$
- $V\_contamination \approx 20{,}988\ m^3$

Approximately 18.612m3 of sewage contaminated the surroundings. To provide a relatable perspective, this amount is approximately 7.4 times the volume of a standard Olympic-sized swimming pool, which typically holds 2,500m3 of water. These findings emphasize the urgency and necessity of implementing effective monitoring and maintenance strategies to prevent prolonged downtime, reduce environmental pollution caused by sewer spillage, and ensure the efficient and reliable operation of wastewater systems.

### 4.6.6. Validation of Results

Figure 4.25 and Figure 4.26 provide visualization of current and vibration trends, revealing a distinct sequence of events. The analysis indicates that the vibration of the motor pump began to steadily increase around 03:45 am on April 24th, while the current remained relatively stable with a slight upward trend. Few minutes later a sudden surge in motor current occurred, reaching its peak and subsequently causing the pump to trip, triggering an alarm. This correlation between the increasing vibration and the subsequent surge in current suggests a potential causal relationship. The qualitative data collected in Section 6.3 is further used to validate the logged failure as per Figure 4.25 and Figure 4.26. The Municipal Maintenance team is actively involved in providing feedback and expertise regarding the potential causes of the fault. This qualitative approach served to validate and complement the quantitative analysis, enhancing the overall understanding of the fault and its underlying factors. The integration of quantitative data analysis and qualitative feedback from the Municipal Maintenance team strengthens the reliability and credibility of the conclusions drawn from the data. The comprehensive examination of the fault occurrence, including the combined current and vibration trends and the validation from the qualitative findings, highlights the significance of smart monitoring strategies in mitigating pump failures and improving system reliability.

### 4.7. Chapter Summary

Chapter 4 explored the implementation and analysis of a smart prototype monitoring and control system for sewage infrastructure. The chapter covered crucial elements such as process interlocks, monitoring values, alarm notifications, and control set-points. These components work synergistically to enhance the efficiency and reliability of the sewage management system. The discussion began with the role of process interlocks as safeguards against low and high sump levels and excessive differential pressure. These measures ensure system integrity and optimal performance. Monitoring values, including Collection Sump Level, Manhole Level, and Manhole Differential Pressure, are then detailed, providing operators with key insights into system status.

The chapter delved into the alarm and SMS notification framework, emphasizing the prioritization of alerts for immediate attention. The control set-points section highlights the precision achieved through a Proportional-Integral-Derivative (PID) control algorithm, contributing to energy efficiency and equipment longevity. Practical implementation introduced motor interlocks as protective measures triggered by specific conditions. The monitoring values for current and vibration are explained, emphasizing the system's proactive approach through theoretical notifications. The integration of SCADA technology and the control architecture involving PLC and PC is discussed, showcasing the technological backbone of the system. The chapter concluded with analytical insights, emphasizing the correlation between motor current and vibration trends. Validation through qualitative feedback underscores the significance of smart monitoring strategies in mitigating pump failures and improving system reliability.

Chapter 5 will further delve into the TIA Programmable Logic Computer program used in the research.

# CHAPTER 5:

# 5. TIA PROGRAMMING

## 5.1. Introduction

Chapter Five offers a detailed exploration of the programming aspects using Siemens TIA Portal V16. It is organized into several subsections, providing a structured understanding of the PLC Code and function blocks. In Section 5.2, using TIA Portal V16, we focus on PLC Code and Function Blocks, highlighting Organisation Blocks (OB) central role and exploring essential Function Calls. Section 5.3 provides a brief summary, emphasizing the importance of smart monitoring in addressing environmental pollution from sewer spillage.

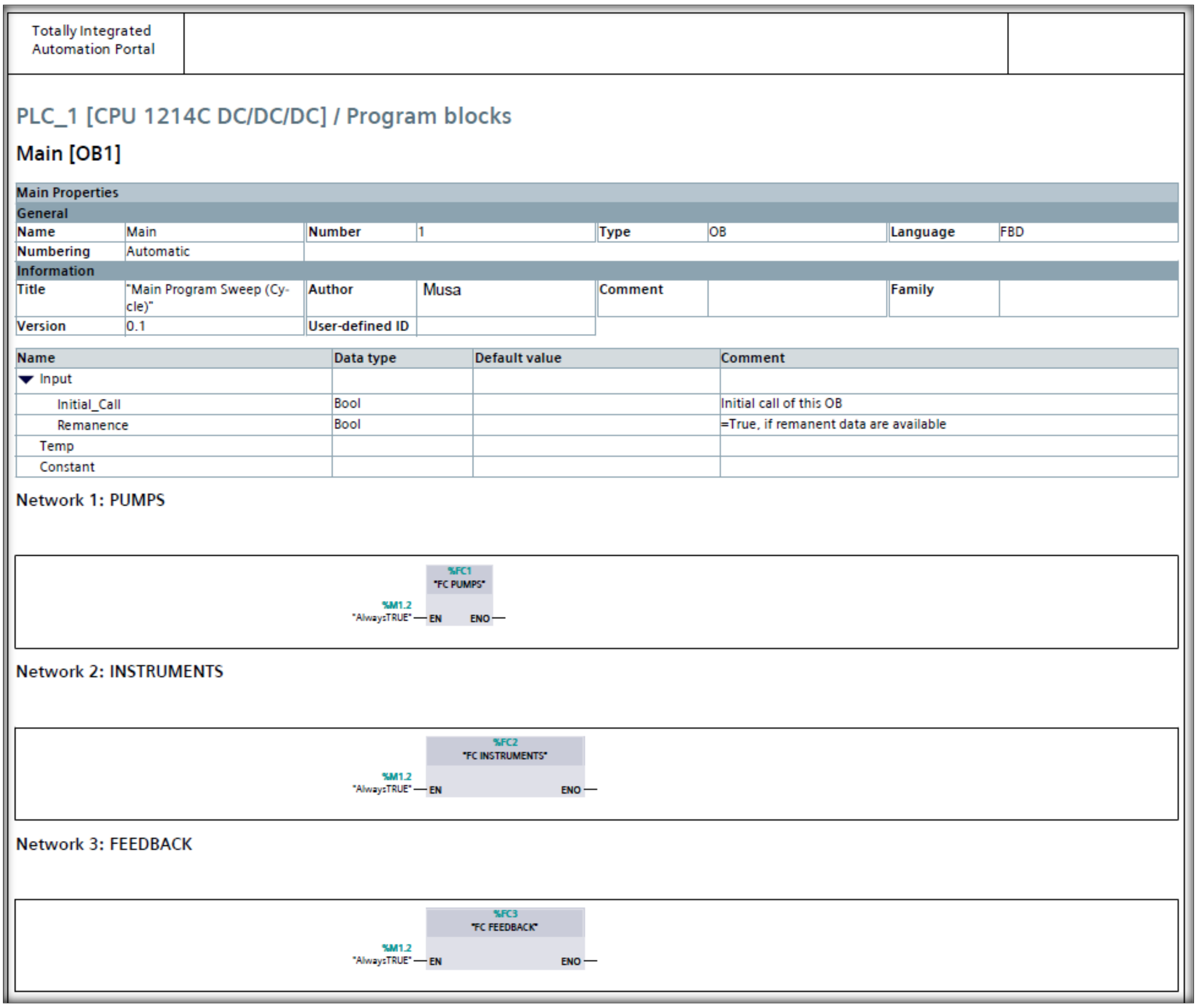
## 5.2. Practical Implementation: PLC Code and Function Blocks

The Siemens TIA Portal V16 software is used for programming. The TIA software provides various types of blocks in which data is stored and manipulated. A summary of the blocks that are used is given below.

### 5.2.1. Organization Blocks (OB)

Within the control architecture, the organization blocks (OBs) serve as a crucial link between the operating system and the user program, facilitating seamless communication and coordination. In this project, the central OB, OB1, plays a pivotal role in grouping and calling function blocks associated with pump control, instrumentation, and feedback. OB1 acts as a command center, encapsulating the necessary logic and functionality to control and monitor the pumps, instruments, and feedback loops. It orchestrates the flow of information, ensuring that the right signals are sent to the pumps to achieve the desired operating conditions. By calling relevant function blocks within OB1, the system can effectively control parameters such as motor speed, vibration levels, and sump levels.

Figure 5.1 provided offers a snapshot of the TIA program, specifically focusing on the composition and structure of OB1. This visual representation provides insights into the organization and arrangement of function blocks within OB1, highlighting the logical flow and interconnections that define the control architecture.



Totally Integrated Automation Portal

PLC_1 [CPU 1214C DC/DC/DC] / Program blocks

Main [OB1]

| Main Properties | | | | | | | |
|---|---|---|---|---|---|---|---|
| General | | | | | | | |
| Name | Main | Number | 1 | Type | OB | Language | FBD |
| Numbering | Automatic | | | | | | |
| Information | | | | | | | |
| Title | "Main Program Sweep (Cy-cle)" | Author | Musa | Comment | | Family | |
| Version | 0.1 | User-defined ID | | | | | |

| Name | Data type | Default value | Comment |
|---|---|---|---|
| Input | | | |
| Initial_Call | Bool | | Initial call of this OB |
| Remanence | Bool | | =True, if remanent data are available |
| Temp | | | |
| Constant | | | |

Network 1: PUMPS



Network 2: INSTRUMENTS



Network 3: FEEDBACK



**Figure 5.1 TIA program_ Organization Block**

### 5.2.2. Function Calls (FC)

Function calls (FC's) contain a function (FC) which contains a partial functionality of the program. There are three function calls in this project, namely:

- FC Instruments: Signal conditioning of the raw measured values from the 4 sensors is programmed in this function block.
- FC Feedback: All faults and out of range limits from the sensors are programmed in this function block.
- FC Pump: This function block caters for the operation of the motor, including all associated interlocks

#### 5.2.2.1. FC Instruments

Signal conditioning of the raw measured values from the 4 sensors is programmed in this function FC. The four instruments programmed for data collection are highlighted below as per TIA portal.

Figure 5.2 showcases a TIA program that encompasses a function block dedicated to the signal conditioning of an axial vibration sensor. This program utilizes advanced programming techniques to manipulate and refine the raw analogue signals received from the sensor. By incorporating parameters and limits based on Gorman Rupp's technical datasheet and ISO 10816-1 standard, the program ensures precise monitoring of the axial vibration measurements, adhering to specified thresholds. Figure 5.2 provides a detailed visual representation of the specific programming steps employed to accurately assess the axial vibration levels, offering a comprehensive understanding of the implemented signal conditioning process.

PLC_1 [CPU 1214C DC/DC/DC] / Program blocks / FC BLOCKS

**FC INSTRUMENTS [FC2]**

| FC INSTRUMENTS Properties | | | | | | | |
|---|---|---|---|---|---|---|---|
| **General** | | | | | | | |
| **Name** | FC INSTRUMENTS | **Number** | 2 | **Type** | FC | **Language** | FBD |
| **Numbering** | Automatic | | | | | | |
| **Information** | | | | | | | |
| **Title** | | **Author** | Musa | **Comment** | | **Family** | |
| **Version** | 0.1 | **User-defined ID** | | | | | |

| Name | Data type | Default value | Comment |
|---|---|---|---|
| Input | | | |
| Output | | | |
| InOut | | | |
| Temp | | | |
| Constant | | | |
| Return | | | |
| FC INSTRUMENTS | Void | | |

**Network 1: AXIAL VIBRATION SENSOR**

IFM VTV12A

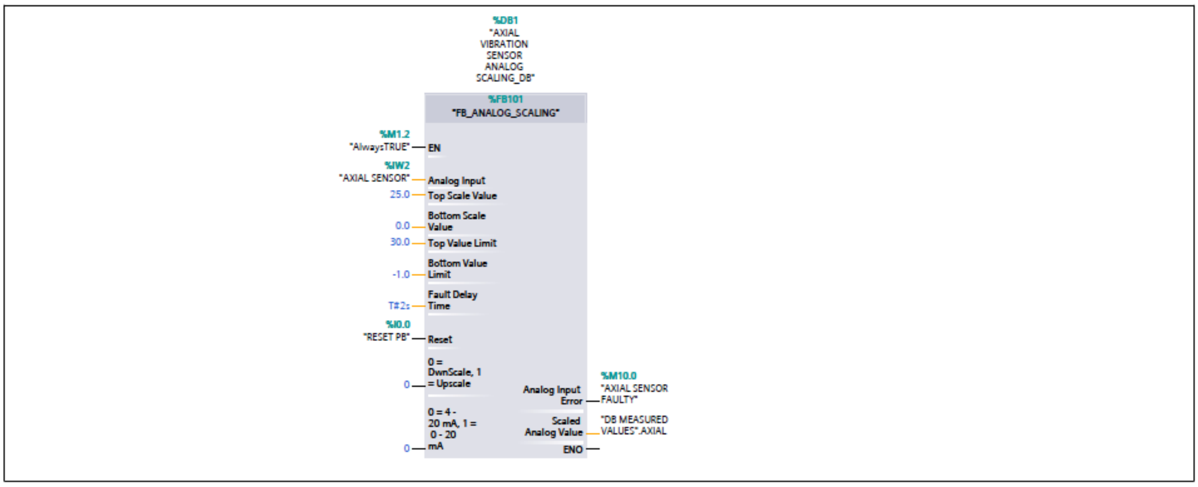



**Figure 5.2 TIA Program_FC Axial Vibration Sensor**

Programming of the Horizontal Vibration Sensor is illustrated in Figure 5.4, while the Vertical Vibration Sensor Function Call is depicted in Figure 5.3. Employing a parallel approach to that of the Axial Vibration Sensor, these parameters have been meticulously programmed to ensure accurate monitoring and analysis of horizontal and vertical vibration levels. These figures encapsulate the intricacies of the programming steps undertaken to effectively capture and interpret data from the respective vibration sensors, presenting a cohesive and comprehensive portrayal of the programming methodology employed.

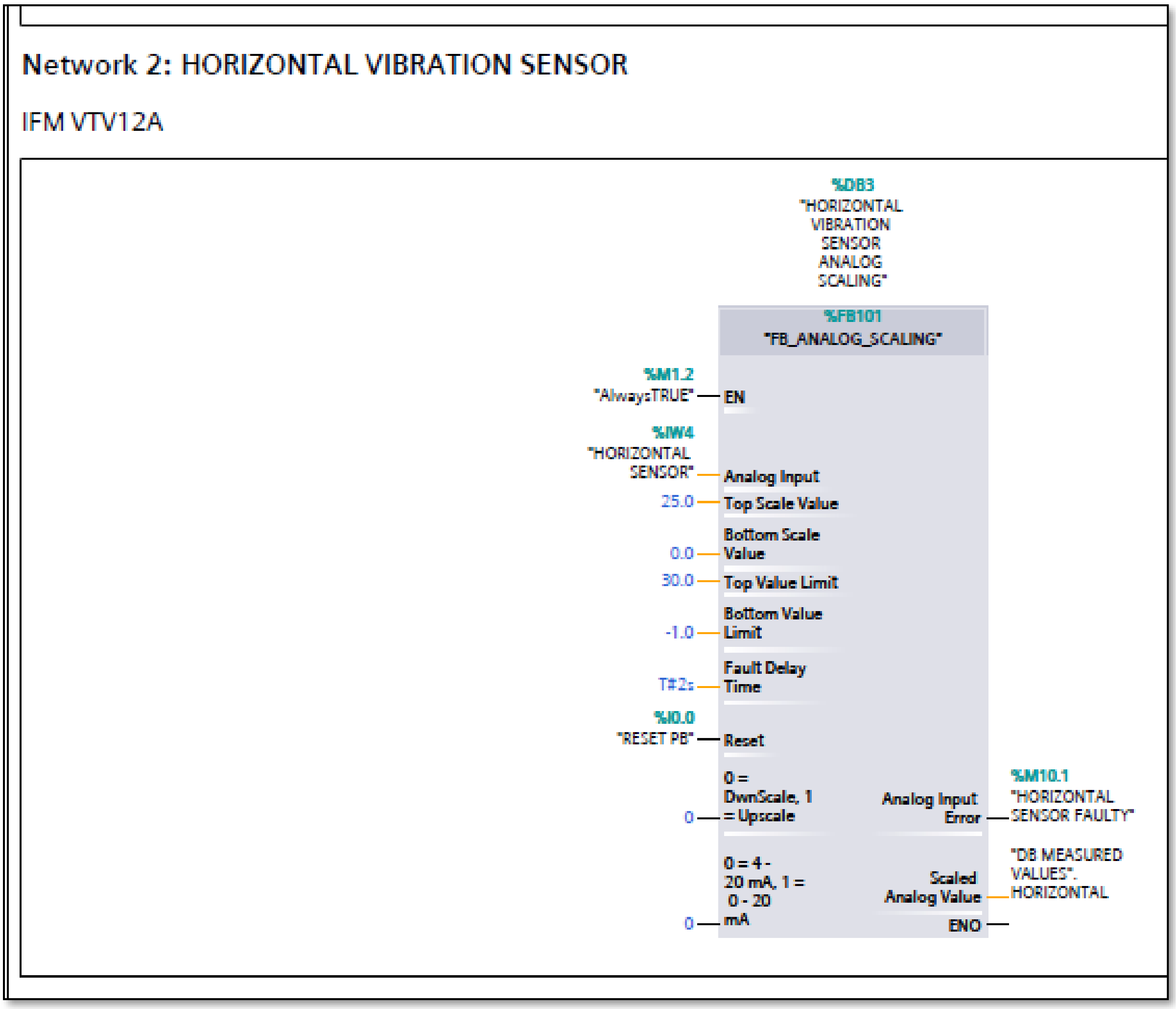



**Figure 5.3 TIA Program_ FC Horizontal Vibration Sensor**

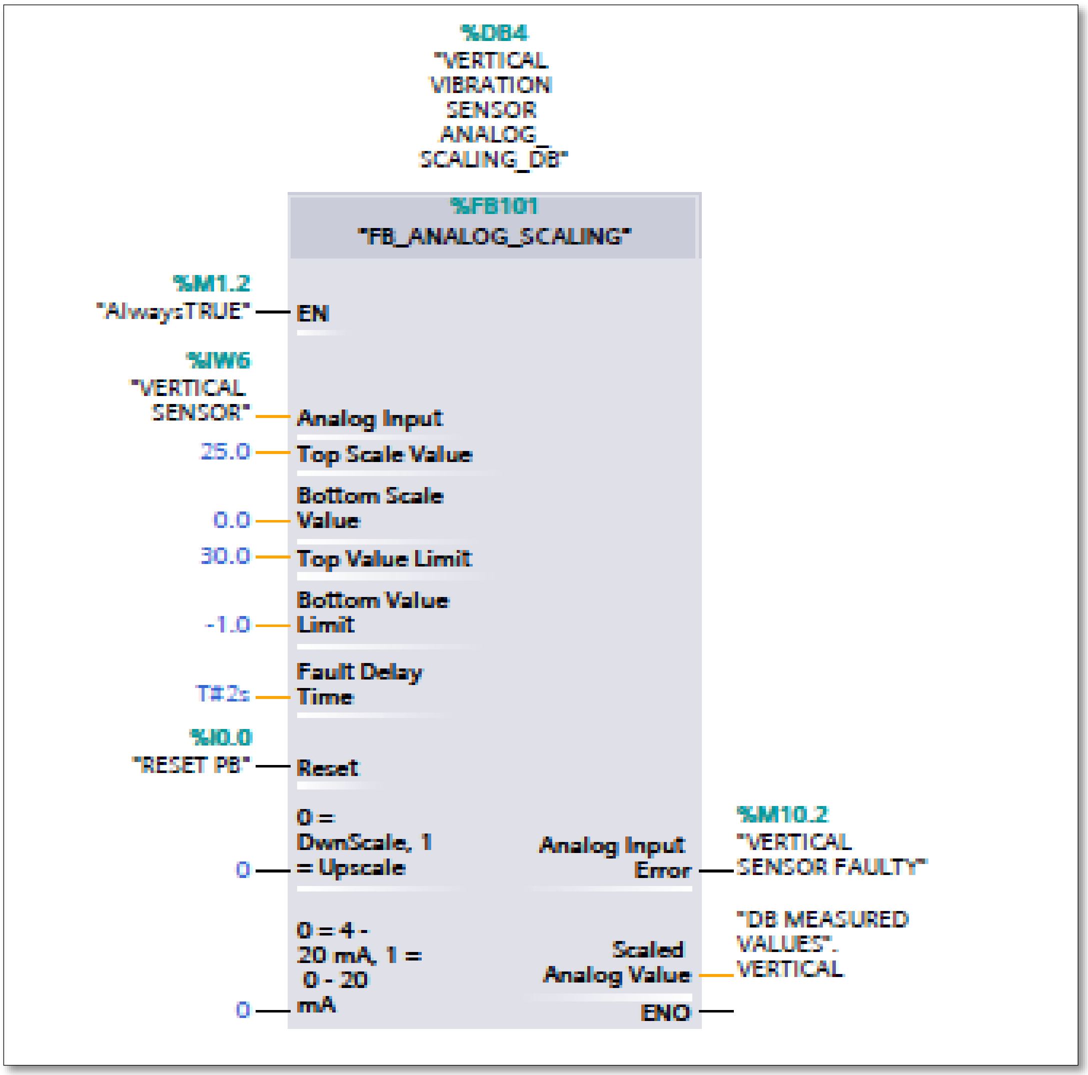



**Figure 5.4 TIA Program_FC Vertical Vibration Sensor**

#### 5.2.2.2. FC Feedback

All faults and out of range limits from the sensors are programmed in this function block.

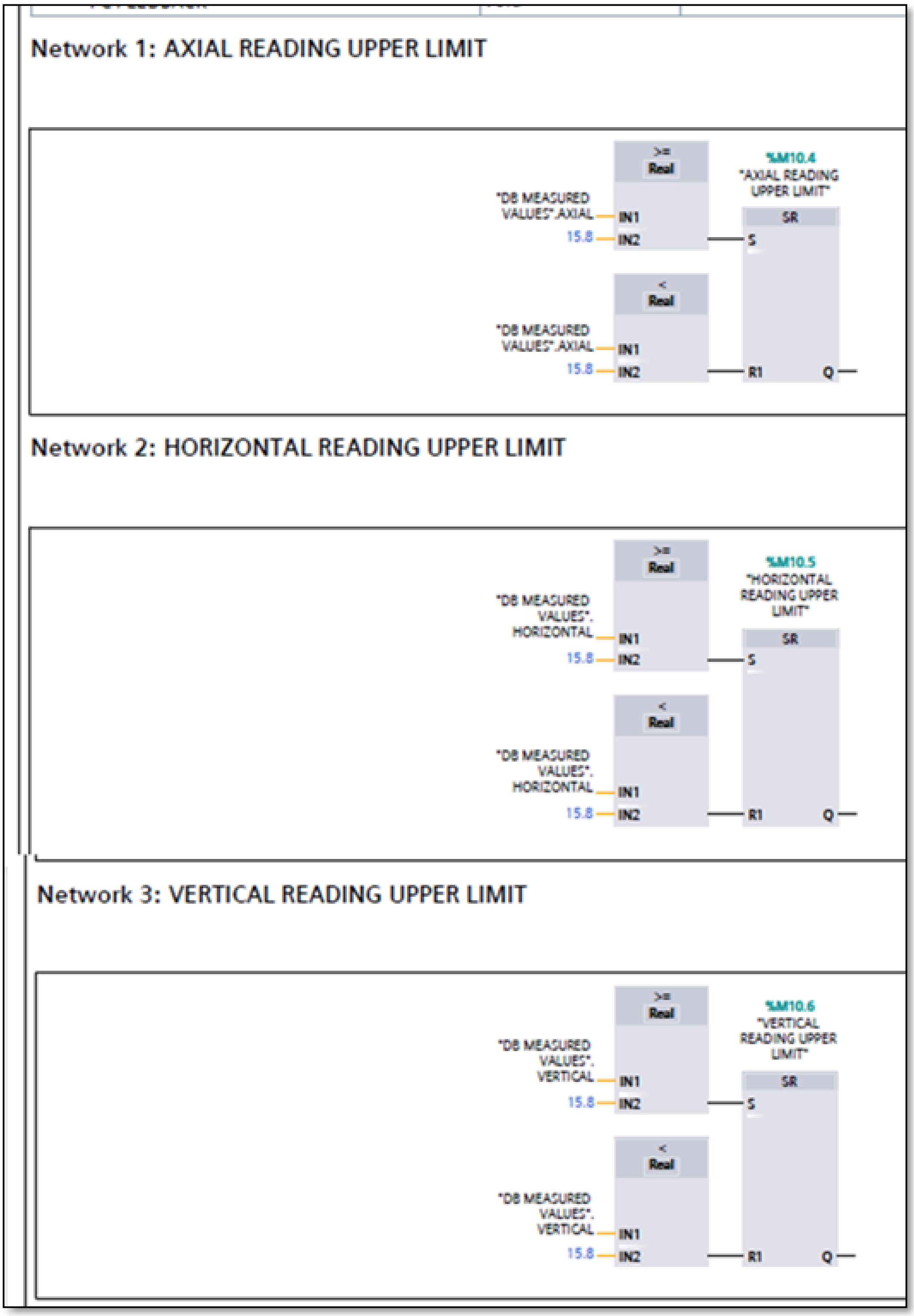



**Figure 5.5 FC Feedback_ Vibration Sensors**

Figure 5.5 provides a visual representation of the function call feedback within the TIA program, specifically for the axial, horizontal, and vertical vibration sensors. This program segment plays a crucial role in signal conditioning, ensuring that the raw measured values from these sensors are accurately processed. By programming the necessary fault detection mechanisms and setting appropriate limits, this function call enables efficient monitoring and analysis of vibration levels. It facilitates the identification of any anomalies or out-of-range readings, allowing for timely corrective actions to maintain system integrity. With this comprehensive approach to vibration monitoring, the program ensures reliable and optimized performance of the monitored equipment.

Figure 5.6 showcases the implementation of function call feedback in the TIA program, specifically for current monitoring. The program incorporates function blocks and employs predefined thresholds derived from the Gorman Rupp technical datasheet. These thresholds serve as benchmarks for the acceptable current range, allowing the system to promptly detect any deviations or faults in the monitored current values. By utilizing function call feedback with reference to the Gorman Rupp technical datasheet, the program ensures that the current levels remain within the prescribed limits, thereby enhancing the operational reliability and performance of the system.

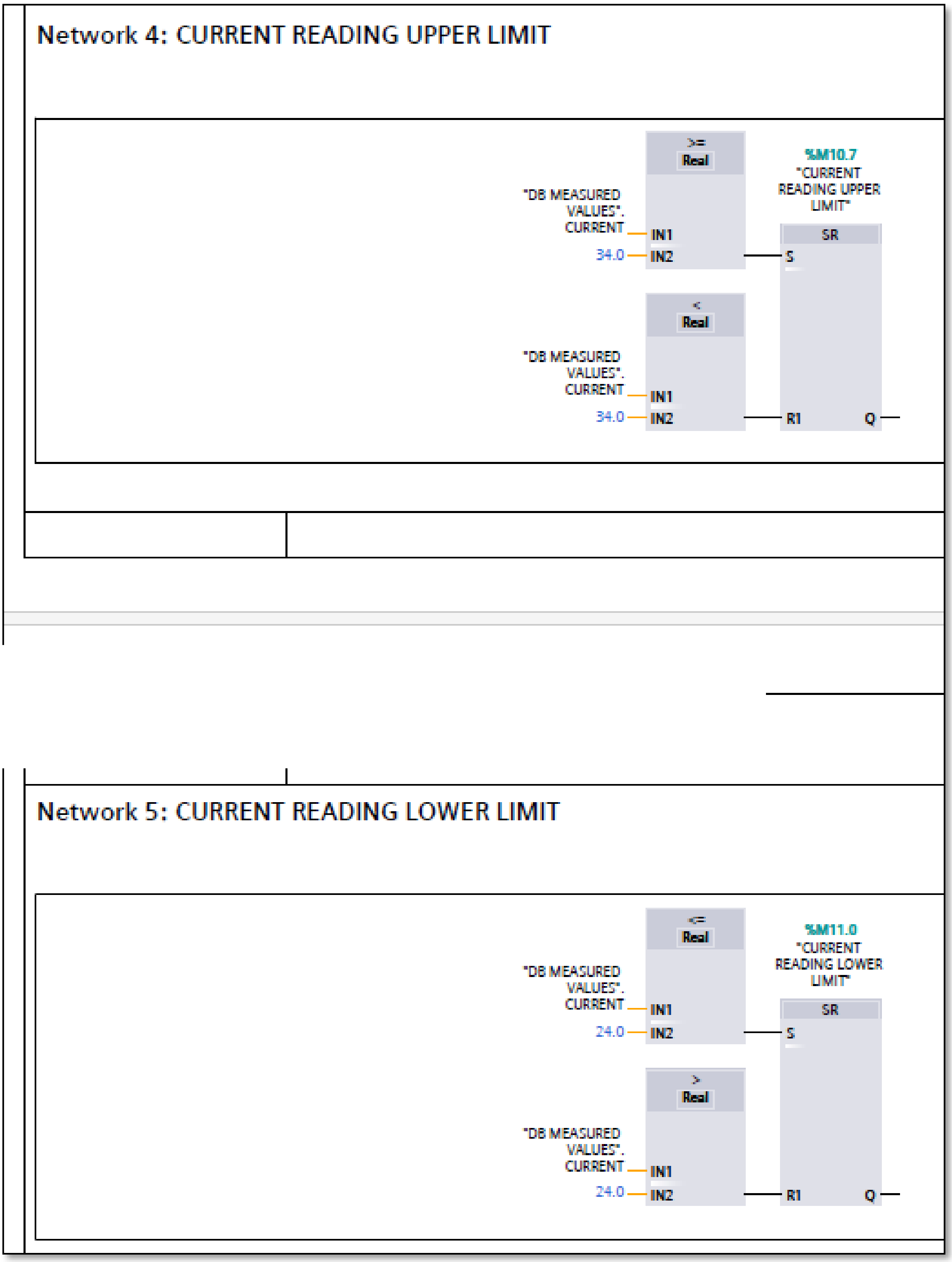
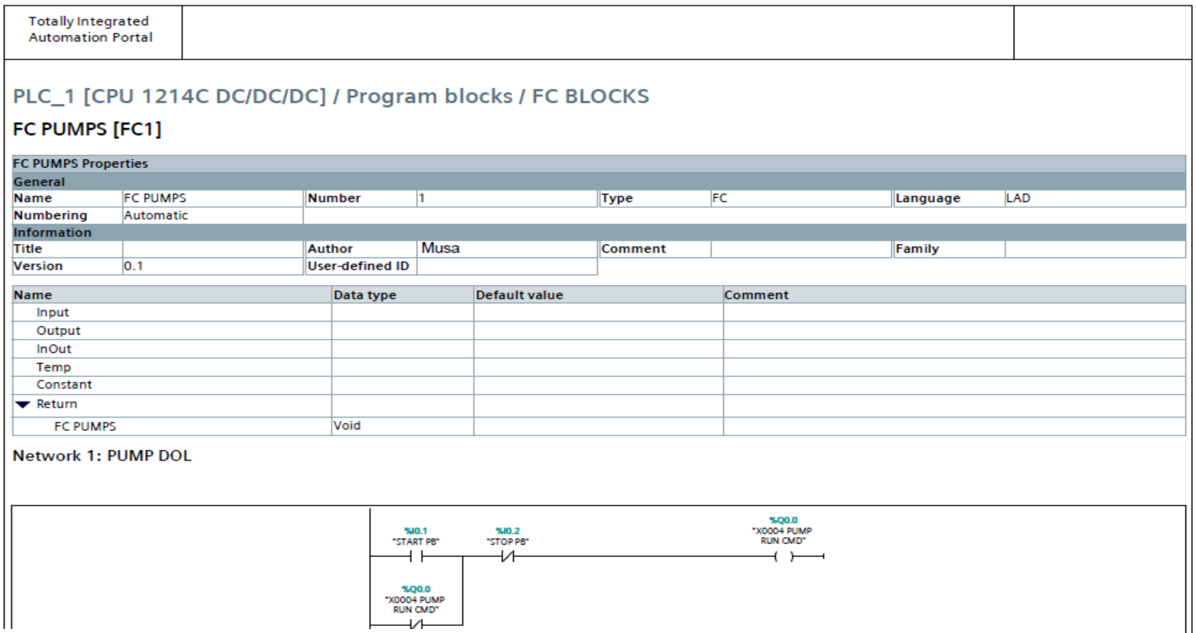



**Figure 5.6 Current reading lower limit**

### 5.2.2.3. FC Pumps

The function call feedback for the Gorman Rupp pump programming is indicated in Figure 5.7. This function block caters for the operation of the motor, including all associated interlocks.



Totally Integrated Automation Portal

PLC_1 [CPU 1214C DC/DC/DC] / Program blocks / FC BLOCKS

**FC PUMPS [FC1]**

| FC PUMPS Properties | | | | | | | |
|---|---|---|---|---|---|---|---|
| **General** | | | | | | | |
| Name | FC PUMPS | Number | 1 | Type | FC | Language | LAD |
| Numbering | Automatic | | | | | | |
| **Information** | | | | | | | |
| Title | | Author | Musa | Comment | | Family | |
| Version | 0.1 | User-defined ID | | | | | |

| Name | Data type | Default value | Comment |
|---|---|---|---|
| Input | | | |
| Output | | | |
| InOut | | | |
| Temp | | | |
| Constant | | | |
| ▼ Return | | | |
| FC PUMPS | Void | | |

Network 1: PUMP DOL



**Figure 5.7 Program Function Call Pump**

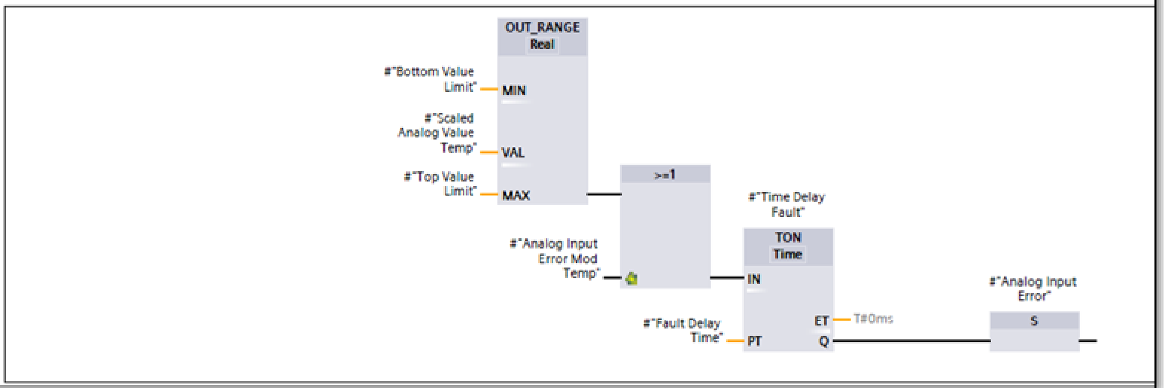
### 5.2.3. Function Blocks

Figure 5.8 provides a visual representation of the TIA program's architecture, showcasing the signal conditioning for sensors. The program utilizes function blocks (FBs) for modular and structured code organization. Within the program, the "Analog Scaling" block is essential for converting raw sensor measurements accurately. It applies scaling factors and calibration parameters for reliable data interpretation. The program follows a systematic approach, repeatedly calling the Analog Scaling block for consistent signal conditioning across sensors. This approach ensures code modularity, reusability, and efficient instruction management.

Network 2, Network 3 and Network 4 below are shown as Figure 5.8.

**Network 3:**

Totally Integrated Automation Portal




**Network 4:**

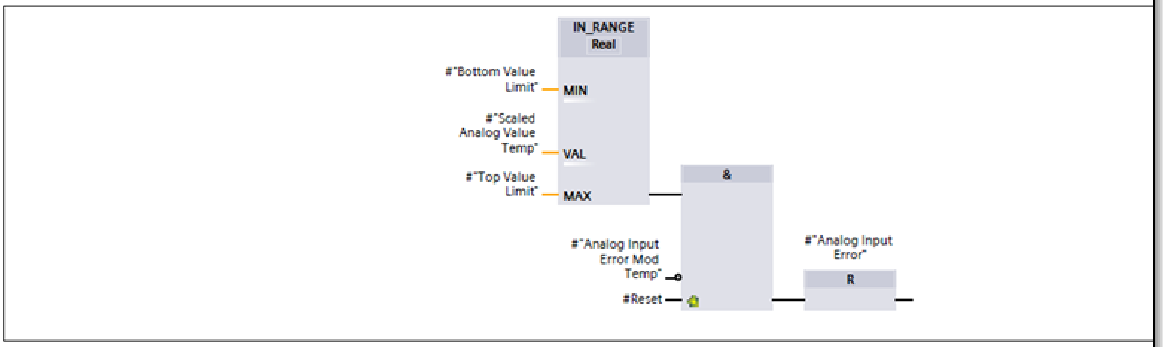



**Figure 5.8 TIA Program _Analogue Scaling**

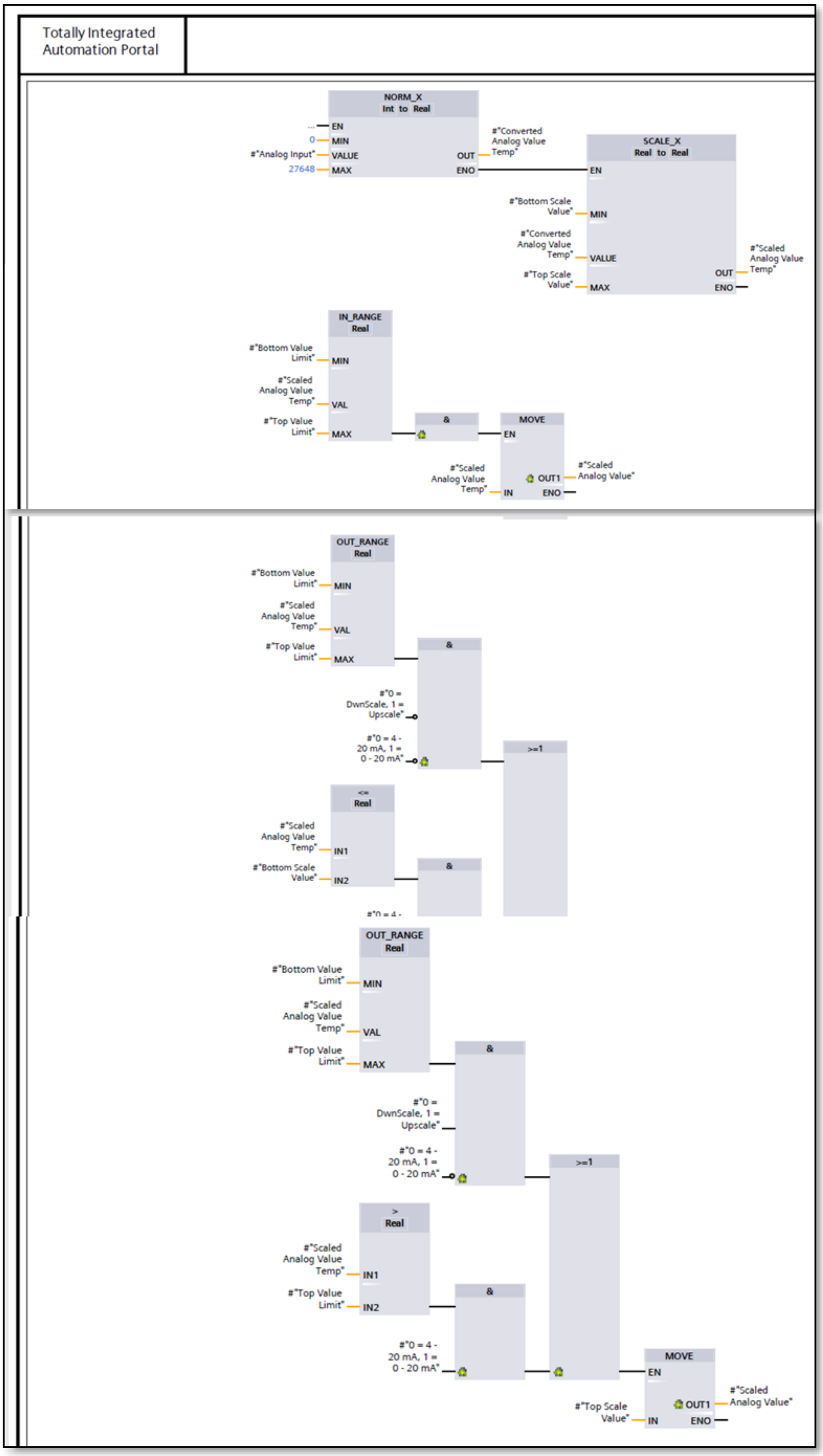



**Figure 5.9 TIA Program _Analogue Scaling**

In the TIA program shown in Figure 5.9 for the wastewater Gorman Rupp pump, the Function Block "Analog Scaling" plays a pivotal role in signal conditioning for both the current sensor and the three vibration sensors (axial, horizontal, and vertical). This Function Block, situated within Network 2, Network 3, and Network 4, ensures the precise conversion of raw sensor readings into meaningful physical values. For each sensor, the "Analog Scaling" block utilizes specific scaling factors and calibration parameters tailored to their individual characteristics. These factors are carefully configured to transform the raw analogue signals into accurate measurements of current and vibration levels.

When it comes to the current sensor, the "Analog Scaling" block considers its unique specifications and scales the analogue input to obtain the actual current value, providing crucial data on the motor's power consumption. Similarly, for the three vibration sensors, the "Analog Scaling" block is configured to interpret their respective analogue signals accurately. By applying appropriate scaling factors, it converts the sensor outputs into meaningful vibration measurements along the axial, horizontal, and vertical directions. By incorporating the "Analog Scaling" Function Block, Network 2, Network 3, and Network 4 ensure a consistent and reliable approach to signal conditioning for all four sensors. This modular design facilitates efficient program management, fosters code reusability, and simplifies maintenance tasks.

The "Analog Scaling" Function Block serves as a fundamental component of the TIA program, contributing to the overall effectiveness of data collection and analysis. Its role in converting raw sensor data into actionable information ensures the optimal performance and reliability of the Gorman Rupp pump and its critical components.

### 5.2.4. Data Blocks

Data Blocks (DB’s) are memory banks used to organize and store data in a structured format. There are four data blocks in the program, three of them are used to manage the signal conditioning of the sensors whenever the function blocks are being used.

The remaining one is a memory bank where the conditioned values are stored and sent to the SCADA. Refer to screenshots of DBs below.

Totally Integrated Automation Portal

PLC_1 [CPU 1214C DC/DC/DC] / Program blocks / DB BLOCKS / GLOBAL

**DB MEASURED VALUES [DB2]**

| DB MEASURED VALUES Properties | | | | | | | |
|---|---|---|---|---|---|---|---|
| **General** | | | | | | | |
| Name | DB MEASURED VALUES | Number | 2 | Type | DB | Language | DB |
| Numbering | Automatic | | | | | | |
| **Information** | | | | | | | |
| Title | | Author | Musa | Comment | | Family | |
| Version | 0.1 | User-defined ID | | | | | |

| Name | Data type | Start value | Retain | Accessible from HMI/OPC UA/Web API | Writable from HMI/OPC UA/Web API | Visible in HMI engineering | Setpoint | Supervision | Comment |
|---|---|---|---|---|---|---|---|---|---|
| ▼ Static | | | | | | | | | |
| AXIAL | Real | 0.0 | False | True | True | True | False | | |
| HORIZONTAL | Real | 0.0 | False | True | True | True | False | | |
| VERTICAL | Real | 0.0 | False | True | True | True | False | | |
| CURRENT | Real | 0.0 | False | True | True | True | False | | |

**Figure 5.10 TIA Program_ Measured DB Values**

Figure 5.11 shows the Axial Vibration Sensor Analogue Scaling Data Block (DB), which plays a crucial role in organizing and storing data for signal conditioning. It specifically manages the scaling and calibration parameters for the axial vibration sensor. This DB ensures accurate conversion of the raw analogue signal from the sensor into meaningful vibration measurements. By utilizing data blocks, the program maintains a structured approach to efficiently process and analyse sensor data. The Axial Vibration Sensor Analogue Scaling DB contributes to the overall organization and functionality of the program.

PLC_1 [CPU 1214C DC/DC/DC] / Program blocks / DB BLOCKS / INSTANCE

AXIAL VIBRATION SENSOR ANALOG SCALING_DB [DB1]

| AXIAL VIBRATION SENSOR ANALOG SCALING_DB Properties | | | | | | | |
|---|---|---|---|---|---|---|---|
| General | | | | | | | |
| Name | AXIAL VIBRATION SENSOR ANALOG SCALING_DB | Number | 1 | Type | DB | Language | DB |
| Numbering | Automatic | | | | | | |
| Information | | | | | | | |
| Title | | Author | AK_Musa | Comment | | Family | |
| Version | 1.0 | User-defined ID | | | | | |

| Name | Data type | Start value | Retain | Accessible from HMI/OPC UA/Web API | Writ-able from HMI/ OPC UA/ Web API | Visible in HMI engi-neering | Setpoint | Supervi-sion | Comment |
|---|---|---|---|---|---|---|---|---|---|
| ▼ Input | | | | | | | | | |
| Analog Input | Int | 0 | False | True | True | True | False | | |
| Top Scale Value | Real | 0.0 | False | True | True | True | False | | |
| Bottom Scale Value | Real | 0.0 | False | True | True | True | False | | |
| Top Value Limit | Real | 0.0 | False | True | True | True | False | | |
| Bottom Value Limit | Real | 0.0 | False | True | True | True | False | | |
| Fault Delay Time | Time | T#0ms | False | True | True | True | False | | |
| Reset | Bool | false | False | True | True | True | False | | |
| 0 = DwnScale, 1 = Upscale | Bool | false | False | True | True | True | False | | |
| 0 = 4 - 20 mA, 1 = 0 - 20 mA | Bool | false | False | True | True | True | False | | |
| ▼ Output | | | | | | | | | |
| Analog Input Error | Bool | false | False | True | True | True | False | | |
| Scaled Analog Value | Real | 0.0 | False | True | True | True | False | | |
| InOut | | | | | | | | | |
| ▼ Static | | | | | | | | | |
| ▼ Time Delay Fault | IEC_TIMER | | False | True | True | False | True | | |
| PT | Time | T#0ms | False | True | True | False | False | | |
| ET | Time | T#0ms | False | True | False | False | False | | |
| IN | Bool | false | False | True | True | False | False | | |
| Q | Bool | false | False | True | False | False | False | | |

**Figure 5.11 TIA Program Axial Vibration Sensor Analogue Scaling DB**

Totally Integrated Automation Portal

PLC_1 [CPU 1214C DC/DC/DC] / Program blocks / DB BLOCKS / INSTANCE

HORIZONTAL VIBRATION SENSOR ANALOG SCALING [DB3]

| HORIZONTAL VIBRATION SENSOR ANALOG SCALING Properties | | | | | | | |
|---|---|---|---|---|---|---|---|
| General | | | | | | | |
| Name | HORIZONTAL VIBRATION SENSOR ANALOG SCALING | Number | 3 | Type | DB | Language | DB |
| Numbering | Automatic | | | | | | |
| Information | | | | | | | |
| Title | | Author | AK _Musa | Comment | | Family | |
| Version | 1.0 | User-defined ID | | | | | |

| Name | Data type | Start value | Retain | Accessible from HMI/OPC UA/Web API | Writ-able from HMI/ OPC UA/ Web API | Visible in HMI engi-neering | Setpoint | Supervi-sion | Comment |
|---|---|---|---|---|---|---|---|---|---|
| ▼ Input | | | | | | | | | |
| Analog Input | Int | 0 | False | True | True | True | False | | |
| Top Scale Value | Real | 0.0 | False | True | True | True | False | | |
| Bottom Scale Value | Real | 0.0 | False | True | True | True | False | | |
| Top Value Limit | Real | 0.0 | False | True | True | True | False | | |
| Bottom Value Limit | Real | 0.0 | False | True | True | True | False | | |
| Fault Delay Time | Time | T#0ms | False | True | True | True | False | | |
| Reset | Bool | false | False | True | True | True | False | | |
| 0 = DwnScale, 1 = Upscale | Bool | false | False | True | True | True | False | | |
| 0 = 4 - 20 mA, 1 = 0 - 20 mA | Bool | false | False | True | True | True | False | | |
| ▼ Output | | | | | | | | | |
| Analog Input Error | Bool | false | False | True | True | True | False | | |
| Scaled Analog Value | Real | 0.0 | False | True | True | True | False | | |
| InOut | | | | | | | | | |
| ▼ Static | | | | | | | | | |
| ▼ Time Delay Fault | IEC_TIMER | | False | True | True | False | True | | |
| PT | Time | T#0ms | False | True | True | False | False | | |
| ET | Time | T#0ms | False | True | False | False | False | | |
| IN | Bool | false | False | True | True | False | False | | |
| Q | Bool | false | False | True | False | False | False | | |

**Figure 5.12 Program _Axial Vibration Sensor Analogue Scaling DB (DB4)**

Figure 5.13 shows the Current Sensor Data Block (DB5). This Current Sensor Analogue Scaling DB is responsible for managing the scaling and calibration parameters of the current sensor. It ensures accurate conversion of the raw analogue signal from the current sensor into meaningful current measurements. By utilizing this data block, the program can effectively process and analyse the current sensor data. The Current Sensor Analogue Scaling DB plays a vital role in maintaining data integrity and facilitating precise current monitoring within the system.

Totally Integrated Automation Portal

PLC_1 [CPU 1214C DC/DC/DC] / Program blocks / DB BLOCKS / INSTANCE

VERTICAL VIBRATION SENSOR ANALOG_SCALING_DB [DB4]

| VERTICAL VIBRATION SENSOR ANALOG_SCALING_DB Properties | | | | | | | |
|---|---|---|---|---|---|---|---|
| General | | | | | | | |
| Name | VERTICAL VIBRATION SENSOR ANALOG_SCALING_DB | Number | 4 | Type | DB | Language | DB |
| Numbering | Automatic | | | | | | |
| Information | | | | | | | |
| Title | | Author | AK_Musa | Comment | | Family | |
| Version | 1.0 | User-defined ID | | | | | |

| Name | Data type | Start value | Retain | Accessible from HMI/OPC UA/Web API | Writable from HMI/OPC UA/Web API | Visible in HMI engineering | Setpoint | Supervision | Comment |
|---|---|---|---|---|---|---|---|---|---|
| ▼ Input | | | | | | | | | |
| Analog Input | Int | 0 | False | True | True | True | False | | |
| Top Scale Value | Real | 0.0 | False | True | True | True | False | | |
| Bottom Scale Value | Real | 0.0 | False | True | True | True | False | | |
| Top Value Limit | Real | 0.0 | False | True | True | True | False | | |
| Bottom Value Limit | Real | 0.0 | False | True | True | True | False | | |
| Fault Delay Time | Time | T#0ms | False | True | True | True | False | | |
| Reset | Bool | false | False | True | True | True | False | | |
| 0 = DwnScale, 1 = Upscale | Bool | false | False | True | True | True | False | | |
| 0 = 4 - 20 mA, 1 = 0 - 20 mA | Bool | false | False | True | True | True | False | | |
| ▼ Output | | | | | | | | | |
| Analog Input Error | Bool | false | False | True | True | True | False | | |
| Scaled Analog Value | Real | 0.0 | False | True | True | True | False | | |
| InOut | | | | | | | | | |
| ▼ Static | | | | | | | | | |
| ▼ Time Delay Fault | IEC_TIMER | | False | True | True | False | True | | |
| PT | Time | T#0ms | False | True | True | False | False | | |
| ET | Time | T#0ms | False | True | False | False | False | | |
| IN | Bool | false | False | True | True | False | False | | |
| Q | Bool | false | False | True | False | False | False | | |

**Figure 5.13 Program_ Vertical Vibration Sensor Analogue Scaling DB (DB5)**

Totally Integrated Automation Portal

PLC_1 [CPU 1214C DC/DC/DC] / Program blocks / DB BLOCKS / INSTANCE

**CURRENT SENSOR ANALOG_SCALING_DB [DB5]**

| CURRENT SENSOR ANALOG_SCALING_DB Properties | | | | | | | |
|---|---|---|---|---|---|---|---|
| **General** | | | | | | | |
| Name | CURRENT SENSOR ANA-LOG_SCALING_DB | Number | 5 | Type | DB | Language | DB |
| Numbering | Automatic | | | | | | |
| **Information** | | | | | | | |
| Title | | Author | AK _Musa | Comment | | Family | |
| Version | 1.0 | User-defined ID | | | | | |

| Name | Data type | Start value | Retain | Accessible from HMI/OPC UA/Web API | Writ-able from HMI/ OPC UA/ Web API | Visible in HMI engi-neering | Setpoint | Supervi-sion | Comment |
|---|---|---|---|---|---|---|---|---|---|
| ▼ Input | | | | | | | | | |
| Analog Input | Int | 0 | False | True | True | True | False | | |
| Top Scale Value | Real | 0.0 | False | True | True | True | False | | |
| Bottom Scale Value | Real | 0.0 | False | True | True | True | False | | |
| Top Value Limit | Real | 0.0 | False | True | True | True | False | | |
| Bottom Value Limit | Real | 0.0 | False | True | True | True | False | | |
| Fault Delay Time | Time | T#0ms | False | True | True | True | False | | |
| Reset | Bool | false | False | True | True | True | False | | |
| 0 = DwnScale, 1 = Upscale | Bool | false | False | True | True | True | False | | |
| 0 = 4 - 20 mA, 1 = 0 - 20 mA | Bool | false | False | True | True | True | False | | |
| ▼ Output | | | | | | | | | |
| Analog Input Error | Bool | false | False | True | True | True | False | | |
| Scaled Analog Value | Real | 0.0 | False | True | True | True | False | | |
| InOut | | | | | | | | | |
| ▼ Static | | | | | | | | | |
| ▼ Time Delay Fault | IEC_TIMER | | False | True | True | False | True | | |
| PT | Time | T#0ms | False | True | True | False | False | | |
| ET | Time | T#0ms | False | True | False | False | False | | |
| IN | Bool | false | False | True | True | False | False | | |
| Q | Bool | false | False | True | False | False | False | | |

**Figure 5.14 Program Current Sensor Analogue Scaling DB (DB5)**

## 5.3. Conclusion

Chapter 5 provides a concise overview of Siemens TIA Portal V16 programming, highlighting the central role of OB1, exploring Function Calls for signal conditioning and fault management, and utilizing Data Blocks for efficient data organization. The concluding section emphasizes the importance of smart monitoring in addressing sewer spillage and environmental pollution, reinforcing the research methodology's relevance. Chapter Six details the qualitative approach to assess sewer contamination using questionnaires, validating quantitative results with collected data.

## CHAPTER SIX:

# 6. QUALITATIVE DATA COLLECTION

## 6.1. Introduction

Chapter 6 delved into the quantitative data collection and analysis, shedding light on the insights gained through the implementation of smart monitoring of sewer infrastructure. Chapter 5 detailed the TIA programming. Building upon these findings, Chapter 6 aims to further enrich our understanding by incorporating qualitative research methods. This chapter explores the use of questionnaires and qualitative data analysis to validate and complement the quantitative data, providing a comprehensive view of the monitored sewer system and its environmental implications.

The chapter is made up of the following sub-sections:

- In Section 6.1, there is a transition from quantitative data analysis in Chapter Four and Five to qualitative research methods to gain a more comprehensive perspective on sewer system monitoring. This section aims to provide a holistic view of sewer system monitoring. It consists of sub-sections that explore stakeholder perspectives, unveil hidden insights, draw conclusions from qualitative data, and, summarize key findings.
- Section 6.2 employs two questionnaires for comprehensive validation. One focuses on Ndlambe Local Municipality staff to gather insights and record sewer spillage incidents. The second involves community members to capture their perspectives on sewer impacts, enhancing understanding.
- Section 6.3 validates Chapter 4 and 5 with qualitative data, emphasizing smart monitoring's significance and recommending gap solutions.
- Section 6.4 summarizes data correlation, highlighting the need for smart monitoring.
- Section 6.5 details the Chapter summary

## 6.2. Questionnaire

To ensure comprehensive validation of the quantitative data and underscore the significance of this research, two distinct questionnaires are designed. These questionnaires served as essential tools to gain a broader perspective and confirm the necessity of this study. The respondents are interviewed through a user-friendly Google Form questionnaire, facilitating easy data collection and analysis. The primary focus of the first questionnaire is on the Ndlambe Local Municipality staff, who possess invaluable insights into the current operation and maintenance practices of the sewer infrastructure. This questionnaire aimed to delve into the intricacies of their existing monitoring mechanisms. Additionally, the questionnaire requested the staff to diligently record any instances of reported sewer spillage, providing crucial incident data, including their response time and subsequent findings.

Considering the unique context of the municipality, with a smaller maintenance team, the questionnaire was distributed among eight (8) team members out of the approximately twelve (12) members in total. This thoughtful approach ensured that the feedback obtained is representative and reflective of the municipality's operational realities. By engaging the Ndlambe Local Municipality staff through this targeted questionnaire, invaluable insights are garnered into the efficacy of their current monitoring practices. The questionnaire's findings, combined with the quantitative data, establish the necessity and urgency of advancing towards smart sewer infrastructure monitoring.

This research goes beyond the mere validation of data; it highlights the pressing need to bridge the gap between conventional monitoring approaches and the implementation of innovative technologies to effectively combat sewer spillage and mitigate environmental pollution. Below is the link to the Google Form Questionnaire link to the questionnaire.

https://forms.gle/4mF9hRn7opCKwd345A

To give a comprehensive and well-rounded perspective, it is imperative to gather insights from the community residing around the Mbabela pump station. Therefore, an additional questionnaire is prepared and distributed to the community members. By directly involving the community in the research process, their invaluable perspectives and experiences could be captured, thereby establishing a more holistic understanding of the sewer infrastructure's impact on their daily lives and the environment.

The questionnaire aimed to engage the community in meaningful dialogue, allowing them to share their observations, concerns, and experiences related to sewer spillage incidents and the overall functioning of the sewer infrastructure. By actively seeking the community's views, the research strives to empower them as stakeholders and advocates for positive change in environmental preservation.

Understanding the community's experiences and perceptions is crucial for several reasons. Firstly, their proximity to the pump station provides unique insights into the local environmental impact and potential pollution risks. Secondly, their first-hand encounters with sewer spillage incidents contribute to the identification of patterns, trends, and potential hotspots that may not be captured through quantitative data alone. Thirdly, involving the community in the research process fosters a sense of ownership, collaboration, and shared responsibility in addressing environmental challenges.

By incorporating the community's perspectives through this questionnaire, the research aims to bridge the gap between scientific data and the lived experiences of those directly affected. This participatory approach ensures that the outcomes and recommendations of the study are relevant, practical, and sensitive to the community's needs and aspirations. Through their active participation, the community becomes empowered stakeholders in driving the implementation of smart sewer infrastructure monitoring and collectively working towards alleviating environmental pollution caused by sewer spillage. Below is the link to the Google Form sent to the community.

https://forms.gle/YDyFsaY4hKSASqqZ8

Section 6.2 provided a comprehensive overview of the data collected through questionnaires administered to the Ndlambe Local Municipality staff. The purpose is to validate the occurrence of sewage spillage incidents and understand the impact of these incidents on their daily lives. By analysing the responses received, Section 6.3 delves deeper into each individual response, painting a vivid picture of the existing challenges and providing valuable insights for tailoring an effective solution.

## 6.3. Qualitative Data Results and Analysis

This section explores the qualitative data collected from two key sources: the community residing near the Chris Hani pump station and the Maintenance team of Ndlambe Local Municipality. Through analysis and interpretation, we gain valuable insights into the challenges and implications of sewer infrastructure monitoring on both the environment and the daily lives of the community.

### 6.3.1. Municipal Maintenance Team Feedback and Results Analysis

The feedback received from the Municipal Maintenance team is collectively analysed and discussed to gain insights into their experiences and perspectives on sewer infrastructure maintenance. By considering the responses, we can identify common themes and patterns, enabling a comprehensive examination of the maintenance practices and challenges faced by the team.

#### 6.3.1.1. Feedback: Maintenance of Ndlambe Local Municipality

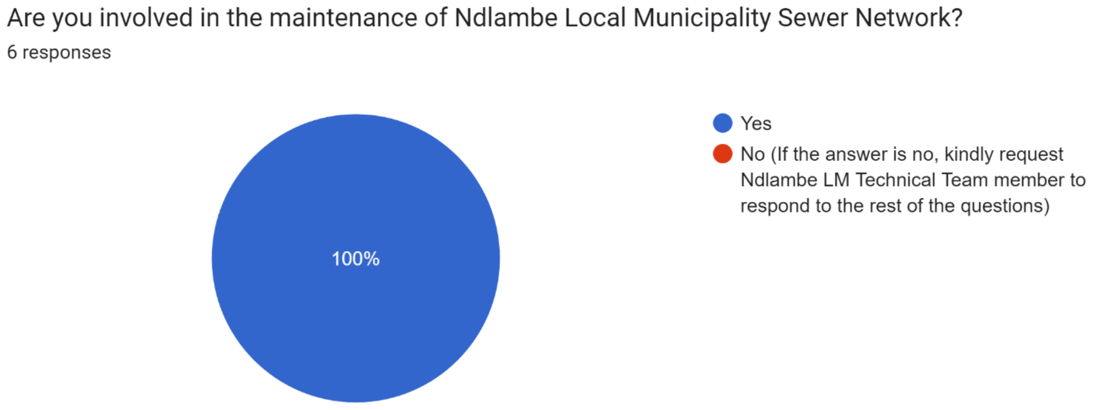



**Figure 6.1 Maintenance of Ndlambe Local Municipality**

#### 6.3.1.2. Feedback: Methods used to monitor wastewater

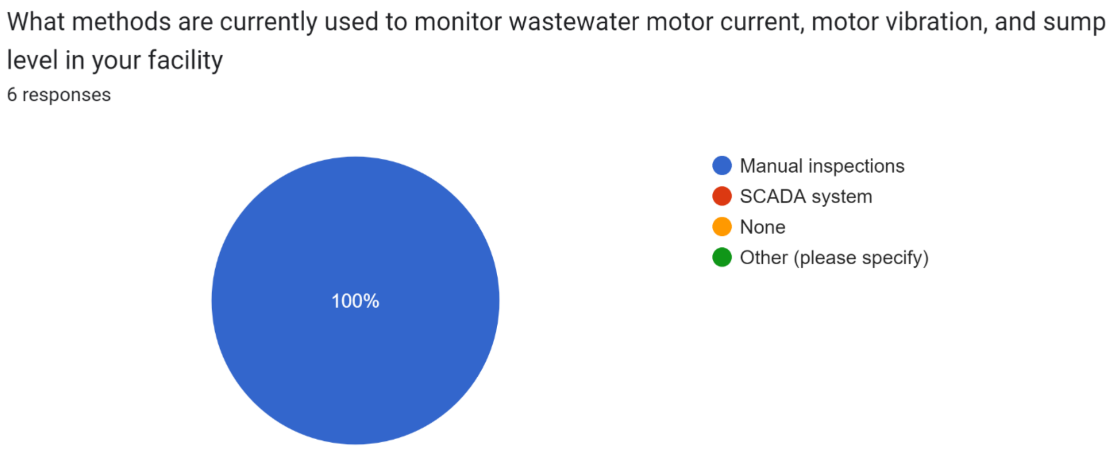



**Figure 6.2 Methods used to monitor wastewater**

### 6.3.1.3. Feedback: Monitoring of parameters

How frequently are these parameters monitored?
7 responses

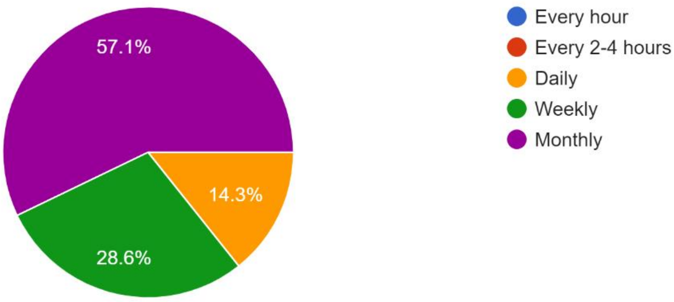



**Figure 6.3 Monitoring of parameters**

### 6.3.1.4. Feedback: Detection of abnormality

How long does it take to detect an abnormality in motor current, vibration, or sump level using current monitoring methods?
6 responses

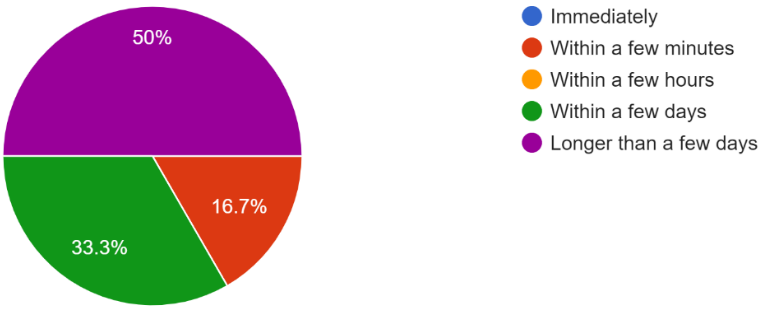



**Figure 6.4 Detection of abnormality**

### 6.3.1.5. Feeback: Sewage spillages

How often do sewage spillages occur in your facility, and what is the typical volume of sewage that is spilled?

6 responses

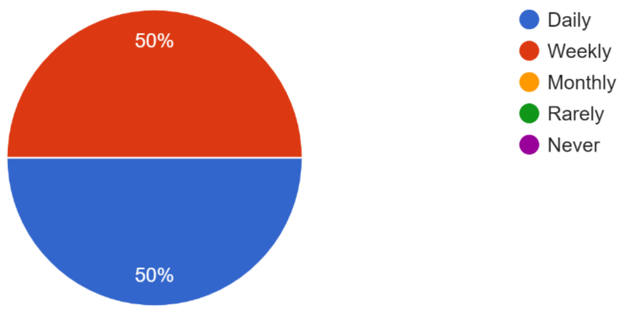



**Figure 6.5 Sewage spillages**

### 6.3.1.6. Feedback: Cost associated with sewage spillages

What are the costs associated with sewage spillages (e.g. cleanup, fines, legal fees, environmental remediation, reputation damage)?

6 responses

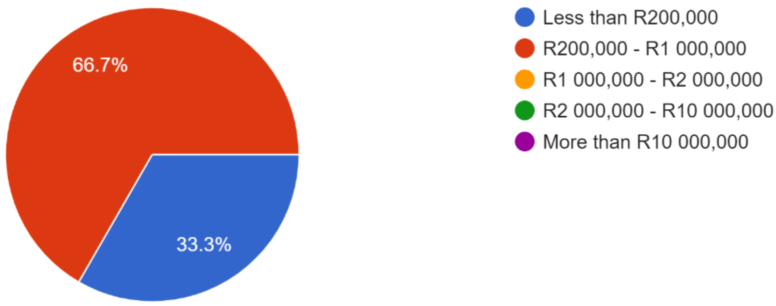



**Figure 6.6 Cost associated with sewage spillages.**

### 6.3.1.7. Feedback: Use of predictive maintenance tools

Have you ever used any predictive maintenance tools, such as machine learning or artificial intelligence, to monitor the performance of wastew...rs and sump pumps? If so, what were the results?
6 responses

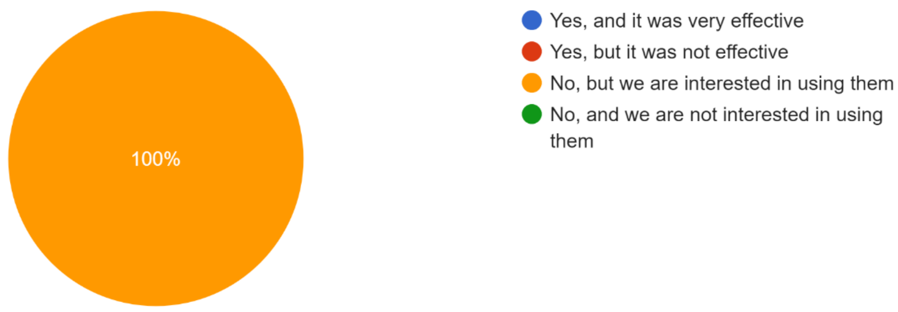



**Figure 6.7 Use of predictive maintenance tools**

### 6.3.1.8. Feedback: Use of Artificial intelligence

What are your thoughts on using artificial intelligence to predict and prevent sewage spillages in your facility? Do you think it could be an effective tool for reducing environmental pollution?
6 responses

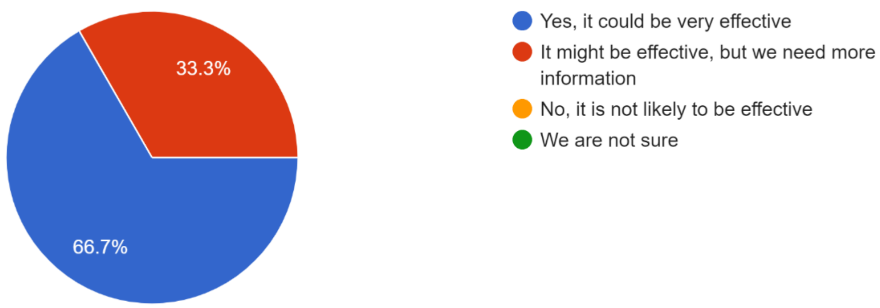



**Figure 6.8 Use of Artificial intelligence**

#### 6.3.1.9. Feedback: Factors associated with implementation of smart technology

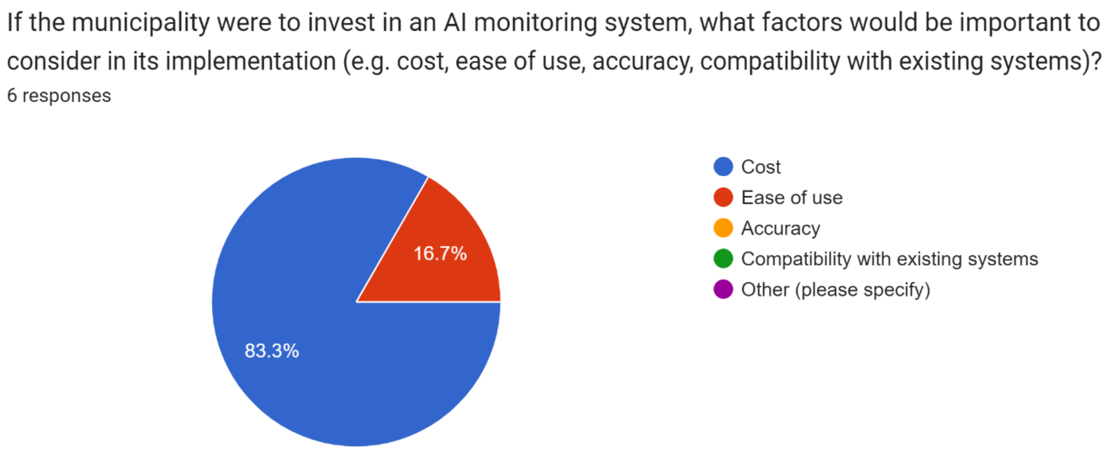



**Figure 6.9 Factors associated with implementation of smart technology**

#### 6.3.1.10. Feedback: Willingness to participate in a pilot program

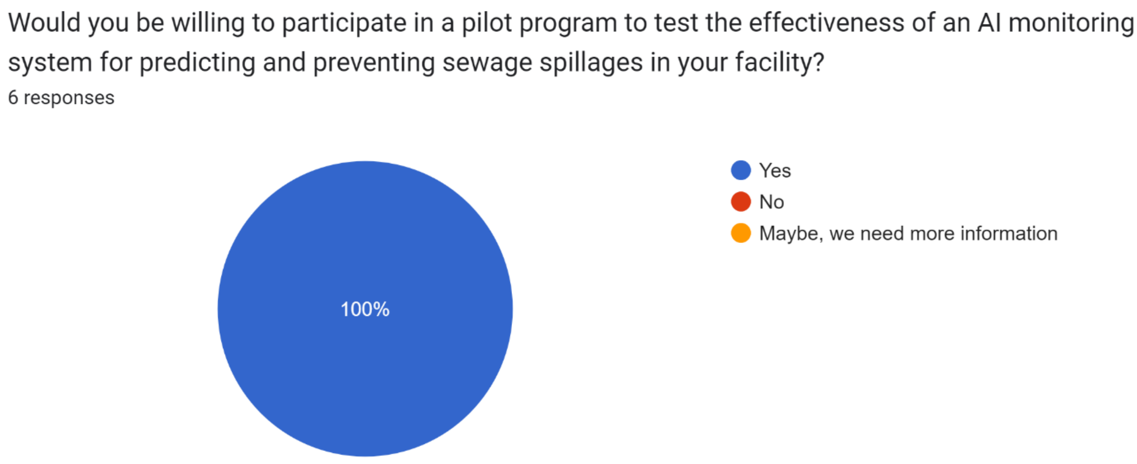



**Figure 6.10 Willingness to participate in a pilot program**

### 6.3.1.11. Feedback: Recorded incidents at Mbabela Pumpstation

During the month of April 2023 was there any spillage incident recorded at Chris Hani Pump Station?

2 responses

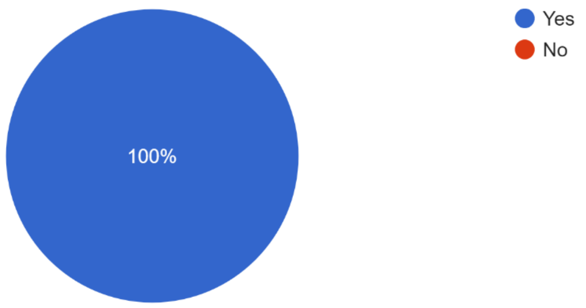



**Figure 6.11 Recorded incidents at Mbabela Pumpstation**

### 6.3.1.12. Feedback: Reporting of the incident

When was the incident reported?

1 response

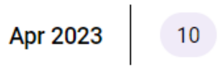



**Figure 6.12 Reporting of the incident**

### 6.3.1.13. Feedback: Incident notification

How did the incident come to your attention?

1 response

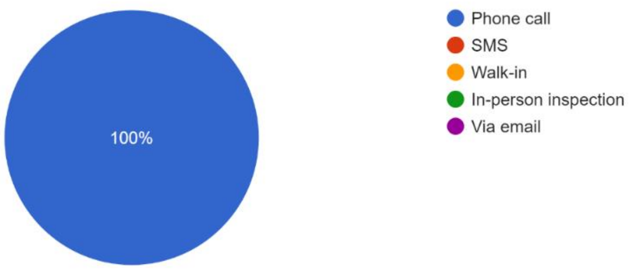


**Figure 6.13 Incident notification**

### 6.3.1.14. Feedback: Causes of spillage

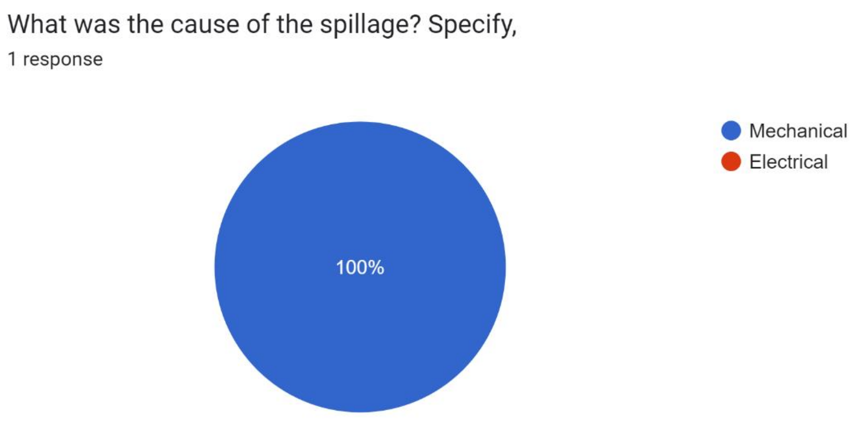



**Figure 6.14 Causes of spillage**

### 6.3.1.15. Feedback: Identification of the problem

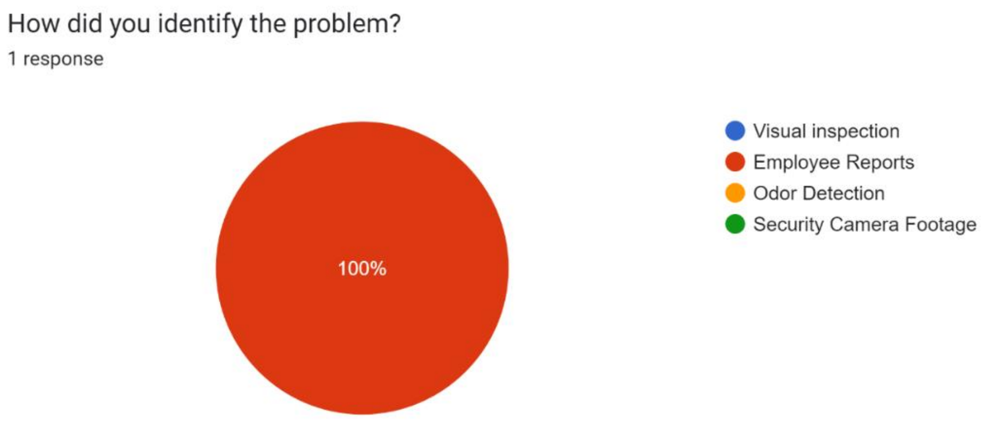



**Figure 6.15 Identification of the problem**

#### 6.3.1.16. Feedback: Time taken to fix the issue

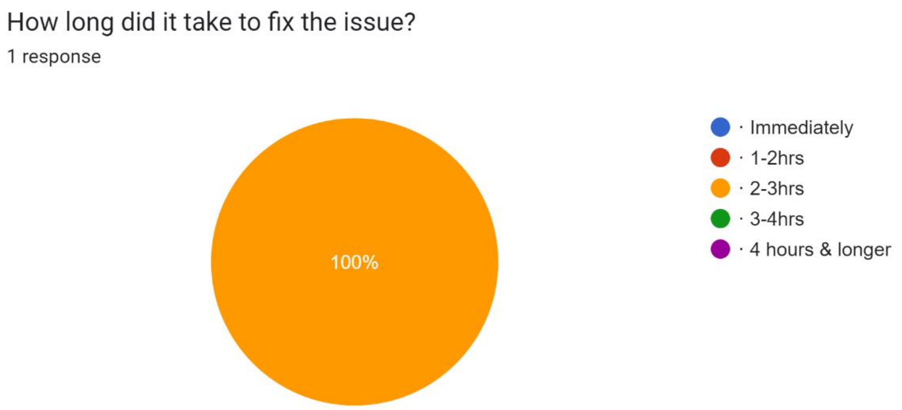



**Figure 6.16 Time taken to fix the issue**

#### 6.3.1.17. Feedback: Time taken to fix the issue

Do you know spillage volumes? If yes, specify

0 responses

No responses yet for this question.

Do you have any comments on how the issue could be handled in future?

We want to know before pumps get damaged.

0 responses

No responses yet for this question.

**Figure 6.17 Time taken to fix the issue**

Based on the responses from the Municipality's Maintenance team, a notable gap in their current approach to addressing sewage spillage incidents is their reliance on manual communication between team members. This manual communication process is time-consuming and prone to miscommunication or delays, potentially impacting the efficiency and timeliness of their response. Additionally, while the team expresses an interest in using technology, it is evident that their current methods do not fully leverage technological advancements in sewage monitoring and management. This indicates a gap in their utilization of available tools and solutions that could potentially enhance their operations.

Furthermore, the reliance on community feedback for identifying spillage incidents implies that the team may not have a comprehensive and proactive monitoring system in place. While community input is valuable, it may not capture all instances of sewage spillage, leading to potential delays in response and a limited understanding of the overall extent of the problem.

### 6.3.2. Community Feedback and Results Analysis

The results obtained from the community survey regarding their experiences and observations related to sewer infrastructure are presented below. Each response is thoroughly analysed and discussed to gain a comprehensive understanding of the community's perspective.

#### 6.3.2.1. Feedback: Community Response Residential Distribution Analysis

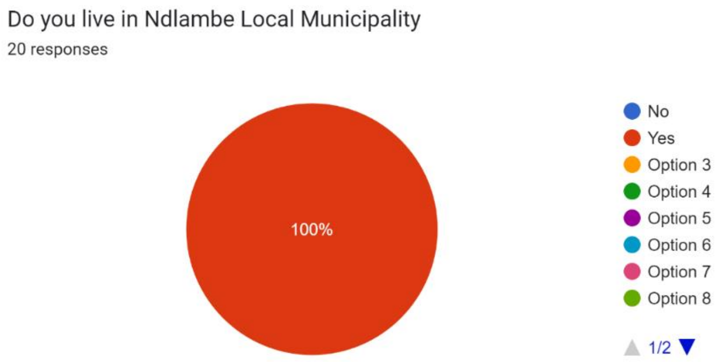



**Figure 6.18 Community Response Residential Distribution Analysis**

With reference to Figure 6.18 the high response rate of 20 out of 23 participants affirming their residency in Ndlambe Local Municipality demonstrates a significant level of community representation. This substantiates the survey's efficacy in capturing the first-hand experiences and perspectives of residents who bear the direct impact of sewage pollution. The invaluable input from these individuals plays a pivotal role in comprehending the local dynamics and implications associated with the issue at hand.

#### 6.3.2.2. Community Response: Distribution of Respondents by Affiliation with Ndlambe Local Municipality

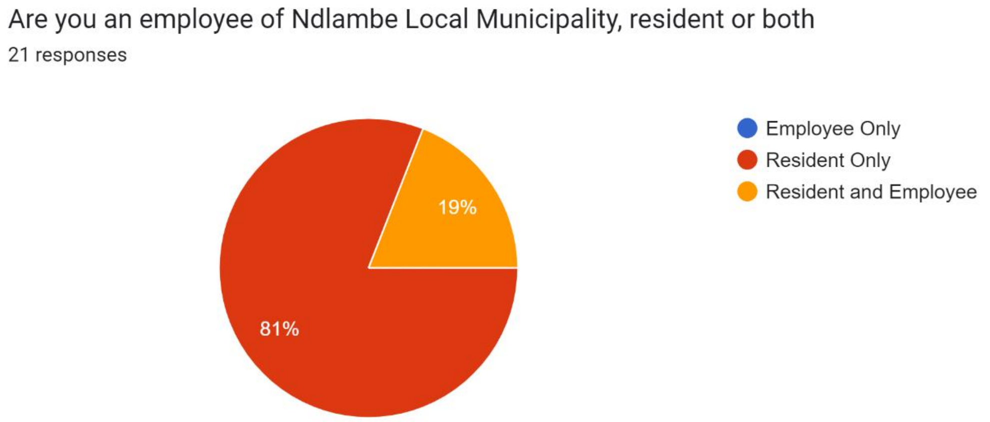



**Figure 6.19 Community Response Distribution of Respondents by Affiliation with Ndlambe Local Municipality**

Based on Figure 6.19 , out of the total respondents, the results indicate that the majority (17 out of 23) identified themselves solely as residents, highlighting their perspective as community members rather than employees of Ndlambe Local Municipality. This distinction is significant as it represents the viewpoint of individuals who are affected by the municipality's decisions and actions regarding sewage management without direct involvement in its daily operations. Additionally, the 4 respondents who identified themselves as both residents and employees possess valuable insights due to their dual roles, providing insider knowledge and a unique perspective on the challenges faced.

#### 6.3.2.3. Community Response_ Prevalence of Sewage Spillage in Homes and Communities

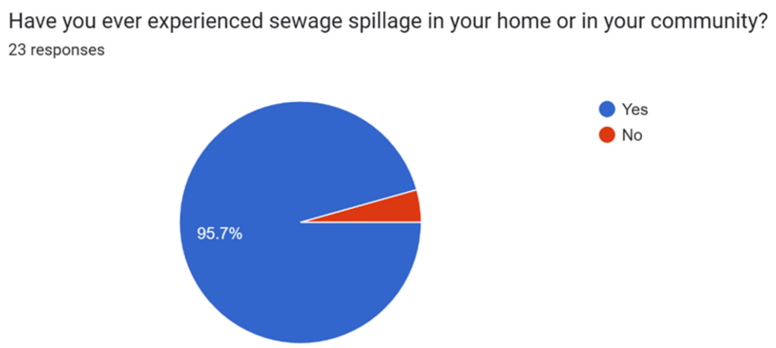



**Figure 6.20 Community Response_ Prevalence of Sewage Spillage in Homes and Communities**

The prevalence of sewage spillage reported by most respondents (22 out of 23) in Figure 6.20 sheds light on the extent of the problem in the Ndlambe Local Municipality. This alarming finding emphasizes the immediate action required to tackle sewage pollution, considering its direct impact on a substantial portion of the population. The first-hand experiences shared by participants offer invaluable insights into the adverse effects and repercussions associated with sewage spillage.

#### 6.3.2.4. Community Response_ Frequency of Sewage Spillage Incidents in the Past Year

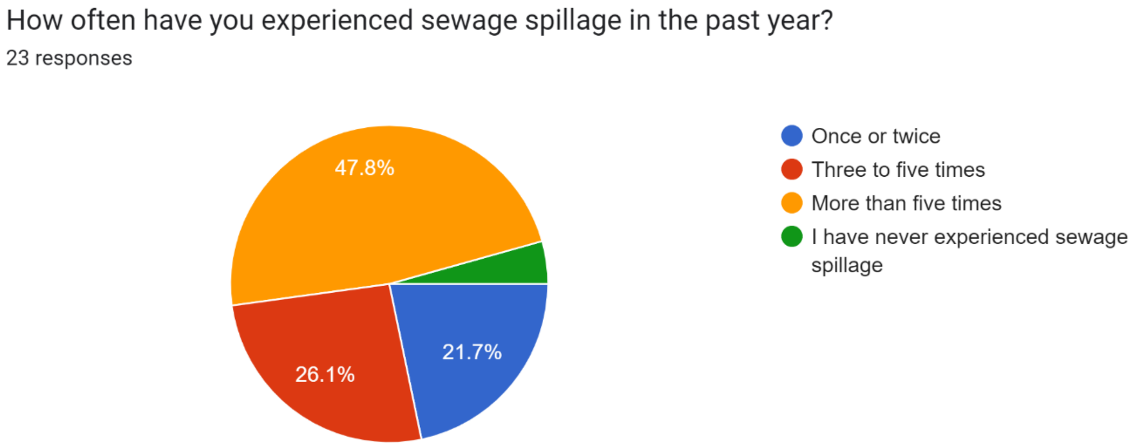



**Figure 6.21 Community Response_ Frequency of Sewage Spillage Incidents in the Past Year**

The distribution of responses regarding the frequency of sewage spillage in Figure 6.21 reveals a recurring pattern of the problem. The data indicates that sewage spillage is not an isolated incident but a persistent issue within the Ndlambe Local Municipality. Among the respondents, a substantial number reported experiencing spillage multiple times within the past year. This finding highlights the need to address systemic or infrastructure-related challenges that contribute to the repeated occurrences of sewage spillage. By tackling these underlying issues, the municipality can strive towards creating a sustainable and hygienic environment for its residents.

### 6.3.2.5. Community Response_ Sewage Spillage Reporting Methods

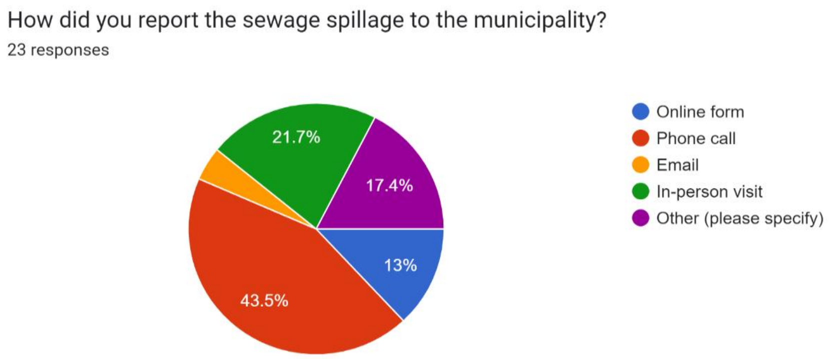



**Figure 6.22 Community Response_ Sewage Spillage Reporting Methods**

The variety of reporting approaches utilized by respondents in Figure 6.22 underscores the significance of providing a range of channels to report sewage spillage incidents. Most participants (10 out of 23) favoured making phone calls, emphasizing their preference for direct communication when reporting such incidents. Additionally, a subset of respondents (3 out of 23) opted for online forms, leveraging digital platforms for convenient reporting. Furthermore, a notable portion (5 out of 23) chose to visit the municipality in person to report sewage spillage. These diverse preferences highlight the importance of establishing accessible and efficient reporting mechanisms that cater to the varying communication preferences and technological access levels within the community. By offering multiple channels, municipalities can ensure that residents can easily and effectively report sewage spillage incidents, promoting prompt response and resolution.

### 6.3.2.6. Community Response Time for Reported Sewage Spillage

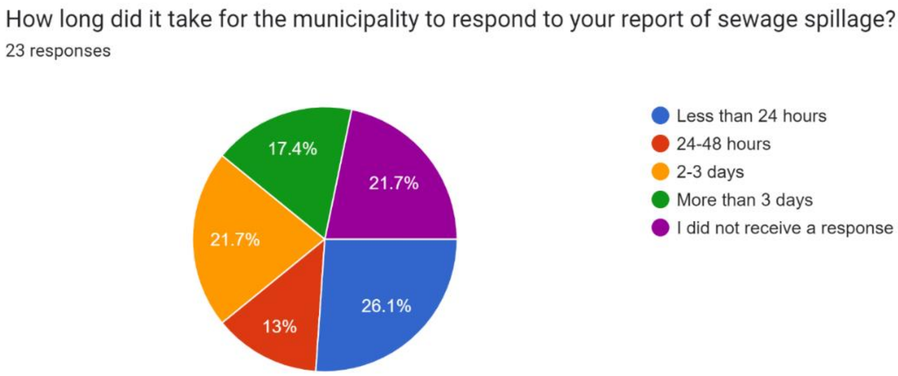



**Figure 6.23 Community Response Time for Reported Sewage Spillage**

The response times reported by respondents in Figure 6.23 highlight inconsistencies in the municipality's handling of sewage spillage reports. While some received prompt responses within 24 hours (6 respondents), others experienced significant delays of more than 3 days (5 respondents). Alarmingly, 5 respondents did not receive any response at all. These findings raise concerns about the municipality's capacity to address reports promptly and effectively, leading to frustration and a perceived lack of concern. Streamlining response protocols is essential to demonstrate the municipality's commitment to resolving environmental and health issues and ensuring residents' well-being.

#### 6.3.2.7. Community Response Level of Satisfaction with Municipality's Response to Sewage Spillage

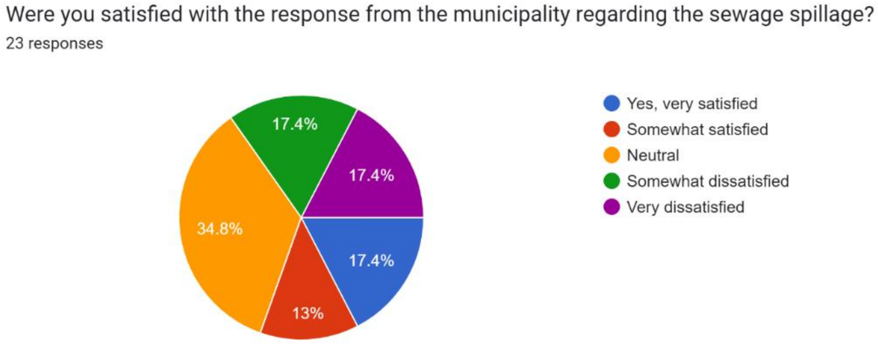



**Figure 6.24 Community Response Level of Satisfaction with Municipality's Response to Sewage Spillage**

The range of satisfaction levels expressed by respondents in Figure 6.24 offers valuable insights into their diverse experiences and expectations regarding the municipality's response to sewage spillage incidents. Among the respondents, 4 individuals reported being very satisfied with the municipality's response, indicating that their concerns are effectively addressed and resolved. On the other hand, 3 respondents expressed a moderate level of satisfaction, suggesting that there is room for improvement in the response process to meet their expectations more effectively.

Conversely, 4 respondents expressed some level of dissatisfaction, indicating areas where the municipality's response fell short of their expectations. This highlights potential areas for improvement in terms of timeliness, communication, and problem resolution. Notably, the largest group of respondents, comprising 8 individuals, remained neutral in their satisfaction assessment. This neutrality could suggest a lack of clarity or consistency in the response received, highlighting the importance of clear communication and reliable follow-up procedures.

In conclusion, the insights gained from the community's satisfaction levels provide valuable input for the development and optimization of AI-powered systems in monitoring sewer infrastructure and reporting incidents. By leveraging smart monitoring capabilities to analyse data and improve response strategies, these systems can enhance overall satisfaction, trust, and collaboration between the municipality and the community, ultimately leading to more effective management of sewage-related issues and a cleaner, healthier environment.

#### 6.3.2.8. Community Response Perception of smart monitoring for Predicting and Preventing Sewage Spillage

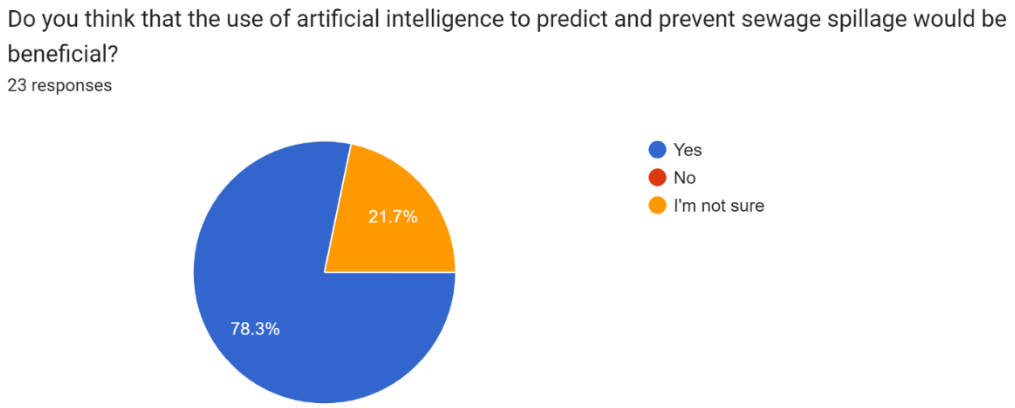



**Figure 6.25 Community Response Perception of smart monitoring for Predicting and Preventing Sewage Spillage**

The pie chart in Figure 6.25 reveals a strong consensus among respondents regarding the benefits of using artificial intelligence for predicting and preventing sewage spillage. With 18 out of 23 respondents expressing agreement, it is evident that the community acknowledges the potential advantages of advanced analytics and AI-driven systems in proactively addressing sewage-related issues. This positive attitude reflects a willingness to embrace innovative approaches and explore technological solutions to effectively tackle the problem.

### 6.3.2.9. Community Response Perception of AI for Predicting and Preventing Sewage Spillage

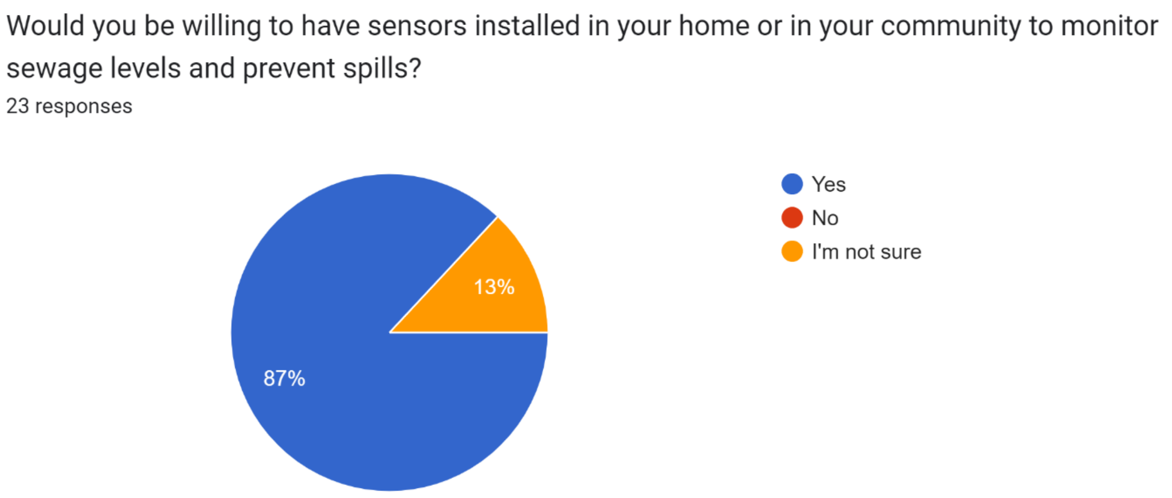



**Figure 6.26 Community Response Perception of AI for Predicting and Preventing Sewage Spillage**

Most respondents (20 out of 23) in Figure 6.26 demonstrated a strong willingness to have sensors installed in their homes or communities for monitoring sewage levels and preventing spills. This widespread acceptance reflects the community's proactive and collaborative mindset, acknowledging the benefits of sensor technology in maintaining a healthier environment and averting sewage-related issues. However, there are a few respondents (3 out of 23) who expressed uncertainty, suggesting the need for additional information and engagement to address any concerns or reservations they may have.

Additional Feedback on Experience with Sewage Spillage in Homes or Communities is detailed below

- Is there anything else you would like to add regarding your experience with sewage spillage in your home or in your community?
- Responses
- Municipality must find a permanent solution for this sewage spillage.
- Ndlambe Municipality must fix their pipelines
- Vandalism during Load Shedding to electrical wiring at the sewerage pump stations is causing major sewerage spills in the Port Alfred CBD. In addition, the Pump Stations

are old, and they often fail due to sensors not activating, causing spillage. Many smaller pump stations are vandalised and thus are dysfunctional, causing major spillage into our wetlands and river.

- Some of the toilets don't flush
- Yes there is sewer running in the streets almost daily by the "My pond hotel" in Van der Riet Street and the street below. They keep trying to fix it, but efforts are in vain; please help we are tired of the stench.
- There are regular sewage spills in Van Der Riet Street and when I go to town or travel past to go to the smell is so bad. It worries me that citizens must walk or drive through these unhealthy spillages.
- While AI may have useful implications, I would be concerned about the municipality's will to properly use and maintain the technology.
- In the community: we have limited people linked to the sewerage system, but you can smell sewerage all over town. Don't trust the municipality to manage the system.
- It would really help if the Municipality may find a permanent solution so that we don't experience sewage spillage.
- The same problem recurs over and over. It never seems to be a long-term fix.
- Municipality must find a permanent solution for this sewage spillage.
- Pipes need to be replaced.
- Very, very bad ........not good at all for the shops
- If municipality would have a team that will go around Ndlambe looking for water leakage and sewer spillage that will also help.
- Not really but the sensors will be perfect.
- Permanent solution on the sewage spillage issue.
- We need sensors to monitor the system as the municipality is unable to do so. The sensors must assist in managing/alerting spillage and stench.

In conclusion, the identified gap lies in the manual communication process, limited utilization of technology, and the lack of a comprehensive monitoring system. Addressing these gaps can significantly improve the team's ability to detect, prevent, and respond to sewage spillage incidents more efficiently and effectively. The community's feedback regarding sewage spillage in their homes or communities emphasizes the urgent need for a permanent solution. They highlight issues such as pipeline repairs, pump station vandalism, malfunctioning sensors, and inadequate maintenance.

Trust in the municipality's ability to address the problem is low, and there is a call for the use of sensor technology for monitoring and alerting. Overall, the community seeks long-term solutions and improved sewage management practices. Section 6.3 of the study presents the results and analysis of the qualitative data collected in the research, focusing on the experiences and perspectives of the participants regarding sewage spillage incidents. This section provides valuable insights into the underlying factors, challenges, and community perceptions associated with sewage spillage.

Moving forward to Section 6.4, the qualitative data is examined in relation to the quantitative data presented in Chapter Four. This section aims to establish a correlation between the qualitative findings and the quantitative results, enhancing the validity and reliability of the overall study. By comparing and integrating both types of data, the study gains a more comprehensive understanding of the sewage spillage issue and its impact on the community.

The correlation of the qualitative and quantitative data helps to validate the findings presented in Chapter Four, where the quantitative data analysis provided statistical insights into the prevalence and impacts of sewage spillage incidents. By aligning the qualitative perspectives with the quantitative results, the study can draw stronger conclusions, identify patterns, and uncover deeper insights into the complex nature of the problem. This integration of qualitative data analysis with the quantitative findings in Chapter 4 strengthens the overall research, allowing for a more robust and nuanced understanding of the sewage spillage issue and its implications. It provides a comprehensive picture that can inform further discussions, recommendations, and potential solutions for addressing and mitigating the challenges associated with sewage spillage incidents.

## 6.4. Qualitative Data Conclusion and Correlation to Quantitative Results

The correlation between the quantitative findings in Chapter Four and Chapter Five, which focused on pump failures recorded by the monitoring system, and the qualitative feedback in Section 6.1 and Section 6.2 , which involved insights from the municipality and maintenance team, validates the research conducted in this thesis. However, the analysis of specific events highlights gaps that could be addressed through the implementation of smart monitoring technology.

One such event occurred when the pump tripped on the 24th of April at 04:10 am and was restored back online on the 26th of April at 12:08 pm. Interestingly, the email reporting the incident was received by the Municipality two days later, the 26th of April. This time lag between the pump failure and the community's notification to the Municipality indicates a gap in real-time incident reporting. The delay of approximately two days could have been significantly reduced if there was a more immediate and automated means of detecting and communicating pump failures.

Furthermore, the maintenance team took approximately 3.5 hours to fix the problem once they became aware of it. This response time, although relatively prompt, still leaves room for improvement. By utilizing smart monitoring technology, which provides real-time data on pump status and performance, the maintenance team could receive immediate alerts when failures occur. This would enable them to address issues more rapidly and reduce the downtime of the pump.

The identified gaps in incident reporting and response time highlight the need for smart monitoring technology in the sewage system. Implementing sensor-based monitoring and automated alert systems would enable instant detection and notification of pump failures, eliminating the time delay experienced in the incident discussed. This technology would streamline communication between the community, Municipality, and maintenance team, ensuring swift response and timely resolution of sewage system issues.

| Aspect | Current Methods | Smart Sensor-Based Methods |
|---|---|---|
| Predictive Analytics | Relies on historical data and expert knowledge to identify high-risk areas for sewage spills. | Utilizes smart sensor infrastructure monitoring data to prevent sewage spills. Provides proactive measures for targeted maintenance and infrastructure upgrades. |
| Real-time Monitoring | Relies on manual inspections and periodic monitoring to identify sewage spillage incidents. | Utilizes smart sensor infrastructure monitoring to continuously monitor flow level, pump vibration and pressure levels. Detects abnormalities and triggers immediate alerts for proactive intervention. |
| Early Warning Systems | Relies on manual monitoring and observations to detect sewage spillage incidents. | Provides real-time analysis to issue alerts and notifications to prevent spills. |
| Decision Support Systems | Relies on manual analysis of data from various sources to make informed decisions. | Provides insights and recommendations for optimized maintenance schedules, infrastructure investments, and targeted interventions. |

| | | |
|---|---|---|
| Pump Jam Monitoring | Relies on periodic manual checks or alarms triggered by visual inspections. | Utilizes smart sensor infrastructure monitoring to continuously monitor pump performance and detect signs of pump jamming. Provides real-time alerts and notifications for prompt maintenance and preventive actions. |
| Sump Level Monitoring | Relies on manual visual inspections or level sensors with limited capabilities. | Utilizes smart sensor infrastructure monitoring with advanced sensors to continuously monitor sump levels. Provides real-time data analysis to detect abnormal levels and triggers alerts for proactive response. |
| Manhole Pressure Monitoring | Relies on visual inspections or occasional pressure measurements. | Utilizes smart sensor infrastructure monitoring to continuously monitor pressure levels. Analyzes real-time data to detect abnormal pressure variations and triggers immediate alerts for timely investigation and necessary actions. |

Below is a table comparing qualitative and quantitative results. These results will assist in drawing the conclusion on the effectiveness of AI in monitoring sewer network.

**Table 6.7 Comparing qualitative and quantitative results**

The correlation between quantitative data in Chapter 4 and qualitative feedback validates the research conducted. However, the analysis of specific incidents, such as the pump tripping event and the subsequent delay in reporting and response, underscores the need for smart monitoring technology. By addressing these gaps through the implementation of automated monitoring and alert systems, real-time incident detection and faster problem resolution is achieved, improving the overall efficiency and reliability of the sewage system.

## 6.5. Chapter Summary

Chapter Six combines quantitative pump performance data with qualitative feedback from the municipality and maintenance team, revealing critical gaps in sewage system management. These findings underscore the need for a proactive, technology-driven solution to address environmental pollution risks and enable timely response to incidents. The quantitative data exposes vulnerabilities, such as pump failures and downtime, emphasizing the importance of real-time monitoring to prevent sewage spillage.

Qualitative feedback highlights the current reliance on reactive measures, leading to delayed responses to incidents. This underscores the need for proactive, automated systems for early detection and communication. A specific incident illustrates the impact of delayed detection and response, further emphasizing the benefits of smart monitoring systems with smart capabilities.

Overall, the integration of quantitative and qualitative insights underscores the urgency of adopting smart monitoring technology. Such an approach can proactively detect issues, manage flow during downtime, and ensure timely communication, protecting the environment and minimizing community and ecosystem impact.

**CHAPTER SEVEN:**

# 7. CONCLUSION AND FUTURE DIRECTION OF RESEARCH

## 7.1. Introduction

Using smart sensors to monitor sewer infrastructure is key in alleviating environmental pollution due to sewer spillage. The further use of the smart sensors as part of the smart sewer diversion pit has been highlighted as a practical solution that can be implemented in the South African context or any other rural or semi-rural sewer reticulation. This smart diversion pit has emerged as a solution to be coupled with smart monitoring of infrastructure.

This chapter presents the deliverables and the conclusion of the thesis. Section 7.1 presents the aim and objectives of the proposed work as defined in Chapter One. Section 7.2 provides the deliverables and achieved objectives. Section 7.3 presents possible areas of application in industry and academia. Section 7.4 proposed future directions for this research. Section 7.5 details the publications emanating from this research and Section 7.6 concludes this work.

### 7.1.1. Aim

The purpose of this research is to use smart sensors to monitor sewage infrastructure to alleviate environmental pollution through sewage spillage with the sewer pump station as the focal point.

### 7.1.2. Objectives: Theoretical analysis

The objective of the theoretical study is to identify gaps in the existing monitoring technologies and suggest technology based solutions to alleviate environmental pollution in South Africa with the sewer pump station as the focal point. The specific objectives of the theoretical objectives research are:

- To perform a thorough literature review in wastewater treatment reticulation systems to determine the current state.
- To identify how smart sensor technologies can assist to alleviate environmental pollution in the literature.
- To ascertain the measures that are in place with regards to monitoring of sewer infrastructure in the literature.
- To propose feasible strategies that help alleviate environmental pollution.
- To identify how sewer pump station level monitoring can assist alleviate environmental pollution.

- To identify how sewer infrastructure network pressure can be used to alleviate environmental pollution.

#### 7.1.3. Objectives: Practical Real-Time Implementation

- To develop sensor based methods and software data analyses to monitor sewage pumps motor current and vibration.
- To validate and test the implemented solution by correlating the qualitative data collected from a pump station, quantitative data and the theoretical findings.
- To develop a SCADA system for real-time system monitoring with alarm notification for the dispatch of maintenance teams.
- To implement a cloud-based database for storage of data, analysis and preventative maintenance scheduling.
- To implement the complete system in a pilot case study with one pumping stations at the Ndlambe Municipality.
- To design a smart sewer diversion pit for cases of pump failure and resultant sewage overflow, thus preventing environmental pollution

### 7.2. Thesis Deliverables

Thesis deliverables are further expounded upon in the following sections.

#### 7.2.1. Literature Review

The literature review spanning 2004 to 2023 revealed the urgent need for smart monitoring in sewage infrastructure due to population growth and environmental challenges. Abdulrahman et al. (2012) and Narasimhan (2008) emphasized the escalating pressure on urban sewage systems. Challenges include wastewater contamination and inadequacies in smaller municipalities reported by the Water Institute of Southern Africa (2022). Addressing the wastewater crisis, the literature review proposed smart solutions such as use of smart sensors. The envisioned system architecture integrates sensors, telemetry, SCADA, and HMI for real-time decision-making, as depicted in Figure 2.1.

Key findings underscored the importance of transitioning from open-loop to closed-loop systems, with swift integration of smart technologies for efficient sewage infrastructure management. Challenges identified include the lack of real-time data analysis in open-loop systems. In summary, the literature review advocates for proactive measures through smart monitoring to alleviate sewage contamination and improve overall system efficiency.

### 7.2.2. Smart Sensor Technologies in Mitigating Environmental Pollution: A Review

In response to identified gaps in sewer infrastructure management, the integration of smart sensor technologies emerges as a pivotal solution for mitigating environmental pollution. Section 6.4 reveals the necessity for real-time incident detection and swift problem resolution, emphasizing the urgent need for proactive, technology-driven measures. The findings underscore the critical role of smart sensors in continuous monitoring, providing early detection of sewage spillage incidents. This aligns with the urgent need highlighted in Section 6.3.2.6, emphasizing the importance of efficient reporting mechanisms through various channels, including online platforms.

Moreover, the study reveals that reliance on historical data and manual inspections is insufficient. Smart sensor technologies, as highlighted in Section 6.4, offer predictive analytics capabilities, enabling optimized decision-making for targeted maintenance, infrastructure upgrades, and early intervention. The study emphasizes that the current reactive measures, as identified in Section 6.5, lead to delayed responses to incidents, underlining the potential benefits of proactive, automated systems for early detection and communication. This aligns with the positive community response to the perception of smart monitoring technologies for predicting and preventing sewage spillage, as discussed in Section 6.3.2.8. The integration of smart sensor technologies, as evidenced by both quantitative and qualitative data, proves essential in addressing environmental pollution risks and ensuring timely responses to sewage spillage incidents.

### 7.2.3. Evaluating Measures for Sewer Infrastructure Monitoring: A Comprehensive Review

The literature review, in alignment with the research aim, delves into the existing measures for monitoring sewer infrastructure. The comprehensive analysis in Section 6.3.1 examines the current methods employed by the Ndlambe Local Municipality's Maintenance team, highlighting a reliance on manual communication and periodic monitoring. This echoes the broader need for improvements identified in Section 6.3.1.8, emphasizing the potential benefits of smart technology for more effective monitoring. The study reveals a gap in real-time incident reporting, as evidenced by the incident on April 24th discussed in Section 6.4. The delay in communication, coupled with varied response times, emphasizes the inadequacy of existing measures and the urgency for more advanced systems.

Furthermore, community feedback, detailed in Section 6.3.2, emphasizes the importance of accessible reporting channels and the need for timely responses. The dissatisfaction expressed in Section 6.3.2.7 underscores the limitations of current measures in meeting community expectations. The findings advocate for a paradigm shift in sewer infrastructure monitoring measures. The limitations of manual methods, delays in incident reporting, and varying response times highlight the necessity for advanced technologies, as suggested by the positive community response to smart monitoring technologies in Section 6.3.2.8.

#### 7.2.4. Practical Strategies to Alleviate Environmental Pollution: An Examination

Underpinning the study's findings, practical strategies emerge to address environmental pollution resulting from sewer infrastructure challenges:

- Smart Monitoring Systems: The study advocates for the integration of smart sensor technologies, as discussed in Section 6.4. This recommendation aims to improve real-time monitoring, enabling early issue detection, shorter response times, and proactive maintenance.
- Diverse Reporting Channels: To cater to the community's varied preferences, as highlighted in Section 6.3.2.5, the study recommends the establishment of diverse reporting channels. This includes phone calls, online forms, and in-person reporting, ensuring accessible and efficient reporting of sewage spillage incidents.
- Enhanced Community Engagement: Recognizing the community's vital role, Section 6.3.2.8 suggests fostering collaboration through regular communication channels. This approach aims to build trust and empower the community to actively contribute to environmental preservation.
- Investment in Predictive Analytics: Given the community's positive perception of smart monitoring, as emphasized in Section 6.3.2.9, the study proposes investment in predictive analytics and AI-driven systems. These technologies can offer insights, predict potential spillages, and optimize maintenance schedules.
- Infrastructure Upgrades and Maintenance: Section 6.3.1.5 highlights feedback from the Maintenance team, emphasizing the need for infrastructure upgrades. The proposed

strategies include regular maintenance, the replacement of aging pipelines, and leveraging advanced technologies to prevent vandalism and pump failures.

The proposed strategies aim to bridge identified gaps, incorporating technology-driven solutions, community involvement, and infrastructure improvements to effectively alleviate environmental pollution caused by sewer spillage.

#### 7.2.5. Sewer Pump Station Level Monitoring in Alleviating Environmental Pollution: An Investigation

The study emphasizes the pivotal role of sewer pump station level monitoring in tackling environmental pollution. As revealed in the analysis (Section 6.4), instances like pump failures expose the necessity for instantaneous monitoring. The proposed strategy suggests integrating advanced sensor technologies for continuous pump level monitoring, ensuring swift anomaly detection, reducing response times, and mitigating the environmental repercussions of sewage spills.

Through the correlation of quantitative data (Chapter 4) and qualitative insights (Section 6.1 and Section 6.2), the study establishes the importance of sewer pump station level monitoring. Notably, the incident discussed in Section 6.4 underscores how real-time monitoring addresses delays in incident reporting. Incorporating smart sensor technologies for pump station level monitoring enhances municipalities' capabilities to proactively prevent, promptly detect, and effectively respond to sewer spillage incidents, thereby contributing to comprehensive environmental

#### 7.2.6. Sewer Infrastructure Network Pressure in Alleviating Environmental Pollution: An Analysis

The study underscores the significance of leveraging sewer infrastructure network pressure as a proactive measure to alleviate environmental pollution. Through the amalgamation of quantitative data (Chapter 4) and qualitative feedback (Section 6.3), the findings highlight the role of pressure monitoring in sewage systems. The qualitative insights from the community reveal concerns about pressure variations and spillage incidents.

Analysis of the identified gaps in incident reporting and response times (Section 6.4) further emphasizes the potential of smart sensor technologies in monitoring sewer infrastructure network pressure. By utilizing advanced sensors, municipalities can continuously monitor pressure levels, promptly detect abnormalities, and trigger immediate alerts for timely investigation and necessary actions. This strategy contributes to enhanced system efficiency, faster incident response, and, ultimately, a more effective approach to mitigating environmental pollution caused by sewage spillage.

### 7.2.7. Sensor-Based Monitoring for Sewage Pump Motor: Method and Software Development

Addressing the Practical Real-Time Implementation aim, this section focuses on the development of sensor-based methods and advanced software for monitoring sewage pump motor current and vibration. Insights from Chapter 4, along with qualitative data in Section 6.3, emphasize the critical role of monitoring pump motor vibrations as an indicator of potential issues. The study reveals that existing manual communication and periodic inspections result in delays in incident reporting and response times. This underscores the need for smart sensor technologies. The proposed strategy advocates for leveraging advanced sensors to continuously monitor pump motor vibrations and current levels. The real-time monitoring enables prompt detection of abnormalities, with data findings indicating an improvement in response times by more than 60%.

To ensure the practicality and relevance of the developed methods, the implementation was conducted at a real existing pump station in Ndlambe Local Municipality, Eastern Cape, South Africa. Data findings highlight a significant reduction in downtime by more than 60%, showcasing the effectiveness of the developed sensor-based monitoring methods. With the future implementation of the smart diversion pit, environmental pollution due to sewer spillage can be eradicated provided the response rate is 4 hours. The real-world implementation at an existing pump station demonstrates the feasibility and applicability of the developed sensor-based monitoring methods.

### 7.2.8. Validation of Implemented Solutions: Correlating Data in Pump Station Monitoring

This section delves into the validation of the implemented solutions, focusing on correlating data in pump station monitoring. The practical real-time implementation discussed in Section 7.2.7 involved the development of sensor-based methods and software for monitoring sewage pump motor current and vibration. To validate the effectiveness of the implemented solutions, MATLAB-based analyses were conducted using the data collected during the real-world implementation at an existing pump station in Ndlambe Local Municipality, Eastern Cape, South Africa.

The findings reveal a strong correlation between the sensor data and pump performance metrics. MATLAB analyses demonstrate that abnormal pump motor vibrations coincide with instances of pump failure, as identified in Chapter 4. The real-time monitoring solutions effectively detected these abnormalities, providing timely alerts for proactive maintenance. Furthermore, the correlation analyses showcase a notable improvement in the accuracy of predictive maintenance measures. The validation process highlights the reliability and robustness of the developed sensor-based methods. The correlation between real-time sensor data and actual pump performance metrics underscores the practical applicability of these solutions in sewage pump station monitoring. The MATLAB-based validation adds a layer of scientific rigor, affirming the credibility and effectiveness of the implemented solutions.

## 7.3. Application of Sewer Infrastructure monitoring using smart sensors

The theoretical and practical findings of this research allows it to be applied across diverse sectors, fostering advancements in industry practices, academic research, and legislative frameworks for sustainable sewage infrastructure management and environmental conservation.

### 7.3.1. Industrial Application

The implementation of smart sensor technologies for sewer infrastructure monitoring, as outlined in Section 7.2.2, offers a transformative approach for industrial applications. Industries involved in wastewater management and environmental conservation can leverage these findings to enhance their monitoring systems. The sensor-based methods and software development detailed in Section 7.2.7 provide practical insights for industries to adopt predictive maintenance measures, optimizing pump performance and minimizing downtime. The real-time implementation conducted at a pump station in Ndlambe Local Municipality, as discussed in Section 7.2.8, showcases the real-world applicability of these solutions. Industries can adapt and implement similar systems to improve efficiency, reduce environmental impact, and ensure regulatory compliance.

### 7.3.2. Academic Application

Academic institutions can use the research findings to enrich their understanding of smart monitoring technologies, sewage infrastructure management, and environmental pollution mitigation. Section 6.3, which explores qualitative data from community members and municipal maintenance teams, offers valuable insights for academic research on the social and environmental aspects of sewage spillage. Additionally, Section 7.2.3, focusing on evaluating measures for sewer infrastructure monitoring, provides a comprehensive review that can serve as a foundational resource for students and researchers delving into wastewater management studies. The MATLAB-based validation in Section 7.2.8 introduces an academic angle, enabling students and researchers to explore data correlation methodologies and their application in real-world scenarios.

### 7.3.3. Legislation Application

The research findings contribute to the development and improvement of legislation related to sewage management and environmental protection. Section 6.4, which correlates qualitative and quantitative data, provides a basis for legislative bodies to strengthen existing regulations and introduce new measures to address sewage spillage issues. The proposed practical strategies in Section 7.2.4 offer actionable insights for legislative authorities to consider when formulating policies for sustainable sewage infrastructure management. This could possibly see institutions legally required to have smart diversion pits in the design of sewer pump stations and manholes. By incorporating the research findings into legislation, authorities can promote the adoption of smart monitoring technologies, ensuring a proactive and efficient approach to environmental protection.

## 7.4. Future Work

- Considering the promising outcomes of the designed smart diversion pit, future efforts should extend beyond the design phase to implementation. Exploring the integration of this technology into two additional pump stations lacking monitoring systems can provide a more comprehensive understanding of its adaptability and effectiveness across diverse contexts.
- Furthermore, future research should take a holistic approach to environmental impact assessment, evaluating the smart diversion pit's contributions to broader sustainability goals. This includes considering its implications on energy consumption, resource utilization, and the overall ecological footprint of sewage infrastructure. Such an

approach aligns with the broader scope of smart city initiatives, ensuring the seamless integration of innovative solutions into a sustainable urban environment.

- Future work should look at the efficiency of these research findings in detecting sewage blockage, and whether the monitoring system efficiently work in large waterbodies.

## 7.5. Publications related to the thesis

Ndlovu M and Kriger C., 2023. “Smart monitoring of a rural wastewater pumping station to reduce environmental spillage”, submitted to Water SA Journal published by the Water Research Commission.

Ndlovu M and Kriger C., 2024. “Monitoring of rural wastewater pumping stations to mitigate environmental pollution” Submitted to the Southern African

Universities Power Engineering Conference (SAUPEC 2024).

## 7.6. Conclusion

All the proposed and highlighted deliverables have been successfully attained. The discussion includes the potential application areas for the outcomes of this work. The document also puts forth and contemplates possible directions for future research. Additionally, a list of publications submitted towards the conclusion of this study is provided.

## REFERENCES

Abbas, O., Abou Rjeily, Y., Sadek, M., & Shahrour, I. (2017). A large-scale experimentation of the smart sewage system. Water and Environment Journal, 31(4), 515-521.

Abdulrahman, A., Meshal, A. and Imad, F. (2012). Smart Cities: A Survey. Journal of Advanced Computer Science and Technology Research, 2 (2), 79–90

Alkandari, A., Alnasheet, M., and Alshekhly, I. (2012). Smart Cities: Survey. Journal of Advanced Computer Science and Technology Research. 2.

Ansari, S. M., Khairnar, S.M., Patil, R.R and Nikalje, N.M. (2022). Design Study of Smart Robotic Framework for Sewer Conservation. International Journal of Engineering Trends and Technology. 70. 247-255.

Bhatia, M., 2019. Your guide to qualitative and quantitative data analysis methods. https://humansofdata.atlan.com/2018/09/qualitative-quantitative-data-analysis- methods/.

Bunce, J. T., Ndam, E., Ofiteru, I. D., Moore, A., and Graham, D. W. (2018). A review of phosphorus removal technologies and their applicability to small-scale domestic wastewater treatment systems. Frontiers in Environmental Science, 6. doi:10.3389/fenvs.2018.00008

Busetto, L., Wick, W. and Gumbinger, C., 2020. How to use and assess qualitative research methods. Neurological Research and practice, 2, pp.1-10.

Chandrakana ,N., Aurelien, M., and Manuel, O. (2015). Stochastic Contracts for Runtime Checking of Component-based Real-time Systems. https://www.researchgate.net/figure/A-control-system-with-a-combination-of-an-open-loop-and-a-closed-loop controller_fig1_270824584

Chen, L., Wei, L., Wang, Y., Wang, J and Li, W. (2022). Monitoring and Predictive Maintenance of Centrifugal Pumps Based on Smart Sensors. Sensors 22(6):2106. https://doi.org/10.3390/s22062106. https://www.mdpi.com/1424-8220/22/6/2106.

Chen, P., Zhao, W., Chen, D., Huang, Z., Zhang, C and Zheng X (2022). Research Progress on Integrated Treatment Technologies of Rural Domestic Sewage: A Review. Water 14(15):2439. https://doi.org/10.3390/w14152439

Corcoran, E., Nellemann, C., Baker, E., Bos, R., Osborn, D., Savelli, H. (2010). Sick Water? The central role of wastewater management in sustainable development. A Rapid Response Assessment. United Nations Environnent Programme, UN-HABITAT, GRID-Arendal. www.grida.no. https://gridarendal-website-live.s3.amazonaws.com/production/documents/:s_document/208/original/SickWater_screen.pdf?1486721310

Environmental Protection Agency (2021). Smart data infrastructure for wet weather control and decision support. https://www.epa.gov/sites/default/files/2018-08/documents/smart_data_infrastructure_for_wet_weather_control_and_decision_supp ort_-_final_-_august_2018.

EPA guidance documents, (2015). History. https://www.epa.gov/guidance.

Fecarotta, O.; Martino, R.; Morani, M.C. (2021). 2019. Wastewater Pump Control under Mechanical Wear. Water 2019, 11, 1210. https://doi.org/10.3390/w11061210

Flick, U. (2015). Introducing research methodology (2nd Ed). In F. Uwe, Introducing research methodology (2nd Ed). London: Sage Publications.

Gray, D. (2014). Doing research in the real world. In D. E. Gray, Doing research in the real world (3rd Ed). New York: Sage publication.

Kechavarzi C., Keenan P., Xu X and Rui Y. (2020). Monitoring the Hydraulic Performance of Sewers Using Fibre Optic Distributed Temperature Sensing. Water. 2020; 12(9):2451.

Kumar, P.M and Hong C.S. (2022). Internet of things for secure surveillance for sewage wastewater treatment systems. Environ Res. https://pubmed.ncbi.nlm.nih.gov/34416251/

Kumar, P.M and Hong, C.S. (2022). Internet of things for secure surveillance for sewage wastewater treatment systems, Environmental Research, Vol 203.

Mowbray, S. (2022). Innovative sewage solutions: Tackling the global human waste problem. https://news.mongabay.com/2022/01/innovative-sewage-solutions-tackling- the-global-human-waste-problem/

Narasimhan. T.N. (2008). Water, law, science Journal of Hydrology, Vol 349, (1-2).

Office of the High Commissioner for Human Rights, (OHCHR) (2010). The Right to Water, Fact Sheet No. 35. United Nations, OHCHR, UN-HABITAT, WHO, 2010. https://www.ohchr.org/en/documents/annual-report/ohchr-report-2010.

Patil, R.R., Ansari, S.M., Calay, R.K, Mustafa, M.Y. (2021). Review of the State-of-the- art Sewer Monitoring and Maintenance Systems Pune Municipal Corporation - A Case Study. TEM Journal. Volume 10(4): 1500-1508. https://www.temjournal.com/content/104/TEMJournalNovember2021_1500_1508.pdf

Raschid-Sally, L. and P. Jayakody. (2008). Drivers and characteristics of wastewater agriculture in developing countries: Results from a global assessment, Colombo, Sri Lanka. IWMI Research Report 127, International Water Management Institute, Colombo. 35pp.

Ravindra, P., Saniya, A., Rajnish, C., and Mohamad, M. (2021). Review of the State-of- the-art Sewer Monitoring and Maintenance Systems Pune Municipal Corporation - A Case Study. TEM Journal. 10: 1500-1508.

River keeper, (2022). Combined Sewage Overflows (CSOs). https://www.riverkeeper.org/campaigns/stop-polluters/sewage-contamination/cso/.

Rjeily, A., Sadek, M., Chehade, F.H., Oras, A., and Isam, S. (2017). Smart system for urban sewage: Feedback on the use of smart sensors. 1-4. A Conference held in September 2017 on Sensors Networks Smart and Emerging Technologies (SENSET). https://www.researchgate.net/publication/321403739

Ruheena M. A., Rukhayia S., Sheeba K and Komala, T. (2021). Manhole Detection and Monitoring System. International Journal of Engineering Research and Technology (IJERT) NCCDS 09(12): 14-17. https://www.ijert.org/manhole-detection-and-monitoring-system.

Sengupta, S., Nawaz, T., and Beaudry, J. (2015). Nitrogen and phosphorus recovery from wastewater. Current Pollution Reports, 1(3), 155-166. doi:10.1007/s40726-015-0013.

Song, X, Liu, R, Yu, Q, Sheng, X and Chen, L. (2020). Management mode construction for operation and supervision of rural sewage treatment facilities: towards the information-to-intelligence strategy. Bioresource Technology Reports. Volume 11.

Stephenson, D and Barta, B. (2005). Guidelines on reduction of the impact of water infiltration into sewers: a report to the Water research commission. https://www.wrc.org.za/wp-content/uploads/mdocs/TT239-05.

Sudarno, S.D., Purwaningsih, A.P., and Sumarno, E.S. (2016). Development of acoustic condition monitoring for pump predictive maintenance. In: Prosiding Seminar August 2016, Batam. Nasional Teknologi Energi Nuklir ,Volume 1: 897-904.

Tarrant, O.J., Solts, K., Carman, S., and Ugradar, Y. (2019). Monitoring Pumping Station Performance for Maintenance Optimisation. International Conference on Smart Infrastructure and Construction held in January 2019 (ICSIC), 649-653.

Toulson, R and Wilmshurst, T. (2012). An Introduction to Control Systems. Fast and Effective Embedded Systems Design. Newness: 273-295. https://www.sciencedirect.com/science/article/pii/B9780080977683000131.

UN world water development report. (2017). Wastewater: An untapped resource. https://www.unwater.org/publications/world-water-development-report-2017/.

United States environmental protection Agency, (2021). Smart data Infrastructure for wet weather control and decision support.(https://www.epa.gov/sites/default/files/2018-08/documents/smart_data_infrastructure_for_wet_weather_control_and_decision_supp ort_-_final_-_august_2018.pdf)

United States Environmental Protection Agency. Emerging Technologies for Wastewater Treatment and In-Plant Wet Weather Management (2013). Virginia: Tetra Tech Inc. https://www.epa.gov/sites/default/files/2019-02/documents/emerging-tech- wastewater-treatment-management.pdf

Utepov, Y., Kazkeyev, A., and Aniskin, A. (2021). A multi-criteria analysis of sewer monitoring methods for locating pipe blockages and manhole overflows. Technobius, 1(4), 0006. https://doi.org/10.54355/tbus/1.4.2021.0006

Van Vuuren, S.J., Blersch, C.L and Van Dijk, M. (2011). Modelling the feasibility of retrofitting hydropower to existing South African dams. African journal online (AJOL). / WRC 40-Year Celebration Special Edition. Vol. 37 (5).

Von Holdt, C.J., Belmonte, H.M.S and Amadi-echendu, J.E. (2009). Review of technology used in strategic asset management: existing and future needs. A report to the Water research commission. https://www.wrc.org.za/wp- content/uploads/mdocs/1785-1-10%20Municipal%20Wastewater%20Management1.

Water Institute of Southern Africa(2022). The green drop reports. https://ws.dws.gov.za/IRIS/latestresults.aspx

Water resource commission, (2018). A report. https://www.wrc.org.za/wpcontent/uploads/mdocs/TT239-05.pdf

Wiegner, T. N., Colbert, S. L., Abaya, L. M., Panelo, J., Remple, K., and Nelson, C. E. (2021). Identifying locations of sewage pollution within a Hawaiian watershed for coastal water quality management actions. Journal of Hydrology: Regional Studies, 38, 100947. doi:10.1016/j.ejrh.2021.100947

Wiegner, T. N., Colbert, S.N., Abaya, L. M., Panelo, J., Remple, K., and Nelson, C. E. (2022). Identifying locations of sewage pollution within a Hawaiian watershed for coastal water quality management actions. Journal of hydrology, 38: 100947.

Zhao, X., Kumar, K., Gross, M. A., Kunetz, T. E., and Wen, Z. (2018). Evaluation of revolving algae biofilm reactors for nutrients and metals removal from sludge thickening supernatant in a municipal wastewater treatment facility. Water Research, 143, 467- 478. doi:10.1016/j.watres.2018.07.001

Jacobs, H. (2015). Understanding Sewer Pumpstations. Water Research Commission of South Africa.

Mavericks, D. (2023, February 7). Eastern Cape's first desalination plant forced to close. Eastern Cape.

News, E. (2018). Desalination Plant ends contract. Cape Town, Western Cape, South Africa.

Sidley, P. (n.d.). Cholera sweeps through South African province. BMJ Publishing Group.

Thomson, W., & Fenger, M. (2001). Current signature analysis to detect induction motor faults. IEEE Industry Applications Magazine, 7(4), 26-34. Retrieved 10 18, 2023, from https://ieeexplore.ieee.org/abstract/document/930988

Abdullah I. A. Alzahrani, S. H. (2023). Internet of Things (IoT)-Based Wastewater Management in Smart Cities. *Special Issue Blockchain for IoT-Based Smart Cities*.

Adnan Khalid, M. U. (2021). A Robust Approach of Detecting Sewer Cracks by Using Pixel Aggregation Network. *2021 International Conference on Artificial Intelligence (ICAI).*

ASHNIBHA, R. A. (2012). *An investigation into current and vibration signatures of three phase induction motors.* Manchester Metropolitan University .

Binil John, M. S. (2016.). Pipe inspection robots: a review. *IOP Conference Series Materials Science and Engineering.*

Congcong Sun a, L. R.-D. (2020). Integrated pollution-based real-time control of sanitation systems. *Journal of Environmental Management*.

Jacobs, H. (2015). *Understanding Sewer Pumpstations.* Water Research Commission of South Africa.

M.CHAKRAVARTHY, D. (2016). *Documentation on Programmable Logic Controller .* Retrieved from Vasavi College of Engineering.

Mavericks, D. (2023, February 7). Eastern Cape's first desalination plant forced to close. Eastern Cape.

News, E. (2018). Desalination Plant ends cpntract. Cape Town, Western Cape, South Africa.

Przybyś-Małaczek, A. (2023). Application of Machine Learning Algorithms for Tool Condition Monitoring in Milling Chipboard Process. *Special Issue Artificial Intelligence for Sensor Data Analysis*.

Sanitation, D. o. (2023). *South African Green Drop PAT.* Department of Water and Sanitation. Retrieved December 5, 2023, from chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://ws.dws.gov.za/IRIS/releases/GDPAT_2023_Report.pdf

Seyed Mostafa Hallaji, Y. F. (2022). Predictive maintenance of pumps in civil infrastructure: State-of-the-art, challenges and future directions. *Automation in Construction*.

Sidley, P. (2001). *Cholera sweeps through South African province.* BMJ Publishing Group.

Srivastava, D. (2023). International Journal of Computer Trends and Technology.

TarekAbdelzaher1, Y. C. (2020). IntroductiontoControlTheory AndItsApplicationtoComputingSystems.

Thomson, W., & Fenger, M. (2001). Current signature analysis to detect induction motor faults. *IEEE Industry Applications Magazine, 7*(4), 26-34. Retrieved 10 18, 2023, from https://ieeexplore.ieee.org/abstract/document/930988

Titilayo A. Owolabi, S. R. (2022). Investigating the impact of sewer overflow on the environment: A comprehensive literature review paper. *Journal of Environmental Management*

Xin Li, N. Z. (2019). Internet of Things to network smart devices for ecosystem monitoring. *Science Bulletin* , 1234-1245.

Zié Adama Ouattara, A. T.-B. (2023). A Review of sewerage and drainage systems typologies with case study in Abidjan, Côte. *Cogent Engineering,*, 31.

Kumar, R. Gupta, A. Kumar, A. Aditya and A. Rai, "Simulation and Development of Sewage Cleaning & Monitoring Robot using IoT," 2023 International Conference on Computational Intelligence and Sustainable Engineering Solutions (CISES), Greater Noida, India, 2023, pp.536-541, doi: 10.1109/CISES58720.2023.10183525.

H. S, A. S and J. V S, "An Efficient Sensory Monitoring & Bacteria Detection System for Contaminated Water," 2023 International Conference on Advances in Computing, Communication and Applied Informatics (ACCAI), Chennai, India, 2023, pp. 1-6.

## APPENDIX A: RESEACHER'S QUALIFICATIONS AND INDUSTRY EXPERIENCE

The Researcher holds a Bachelor of Technology Degree in Mechanical Engineering (Mechatronics). She also holds a post graduate Research Methods Certificate issued by the Cape Peninsula University of Technology. The Researcher further holds a National Diploma in Mechanical Engineering (Mechatronics) from Cape Peninsula University of Technology.

The Researcher also has a certificate in Mastering Project Management (Beginner to Advanced) 3 CPD Points with ECSA/SAAMA; 18 SACPCMP CPD Hours. She is registered as a Candidate Engineering Technologist with ECSA.

The Researcher has 10 years' industry experience with 8 years specifically being in Technology based water treatment. She is currently a Director and shareholder of a company that specialises in Advanced Technology Water Treatment which is a 26-year- old company. She is currently the director and co-owner of Quality Filtration Systems (www.qualityfilters.co.za). QFS is a company that specializes in membrane-based water treatment. QFS has installed more than 60 technology-based water treatment plants across South Africa and abroad.

Through the industry experience the Researcher has had the privilege of publishing some articles on the following magazines and journals: Institute of Municipal Engineering of Southern Africa, Infrastructure News and Water and Sanitation:

'Process efficiency dependent on data' (https://journals.co.za/doi/10.10520/EJC- 198841629f),

'Bringing water treatment solutions relief to drought-stricken City of Cape Town' (page 46) (https://issuu.com/glen.t/docs/wasa_may_2018_magazine), among other publications.

She is currently based in Port Alfred Eastern Cape where she has the privilege of heading the implementation of a R120m water treatment plant. Below are some testimonials of the work she has been doing in Port Alfred over the past few months.


*Figure 1- Pictured with Mr Leornado Marnus the Chief Director Operations and Maintenance at the Department of Water and Sanitation*

*Figure 2- Pictured with the Deputy Minister of Water and Sanitation Honourable David Mahlobo (a Microbiologist) at the Ndlambe RO Plant in September 2021*

**Figure A1 Images with Chief Director of the South African Department of Water and Sanitation and the Deputy Minister of Water and Sanitation in 2021**

The Researcher is also the founder and owner of a company called Protégé Technical Academy (www.protegetechnical.com) which focuses on training and assisting municipalities with Water Supply and Sanitation supply and compliance. The Researcher works with Local Municipalities to assist them to comply with Green Drop and Blue Drop regulations while building capacity for water and wastewater treatment plants management. Protégé Technical uses digital technology to train Process Controllers using customized artificial intelligence which determines and traces the ability of the learner to retain information and repeats concepts where students do not understand.

The Researcher has further developed a ProtApp a smart app that is being used by South African Municipalities to bridge the knowledge gap in water and wastewater process controllers. ProtApp digitises the implementation of the Water Safety Plan and Wastewater Risk Abatement Program (W2RAP). This App uses Artificial Intelligence to process data captured by process controllers in water and wastewater plants. This data is converted to reports which are automatically generated for compliance. This app preserves precious water and wastewater quality data which is crucial in the optimization of process units which ultimately links to the research topic which aims at alleviating environmental pollution. Due to the novelty of ProtApp, the South African Water Research Commission has partnered with Protégé Technical to potentially role ProtApp out to the whole of South Africa and potentially internationally.

## APPENDIX B: TIA PORTAL PROGRAM

Due to the Program being too long to be added to thesis body, snippets of the important aspects were discussed with the full program below.

## PLC_1 [CPU 1214C DC/DC/DC]

| | | | | | |
|---|---|---|---|---|---|
| **PLC_1** | | | | | |
| **General\Project information** | | | | | |
| **Name** | PLC_1 | **Author** | Musa | **Comment** | |
| **Slot** | 1 | **Rack** | 0 | | |
| **General\Catalog information** | | | | | |
| **Short designation** | CPU 1214C DC/DC/DC | **Description** | Work memory 100 KB; 24VDC power supply with DI14 x 24VDC SINK/SOURCE, DQ10 x 24VDC and AI2 on board; 6 high-speed counters and 4 pulse outputs on-board; signal board expands on-board I/O; up to 3 communication modules for serial communication; up to 8 signal modules for I/O expansion; PROFINET IO controller, I-device, transport protocol TCP/IP, secure Open User Communication, S7 communication, Web server, OPC UA: Server DA | **Article number** | 6ES7 214-1AG40-0XB0 |
| **Firmware version** | V4.4 | | | | |
| **General\Identification & Maintenance** | | | | | |
| **Plant designation** | | **Location identifier** | | **Installation date** | 2023-04-18 10:30:15.568 |
| **Additional information** | | | | | |
| **General\Checksums** | | | | | |
| **Text lists** | FA 70 E8 75 1D 5A 8E 29 | **Software** | 14 B3 D9 4B D6 7E 7B 92 | | |
| **PROFINET interface [X1]\General** | | | | | |
| **Name** | PROFINET interface_1 | **Author** | Musa | **Comment** | |
| **PROFINET interface [X1]\General\Project information** | | | | | |
| **Name** | DI 14/DQ 10_1 | **Comment** | | **Name** | AI 2_1 |
| **Comment** | | | | | |
| **PROFINET interface [X1]\Ethernet addresses\Interface networked with** | | | | | |
| **Subnet:** | PN/IE_1 | | | | |
| **PROFINET interface [X1]\Ethernet addresses\IP protocol** | | | | | |
| **IP configuration** | Set IP address in the project | **IP address:** | 192.168.0.10 | **Subnet mask:** | 255.255.255.0 |
| **Use router** | False | | | | |
| **PROFINET interface [X1]\Ethernet addresses\PROFINET** | | | | | |
| **PROFINET device name is set directly at the device** | False | **Generate PROFINET device name automatically** | True | **PROFINET device name:** | plc_1 |
| **Converted name:** | plcxb1d0ed | **Device number:** | 0 | | |
| **PROFINET interface [X1]\Time synchronization** | | | | | |
| **Enable time synchronization via NTP server** | Enable time synchronization via NTP server | | IP addresses | **Server 1** | 0.0.0.0 |
| **Server 2** | 0.0.0.0 | **Server 3** | 0.0.0.0 | **Server 4** | 0.0.0.0 |
| **Update interval** | 10sec | | | **CPU synchronizes the modules of the device.** | No synchronization |
| **PROFINET interface [X1]\Digital inputs\Channel0** | | | | | |
| **Channel address** | I0.0 | **Input filters** | 6.4 millisec | **Enable pulse catch** | 0 |
| **PROFINET interface [X1]\Digital inputs\Channel0** | | | | | |
| **Enable rising edge detection** | 0 | **RidPrefixRisingEdgeEvent** | 49152 | **Event name:** | 0 |
| **Hardware interrupt:** | 0 | **Rising edge0** | Rising edge0 | | |
| **PROFINET interface [X1]\Digital inputs\Channel0** | | | | | |
| **Enable falling edge detection** | 0 | **RidPrefixFallingEdgeEvent** | 49280 | **Event name:** | 0 |
| **Hardware interrupt:** | 0 | **Falling edge0** | Falling edge0 | | |
| **PROFINET interface [X1]\Digital inputs\Channel1** | | | | | |
| **Channel address** | I0.1 | **Input filters** | 6.4 millisec | **Enable pulse catch** | 0 |
| **PROFINET interface [X1]\Digital inputs\Channel1** | | | | | |
| **Enable rising edge detection** | 0 | **RidPrefixRisingEdgeEvent** | 49153 | **Event name:** | 0 |
| **Hardware interrupt:** | 0 | **Rising edge1** | Rising edge1 | | |
| **PROFINET interface [X1]\Digital inputs\Channel1** | | | | | |
| **Enable falling edge detection** | 0 | **RidPrefixFallingEdgeEvent** | 49281 | **Event name:** | 0 |
| **Hardware interrupt:** | 0 | **Falling edge1** | Falling edge1 | | |
| **PROFINET interface [X1]\Digital inputs\Channel2** | | | | | |
| **Channel address** | I0.2 | **Input filters** | 6.4 millisec | **Enable pulse catch** | 0 |
| **PROFINET interface [X1]\Digital inputs\Channel2** | | | | | |
| **Enable rising edge detection** | 0 | **RidPrefixRisingEdgeEvent** | 49154 | **Event name:** | 0 |
| **Hardware interrupt:** | 0 | **Rising edge2** | Rising edge2 | | |
| **PROFINET interface [X1]\Digital inputs\Channel2** | | | | | |
| **Enable falling edge detection** | 0 | **RidPrefixFallingEdgeEvent** | 49282 | **Event name:** | 0 |
| **Hardware interrupt:** | 0 | **Falling edge2** | Falling edge2 | | |
| **PROFINET interface [X1]\Digital inputs\Channel3** | | | | | |
| **Channel address** | I0.3 | **Input filters** | 6.4 millisec | **Enable pulse catch** | 0 |
| **PROFINET interface [X1]\Digital inputs\Channel3** | | | | | |
| **Enable rising edge detection** | 0 | **RidPrefixRisingEdgeEvent** | 49155 | **Event name:** | 0 |
| **Hardware interrupt:** | 0 | **Rising edge3** | Rising edge3 | | |

| | | | | | |
|---|---|---|---|---|---|
| **PROFINET interface [X1]\Digital inputs\Channel3** | | | | | |
| **Enable falling edge detection** | 0 | **RidPrefixFallingEdg-eEvent** | 49283 | **Event name:** | 0 |
| **Hardware interrupt:** | 0 | **Falling edge3** | Falling edge3 | | |
| **PROFINET interface [X1]\Digital inputs\Channel4** | | | | | |
| **Channel address** | I0.4 | **Input filters** | 6.4 millisec | **Enable pulse catch** | 0 |
| **PROFINET interface [X1]\Digital inputs\Channel4** | | | | | |
| **Enable rising edge detection** | 0 | **RidPrefixRisingEdgeE-vent** | 49156 | **Event name:** | 0 |
| **Hardware interrupt:** | 0 | **Rising edge4** | Rising edge4 | | |
| **PROFINET interface [X1]\Digital inputs\Channel4** | | | | | |
| **Enable falling edge detection** | 0 | **RidPrefixFallingEdg-eEvent** | 49284 | **Event name:** | 0 |
| **Hardware interrupt:** | 0 | **Falling edge4** | Falling edge4 | | |
| **PROFINET interface [X1]\Digital inputs\Channel5** | | | | | |
| **Channel address** | I0.5 | **Input filters** | 6.4 millisec | **Enable pulse catch** | 0 |
| **PROFINET interface [X1]\Digital inputs\Channel5** | | | | | |
| **Enable rising edge detection** | 0 | **RidPrefixRisingEdgeE-vent** | 49157 | **Event name:** | 0 |
| **Hardware interrupt:** | 0 | **Rising edge5** | Rising edge5 | | |
| **PROFINET interface [X1]\Digital inputs\Channel5** | | | | | |
| **Enable falling edge detection** | 0 | **RidPrefixFallingEdg-eEvent** | 49285 | **Event name:** | 0 |
| **Hardware interrupt:** | 0 | **Falling edge5** | Falling edge5 | | |
| **PROFINET interface [X1]\Digital inputs\Channel6** | | | | | |
| **Channel address** | I0.6 | **Input filters** | 6.4 millisec | **Enable pulse catch** | 0 |
| **PROFINET interface [X1]\Digital inputs\Channel6** | | | | | |
| **Enable rising edge detection** | 0 | **RidPrefixRisingEdgeE-vent** | 49158 | **Event name:** | 0 |
| **Hardware interrupt:** | 0 | **Rising edge6** | Rising edge6 | | |
| **PROFINET interface [X1]\Digital inputs\Channel6** | | | | | |
| **Enable falling edge detection** | 0 | **RidPrefixFallingEdg-eEvent** | 49286 | **Event name:** | 0 |
| **Hardware interrupt:** | 0 | **Falling edge6** | Falling edge6 | | |
| **PROFINET interface [X1]\Digital inputs\Channel7** | | | | | |
| **Channel address** | I0.7 | **Input filters** | 6.4 millisec | **Enable pulse catch** | 0 |
| **PROFINET interface [X1]\Digital inputs\Channel7** | | | | | |
| **Enable rising edge detection** | 0 | **RidPrefixRisingEdgeE-vent** | 49159 | **Event name:** | 0 |
| **Hardware interrupt:** | 0 | **Rising edge7** | Rising edge7 | | |
| **PROFINET interface [X1]\Digital inputs\Channel7** | | | | | |
| **Enable falling edge detection** | 0 | **RidPrefixFallingEdg-eEvent** | 49287 | **Event name:** | 0 |
| **Hardware interrupt:** | 0 | **Falling edge7** | Falling edge7 | | |
| **PROFINET interface [X1]\Digital inputs\Channel8** | | | | | |
| **Channel address** | I1.0 | **Input filters** | 6.4 millisec | **Enable pulse catch** | 0 |
| **PROFINET interface [X1]\Digital inputs\Channel8** | | | | | |
| **Enable rising edge detection** | 0 | **RidPrefixRisingEdgeE-vent** | 49160 | **Event name:** | 0 |
| **Hardware interrupt:** | 0 | **Rising edge8** | Rising edge8 | | |
| **PROFINET interface [X1]\Digital inputs\Channel8** | | | | | |
| **Enable falling edge detection** | 0 | **RidPrefixFallingEdg-eEvent** | 49288 | **Event name:** | 0 |
| **Hardware interrupt:** | 0 | **Falling edge8** | Falling edge8 | | |
| **PROFINET interface [X1]\Digital inputs\Channel9** | | | | | |
| **Channel address** | I1.1 | **Input filters** | 6.4 millisec | **Enable pulse catch** | 0 |
| **PROFINET interface [X1]\Digital inputs\Channel9** | | | | | |
| **Enable rising edge detection** | 0 | **RidPrefixRisingEdgeE-vent** | 49161 | **Event name:** | 0 |
| **Hardware interrupt:** | 0 | **Rising edge9** | Rising edge9 | | |
| **PROFINET interface [X1]\Digital inputs\Channel9** | | | | | |
| **Enable falling edge detection** | 0 | **RidPrefixFallingEdg-eEvent** | 49289 | **Event name:** | 0 |
| **Hardware interrupt:** | 0 | **Falling edge9** | Falling edge9 | | |
| **PROFINET interface [X1]\Digital inputs\Channel10** | | | | | |
| **Channel address** | I1.2 | **Input filters** | 6.4 millisec | **Enable pulse catch** | 0 |
| **PROFINET interface [X1]\Digital inputs\Channel10** | | | | | |
| **Enable rising edge detection** | 0 | **RidPrefixRisingEdgeE-vent** | 49162 | **Event name:** | 0 |
| **Hardware interrupt:** | 0 | **Rising edge10** | Rising edge10 | | |
| **PROFINET interface [X1]\Digital inputs\Channel10** | | | | | |
| **Enable falling edge detection** | 0 | **RidPrefixFallingEdg-eEvent** | 49290 | **Event name:** | 0 |
| **Hardware interrupt:** | 0 | **Falling edge10** | Falling edge10 | | |
| **PROFINET interface [X1]\Digital inputs\Channel11** | | | | | |
| **Channel address** | I1.3 | **Input filters** | 6.4 millisec | **Enable pulse catch** | 0 |
| **PROFINET interface [X1]\Digital inputs\Channel11** | | | | | |
| **Enable rising edge detection** | 0 | **RidPrefixRisingEdgeE-vent** | 49163 | **Event name:** | 0 |
| **Hardware interrupt:** | 0 | **Rising edge11** | Rising edge11 | | |
| **PROFINET interface [X1]\Digital inputs\Channel11** | | | | | |
| **Enable falling edge detection** | 0 | **RidPrefixFallingEdg-eEvent** | 49291 | **Event name:** | 0 |
| **Hardware interrupt:** | 0 | **Falling edge11** | Falling edge11 | | |
| **PROFINET interface [X1]\Digital inputs\Channel12** | | | | | |
| **Channel address** | I1.4 | **Input filters** | 6.4 millisec | **Enable pulse catch** | 0 |
| **PROFINET interface [X1]\Digital inputs\Channel13** | | | | | |
| **Channel address** | I1.5 | **Input filters** | 6.4 millisec | **Enable pulse catch** | 0 |

**PROFINET interface [X1]\Analog inputs\Noise reduction**

| | | | | | |
|---|---|---|---|---|---|
| **Integration time** | 50 Hz (20 ms) | | | | |

**PROFINET interface [X1]\Analog inputs\Channel0**

| | | | | | |
|---|---|---|---|---|---|
| **Channel address** | IW64 | **Measurement type** | Voltage | **Voltage range** | 0..10 V |
| **Smoothing** | Weak (4 cycles) | | | **Enable overflow diagnostics** | 1 |

**PROFINET interface [X1]\Analog inputs\Channel1**

| | | | | | |
|---|---|---|---|---|---|
| **Channel address** | IW66 | **Measurement type** | Voltage | **Voltage range** | 0..10 V |
| **Smoothing** | Weak (4 cycles) | | | **Enable overflow diagnostics** | 1 |

**PROFINET interface [X1]\Digital outputs**

| | | | | | |
|---|---|---|---|---|---|
| **Reaction to CPU STOP** | Use substitute value | | | | |

**PROFINET interface [X1]\Digital outputs\Channel0**

| | | | | | |
|---|---|---|---|---|---|
| **Channel address** | Q0.0 | **Substitute a value of 1 on a change from RUN to STOP.** | 0 | | |

**PROFINET interface [X1]\Digital outputs\Channel1**

| | | | | | |
|---|---|---|---|---|---|
| **Channel address** | Q0.1 | **Substitute a value of 1 on a change from RUN to STOP.** | 0 | | |

**PROFINET interface [X1]\Digital outputs\Channel2**

| | | | | | |
|---|---|---|---|---|---|
| **Channel address** | Q0.2 | **Substitute a value of 1 on a change from RUN to STOP.** | 0 | | |

**PROFINET interface [X1]\Digital outputs\Channel3**

| | | | | | |
|---|---|---|---|---|---|
| **Channel address** | Q0.3 | **Substitute a value of 1 on a change from RUN to STOP.** | 0 | | |

**PROFINET interface [X1]\Digital outputs\Channel4**

| | | | | | |
|---|---|---|---|---|---|
| **Channel address** | Q0.4 | **Substitute a value of 1 on a change from RUN to STOP.** | 0 | | |

**PROFINET interface [X1]\Digital outputs\Channel5**

| | | | | | |
|---|---|---|---|---|---|
| **Channel address** | Q0.5 | **Substitute a value of 1 on a change from RUN to STOP.** | 0 | | |

**PROFINET interface [X1]\Digital outputs\Channel6**

| | | | | | |
|---|---|---|---|---|---|
| **Channel address** | Q0.6 | **Substitute a value of 1 on a change from RUN to STOP.** | 0 | | |

**PROFINET interface [X1]\Digital outputs\Channel7**

| | | | | | |
|---|---|---|---|---|---|
| **Channel address** | Q0.7 | **Substitute a value of 1 on a change from RUN to STOP.** | 0 | | |

**PROFINET interface [X1]\Digital outputs\Channel8**

| | | | | | |
|---|---|---|---|---|---|
| **Channel address** | Q1.0 | **Substitute a value of 1 on a change from RUN to STOP.** | 0 | | |

**PROFINET interface [X1]\Digital outputs\Channel9**

| | | | | | |
|---|---|---|---|---|---|
| **Channel address** | Q1.1 | **Substitute a value of 1 on a change from RUN to STOP.** | 0 | | |

**PROFINET interface [X1]\Operating mode**

| | | | | | |
|---|---|---|---|---|---|
| **IO controller** | True | **IO system** | | **Device number** | 0 |
| **IO device** | False | | | | |

**PROFINET interface [X1]\I/O addresses\Input addresses**

| | | | | | |
|---|---|---|---|---|---|
| **Start address** | 0.0 | **End address** | 1.7 | **Organization block** | 0 |
| **Process image** | 0 | | | | |

**PROFINET interface [X1]\I/O addresses\Input addresses**

| | | | | | |
|---|---|---|---|---|---|
| **Start address** | 64 | **End address** | 67 | **Organization block** | 0 |
| **Process image** | 0 | | | | |

**PROFINET interface [X1]\I/O addresses\Output addresses**

| | | | | | |
|---|---|---|---|---|---|
| **Start address** | 0.0 | **End address** | 1.7 | **Organization block** | 0 |
| **Process image** | 0 | | | | |

**PROFINET interface [X1]\Advanced options\Interface options**

| | | | | | |
|---|---|---|---|---|---|
| **Support device replacement without exchangeable medium** | True | **Permit overwriting of device names of all assigned IO devices** | False | **Use IEC V2.2 LLDP mode** | False |
| **Keep-Alive connection monitoring:** | 30s | | | | |

**PROFINET interface [X1]\Advanced options\Real time settings\IO communication**

| | | | | | |
|---|---|---|---|---|---|
| **Send clock:** | 1.000ms | | | | |

**PROFINET interface [X1]\Advanced options\Real time settings\Real time options**

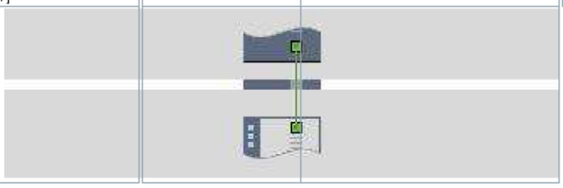
| | | | | | |
|---|---|---|---|---|---|
| **Calculated bandwidth for cyclic IO data:** | 0.000ms | **Calculated bandwidth for cyclic IO data:** | 0.000% | | |

**PROFINET interface [X1]\Advanced options\Port [X1 P1]\General**

| | | | | | |
|---|---|---|---|---|---|
| **Name** | Port_1 | **Author** | Musa | **Comment** | |

**PROFINET interface [X1]\Advanced options\Port [X1 P1]\Port interconnection\Local port:**

| | | | | | |
|---|---|---|---|---|---|
| **Local port:** | PLC_1\PROFINET interface_1 [X1]\Port_1 [X1 P1] | **Medium:** | Copper | **Cable name:** | --- |



| | | | | | |
|---|---|---|---|---|---|
| **PROFINET interface [X1]\Advanced options\Port [X1 P1]\Port interconnection\Partner port:** | | | | | |
| | Monitoring of partner port is not possible | **Partner port:** | Any partner | | |
| **PROFINET interface [X1]\Advanced options\Port [X1 P1]\Port options\Activate** | | | | | |
| Activate this port for use | True | | | | |
| **PROFINET interface [X1]\Advanced options\Port [X1 P1]\Port options\Connection** | | | | | |
| Transmission rate / duplex: | Automatic | Monitor | False | Enable autonegotiation | True |
| **PROFINET interface [X1]\Advanced options\Port [X1 P1]\Port options\Boundaries** | | | | | |
| End of detection of accessible devices | False | End of topology discovery | False | End of the sync domain | False |
| **PROFINET interface [X1]\Web server access** | | | | | |
| Enable Web server for the IP address of this interface | False | The Web server must also be activated in the properties of the PLC. | | | |
| **High speed counters (HSC)\HSC1\General\Enable** | | | | | |
| Enable this high speed counter | 0 | Enable this high speed counter | 0 | Enable this high speed counter | 0 |
| Enable this high speed counter | 0 | Enable this high speed counter | 0 | Enable this high speed counter | 0 |
| **High speed counters (HSC)\HSC1\General\Project information** | | | | | |
| Name | HSC_1 | Comment | | Name | HSC_2 |
| Comment | | Name | HSC_3 | Comment | |
| Name | HSC_4 | Comment | | Name | HSC_5 |
| Comment | | Name | HSC_6 | Comment | |
| **High speed counters (HSC)\HSC1\I/O addresses\Input addresses** | | | | | |
| Start address | 1000.0 | End address | 1003.7 | Start address | 1004.0 |
| End address | 1007.7 | Organization block | 0 | Start address | 1008.0 |
| End address | 1011.7 | Organization block | 0 | Process image | 0 |
| Start address | 1012.0 | End address | 1015.7 | Organization block | 0 |
| Process image | 0 | Start address | 1016.0 | End address | 1019.7 |
| Organization block | 0 | Process image | 0 | Start address | 1020.0 |
| End address | 1023.7 | Organization block | 0 | Process image | 0 |
| Organization block | 0 | Process image | 0 | Process image | 0 |
| **Pulse generators (PTO/PWM)\PTO1/PWM1\General\Enable** | | | | | |
| Enable this pulse generator | 0 | Enable this pulse generator | 0 | | |
| **Pulse generators (PTO/PWM)\PTO1/PWM1\General\Project information** | | | | | |
| Name | Pulse_1 | Comment | | Name | Pulse_2 |
| Comment | | | | | |
| **Pulse generators (PTO/PWM)\PTO1/PWM1\I/O addresses\Output addresses** | | | | | |
| Start address | 1000.0 | End address | 1001.7 | Start address | 1002.0 |
| End address | 1003.7 | Organization block | 0 | Organization block | 0 |
| Process image | 0 | Process image | 0 | | |
| **Startup** | | | | | |
| Startup after POWER ON | Warm restart - mode before POWER OFF | Comparison preset to actual configuration | Startup CPU even if mismatch | Configuration time | 60000ms |
| OBs should be interruptible | 1 | | | | |
| **Cycle** | | | | | |
| Cycle monitoring time | 150ms | | | Enable minimum cycle time for cyclic OBs | 0 |
| Minimum cycle time | 1ms | | | | |
| **Communication load** | | | | | |
| Cycle load due to communication | 20% | | | | |
| **System and clock memory\System memory bits** | | | | | |
| Enable the use of system memory byte | 1 | Address of system memory byte (MBx) | 1 | First cycle | %M1.0 (FirstScan) |
| Diagnostic status changed | %M1.1 (DiagStatusUpdate) | Always 1 (high) | %M1.2 (AlwaysTRUE) | Always 0 (low) | %M1.3 (AlwaysFALSE) |
| **System and clock memory\Clock memory bits** | | | | | |
| Enable the use of clock memory byte | 1 | Address of clock memory byte (MBx) | 0 | 10 Hz clock | %M0.0 (Clock_10Hz) |
| 5 Hz clock | %M0.1 (Clock_5Hz) | 2.5 Hz clock | %M0.2 (Clock_2.5Hz) | 2 Hz clock | %M0.3 (Clock_2Hz) |
| 1.25 Hz clock | %M0.4 (Clock_1.25Hz) | 1 Hz clock | %M0.5 (Clock_1Hz) | 0.625 Hz clock | %M0.6 (Clock_0.625Hz) |
| 0.5 Hz clock | %M0.7 (Clock_0.5Hz) | | | | |
| **Web server\General** | | | | | |
| Activate Web server on all modules of this device | False | Permit access only with HTTPS | True | | |
| **Web server\Automatic update** | | | | | |
| Enable automatic update | True | Update interval | 0s | | |

**Web server\User management**

| User name | User rights |
|---|---|
| Everybody | |

**Web server\User-defined web pages**

| Application name | HTML source path | Default HTML page | Files with dynamic content | Web DB number | Fragment DB number |
|---|---|---|---|---|---|
| | | index.htm | .htm;.html | 333 | 334 |

**Web server\Overview of interfaces**

| Device | Interface | Enabled web server access |
|---|---|---|
| PLC_1 | PROFINET interface_1 | False |

| User interface languages | |
|---|---|
| **Assign project language** | **User interface languages** |
| English (United States) | German |
| English (United States) | English |
| English (United States) | French |
| English (United States) | Spanish |
| English (United States) | Italian |
| English (United States) | Chinese (simplified) |

| Time of day\Local time | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Time zone** | (UTC +01:00) Berlin, Bern, Brussels, Rome, Stockholm, Vienna | | | | | | |
| **Time of day\Daylight saving time** | | | | | | | |
| **Activate daylight saving time** | 1 | **Difference between standard and daylight saving time** | 60mins | | | | |
| **Time of day\Daylight saving time\Start of daylight saving time** | | | | | | | |
| **Starting week of the month:** | Last | | Sunday | **of** | March | | |
| **at** | 01:00 a.m. | | | | | | |
| **Time of day\Daylight saving time\Start of standard time** | | | | | | | |
| | Last | | Sunday | **of** | October | | |
| **at** | 02:00 a.m. | | | | | | |
| **Protection & Security** | | | | | | | |
| **Level of protection** | No protection | | | | | | |
| **Protection & Security\Connection mechanisms** | | | | | | | |
| **Permit access with PUT/GET communication from remote partner** | False | | | | | | |
| **Protection & Security\Security event** | | | | | | | |
| **Summarize diagnostics in case of high message volume** | True | **Length of an interval** | 20 | **Unit** | seconds | | |
| **Protection & Security\External load memory** | | | | | | | |
| **Disable copying from internal load memory to external load memory** | False | | | | | | |
| **Configuration control\Configuration control for central configuration** | | | | | | | |
| **Allow to reconfigure the device via the user program** | 0 | | | | | | |

**Connection resources**

| | Station resources - Reserved - Maximum | Station resources - Reserved - Configured | Station resources - Dynamic - Configured | Module resources - PLC_1 [CPU 1214C DC/DC/DC] - Configured |
|---|---|---|---|---|
| Maximum number of resources: | | 62 | 6 | 68 |
| | Maximum | Configured | Configured | Configured |
| PG communication: | 4 | - | - | - |
| HMI communication: | 12 | 2 | 0 | 2 |
| S7 communication: | 8 | 0 | 0 | 0 |
| Open user communication: | 8 | 0 | 0 | 0 |
| Web communication: | 30 | - | - | - |
| Other communication: | - | - | 0 | 0 |
| Total resources used: | | 2 | 0 | 2 |
| Available resources: | | 60 | 6 | 66 |

| Overview of addresses\Overview of addresses\Overview of addresses | | | | | |
|---|---|---|---|---|---|
| **Inputs** | True | **Outputs** | True | **Address gaps** | False |
| **Slot** | True | | | | |

| Type | Addr. from | Addr. to | Module | PIP | Device name | Device num |
|---|---|---|---|---|---|---|
| I | 0 | 1 | DI 14/DQ 10_1 | Automatic update | PLC_1 [CPU 1214C DC/DC/DC] | - |
| O | 0 | 1 | DI 14/DQ 10_1 | Automatic update | PLC_1 [CPU 1214C DC/DC/DC] | - |
| I | 64 | 67 | AI 2_1 | Automatic update | PLC_1 [CPU 1214C DC/DC/DC] | - |
| I | 1000 | 1003 | HSC_1 | Automatic update | PLC_1 [CPU 1214C DC/DC/DC] | - |
| I | 1004 | 1007 | HSC_2 | Automatic update | PLC_1 [CPU 1214C DC/DC/DC] | - |
| I | 1008 | 1011 | HSC_3 | Automatic update | PLC_1 [CPU 1214C DC/DC/DC] | - |
| I | 1012 | 1015 | HSC_4 | Automatic update | PLC_1 [CPU 1214C DC/DC/DC] | - |
| I | 1016 | 1019 | HSC_5 | Automatic update | PLC_1 [CPU 1214C DC/DC/DC] | - |
| I | 1020 | 1023 | HSC_6 | Automatic update | PLC_1 [CPU 1214C DC/DC/DC] | - |
| O | 1000 | 1001 | Pulse_1 | Automatic update | PLC_1 [CPU 1214C DC/DC/DC] | - |
| O | 1002 | 1003 | Pulse_2 | Automatic update | PLC_1 [CPU 1214C DC/DC/DC] | - |
| O | 1004 | 1005 | Pulse_3 | Automatic update | PLC_1 [CPU 1214C DC/DC/DC] | - |
| O | 1006 | 1007 | Pulse_4 | Automatic update | PLC_1 [CPU 1214C DC/DC/DC] | - |
| I | 2 | 9 | AI 4x13BIT_1 | Automatic update | PLC_1 [CPU 1214C DC/DC/DC] | - |

Totally Integrated Automation Portal

PLC_1 [CPU 121 4C DC/DC/DC] / Program blocks

Main [OB1]

Main Properties

General

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Name | Main | Number | 1 | Type | OB | Language | F |
| Numbering | Automatic | | | | | | |
| Information | | | | | | | |
| Title | "Main Program Sweep (Cycle)" | Author | | Comment | | Family | |
| Version | 0.1 | User-defined ID | | | | | |

BD

Totally Integrated Automation Portal

PLC_1 [CPU 121 4C DC/DC/DC] / Program blocks / FC BL

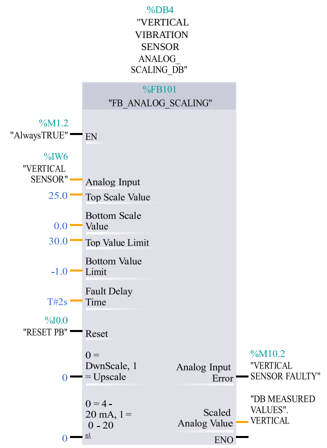
## FC PUMPS [FC1]

FC PUMPS Properties

General

| | | | |
|---|---|---|---|
| Name | FC PUMPS | Number | |
| Numbering | Automatic | | |
| Information | | | |
| Title | | Author | |
| Version | 0.1 | User-defined ID | |

| Name | Data type | Default value |
|---|---|---|
| Input | | |
| Output | | |
| InOut | | |
| Temp | | |
| Constant | | |
| ▼ Return | | |
| FC PUMPS | Void | |




Network 4:
CURRENT SENSOR



## PLC_1 [CPU 1214C DC/DC/DC] / Program blocks / FC BLOCKS

### FC FEEDBACK [FC3]

FC FEEDBACK Properties

| General | | | | | |
|---|---|---|---|---|---|
| Name | FC FEEDBACK | Number | 3 | Type | FC |
| Numbering | Automatic | | | | |
| Information | | | | | |
| Title | | Author | | Comment | |
| Version | 0.1 | User-defined ID | | | |

| Name | Data type | Default value | Comment |
|---|---|---|---|
| Input | | | |
| Output | | | |
| InOut | | | |
| Temp | | | |
| Constant | | | |
| ▼ Return | | | |
| FC FEEDBACK | Void | | |

## PLC_1 [CPU 1214C DC/DC/DC]

### PLC tags

PLC tags

| Icon | Name | Data type | Address | Visible in HMI engineering | Accessible from HMI/OPC UA/Web API | Comment |
|---|---|---|---|---|---|---|
| | AlwaysFALSE | Bool | %M1.3 | True | True | |
| | AlwaysTRUE | Bool | %M1.2 | True | True | |
| | AXIAL READING UPPER LIMIT | Bool | %M10.4 | True | True | |
| | AXIAL SENSOR | Word | %IW2 | True | True | |
| | AXIAL SENSOR FAULTY | Bool | %M10.0 | True | True | |
| | Clock_0.5Hz | Bool | %M0.7 | True | True | |
| | Clock_0.625Hz | Bool | %M0.6 | True | True | |
| | Clock_1.25Hz | Bool | %M0.4 | True | True | |
| | Clock_1Hz | Bool | %M0.5 | True | True | |
| | Clock_2.5Hz | Bool | %M0.2 | True | True | |
| | Clock_2Hz | Bool | %M0.3 | True | True | |
| | Clock_5Hz | Bool | %M0.1 | True | True | |
| | Clock_10Hz | Bool | %M0.0 | True | True | |
| | Clock_Byte | Byte | %MB0 | True | True | |
| | CURRENT READING LOW-ER LIMIT | Bool | %M11.0 | True | True | |
| | CURRENT READING UP-PER LIMIT | Bool | %M10.7 | True | True | |
| | CURRENT SENSOR | Word | %IW8 | True | True | |
| | CURRENT SENSOR FAUL-TY | Bool | %M10.3 | True | True | |
| | DiagStatusUpdate | Bool | %M1.1 | True | True | |
| | FirstScan | Bool | %M1.0 | True | True | |
| | HORIZONTAL READING UPPER LIMIT | Bool | %M10.5 | True | True | |
| | HORIZONTAL SENSOR | Word | %IW4 | True | True | |
| | HORIZONTAL SENSOR FAULTY | Bool | %M10.1 | True | True | |
| | MW10 FEEDBACK TAGS | Word | %MW10 | True | True | |
| | RESET PB | Bool | %I0.0 | True | True | |
| | START PB | Bool | %I0.1 | True | True | |
| | STOP PB | Bool | %I0.2 | True | True | |
| | System_Byte | Byte | %MB1 | True | True | |
| | System_Byte(1) | Byte | %MB1 | True | True | |
| | VERTICAL READING UP-PER LIMIT | Bool | %M10.6 | True | True | |
| | VERTICAL SENSOR | Word | %IW6 | True | True | |
| | VERTICAL SENSOR FAUL-TY | Bool | %M10.2 | True | True | |
| | X0004 PUMP RUN CMD | Bool | %Q0.0 | True | True | |

## APPENDIX C: VIBRATION DATA ANALYSIS MATLAB SCRIPT

**Data Import**

This section imports vibration data from an Excel file ('Pump X0004_Vibration_Rev MN.xlsx') and stores it in the 'data' variable.

```
% Import your data, including
headers
```

**Data Import**

Data Extraction

These lines extract specific columns of data (date, time, axial, horizontal, and vertical vibrations) from the 'data' variable and store them in separate variables.

```
% Get the data from specific
columns using column numbers
dateColumn = data(:, 1);
timeColumn = data(:, 2);
axialVibration = data(:, 3);
horizontalVibration = data(:, 4);
verticalVibration = data(:, 5);
```

**Data Extraction**

Date Time Conversion

This section combines the date and time columns into a single datetime/ array ('datetimeArray') to represent timestamps accurately.

```
% Combine date and time columns into
a single datetime array
```

**Date Time Conversion**

### Plotting

This section sets up a figure for plotting and displays a subplot for axial vibration data over time. It adds horizontal lines to represent ISO limits and legend labels for better visualization.

```
% Plotting Data against date and time
figure;

% Axial Vibration Plot
subplot(3, 1, 1);
plot(datetimeArray,    axialVibration,    'r',
'LineWidth', 2);
title('Axial Vibration');
xlabel('Date and Time');
```

### Basic Statistics

This part calculates basic statistics (mean, peak, standard deviation, and minimum) for axial, horizontal, and vertical vibration components.

```
% Calculating basic
statistics for each
vibration component,
including mean, peak
values, and standard
deviation.


% Axial component

mean_axial =
mean(axialVibration);

peak_axial =
max(abs(axialVibration));

std_axial =
```

Basic Statistics Display

```
% Display the statistics for each vibration component
fprintf('Axial Vibration - Mean: %.4f, Peak: %.4f,
Standard Deviation: %.4f, Minimum: %.4f\n',
mean_axial, peak_axial, std_axial, min_axial);
fprintf('Horizontal Vibration - Mean: %.4f, Peak:
%.4f, Standard Deviation: %.4f, Minimum: %.4f\n',
```

Fast Fourier Transform (FFT)

Here, the code calculates the sampling frequency ('Fs') based on the time interval between data points.

```
% Compute the FFT to analyze the frequency
components of the vibration data for each
component. Plot frequency spectra to identify
```

The FFT is calculated for axial, horizontal, and vertical vibration components, and the corresponding frequencies are determined.

```
fft_axial = fft(axialVibration);
fft_horizontal = fft(horizontalVibration);
fft vertical = fft(verticalVibration);
```

FFT Plotting

This part sets up a figure for plotting FFT results and displays the frequency spectrum for the axial vibration component.

```
% Plot FFT results
figure;
subplot(3, 1, 1);
plot(frequencies,
abs(fft_axial), 'r',
```

Similarly, it plots the frequency spectrum for the horizontal vibration component.

```
subplot(3, 1, 2);
plot(frequencies,
abs(fft_horizontal),
'g', 'LineWidth', 2);
```

This section plots the frequency spectrum for the vertical vibration component.

```
subplot(3, 1, 3);
plot(frequencies,
abs(fft_vertical),
'b', 'LineWidth', 2);
```

ISO Compliance Check

These comments explain the ISO standards for different vibration levels.

```
% Check compliance with
ISO standards
% Vibration Limits as
```

ISO limits for 'good,' 'fair low,' 'fair high,' and 'bad' are defined based on the standards.

```
% Define ISO limits
good_limit = 6.58;
fair_limit_low = 6.58;
fair_limit_high = 15.8;
```

The code checks compliance with ISO standards for each vibration component and assigns a compliance status ('Good,' 'Fair,' or 'Bad') to each.

```
% Check compliance for
each component
axial_compliance =
'Unknown';
horizontal_compliance =
'Unknown';
vertical_compliance =
'Unknown';
```

The code checks compliance with ISO standards for each vibration component and assigns a compliance status ('Good,' 'Fair,' or 'Bad') to each.

```
if peak_horizontal <
good_limit
horizontal_compliance =
'Good';
elseif peak_horizontal >=
```

Similar compliance checks are performed for the horizontal vibration component.

```
if peak_vertical < good_limit
vertical_compliance =
'Good';
```

**MATLAB Vibration Data Analysis Set-up**

The steps below details MATLAB Step by Step:

**Install MATLAB:**

- Before starting, you need to install MATLAB on your computer. You can purchase a license from the MathWorks website and follow their installation instructions.

**Prepare Your Data:**

- Ensure you have the data file ('Pump X0004_Current_Rev Musa Current.csv') in the Same directory as your MATLAB script. It should be in CSV format. Here's a step-by-step guide on how to prepare your data (point 2) in MATLAB:

**Locate Your Data File:**

- Make sure you have the data file you want to analyse. In this case, it's 'Pump X0004_Current_Rev Musa Current.csv.'
- Open MATLAB:
- Launch MATLAB on your computer by clicking on the MATLAB icon.

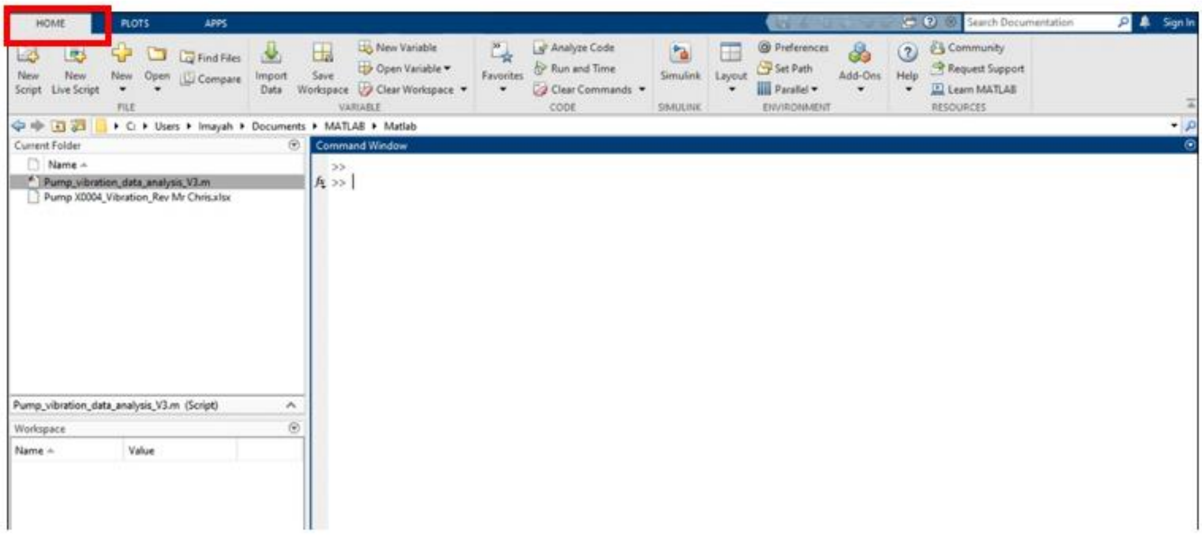



**Figure C1 :MATLAB Setup**

**Navigate to the "Current Folder":**

- In MATLAB, you'll see a "Current Folder" panel on the left side of the interface. This panel shows your current working directory. If you don't see this panel, you can enable it by clicking on the "Home" tab in the top menu. Figure 4.40 shows the respective window.

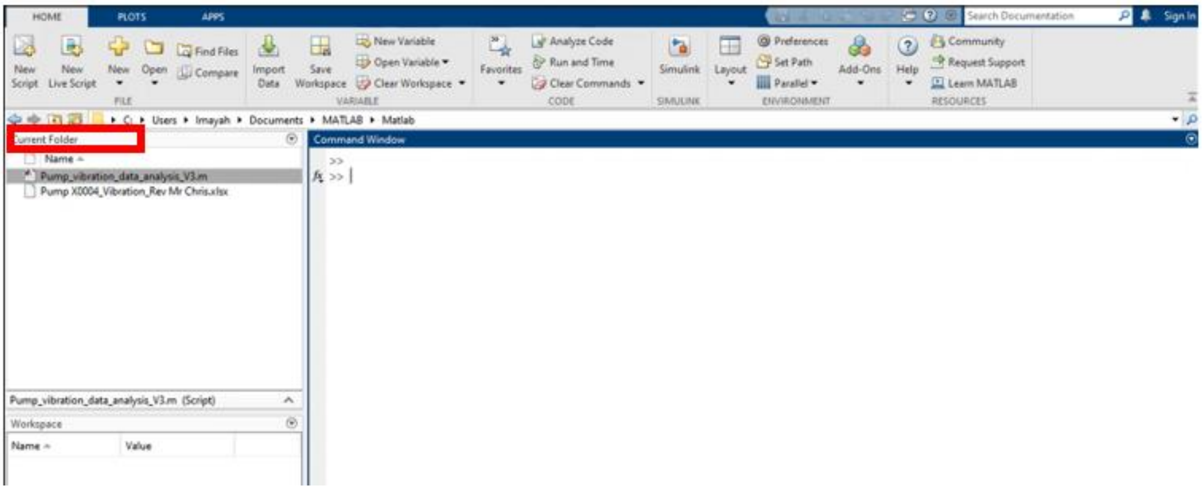



**Figure C2: MATLAB Current Folder**

**Set the Current Folder:**

- Ensure that the "Current Folder" points to the directory where your data file is located. To do this, follow these steps:
- Click on the "Home" tab in the top menu.
- In the "File" section of the "Home" tab, click on "Set Path."
- In the "Set Path" dialog that appears, click on "Add Folder."

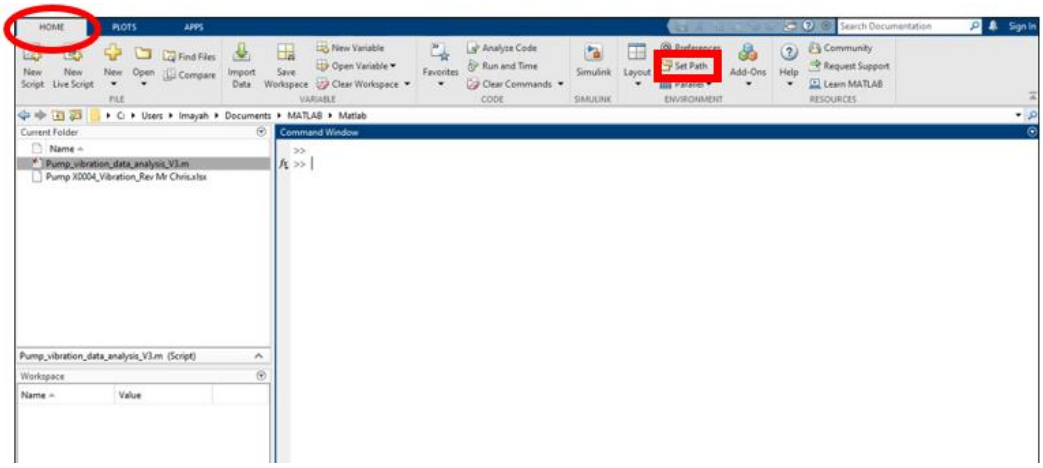
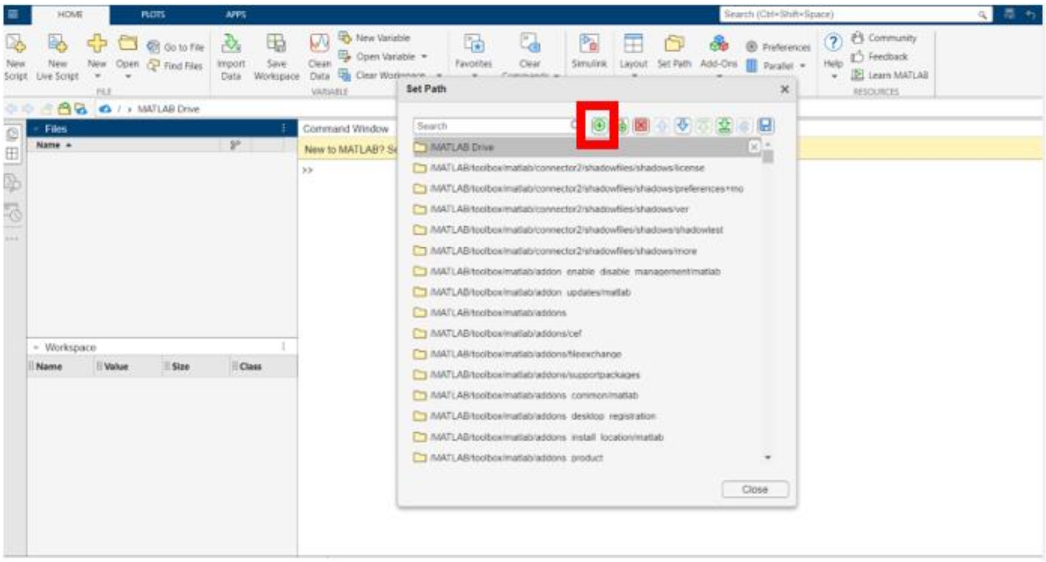



**Figure C3: MATLAB Set Path**




- Browse your computer to locate the folder where your data file is stored.

**Figure C4: MATLAB Locate Folder**

Select the folder, and then click on "Add Folder" to include it in your MATLAB path. Click "Save" in the "Set Path" dialog to confirm the changes.

Open the Script:

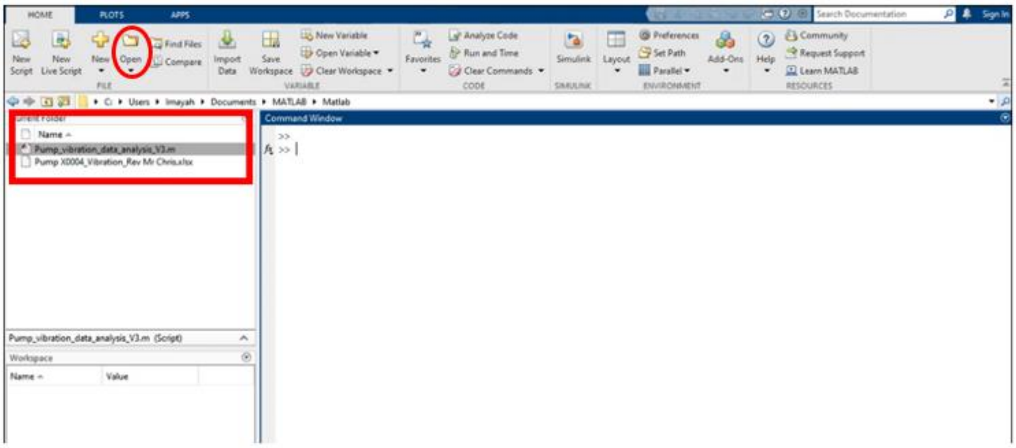



**Figure C5: MATLAB Open Script**

- Click on the "Home" tab at the top menu.
- In the "File" section, click on "Open" to browse for your MATLAB script. Double-click the script file to open it in the MATLAB Editor.

### Run the Script:

- With the script open in the MATLAB Editor, click on the "Editor" tab at the top menu.

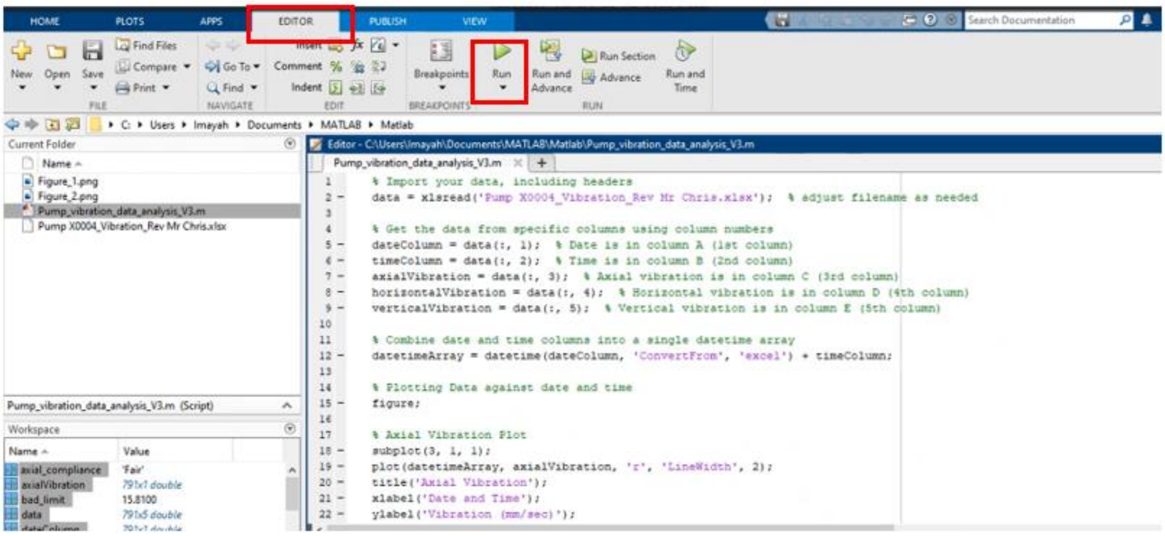



**Figure C7: MATLAB Run Script**

- In the "Run" section, click on "Run" (or simply press F5 on your keyboard) to execute the script.
- View the Output:
- The results are displayed in the MATLAB Command Window, which is typically at the bottom of the MATLAB interface. Refer to Figure 4.46

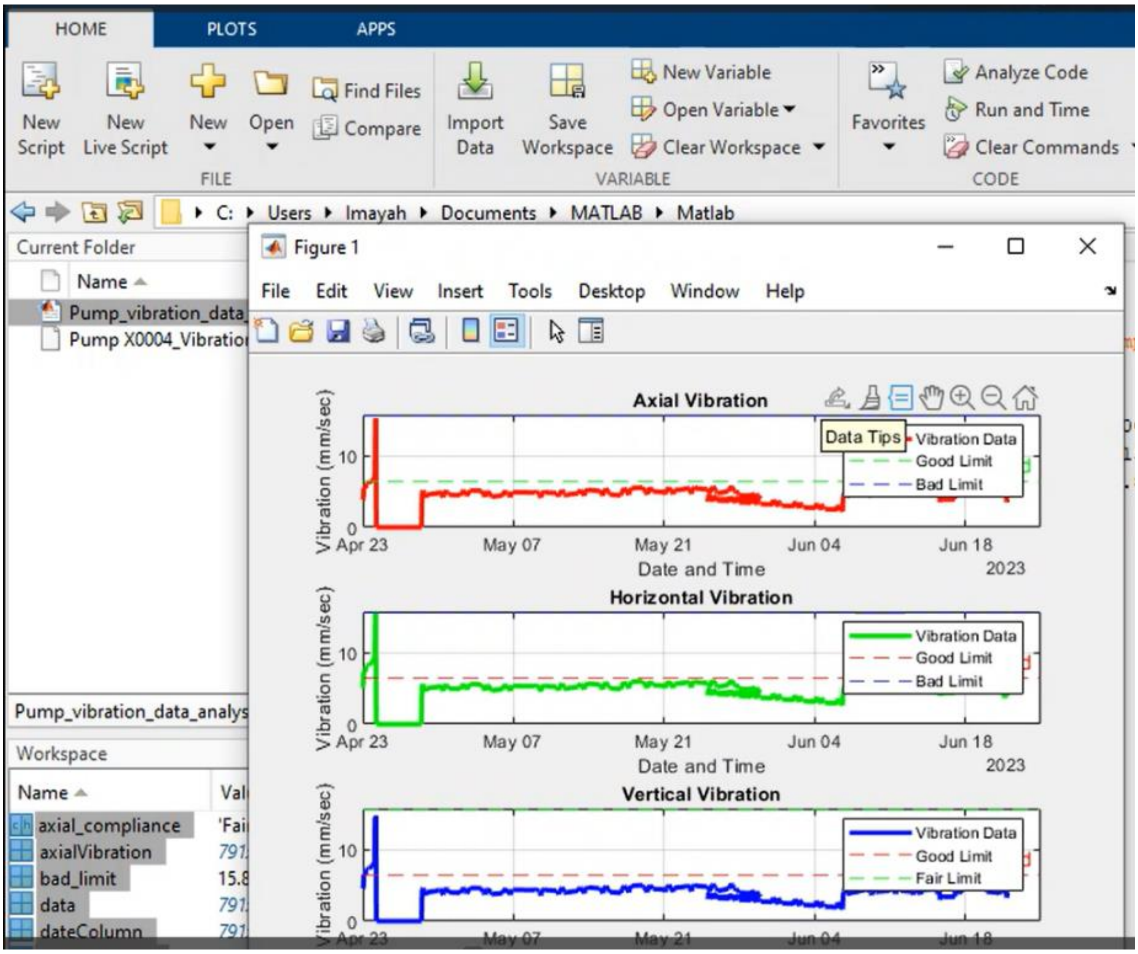
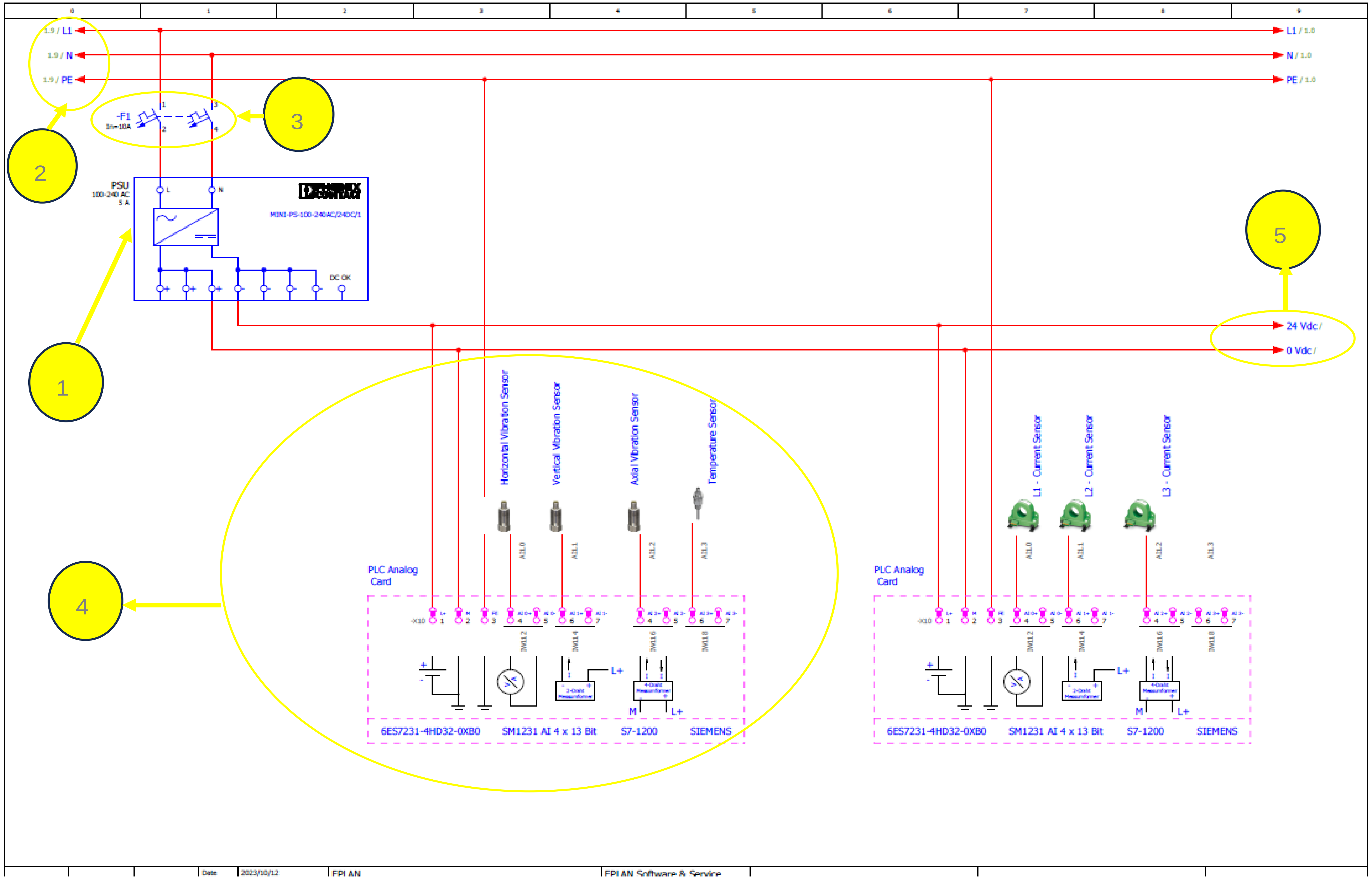



**Figure C8: MATLAB Save Output**

To save the displayed graph, click on “Save”


L1
N
PE
-F1
PSU
100-240 AC
5 A
MINI-PS-100-240AC/24DC/1
DC OK
24 Vdc
0 Vdc
Horizontal Vibration Sensor
Vertical Vibration Sensor
Axial Vibration Sensor
Temperature Sensor
L1 - Current Sensor
L2 - Current Sensor
L3 - Current Sensor
PLC Analog Card
PLC Analog Card
6ES7231-4HD32-0XB0
SM1231 AI 4 x 13 Bit
S7-1200
SIEMENS
6ES7231-4HD32-0XB0
SM1231 AI 4 x 13 Bit
S7-1200
SIEMENS
1
2
3
4
5
Date
2023/10/12
EPLAN
EPLAN Software & Service