Cape Peninsula
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DEVELOPMENT OF METHODS FOR DISTRIBUTION NETWORK POWER QUALITY VARIATION MONITORING

by

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DECLARATION

I, Nyaniso Nduku, declare that the contents of this dissertation/thesis represent my own unaided work, and that the dissertation/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**

ABSTRACT

The purpose of this project is to develop methods for distribution network power quality variations monitoring. Power quality (PQ) has become a significant issue for both power suppliers and customers. There have been important changes in power system regarding to power quality requirements. "Power quality" is the combination of voltage quality and current quality. The main research problem of the project is to investigate the power quality of a distribution network by selection of proper measurement, applying and developing the existing classic and modern signal conditioning methods for power disturbance's parameters extracting and monitoring. The research objectives are:

- To study the standard IEC 61000-4-30 requirements, to investigate the common couplings in the distribution network.
- To identify the points for measurement, to develop MySQL database for the data from the measurement and to develop MATLAB software for simulation of the network.
- To develop methods based on Fourier transforms for estimation of the parameters of the disturbances.
- To develop software for the methods implementation.

The influence of different loads on power quality disturbances are considered in the distribution network. Points on the network and meters according to the IEC power quality standards are investigated and applied for the CPUT Bellville campus distribution network. The implementation of the power quality monitoring for the CPUT Bellville campus helps the quality of power supply to be improved and the used power to be reduced.

MATLAB programs to communicate with the database and calculate the disturbances and power quality parameters are developed.

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O Lord my God, I will give you thanks forever. Psam 30:12

DEDICATION

I would like to dedicate this thesis to my mother Nomfanelo Nduku and brother Ntsindiso Charles Nduku. I also want to extend my dedication to my daughter Phelisa Nduku and the entire family for all their patience and support.

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GLOSSARY

Abbreviations	**Definition**
AC	Alternating Current
DC	Direct current
PF	Power Factor
CF	Crest Factor
VDF	Voltage Distribution Factor
TF	Transfer Function
RMS	Root Mean Square
PQ	Power Quality
P_{st}	Short-term Flicker Severity
PQMS	Power Quality Measurement System
PQDS	Power Quality Diagnosis System
PQRM	Power Quality Recorder Manager
WT	Wavelet Transform
CWT	Continuous Wavelet Transform
WFT	Windowed Fourier Transform
PCC	Point of Common Coupling
THD	Total Harmonic Distortion
EMTP	Electromagnetic Transients Program
DFT	Discrete Fourier Transform
IDFT	Inverse Discrete Fourier Transform
FFT	Fast Fourier Transform
CRT	Cathode Ray Tube
HV	High Voltage
STFT	Short time Discrete Fourier Transform
UPS	Uninterruptable Power Supply
THDG	THDG
THDS	Sub-Group Total Harmonic Distortion
EPRI	Electrical Power Research Institute
DHT	Discrete Harley Transform
DTTs	Discrete Trigonometric Transform
DCT	Discrete Cosine Transform
DST	Discrete Sine Transform
FST	Fourier Series Transform
WDFT	Windowed Discrete Fourier Transform
NEPRI	Norwegian Electric Power Research Institute
SLG	Single-line ground
LV	Low Voltage
MV	Medium Voltage
SNR	Signal to Noise ratio
UTP	Unit test period
WTCs	Wavelet Transform Coefficients
IEC	International Electrotechnical Commission
CPUT	Cape Peninsula University of Technology
SLG	Satellite Logistics group
Hz	Hertz
S	Apparent Power
Q	Reactive Power
W	Active Power
AADS	Adagio Audio Distribution System
IT	Information Technology
MGR	Mathew Goniwe Residence
kW	kilowatt
PC	Personal Computer
kVAR	kilo-volt amps-reactive

VA	Volt-Amps
W	Watts
VAR	Volt-Amps-Reactive
kVA	kilovolt-amps
ASD	Adjustable Speed Drives
PCC	Point of Common Coupling

NOMENCLATURE

DC_0	DC Component
C_{Uh}	Amplitude of h ordered voltage harmonic
Φ_{Uh}	Phase shift of h ordered voltage harmonic
f	frequency
U_h	RMS value of h order voltage harmonics
U_1	RMS value of the fundamental voltage
M_h	is the rms value of harmonic component h of the quantity M
θ	phase angle between voltage and current.
h_r	resonant frequency as a multiple of the fundamental frequency
$kVAsc$	short circuit current at the point of study
$kVARc$	capacitor rating at the system voltage
C_{10}	is the 10 cycle value.
C_{qk}	is evaluated with a simple sum taking into account the zeros of $cos(k\omega t)dt$
$\cos\theta$	is commonly called the power factor
$f(t)\in L^2(R)$	can be presented as a series expansion by using a combination of these scaling functions and wavelets functions
$L^2(R)$	is the Hilbert space.
$C_j(k)$	is the set of approximate coefficients
$d_j(k)$	is the set of j-level detail coefficients
$h(n)$	Is the scaling function coefficients
$h_1(n)$	Is the wavelet function coefficients
P_{st}	is a short-term flicker severity
S	is the magnitude of apparent power
P	is the magnitude of the active power
Q	is the magnitude of the reactive power
$Vrms$	is the root mean square voltage
$Irms$	is the mean square current

PFc	is the calculated power factor value
PFm	is the measured power factor value
x_k	coeffierents
N	is the number of samples within the measurement window **T**
h-th	order of harmonic is hf_0

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CHAPTER ONE

BACKGROUND, AIM, AND OBJECTIVES OF THE THESIS

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1. Awareness of problem

Power systems operate with a constant line voltage, supplying power to a wide variety of load equipment. *Power levels range from small watts to megawatts and the voltage at which the* energy is generated, transported, and distributed in the range from hundreds of volts to kilovolts. Transmission and distribution of power are made at high voltages, from tens to hundreds of kilovolts, in order to provide efficient and economic transportation of the energy over long distances. Recently, Power quality (PQ) has become a significant issue for both power suppliers and customers. There have been important changes in power system regarding to power quality importance. There are different definitions of power quality connecting it with the equipment of the power system performance. The definition accepted in the thesis is as in (Bullen et al, 200:6): "Power quality" is the combination of voltage quality and current quality. Voltage quality is concerned with deviation of the actual voltage from the ideal voltage. Current quality is the equivalent definition for the current.

The ideal voltage is the sinusoidal one with constant amplitude and constant frequency, both equal to their nominal values. Voltage and current disturbances are connected but it could be said that the voltage disturbances originate in the power network and potentially affect the customers. The current disturbances originate with the customers and potentially affect the network.

The following issues are very important in the operation of the power system today:

- Increased awareness of power quality issues by the end users.
- Customers are better informed about such disturbances as interruptions, sags and switched transients.
- Less tolerant equipment toward voltage quality disturbances. Less tolerant production process towards incorrect functioning of the equipment and less tolerant companies towards the production stoppages because of the increased costs paid.

Some of the characteristics of the power system disturbances in the last years are:

- The main reasons for equipment malfunction are the interruptions and voltage dips.
- Integration of the power processes means that the failure of any component has much more important consequences.
- Load equipment is more sensitive to power quality variations than equipment applied in the past. Many new load devices contain microprocessor-based controls and power electronic devices that are sensitive to many types of disturbances.
- Equipment produces increased the current disturbances than before. Use of energy efficient equipment as adjustable-speed drives and energy saving lamps creates waveform distortion.
- The increasing emphasis on overall power system efficiency has resulted in a continued growth in the application of devices such as high-efficiency, adjustable-speed motor drives and shunt capacitors for power factor correction to reduce losses.

It used to be with large AC power systems that "power quality" was an unheard-of concept, aside from power factor. Loads controlled by nonlinear electronic components are becoming more prevalent in both home and industry, meaning that the voltages and currents in the power system feeding these loads are rich in harmonics. Clean sine-wave voltage and currents are becoming highly distorted, which is equivalent to the presence of an infinite series of high-frequency sine waves at multiples of the fundamental power line frequency. Excessive harmonics in an AC power system can overheat transformers, cause exceedingly high neutral conductor currents in three-phase systems, create electromagnetic noise in the form of radio emissions that can interfere with sensitive electronic equipment, reduce electronic motor horsepower output, and can be difficult to pinpoint.

On the basis of the above the technical aim of power network becomes one of allowing the transport of electrical energy between the different customers, guaranteeing an acceptable and quality voltage and currents to be taken by the customers. This means that the problems for measurement and monitoring of the quality of the power system are important in these days. They require proper, economic and fast solution giving possibilities for application of different methods for mitigation and control of the appearing disturbances. The number of papers and research reports in the field of power quality is growing every year, but the problem is still not very well understood and investigated. The new measuring and computer technologies allow automatic measurement and processing of large amount of data which enables an accurate quantification of the power quality. The research work on the project is based on these new technologies for power system quality measurement and monitoring which can be grouped as methods of signal processing/ digital signal processing. The fundamental signal processing methods used in practical power quality monitoring are the discrete Fourier transform (DFT) and rms. Lately many new methods have appeared. The research question of the thesis is how signal processing methods are applicable and how further they can be developed and applied for monitoring and analysis of a distribution network with different type of loads and one supplier of power energy.

1.2 Statement of the problem

Power quality becomes an important concern to customers as well as utilities and facilities. New power quality problems such as sag, swell, harmonic distortion, unbalance, transient and flicker may impact on customer devices and cause malfunctions.

The main research problem of the project is to investigate the power quality of a distribution network by selection of proper measurement, applying and implementing the existing classic and modern signal conditioning methods for power disturbance's parameters extracting and monitoring.

1.2.1 Design based sub-problems.

1.2.1.1 Sub-problem 1: Problem Categorisation

The proposed research project is mainly focused on power quality. Measurement and monitoring power quality (PQ) covers a wide range issues from voltage disturbances like sags, swells, outages and transients to current harmonics, to performance wiring and grounding. These problems are studied and the research papers considering the problems for power quality disturbances measurement and monitoring are reviewed and compared.

1.2.1.2 Sub-problem 2: Identify power quality problems in a distribution network and provide proper measurements of the voltage and current disturbances

Power quality disturbances should be measured and assessed.

The influence of different loads on power quality disturbances are considered in the distribution network. Points on the network and meters according to the IEC power quality standards are investigated and applied for the CPUT Bellville campus distribution network.

1.2.1.3 Sub-problem 3: Power quality database creation

The data from the measurement at different points of the network are saved in the created MySQL database.

1.2.1.4 Sub-problem 4: Implementation of signal processing methods for identification and estimation of the parameters of the disturbances.

The classic methods of Fourier transform are investigated and applied to the data from the measurement.

1.2.1.5 Sub-problem 5: Implementation of calculation procedures for evaluation of power quality parameters.

1.3 Software Implementations sub-problems.

1.3.1 Sub-problem 6: Implementations of MySQL database.

MySQL database is created and all data of measurements is saved in it

1.3.2 Sub- problem 7: Implementation software for application of the signal processing methods.

MATLAB programs are implemented for communication with the database and calculation of the *estimated disturbance parameters* using Fourier transform.

1.3.3 Sub-problem 8: Implementation of software for calculation of power quality parameters

MATLAB programs are implemented for calculation of power quality parameters using the data from measurement.

1.4 Research Aim and Objectives

1.4.1 Aim

The aim of the research project is to implement methods, algorithms and software for *measurements, analysis and monitoring* of the power quality disturbances on the basis of the IEC 61000-4-30 standard.

1.4.2 Research objectives

1) Study of the standard IEC 61000-4-30 requirements.

2) Investigation of common couplings in the distribution network. Identification of the points for measurement.

3) Implementation of MySQL data-base for the data from the measurement.

4) Implementation of signal processing methods for:

- Investigation of current distortion by customers.
- Investigation of harmonic distortion as a main disturbance.
- Determining the frequency variations.
- Determining the voltage variations.
- Determining the voltage fluctuations.
- Determining the voltage unbalance.

5) Implementation of MATLAB software for disturbance parameters estimation.

1.5 Motivation for project

Recently, Power quality (PQ) has become a significant issue for both power suppliers and customers.

Power quality is very important because of sensitive equipment used in homeholds, schools, universities, offices, restaurants and shops. There is also a concern about premature loss of equipment life due to harmonics, voltage fluctuations and system transients. So it becomes more important to precisely measure and monitor power quality, identify the causes and try to come up with solution of power quality corruption. The project identifies the distribution network power quality problems and determines their characteristics. The Implemented software will be included as a part of the monitoring and control system for the reticulation network of the Bellville campus. It will help to reduce the energy consumption and its cost.

1.6 Delimitation of Research

1.6.1 The research is mainly based on designing and implementation of proper measurement, monitoring and analysis of Power quality (PQ) of a distribution network. Power quality of generation and transmission are not considered.

1.6.2 The research work considers every disturbance as a power quality issue. The definition of the quality is different from some previously used as "continuity" and "quality". Continuity includes interruptions, quality includes all other disturbances. The used definition is different also from the used by the council of European Energy Regulators term quality of service electricity supply which includes commercial quality, continuity of supply and voltage quality (Bullen et al. 2006:6).

1.6.3 There is a difference between disturbance and interference. The disturbance is a phenomenon that can degrade the performance of some equipment or system. Interference is the actual degradation of the equipment or system caused by the disturbance. The research concentrates on the power quality disturbances.

1.6.4 The power quality disturbances can be classified as events and variations. Variations are steady state or quasi-steady state disturbances that allow continuous measurements. Events are sudden disturbances with beginning and end. Variation types of disturbances are mainly considered in the thesis.

1.6.5 From a measurement point of view no difference will subsists between power quality measurement and measurement of voltages and currents for protection or control purpose. The difference is in the further processing and application of the measured signals.

1.6.6 Most power systems consist of three phases, but in the analysis of power quality they are not considered as such because of:

- The system voltages are balanced and a single phase approach is sufficient.
- The standards apply to devices, most of which are single phase.
- The three phase requirement makes the approach very difficult.

The only phenomenon treated in a 3 phase sense is unbalance. It is considered in the thesis.

1.7 Assumptions

- Measurement of power quality data at the various selected points in a power system will be possible.
- The points for measurements are selected according to the IEC power quality standard IEC 6100-4-30.The requirements of the standard are enough for adequate identification and estimation of the disturbances.
- The sampled and digitized voltage and current waveforms are available for processing.

- The measured signals have stationary statistical characteristics and can be represented by time invariant models.
- MATLAB software will be capable to simulate all types of power quality disturbances.

1.8 Hypothesis

Measurement of the current and voltage at selected points of the distribution network can give enough information for identification of power quality disturbances and estimation of their parameters.

1.9 Methodology

The research follows the methodology of the power quality monitoring. It consists of combination of technologies from the analog voltages and currents measurement till the technologies for post processing and calculations of the characteristics of these measured waveforms. The measurements are done using meters called power quality monitors with the help of instrument transformers. The post processing is done in a computer.

1.10 Literature review.

1.10.1 Definition of Power *Quality*

Various sources give different and sometimes conflicting definitions of power quality. Power quality is the combination of voltage quality and current quality. Voltage quality is concerned with deviations of the actual voltage from ideal voltage. Current quality is the equivalent definition for the current. A simple and straightforward solution is to define the ideal voltage as a sinusoidal voltage waveform with constant amplitude and constant frequency, where both amplitude and frequency are equal to their nominal value. A disturbance can be a voltage disturbance or a current disturbance, but it is often not possible to distinguish between two. Any change in current gives a change in voltage and the other way around (Bullen et al, 2006:6).

Power Quality (PQ) covers a wide range of disturbances like:

- Flicker
- Voltage swells
- Transient voltage behavior
- Harmonics
- Supply interruptions

The symptoms of poor Power Quality include intermittent lock-ups, resets, corrupted data, premature equipment failure, over-heating of components for no apparent cause. The ultimate cost is in downtime, decreased productivity and frustrated personnel (Bullen et al, 2006:8).

1.10.2 Power Quality disturbances

1.10.2.1 Flicker

Loads which can exhibit continuous, rapid variations in the load current magnitude can cause voltages that are often referred to as *flicker.* The term flicker is derived from the impact of the voltage fluctuation on lamps such that they are perceived to flicker by the human eye. To be technically correct, voltage fluctuation is an electromagnetic phenomenon while flicker is an undesirable result of the voltage fluctuation in some loads. However, the two terms are often linked together in standards. The flicker signal is defined by its root mean square (rms) magnitude expressed as a percent of the fundamental. Voltage flicker is measured with respect to the sensitivity of the human eye. Two types of loads lead to light flicker.

- Loads that provoke separate voltage changes are heating *and cooling loads. They have very short duty cycle. Loads with electrical motors are the worst-case as air conditioners and refrigerators, large photocopies.* The light flicker is due to repetitive events.
- Loads for which the current changes continuously are furnace arc and resistance welding, traction load, wind turbines. This is light flicker due to fast current variations (Dugan et al, 1996:27).

1.10.2.2 Voltage swells

Voltage swell along with extended undervoltage conditions and voltage harmonics are of vital concern to the majority of industries today. A swell is defined as a decrease or increase in the rms value ranging from a half cycle to a few seconds. As with sags, swells are usually associated with system fault conditions, but they are not as common as voltage sags. Swells can also be caused by switching off a large load or energizing a large capacitor bank. Swells are characterized by their magnitude (rms value) and duration. The severity of a voltage swell during a fault condition is a function of the fault location, system impedance and grounding. On an ungrounded system, with infinite zero-sequence impendence, the line-to-ground voltages on the ungrounded phases will be 1.73 per unit during a SLG fault condition. Therefore, it is important to know what levels of abnormal voltage and for how long specific equipment will tolerate it. (Dungan et al.1996:233).

1.10.2.3 Harmonics

Harmonic is a sinusoidal component of a periodic wave having a frequency that is an integral multiple of the fundamental frequency. Electrical generators try to produce electric power where the voltage waveform has only one frequency associated with it, the fundamental frequency. The frequency of the harmonics is different, depending on the fundamental frequency. For example, the 2nd harmonic on a 60 Hz system is 2×60 or 120 Hz. At 50 Hz, the second harmonic is 2×50 or 100Hz. 300Hz is the 5th harmonic in 60 Hz system or the 6th harmonic in a 50 Hz system. Harmonics cause different problems:

- Heating effects
- Resonance
- Very high current in the neutral (vector addition)
- Vibration
- Electromagnetic interference.

In order to be able to analyze complex signals that have many different frequencies, a number of mathematical methods were developed. One of the more popular is called the Fourier Transform (Bullen et al, 2006:19).

1.10.2.4 Harmonics distortion

The uses of nonlinear loads in power networks changes the sinusoidal nature of the ac power current (and consequently the ac voltage drop), thereby resulting in the flow of harmonic currents in the ac power system that can cause interference with communication circuits and other types of equipment. The effect of the nonlinear and time-varying loads can be amplified under certain conditions of the electrical network, for example by resonances. The resonant conditions may result in high levels of harmonic voltage and current distortion when the resonant condition occurs at a harmonic assorted with nonlinear loads (Reza et al,2001:(pp 165-184)).

1.10.2.5 Total Harmonic Distortion and rms Value

There are several measures commonly used for indicating the harmonic content of a waveform with a single number. One of the most common is *Total Harmonic Distortion* (THD), *which can* be calculated for either voltage or current. THD is a very useful quantity for many applications, but its limitations must be realised. It can provide a good idea of how much extra heat will be realised when a distorted voltage is applied across a resistive load (Dugan et al, 1996:129).

1.10.2.6 Harmonic resonance

Harmonic resonance can cause normal levels of current harmonics to produce unacceptable results. Among those results are telephone noises, overheated transformers and failed power factor correction capacitors. Determining which elements in the power system are responsible for harmonic resonances is therefore very important to power system engineers.Before reliable digital computer simulations of harmonics were available, utility crews would simply go to the field, remove capacitors from the system, *reinstall them elsewhere, and hope that the problem* was resolved. This same process is still used, only now digital computer harmonics simulations, such as the Electromagnetic Transients Program (EMTP), are used to analyze the effects of moving capacitors on the system (Reza et al,2001:(pp 165-184)).

1.10.2.7 Power and Power Factor

Harmonic distortion complicates the computation of power and power factor because the simplifications power engineers use for power frequency analysis do not apply.

There are three standard quantities associated with power:

Apparent power, **S** The product of the rms voltage and current.

Active power, **P**. The average rate of delivery of energy

Reactive Power, **Q**. The portion of the apparent power that is out of phase, or in quadrature, with the active power.

At fundamental frequency, it is common to relate these quantities as follows:

$$S = V_{rms}\ I_{rms} \quad (1.1)$$

$$S = \sqrt{P^2 + Q^2 + D^2} \quad (1.2)$$

$$P = S\ \cos\theta$$

$Q = S\sin\theta$

Where $\theta =$ phase angle between voltage and current.

D represents the additional contribution to the apparent power by the harmonics.

The factor $\cos\theta$ is commonly called the power factor. However, a more correct definition is to simply define the factor (PF) as

$$PF = \frac{P}{S} \tag{1.3}$$

S and P are unambiguously defined even with distorted voltage and current, while there is no clear concept of phase angle that applies to the multiple-frequency situation (Dugan et al, 1996:129).

1.10.2.8 Effects and Negative Consequences

High levels of harmonic distortion can lead to problems for the utility's distribution system, plant distribution system and any other equipment serviced by that distribution system. Effects can range from spurious operation of equipment to a shutdown of important plant equipment, such as machines or assembly lines.

Harmonics can lead to power system inefficiency. Some of the negative ways that harmonics may affect plant equipment are listed below:

- **Conductor Overheating:** a function of the square rms current per unit volume of the conductor.
- **Capacitors:** can be affected by heat rise increases due to power loss and reduced life on the capacitors. If a capacitor is tuned to one of the characteristic harmonics such as the 5th or 7th, overvoltage and resonance can cause dielectric failure or rupture the capacitor.
- **Fuses and Circuit Breakers:** harmonics can cause false or spurious operations and trips, damaging or blowing components for no apparent reason.
- **Transformers:** have increased iron and copper losses or eddy currents due to stray flux losses. This causes excessive overheating in the transformer windings. Typically, the use of appropriate " K factor" rated units are recommended for non-linear loads.
- **Generators:** have similar problems to transformers. Sizing and coordination is critical to the operation of the voltage regular and controls. Excessive harmonic voltage distortion will cause multiple zero crossings of the current waveform. Multiple zero crossings affect the timing of the voltage regulator, causing interference and operation instability.
- **Utility Meters:** may record measurements incorrectly, resulting in higher billings to

consumers.

- **Drives/ Power Supplies:** can be affected by misoperation due to multiple zero crossings. Harmonics can cause failure of the commutation circuits, found in DC drives and AC drives with silicon controlled rectifiers (SCRs).
- **Computers/ Telephones:** may experience interference or failures (Square D product Data Bulletin1994:4).

1.11 Power Quality measurement

Measurement of voltages and currents is necessary for monitoring of the power quality. The difference is in further processing and application of the measured signals. Power quality measurement is performed to:

- Find the cause of equipment malfunction and other power quality problems at the interrate with the customer. The recorded waveforms are analyzed and interpreted.
- Permanent and semi permanent measurement to monitor the network and to analyze the system events.

The simplest way to determine power quality without sophisticated equipment is to compare voltage readings between two accurate voltmeters measuring the same system voltage: one meter being an averaging type of unit (such as an electromechanical movement meter) and the other being a true-RMS type of unit (such as a high-quality digital meter). Averaging type meters are calibrated so that the scales indicate volts RMS, based on the assumption that the AC voltage being measured is sinusoidal. If the voltage is anything but sinewave-shaped, the averaging meter will not register the proper value, whereas the true-RMS meter always will, regardless of waveshape.

Another qualitative measurement of power quality is the oscilloscope test: connect an oscilloscope Cathode Ray Tube (CRT) to the AC voltage and observe the shape of the wave.

Measurement covers:

- Single phase-1 voltage: Single phase power systems are defined by having an AC source with only one voltage waveform.
- Three phase -3 voltages: Three phase is nothing more than single phase with two extra coils slightly out of phase with first.
- Current measurement: Small currents in HV circuitry can be measured by the usual means, resistors across which the voltage is measured or transformers. (Luis et al.

2005:12).

1.11.1 Types of instruments

Although instruments have been developed which measure a wide variety of disturbances, a number of different instruments are generally necessary, depending on the phenomena being investigated. Basic categories of instruments which may be applicable include:

- Wiring and grounding test devices
- Multimeters
- Oscilloscope
- Disturbance analyzers
- Harmonic analyzers/spectrum analyzers
- Combination disturbance and harmonic analyzers
- Flicker meters
- Energy monitors (Dungan et al, 1996:233).

The measurements done in the thesis is according to IEC 6100-4-30 measurement standard. The standard determines the methods to be used for calculation of the power quality variations. The standard supports two types of instruments: From class A and class B performance. The class A is for precise measurements for contractual applications, verifying compliance with standards and resolving disputes. Class B is for less precise measurements for statistical surveys and troubleshooting applications.

The most of the measurements in the thesis is done with class A measurements instrument.

1.12 Power Quality Monitoring by installation of the meter-monitors

Power quality monitoring beyond the initial site survey is performed to characterize power quality variations at specific system locations over a period of time. The monitoring requirements depend on the particular problem that is being experienced. For instance, problems that are caused by voltage sags during remote faults on the utility system could require monitoring for a significant length of time because system faults are probably rare. If the problem involves capacitor switching, it may be possible to characterize the conditions over the period of a couple days. Harmonic distortion problems should be characterized over a period of at least one week to get a picture of how the harmonics vary with load changes (Dungan et al, 1996:233).

1.12.1 Choosing a monitoring location

It is best to start monitoring as close as possible to the sensitive equipment being affected by power quality variations. It is important that the monitor sees the same variations that the sensitive equipment sees. High-frequency transients, in particular, can be significantly different if there is significant separation between the monitor and the affected equipment (Dungan et al, 1996:234).

1.12.2 Disturbance monitor connections

The recommended practice is to provide input power to the monitor from a circuit other than the circuit to be monitored. Some manufactures include input filters or surge suppressors on their power supplies that can alter disturbance data if the monitor is powered from the same circuit that is being monitored. The grounding of the power disturbance monitor is an important consideration. The disturbance monitor will have a ground connection for the signal to be monitored and a ground connection for the power supply of the instrument. Both of these grounds will be connected to the instrument chassis. For safety reasons, both of these ground terminals should be connected to earth ground. However, this has the potential of creating ground loops if different circuits are involved (Dungan et al, 1996:234).

1.13 Power quality monitoring by signal processing methods

The process of power quality monitoring is based on application and development methods of the signal processing. The steps of the process of analysis are:

- Choice of features for characterizing of variation.

  Magnitude of the voltage and current waveforms can be done by measurements. The severity of the voltage and current variation has to be done by signal processing as the absolute values of the complex voltage and current, the rms$_s$, the peaks calculations.

  The choices as the sampling frequency, the length of the window over which the characteristics are extracted, the choice of the measurement method according to IEC standards are important.
- Distinguishing between a variation and an event by appropriate selection of triggering mechanism. The method using comparison of a sliding window rms value with the threshold value can used. This requires selection of the size of the window, the overlap between the successive windows and the choice of the threshold values.

- Classification of the events according to their underlying causes on the basis of extracted features.

1.13.1 Methods to reduce influences of disturbances.

The following methods are described in the literature.

- **Voltage Regulation**

  Solutions:

  - Tap changing on the supply transformer
  - Independent generator
  - Constant voltage transformer
- **Unbalance**

  Solutions:

  - Distribute single phase loads equally across the 3 phases
  - Check three phase loads for faults on one or more phases
- **Harmonics**

  Solutions:

  - In-line inductors or chokes
  - Passive filter (Combination of resistors, capacitors and inductors)
  - Active filters (switch capacitor)
- **Flicker**

  Solutions:

  - Passive filters
  - Static Var compensator
  - Increasing the supply fault level
  - **Transients**

  Solutions:

  - Surge arrestors and transient voltage suppressors
  - Isolation transformers
  - Low pass filter (Luis et al,2005:23]

1.14 Methods for modelling disturbances

Disturbance modelling under power quality, requires good equipments to detect different disturbances that may be localized in a wide time-frequency range. Applying multi-resolution analysis, the distorted signal, $f(t) \in L^2(R)$, can be presented as a series expansion by using a combination of these scaling functions and wavelets functions as:

$$f(t) = \sum_k c_0(k)\theta(t-k) + \sum_k \sum_{j=0}^{j-1} d_j(k) 2^{j/2} \psi(2^j t - k) \qquad (1.4)$$

Where, $L^2(R)$ is the Hilbert space.

$c_j(k)$ is the set of approximate coefficients and $d_j(k)$ is the set of j-level detail coefficients and mathematically presented as:

$$c_j(k) = (f(t), \varphi_{j,k}(t)) = \sum_m h(m-2k) c_{j+1}(m), \qquad (1.5)$$

$$d_j(k) = (f(t), \psi_{j,k}(t)) = \sum_m h_1(m-2k) c_{j+1}(m), \qquad (1.6)$$

where $h(n)$ are the scaling function coefficients and $h_1(n)$ are the wavelet function coefficients.

This technique is implemented to the learn dissimilar cases on the Adagio Audio Distribution System (AADS). "The goal of these applications is to emphasize on the efficiency of the proposed technique in modeling different disturbances during the following cases"(Gounda, A.M.2006:2):

1. Compatibility measures of utility service and the sensitive equipment during faults in a multi-owner system.
2. Multi-Stage Capacitor bank switching in distorted environment (Gounda, A.M.2006:2)

1.15 Outline of Chapters

The thesis consists of eight chapters describing the concepts development and the results of the research.

Chapter 1 briefly presents the definition of power quality, background, aim, and objectives of the thesis.

Chapter 2 briefly describes the characteristics of different power quality disturbances and the important of power quality in these days.

Chapter 3 It briefly discusses the process of power quality monitoring and steps should be followed to monitor the power quality for example the installation of the meter-monitors and choosing a monitoring location.

Chapter 4 discusses the power quality standards and power quality measurements, where the power quality standards give guidelines for contractors and consultants dealing with electrical power quality, while power quality measurements make it possible to obtain the most reliable and comparable results depending on the instrument being used.

Chapter 5 discusses the data collection

Chapter 6 describes the power quality characteristics using the measured and saved in MySQL database data from Cape Peninsula University of Technology network. MATLAB programs to communicate with the database and calculate disturbances and power quality indicators parameters are developed. Results from calculations are shown.

Chapter 7 Describes two ways of generating data for application of Fourier transform using Simulink model and an injector. Fourier transform algorithm is described and software for calculation of harmonics is developed. Results from calculations are shown.

Chapter 8 Gives framework of the project deliverables, conclusions, and future research work.

1.16 Conclusion

This chapter discusses the research project aims, research objectives, research methods and literature review of the project. The project is about investigation of power quality. Power quality is considered as part of the modern, customer based view on power systems and is defined as a combination of voltage and current quality. A distinction is made between two types of disturbances: variations of the voltage and current and events of the voltage and current. The methods used to analyse the power quality for these two types of disturbances are different.

Signal processing techniques form an important part of the power quality monitoring. With their help the features of the variations and events are extracted. Signal processing methods for estimation of power quality disturbances developed and applied for the distribution network of the Bellville campus CPUT. The methods will be included as a part of the software of the network control center.

CHAPTER TWO

POWER QUALITY

2.1 Introduction*

This chapter discusses the importance of power quality. The influence of different loads in the distribution network on power quality is considered. Points for power quality measurement on the network according to the IEC power quality standards are investigated and applied for the CPUT Bellville campus distribution network.

2.2 Power Quality

Customers and power suppliers face some problems with power quality caused by some electronic devices which are very common. The present equipment setups and devices used in commercial and industrial facilities, like power electronic devices, digital cameras and computers are sensitive to many types of power disturbances.

2.3 Symptoms of Poor Power Quality

- Voltage sags and swells, it is when the voltage is too high or very low for the period of several cycles to a couple of minutes.
- Momentary outages, which cause completely interruptions of electrical power service for up to a couple of minutes.
- Voltage spikes –produce a temporary increase of a current flow.

2.4 Why Power Quality is Important. Types of disturbances.

Power quality is very important these days because of the use of more sensitive electronic equipment. All electronic equipment operates on AC power. So AC power supply generates and delivers electrical power problems or disturbances to those sensitive equipments. Some dramatic outside of the buildings sources of disturbances are like capacitor bank switching.

circuit breaker re-closures and equipment failures. Inside sources include fluorescent lighting assembly line equipment and air conditioning. These produce different type power quality disturbances.

The different existing types of power quality disturbances are shown in Figure 2.1

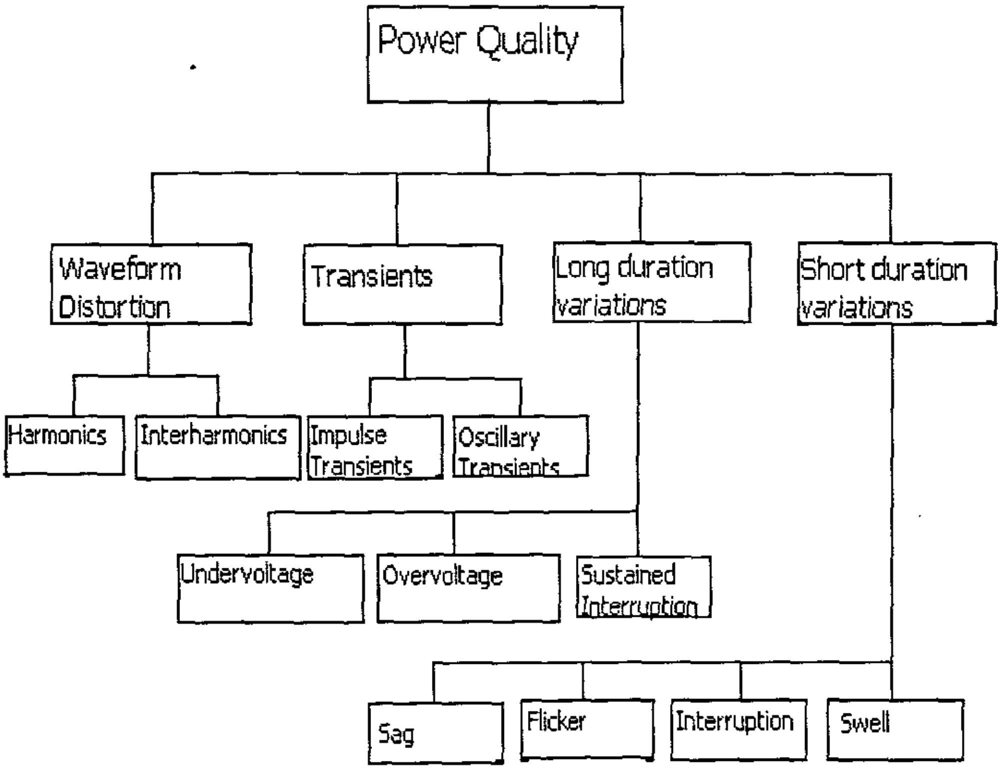


Figure 2.1: Types of Power Quality disturbances.

2.4.1 Short Duration Variation

Short duration variations are divided into instantaneous, momentary, and temporary. Short duration variations are actually caused by the fault conditions, and the energization of large loads which require high starting currents.

2.4.2 Long Duration Variation

Long duration variation is defined to last longer than one minute. These variations are categorized as undervoltage and sustained interruption.

2.4.3 Transients

Transients can be power system variations where they signify an event that is undesirable but momentary in nature. *There are two kinds of power quality variations that can cause problems with sensitive loads.*

- Events that generate abnormal system conditions in the power system and the system status may change from normal to emergency.
- Steady-state variations – variations measured by sampling the voltage or current over time.

There are two categories of transients: Impulse transients and oscillatory transients.

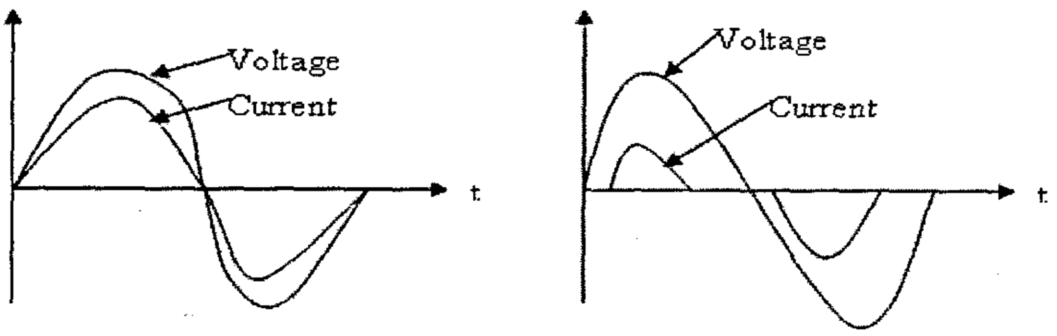
2.4.4 Waveform Distortion

It is deviation from an ideal sine wave of power frequency principally characterized by the spectral content of the deviation. *Harmonics is one of the many types of waveform distortion* [H. S. *Birdi 2006:29*].

2.5 Linear and Non- Linear Loads

The biggest reason for poor power quality is the proliferation of the electronics devices. At the forefront is the switched mode power supply. The switched power supply is found in information technology equipment like computers, fax machines, laser printers, office copiers, etc.

A linear electrical load draws a sinusoidal current proportional to the sinusoidal voltage as shown in Figure 2.2(a). The reason for such behaviour is that the linear loads do not depend on the voltage to determine their impedance at a given frequency. *These loads do not cause any* problem to the network to which they are connected *or other consumers of a utility. They always* follow the Ohm's *law (Birdi 2006:30).*



(a) Linear load (b) Non-linear load

Figure 2.2: Voltage and Current Relationship for the Two Kinds of Loads (Birdi 2006:30).

Power electronic loads do not always follow the Ohm's law. Unlike the linear loads they do not consume power continuously. When a sinusoidal voltage is applied to a non-linear electrical load, it does not draw a sinusoidal current. Also the current is not proportional to the applied voltage. The non-sinusoidal current is due to the device impedance changing over a complete voltage cycle. These loads have the potential of distorting the supply voltage waveform and might as well cause problems to other loads, for example, Figure 2.2(b) shows a sinusoidal voltage applied to a solid state power supply. The current drawn is approximately zero until a critical firing voltage is reached on the sinusoidal wave. At this firing voltage, the transistor gates allows current to be conducted. The current increases until the peak of the sinusoidal voltage waveform is reached and then decreases until the critical firing voltage is reached on the downward side of the sine wave. The device shuts off and the current goes to zero. A second negative pulse of current is drawn in the negative half cycle of the sine wave. The current drawn is a series of positive and negative pulses and not the sine wave drawn by linear systems (Birdi 2006:30).

2.6 Description of the Power Quality Disturbances

In general, Power Quality disturbances contain some several types such as Sag, Swells, Interruption, Under-voltage, Over-voltage, Unbalance and Flicker. There are techniques used to analyse Power Quality disturbances. Some of these techniques are Fast Fourier Transform (FFT), the Short time Discrete Fourier Transform (STFT), Wavelet Transform (WT) and so on.

2.6.1 Voltage Sags

Another name for voltage sags is called voltage dips. Voltage sag can be defined "as a decrease in RMS voltage at the power frequency for durations from half cycles to one minute. It is whereby the measurement of the voltage sag is declared as a percentage of the nominal voltage, which means that voltage sag to 60% is equivalent to 60% of the nominal voltage".

2.6.1.1 Causes of Voltage Sags

Thunderstorms, blowing winds and ice storms are the most common features that cause voltage sags. The example of lightning which strikes on the power lines and continues to ground, is shown in Figure 2.3

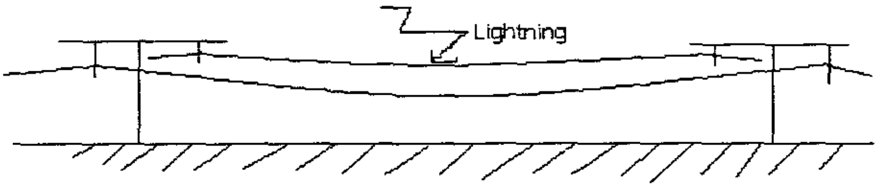


Figure 2.3: Lightning to overhead power lines

Example of line to ground fault is shown in Figure 2.4

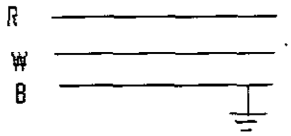


Figure 2.4: Line to ground fault.

Most of electronic equipment get corrupted because of lightning strikes and electrical equipment fails due to overloading, cable faults. The protective equipment will operate at the substation, then the voltage sags will be formed on the feeder lines across the utility system.

2.6.1.2 Solutions to voltage sags problems

Utilities can take some steps to reduce the harmful effects of voltage sags, for example fault prevention. The fault prevention includes some activities like adding line arrests and tree trimming.

Solutions available to provide through capability to crucial loads

- Uninterruptable Power Supplies (UPS) is the solution that can be used.
- Magnetic synthesizers
- Coil hold-in device installation.
- Motor generator sets.

2.6.2 Voltage swells

Swells can be described as a converse form of sag, as AC voltage with duration of 0.5 cycles to 1minute. Swells occur occasionally, and then they cause light flickering, equipment malfunction and data errors. The reason is that nothing exists within this technology to fight the problem.

2.6.2.1 Typical Causes

- Switching on a large capacitor banks, removing large loads and fault conditions can cause voltage swells.
- Single line to ground fault on the system.
- Sudden load decreases.
- Improper grounding.

2.6.2.2 Examples of Power Conditioning Solutions

- Uninterruptible power supply (UPS)
- Power conditioner- is an electrical device that can clean AC power going to sensitive electrical equipment. It provides surge protection and noise filtering.
- Voltage regulator- is an electrical regulator designed to maintain a constant voltage level. It is used to regulate one or more AC or DC voltages.

2.6.3 Interruption

The interruption can be defined as a failure of supply voltage with the duration of 0.5-30 cycles. Interruption due to the fault is shown in *Figure 2.5*

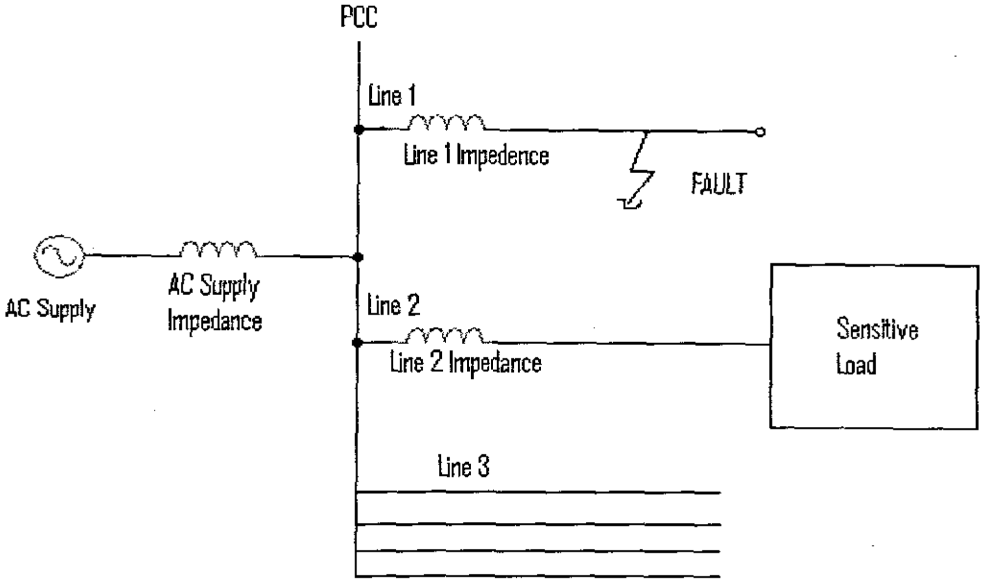


Figure 2.5: Interruption due to fault.

The interruption usually is caused by lightning strikes, trees, animals etc. There are many events that can cause the interruption, so it depends on the nature of the fault. If the power supply is suddenly shutdown, the electronic equipment can be damaged immediately. Then cost will be associated with downtime, cleanup and restart, so the company will run with expenses. It can be assumed that without protective measures, voltage interruptions can damage the sensitive equipment all the time.

2.6.3.1 Solutions to help against interruptions in both effectiveness and cost

- *Good design and reliability of the system.*
- *Distributors should always take measurements.*
- Design methods are needed to allow the customer equipment to restart after unavoidable interruptions.

2.6.4 Voltage Flicker

Voltage flicker is the power quality disturbance that is caused by the continuous repetitive voltage fluctuation. The continuous repetitive voltage fluctuation can cause the flickering of lights. Loads draw more current when they turned on and the voltage drop starts to apply. Most of the time, residential consumers near to the large industrial plants can experience the flickering of lights and it can cause the equipment malfunction, and also leads the equipment to deterioration.

2.6.4.1 Typical causes

- *Intermittent loads*
- Motor starting
- Arc fumaces (Sabin et al, 2009:3).

2.6.4.2 *Examples of Power Conditioning* Solutions

- Distributed static compensator.
- Adaptive var compensator
- Transformer tapped higher voltage

2.6.5 Harmonics

Harmonic are already defined in the previous chapter that, "Harmonic is a sinusoidal component of a periodic wave having a frequency that is an integral multiple of the fundamental frequency". (Bollen and Gu, 2006:19).

2.6.5.1 Typical Causes.

Harmonics are really produced by non-linear loads in electrical power systems. Non-linear loads suppose to draw current in proportion with the applied 50 or 60 Hertz sinusoidal voltage waveform. Harmonics releasing non-linear loads come from devices with power electronics such as:

- Consumer electronics.
- Adjustable speed motor drives.
- Computer equipment.
- Electronic lighting ballasts.
- Welders

2.6.5.2 Symptoms of harmonics

In order to know the harmonic that exists in electrical power system, attention has to be paid to the following symptoms:

- *Capacitor failure.*
- *Over-loaded neutral conductors.*
- *Failure of power factor correction capacitor.*
- Failure of electronic equipment.
- Blinking of incandescent bulbs.
- Excessive neutral current.
- Neutral conductor and terminal failures.
- Transformer failure.
- Timing errors in sensitive electronic equipment.
- Failure of electromagnetic loads.
- Blown fuses or circuit breakers tripping repeatedly.
- Overheating of metal enclosures.
- Power interference on voice communication.

2.6.5.3 Measures to Reduce the Harmonics influence.

- Harmonic mitigating transformers.
- *Passive and active filters can be applied in specific situations. Passive harmonic filters are the most common ones and are custom-designed* for the application or site.
- *Filter capacitor banks.*
- *In-line inductor or chokes.*
- Phase shifting (zig-zag) transformers
- Isolate harmonic loads on separate circuit.
- 12 pulses converters. In this configuration, Figure 2.6, the front end of the bridge rectifier circuit uses twelve diodes. The improvement is that the 5th and 7th harmonics are transferred to a higher order where the 11th and 13th harmonics. This will minimize the magnitude of harmonics, but will not eliminate them

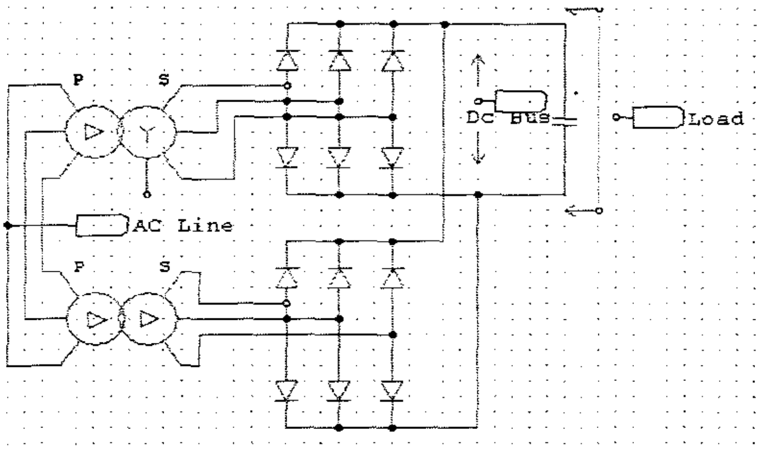


Figure 2.6: Typical Twelve-Pulse Front End Converter for AC Drive

- Harmonic Trap Filters -Filters are tuned to cancel for a strict harmonic such as the 5th, 7th, 11th. Harmonic trap filters provide true distortion power factor correction, Figure 2.7

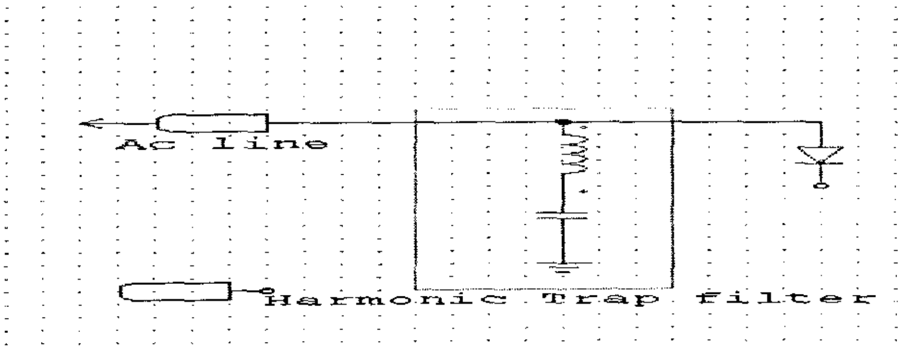


Figure 2.7: Typical Harmonic Trap Filter.

2.7 Harmonic Distortion

Harmonic distortion is actually found in both voltage and current waveform. Current distortion sometimes is created through the electronic loads, also called non-linear loads. Current distortion is conducted through normal system wiring, so it forms voltage distortion. This current distortion always affects the power system and distribution equipment. It directly causes the damage of loads or loss of product. Transformers overheat and fail even if they are not fully loaded.

Some example of harmonic distortion is shown in Figure 2.8. It represents a sum of the fundamental sine wave and the wave of the third harmonic. The resulted wave is distorted

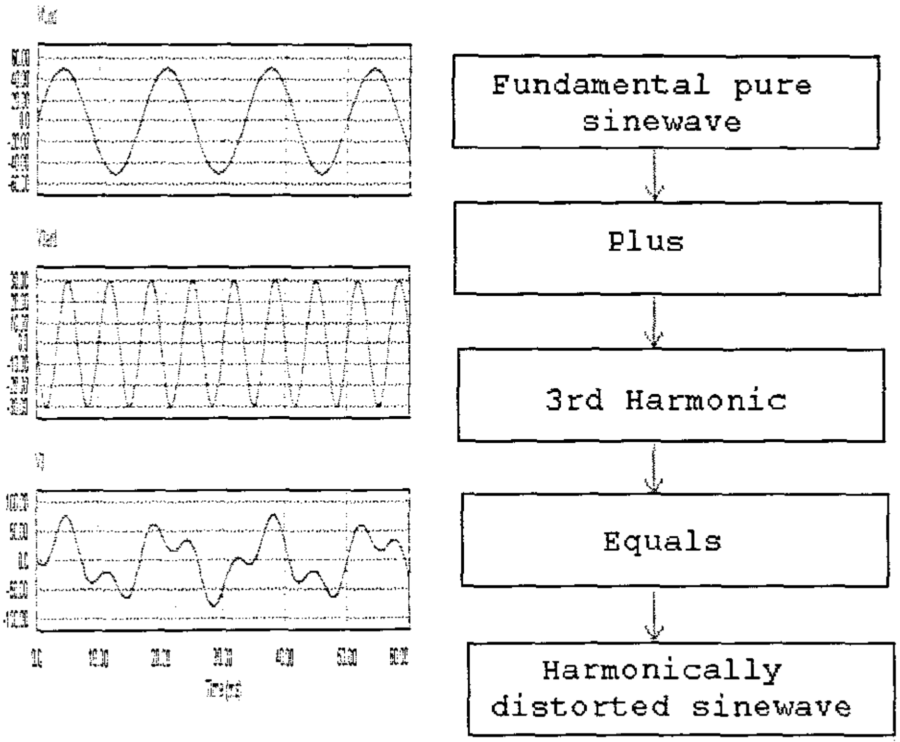


Figure 2.8: Combination of Fundamental sine wave and the 3rd harmonic

2.7.1 Total Harmonic Distortion and rms Value

There are several measures commonly used for indicating the harmonic content of a waveform with a single number. One of the most common is the Total Harmonic Distortion (THD), which can be calculated for either voltage or current (Dugan et al. 1996:129):

$$THD = \frac{\sqrt{\sum_{h=2}^{h_{\max}} M_h^2}}{M_1} \tag{2.1}$$

Where M_h is the rms value of harmonic component h of the quantity M. THD is a measure of the effective value of the harmonic components of a distorted waveform, that is, the potential heating value of the harmonics relative to the fundamental. The rms value of the total waveform is not the sum of the individual components, but is the square root of the sum of the squares. THD is related to the rms value of the waveform as follows:

$$rms = \sqrt{\sum_{h=1}^{h_{\max}} M_h^2} = M_1.\sqrt{1+THD^2} \tag{2.2}$$

THD is a very useful quantity for many applications, but its limitations must be realised. It can provide a good idea of how much extra heat will be realised when a distorted voltage is applied across a resistive load (Dugan et al, 1996:129).

A sinusoidal wave with a frequency h times higher than the fundamental (h shall be an Integer) is considered as a harmonic wave and is denoted with amplitude and phase shift to the fundamental frequency signal. The ratio between the harmonic frequency and the fundamental frequency is called the harmonic order. Fast Fourier Transform (FFT) is used to analyze the distorted waveform into sinusoidal components of different harmonic order of amplitude and phase shift. The following equation relates the amplitude and phase shift of h order of voltage harmonics (Chang and Ribeiro, 2001:89):

$$U(t) = DC_o + \sum_{h=0}^{\infty} C_{Uh} \sin(h.2\pi ft + \Phi_{Uh}) \tag{2.3}$$

Where,

DC_0 - DC Component

C_{Uh} - Amplitude of the h ordered voltage harmonic

Φ_{Uh} - Phase shift of the h ordered voltage harmonic

f - Fundamental frequency

The presence of harmonics is evaluated through Total Harmonic Distortion (THD).

THD voltage harmonics are asserted with THD_u. THD_u is a ratio of the RMS value of the harmonic voltage to RMS value of the fundamental voltage.(Chang,1993:196):

2.8 Recent papers review

A review of the recent papers analysing different power quality disturbances and proposing effective solutions is done. The papers are considered according to the following criteria:

- The type of system considered in the paper.
- Type of the power quality disturbance analyzed.
- Methods of characterizing the considered disturbance.
- Type of causes for the disturbance.
- Proposed solutions.

The results from the investigation are shown in Table 2.1.

Table 2.1:Analysis of the Power Quality Disturbances

[Dan Sabin, Mark McGranaghan, Ashok Sundaram, (2009:3)]

A Systems Approach to Power Quality Monitoring for Performance Assessment

What type of system	***Power Quality disturbances***	***Method of characterizing***	***Typical causes***	**Example of power conditioning solutions**
Monitoring	Impulse transients Transient disturbance	1) Peak magnitude 2) Rise time 3) Duration	1) Lightning 2) Electro-static discharge 3) Load switching 4) Capacitor switching	1) Surge arresters 2) Filters 3) Isolation transformers
Monitoring	Oscillatory transients Transient disturbance	1) Waveforms 2) Peak magnitude 3) Frequency components	1)Line/cable switching 2)Capacitor switching 3)Load switching	1) Surge arresters 2) Filters 3) Isolation transformers
Monitoring	*Sags/swells* RMS disturbance	1) RMS versus time 2) Magnitude 3) Duration	1) Remote system 2) faults	1) Ferroresonant transformers 2) Energy storage technologies 3) UPS
Monitoring	Interruptions RMS disturbance	1) Duration	1) System protection 2) Breakers 3) Fuses 4) Maintenance	1) Energy storage technologies 2) UPS 3) Backup generators
Monitoring	Undervoltages/ Overvoltages Steady-state variation	*2) RMS versus time* 3) Statistics	*1) Motor starting* 2) Load variations 3) Load dropping	*1) Voltage regulators* 2) Ferroresonant transformers
Monitoring	Harmonic distortion Steady-state variation	1) Harmonics spectrum *2) Total harmonic* distortion 3) Statistics	1) Nonlinear loads *2) System resonance*	1) Active or Passive filters *2) Transformers with cancellation or zero* sequence components

Monitoring	Voltage flicker	1) Variation magnitude 2) Frequency of occurrence 3) Modulation frequency	1) Intermittent loads 2) Motor starting 3) Arc furnaces	1) Static var systems

[Christopher J. Melhorn, Mark F. McGranaghan (2009:2)]

Interpretation and Analysis of Power Quality Measurements

What type of system	***Power Quality* disturbances**	**Method of characterizing**	**Typical causes**	**Example of power conditioning solutions**
Measurements	Impulsive transients	1) Peak magnitude 2)Rise time 3)Duration	1) Lightning 2) Electro-static discharge 3) Load switching	1) Surge arresters 2) Filters 3) Isolation transformers
Measurement	Oscillatory transients	1) Waveforms 2) Peak magnitude 3) Frequency components	1) Line/cable switching 2)Capacitor switching 3)Load switching	1) Surge arresters *2) Filters* 3) Isolation transformers
Measurement	*Sags/swells* Interruptions	1) RMS vs Time 2) Magnitude 3) Duration 4) Duration	1) Remote system faults system protection (Breakers, fuses) *2) Maintenance*	1) Ferroresonant transformers *2) Energy storage* technologies 3) UPS 4) Backup generators
Measurement	Undervolages/ Overvoltages	1) RMS vs time 2) Statistics	1) Motor starting *2) Load variations*	1) Voltage regulators *2) Ferroresonant* transformers

Measurement	*Harmonic* distortion	1) *Harmonic spectrum* 2) Total harmonic Distortion 3)Statistics	1) *Nonlinear loads* 2) System resonance	1) Filters(active or passive) 2) Transformers (cancellation or zero sequence components)
Measurement	Voltage	1) Variation magnitude 2) Frequency of Occurrence 3) Modulation frequency	1) Intermittent loads 2) Motor starting 3) Arc furnaces	1) Static var systems

(Philippe FERRACCI 2009:26)

Cahier technique no. 199, Power Quality

What type of system	Type of disturbance	Origins	Consequences	Examples of mitigation solutions
Monitoring	Voltage variations and fluctuations	Large load variations (welding machines, arc furnaces, etc).	Fluctuation in the luminance of lamps(flicker)	Electromechanical reactive power compensator, real time reactive compensator, series electronic conditioner, tap changer.

Monitoring	Voltage dips.	Short-circuit, switching of large loads (motor starting, etc.).	Disturbance or shutdown of process: loss of data, incorrect data, opening of contactors, locking of drives, slowdown or stalling of motors, extinguishing of discharge lamps.	UPS, real time compensator, dynamic electronic voltage regulator, soft starter, series electronic conditioner. Increase the short-circuit, power (Scc). Modify the discrimination of protective devices.
Monitoring	Interruptions	Short-circuit, overloads, maintenance, unwanted tripping.	Disturbance or shutdown of process: loss of data, incorrect data, opening of contactors, locking of drives, slowdown or stalling of motors, extinguishing of discharge lamps.	UPS, mechanical source transfer, static transfer switch, zero-time set, shunt circuit breaker, remote management.
Monitoring	Harmonics	Non-linear loads (adjustable speed drives, arc furnaces, welding machines, discharge lamps, fluorescent tubes, etc.).	Overloads (of neutral conductor, sources, etc.) unwanted tripping, accelerated ageing, degradation of energy efficiency, loss of productivity.	Anti-harmonic choke, passive or active filter, hybrid filter, line choke. Increase the Scc. Contain polluting loads. Derate the equipment.
Monitoring	Inter-harmonics	Fluctuating loads (arc furnaces, welding machines, etc.), frequency inverters.	Interruption of metering signals, flicker.	Series reactance.

Monitoring	Transient overvoltages	Operation of switchgear and capacitors, lightning.	Locking of drives, unwanted tripping, destruction of switchgear, fire, operating losses.	Surge arrester, surge diverter, controlled switching, pre-insertion resistor, line chokes, static automatic compensator.
Monitoring	Voltage unbalance	Unbalance loads (large single-phase loads, etc.).	Inverse motor torque (vibration) and overheating of asynchronous machines.	Balance the loads. Shunt electronic compensator, dynamic electronic voltage regulator. Increase the Scc.

(A. Moreno-Munoz (Ed) 2002:12)

Power Quality Mitigation Technologies in a Distributed Environment

What type of system	Perturbation	Causes	Typical effects	Solution
Distributed environment	Voltage Variations	Load variations and other switching events that cause long-term changes in the system voltage.	Premature ageing, preheating or malfunctioning of connected equipment	Line-voltage regulators , UPS, Motor-generator set
Distributed environment	Voltage fluctuations(Flicker)	Arcing condition on the power system (e.g resistance welder or an electric arc furnace)	Disturbing effect in lighting systems, TV and monitoring equipment.	Installation of filters, static VAR systems, or distribution static compensators.

Distributed environment	Transients	Direct lightning strike to the building. Induced in the distribution circuits by a nearby lightning strike. Switching events (e.g. capacitor, load switching). Switching from fault clearing..	Upsets barely noticeable, with self-recovery like a click in a sound system or a flash on a video screen; upset permanent and noticeable, requiring, manual reset: blinking, clocks and VCRs; upset permanent but not readily noticeable: data corruption.	Transient suppressors
Distributed environment	Sag(dip) Short interruptions of supply voltage.	Fault in the network or by excessively large inrush currents.	Malfunctions of electronic drives, converters and equipment with an electronic input stage.	UPS, constant-voltage transformer, energy storage in electronic equipment, new energy-storage technologies (SMES, flywheels..)
Distributed environment	Swell	Single-line ground failures (SLG), upstream failures, switching off a large load or switching on a large capacitor.	Trip-out of protective circuitry in some power-electronic systems.	UPS Power conditioner
Distributed environment	Long interruptions of supply voltage	Distribution faults Installation failures	Current data can be lost and the system can be corrupted. After interruption is over, the reboot process, especially on a large and complex system, can last for several hours.	UPS. Distributed energy sources.

Distributed environment	Harmonic distortion	Non lineal industrial loads: variable-speed drives, welders, large UPS systems, lighting systems. Non lineal residential and commercial loads: computers, electronic devices and lighting.	Overheating and fuse blowing of power-factor-correction capacitors. Overheating of supply transformers. Tripping of overcurrent protection. Overheating of neutral conductors and transformers.	Passive and active filters.
Distributed environment	Voltage unbalance.	Less than 2% is unbalanced single-phase loads on a three-phase circuit, capacitor bank anomalies such as a blown fuse on one phase of a three-phase bank. Severe (greater than 5%) can result from single-phasing conditions.	Overheating of motors. Skipping some of the six half-cycles that are expected in variable-speed drives.	To reasons the allocation of single-phase loads from the three-phase system.

[Dash.P.K. ,Panda, S.K. , Liew, A.C. , Mishra, B. , Jena, R.K. :1997]
Estimation of harmonic distortions and power quality in power networks

What type of Problem	**Part of Power System**	**Softwares**	**Signal processing methods used**	**Real-Time Implementation**

<table>
<tr><td>Monitoring</td><td>Harmonic Distortion</td><td>1) Adaptive neural networks.
2) Numeral simulation tests using the EMTDC software.</td><td>Most frequency domain harmonic analysis techniques use discrete Fourier transform or fast Fourier transform to obtain harmonic estimation of distorted signals.</td><td>Application of Kalman filters, recursive LMS and RLS filters have been reported in the literature for tracking time varying signals embedded in random noise and decaying dc components.</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="5">[Chung, H.Y., Won, D., Kim, J., Ahn, S., Moon,.S :2006]
Development of network -based power quality diagnosis system</td></tr>
<tr><td>What type of Problem</td><td>Part of Power System</td><td>Softwares</td><td>Signal processing methods used</td><td>Real-Time implementation</td></tr>
<tr><td>Diagnosis system</td><td>Distribution networks</td><td>1) RTDS (real-time digital simulator)
2) PSCAD/ EMTD.</td><td>1) PQDS
2) <i>PQMS</i></td><td>RTDS (real-time digital <i>simulator)</i>
• Positive characteristics of the solution
The developed PQDS provides various PQ diagnosis functions that can give sufficient information for users to manage and improve their power quality.</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="5">[Janik, P., Leonowicz,Z., Lobos,T., Waclawek, Z.:1999]
Analysis of influence of power quality disturbances using a neuro- fuzzy system</td></tr>
</table>

<table>
<tr><td>Monitoring</td><td>Harmonic Distortion</td><td>1) Adaptive neural networks.
2) Numeral simulation tests using the EMTDC software.</td><td>Most frequency domain harmonic analysis techniques use discrete Fourier transform or fast Fourier transform to obtain harmonic estimation of distorted signals.</td><td>Application of Kalman filters, recursive LMS and RLS filters have been reported in the literature for tracking time varying signals embedded in random noise and decaying dc components.</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="5">[Chung, Il.Y., Won, D., Kim, J., Ahn, S., Moon,.S :2006]
Development of network -based power quality diagnosis system</td></tr>
<tr><td>What type of Problem</td><td>Part of Power System</td><td>Softwares</td><td>Signal processing methods used</td><td>Real-Time Implementation</td></tr>
<tr><td>Diagnosis system</td><td>Distribution networks</td><td>1) RTDS (real-time digital simulator)
2) PSCAD/ EMTD.</td><td>1) PQDS
2) PQMS</td><td>RTDS (real-time digital simulator)
• Positive characteristics of the solution
The developed PQDS provides various PQ diagnosis functions that can give sufficient information for users to manage and improve their power quality.</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="5">[Janik, P., Leonowicz,Z., Lobos,T., Waclawek, Z.:1999]
Analysis of influence of power quality disturbances using a neuro- fuzzy system</td></tr>
</table>

What type of Problem	Part of Power System	Softwares	Signal processing methods used	Real-Time implementation
Influence of power quality disturbances • Hardware • Instrument transformers and Capacitor banks. • Softwares	Distribution networks	Neuro-Fuzzy system.	Verification of neuro-fuzzy system flexibility and adaptability to equipment susceptibility patterns was tested using patterns with transients and higher order harmonics. **Positive characteristics of the solution** Important advantage of this approach to power quality assessment is the reduction of data to be analyzed by a human system operator.	In some cases the neuro-fuzzy output can not be clearly interpreted, but such conditions are rare and do not overshadow the generally right reasoning of such system.
[Dogan, G.E., Omer, N. G: 2003] **Power quality Analysis using an adaptive decomposition structure.**				
What type of Problem	**Part of Power System**	**Softwares**	**Signal processing methods used**	**Real-Time implementation**

Adaptive Decomposition structure • Hardware	Transmission, Distribution networks	MATLAB Simulink DSP Blockset	The adaptive method is developed to detect and classify power quality disturbances regardless of the type of the pre-event voltage or current waveforms. The significance of the proposed method is that it provides a way of detecting variety of events without changing the structure.	**Positive characteristics of the solution** The experimental results indicate that histogram based analysis of the adaptive decomposition outputs can clearly distinguish events such as faults abrupt changes from the steady state waveforms
[Griffo, A., C arpinelli,G., Lauria, D., Russo, A.:2006] **An optimal control strategy for power quality enhancement in a competitive environment**				
What type of Problem	**Part of Power System**	**Softwares**	**Signal processing methods used**	**Real-Time implementation**
An Optimal control strategy	Distribution networks	SymPowerSystems of MATLAB.	Kalman filter based estimation technique, which enables an accurate tracking of relevant network state variables, as well as of harmonic disturbances injected into the power system.	A control strategy for an active compensator as well as an estimation technique of the state of the distribution network have been proposed, both being useful in real time operating stage.
[Dalgerti, L. M., Ciric,R.M.,:2006] **A new method for real time computation of power quality indices based on instantaneous space phasors**				

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What type of Problem	Part of Power System	Softwares	Signal processing methods used	Real-Time Implementation
Instantaneous space phasors	Distribution networks	MATLAB program	Obtained power flow results are analyzed using (instantaneous space phasors) ISP method and MATLAB	**Positive characteristics of the solution** The simulation results show that the integration of the dispersed generation (DG) into the considered distribution network (DN) Improved the system voltage profile and decreased the *effective apparent* power and consequently the line losses.

[Yu-Hua Gu, I., Styvaktakis, E:2003]
Signal processing for power quality applications

What type of Problem	Part of Power System	Softwares	Signal processing methods used	Real-Time Implementation

Signal processing	*Distribution networks*	*fuzzy logic*	Rms is defined for periodic signals, although it is generally used to extract the voltage magnitudes from measurements which are non-periodic. The following formula is typically used for calculating the rms voltage over a multiple of 1/2 – cycle of the power frequency: $V_{rms}(t_m) = \frac{1}{N}\sqrt{\sum_{n=m}^{m+N-1} V^2(t_n)}$ Time-frequency waveform decomposition methods.	-The signals were generated by a simulation program (EMTP): Electromagnetic Transients Program) using a distribution system of capacitor energizing. -*High-pass linear-phase* FIR filter

[Bollen, M.H.J.:2003]
What is power quality

What type of Problem	Part of Power System	Hardware	Signal processing methods used	Real-Time Implementation
Power quality	Generation, transmission, distribution networks	A more common way of tacking the harmonic problem is by *installing filters*, typically LC-series connections that shunt the unwanted harmonic current components back to the load	**-Reducing the number of faults** There are several well-known methods for this like tree-trimming, animal guards and shielding wires, but also replacing over-head lines by underground cables. As most of *the severe dips are due to faults*, this will directly affect the dip frequency.	1) Faster fault clearing. 2)Improved network design and operation. 3)Reducing the number of faults.

[Cerqueira,A.S.,Ferreira, D.D.,Ribeiro,M.V:2005]
Power quality events recognition using a SVM-based method

What type of Problem	**Part of Power System**	**Hardware**	**Signal processing methods used**	**Real-Time Implementation**
Events recognition using a SVM-based method.	Distribution networks	OTFR and LCEC method	The first step to detect the PQ events is the generation of the error signal *e*(*n*), defined as the *difference between the acquired* samples of the voltage signal waveform *x*(*n*) and the estimated fundamental sinusoidal component ˆf (*n*) of *x*(*n*). The second step is the event detection itself, which is based on the Error Energy Innovation Concept.	The algorithm returns the sample *n*b where the event starts, when *the output of the filter* is greater than a defined thresholdΛ. The value of Λ depends on the signal to noise ratio (SNR).

[O¨ mer Nezih Gerek, Dog˘an Go¨khan Ece : 2006]
Compression of power quality event data using 2D representation

What type of Problem	**Part of Power System**	**Hardware**	**Signal processing methods used**	**Real-Time Implementation**

2D representation of PQ event data	Transmission and Distribution networks	1) The 2D representation 2) 2D discrete wavelet transform (DWT) 3) 1D and 2D compression efficiency via DWT shrinkage.	The 2D representation of the recorded event data has several advantages. 1) Events of voltage sags with smooth variations. 2) Interharmonics Compactly visualizing very long segments of acquired data at once	**Positive characteristics of the solution** 2D representation is observed to have energy compaction advantages over the classical 1D data representation which makes it suitable for PQ event data compression.
[Dash, P.K., Panda S.K., Liew A.C., Mishra B., Jena R.K.:1998] **A new approach to monitoring electric power quality.**				
What type of Problem	**Part of Power System**	**Software**	**Signal processing methods used**	**Real-Time Implementation**

<table>
<tr><td>Monitoring electric power quality</td><td>Distribution networks</td><td>EMTDC software package.</td><td>The proposed estimation technique is adaptive and is capable of tracking the variations of amplitude and phase angle of the harmonics.</td><td>Numerical simulation tests using the EMTDC software package clearly demonstrate the capability of the algorithm in quantifying power quality Real-time laboratory tests confirm the validity of the new approach for computing harmonic distortions and power quality on-line.</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="5">[Suriya Kaewarsa, Kitti Attakitmongcol, Thanatchai Kulworawanichpong:2006]
Recognition of power quality events by using multiwavelet-based neural networks</td></tr>
<tr><td>What type of Problem</td><td>Part of Power System</td><td>Software</td><td>Signal processing methods used</td><td>Real-Time Implementation</td></tr>
</table>

Using multiwavelet-based neural networks and monitoring	Distribution networks	multiwavelet-based neural networks	The proposed method employs the multiwavelet transform using multiresolution signal decomposition techniques working together with multiple neural networks using a learning vector quantization network as a powerful classifier	The simulation of the multiwavelet-based neural network classifier for recognizing power quality disturbance types. The proposed method is performed using MATLAB program. The random selected signal from 110 signals of each disturbance type is used to test neural networks.

2.9 Discussion of the results from the literature analysis

2.9.1 Detecting and Classifying Power Quality Disturbances

Power quality disturbances may occur in power systems in a different ways and with different characteristics. Many methods for detection and classification of power quality disturbances have been published. Some of them focus only on one particular type of a disturbance. To take measurements of the power quality disturbances it is wise because it will be easy to identity the problem and come up with a solution. MATLAB is good software to simulate power disturbances (Radil et al, 2009:1).

2.9.2 Characterizing power Quality disturbances

The power quality disturbance characterization is to define and obtain distinctive and pertinent parameters for describing specific types of disturbance waveforms. Accurate calculation of the parameters may be helpful for system planning, troubleshooting and control. Automated characterization of power quality disturbances is highly desirable due to the large volume of power quality data to be processed. Not all types of disturbances have been considered in the past and for the disturbances already studied, the accuracy may still be improved. The existing approaches for characterizing harmonics and flickers can be employed directly. The disturbance parameters of interest mainly consist of time-related parameters such as the disturbance starting time, ending time, points-on-wave, etc. and magnitude related parameters such as the fundamental component, harmonic components, unbalance ratio (Yuan, 2009:25).

2.9.3 Source of the Power Quality disturbances

There are some problems that might be considered as responsibility of the utility, but power quality problems originate inside the facility. Most of the time, the major sources of power quality disturbances are lightning, energy-efficient devices, adjustable-speed and energy-saving lamps, etc.

In terms of lightning the greater use of underground facilities can minimize the power quality disturbances. One example is the creation of premium power parks, where sensitive load customers locate. At least these parks will be connected by underground feeders from distribution substation.

2.9.4 Load Sensitivity: Electrical Equipment affected by Poor Power Quality

Poor Power Quality affects a lot of operational equipment like Computers, Digital electronics and Microprocessors. Normally some the microprocessors work with five volts direct current, which makes microprocessors to be more sensitive to power anomalies. Weak current source starves loads of power and causes over-heating, then each cause premature insulation failure. For the motors, voltage above the rated motor value, can cause increased starting current, as well as motor heating.

2.9.5 Studying Equipment Sensitivity during Power Quality Disturbances

The nuisance of unexpected tripping or mis-operation of the sensitive customer loads stimulated the research interests in the power quality area. One important facet of the power quality study is to find out efficient approaches to improve the immunity or ride-through ability of the customer loads during power quality disturbances. Equipment sensitivity study serves such a purpose. Only certain types of disturbances have been treated in the past and for these disturbances the treatment is still not quite satisfactory (Yuan Liao, 2000:5).

2.9.6 Solutions for improving Power Quality

A degradation of quality may lead to a change in behaviour, performance or even the destruction of equipment and dependent processes with possible consequences for the safety of personnel and additional economic costs.

This assumes three elements:

- One or more generators of disturbance
- One or more loads sensitive to the disturbance
- A channel for the disturbance to be propagated between them.

The solutions consist in taking action with regard to all or part of the three elements, either globally (the installation) or locally (one or more loads).

The solutions can be implemented to:

- Correct a malfunction in an installation
- Take preventive action when polluting loads are to be connected.
- Ensure the installation conforms to a standard or to the power distributor's recommendations.
- Reduce energy bills (reduction of subscribed power in kVA, reduction in consumption).

Loads are not sensitive to the same type of disturbance and have different levels of sensitivity. The solution adopted, as well as being the best from a technical and economic point of view, must ensure an appropriate level of Power Quality which meets actual requirements. It is vital that specialists carry out a prior diagnosis to determine the nature of the disturbance to be prevented (e.g. remedies may differ depending on the duration of an interruption). This determines the effectiveness of the chosen solution. This definition, choice, implementation and maintenance (to ensure long-term effectiveness) of solutions must also be carried out by specialist.

The value of the choice and implementation of a solution depends on:

- The required level of performance

  Malfunction is not permitted if it would put lives at risk (e.g. in hospitals, airport lighting systems, lighting and safety systems in public buildings, auxiliary plant for power stations, etc.).
- The financial consequences of malfunction. Any unprogrammed stop, even when is very short of certain processes a (manufacture of semi-conductors, steelworks, petrochemicals, etc) result in loss or non-quality production or even restarting of production facilities.
- The time required for a return on the investment.

This is the ratio of financial losses (raw materials, production losses, etc.) caused by the non-quality of electrical power and the cost (research, implementation, operation, maintenance) of the solution.

Other criteria such as practices, regulation and the limits on disturbance imposed by the distributor must also be taken into account (Ferracci, 2009:19).

2.10 Conclusion

This chapter describes the characteristics of different power quality disturbances and discuses the importance of power quality these days, because there are many sensitive electronic devices in use. Also discussion of the solutions to improve the power quality is given. A review of the literature considering different areas of power quality research is provided in a table form. The importance of power quality monitoring and the methods that are used for monitoring is presented in the next chapter.

CHAPTER THREE

POWER QUALITY MONITORING

3.1 Introduction

This chapter discusses the importance of monitoring the power system. Monitoring a system can provide good information about the power system disturbances. The methodology used to monitor the power quality disturbances is described.

To monitor the power system is useful, because it is easily to determine the need for mitigation equipment for example analyzing events trends in the power system.

3.2 Definition of Power Quality Monitoring

In the dawn of deregulation, power providers and consumers are changing their view of system performance. This evolution is being driven due to the increasing awareness of power quality's role in customer systems. Already many providers are laying the groundwork worldwide for a new type of service contract in which a provider may promise one or more of its large industrial or commercial customers a certain level of "quality" in delivered power. In return, the customer agrees that for the duration of the contract it will not turn to another source- an important new option with the advent of retail wheeling in the electric power industry. Some states are revolutionizing the electric industry by permitting even residential customers to select their provider (Sabin et al, 2009:1).

Power quality monitoring involves measurement and recording the power quality disturbances like sag, Swell, Interruption, Under voltage, Overvoltage, Unbalance, Flicker etc.

3.3 Importance of Monitoring Power Quality

The importance of power quality event for detection as well as classification, because of wide use of electronic devices in these days it is wise to detect and classify the disturbance in power system. Microcontrollers and voltage disturbances are the most important things that cause poor power quality. Monitoring is the only solution for power quality disturbances and to achieve a large amount of data from power system in distribution system.

Listed below are some of the reasons outlining the importance of monitoring power quality.

- Detection and classification of power system disturbances at an exacting location on the power system, power quality monitoring can play an important role. Monitoring system is highly-efficient to prevent some problems on both utility and customers power systems, because of new technology and availability of software. Monitoring system provide the information about all power system disturbances and their possible causes. (Birdi, 2006:9).
- Monitoring power system helps benchmarking overall power system performance.
- Power system monitoring helps to detected problems before they causes widespread damage by conveyance automated alerts when conditions begin to deteriorate. It also helps in the classification of problems source position, frequency and timing of events. Based on power quality trends maintenance schedules can be developed (Birdi, 2006:9).
- Power quality monitoring support in defensive and prognostic maintenance. Classifying some pattern changes allows better preparation of maintenance activities and avoids disturbances of decisive business progression, while system data allows just-in-time maintenance procedures to be developed and implemented.
- Monitoring power system is very important because it can be used to determine the need for alleviation equipment by monitoring and trending conditions e.g by analyzing voltage sag, harmonics, and power factor correction. (Birdi, 2006:9).

3.4 The methodology of power quality monitoring.

It consists of combination of technologies from the analog voltages and currents measurement till the technologies for post processing and calculations of the characteristics of these measured waveforms. The measurement is done using meters called power quality monitors with the help of instrument transformers. The post processing is done using a computer. The general scheme of the power quality monitoring is given in figure 3.1(Bollen et al, 2006:13).

It consists of the following operations: measurement, pre-processing, post-processing, statistical post-processing and analysis.

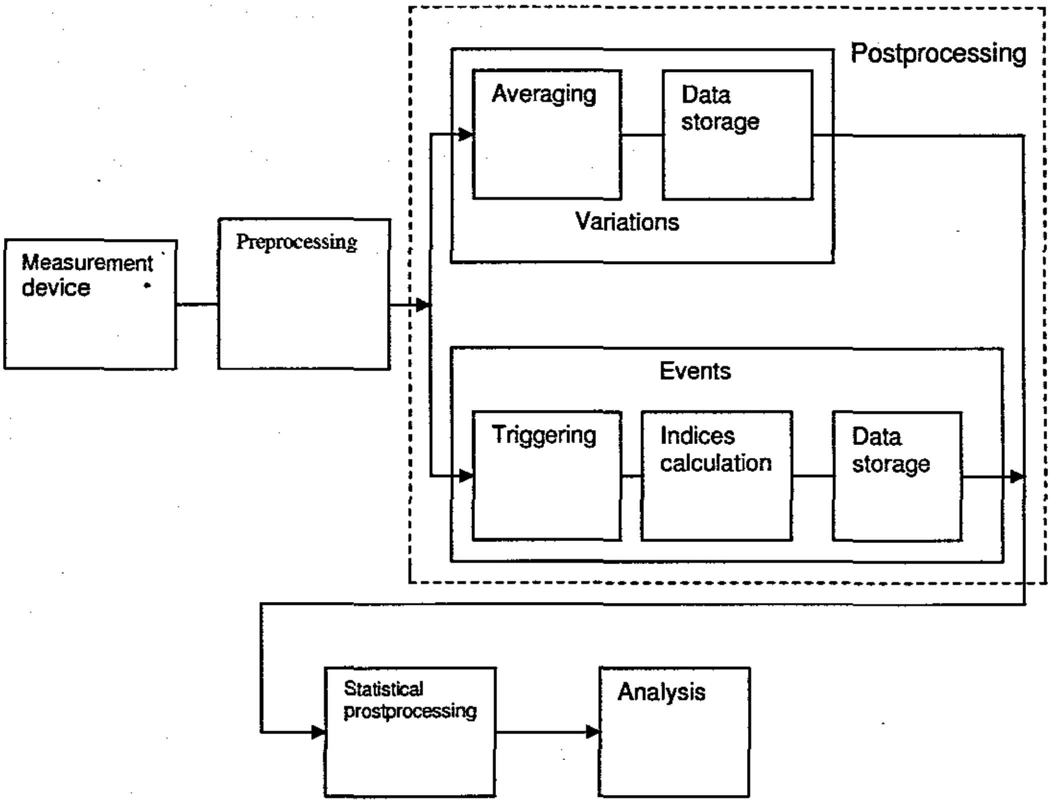

Figure 3.1: General scheme of the power quality monitoring.

3.4.1 Measurement

3.4.1.1 Installation of the meter-monitors

Power quality monitoring beyond the initial site survey is performed to characterize power quality variations at specific system locations over a period of time. The monitoring requirements depend on the particular problem that is being experienced. For instance, problems that are caused by voltage sags during remote faults on the utility system could require monitoring for a significant length of time because system faults are probably rare. If the problem involves capacitor switching, it may be possible to characterize the conditions over the period of a couple days. Harmonic distortion problems should be characterized over a period of at least one week to get a picture of how the harmonics vary with load changes (Dungan et al, 1996:233).

3.4.1.2 Choosing a monitoring location

When power quality problems that are being experienced by the customers on the distribution system part of power system appears it is the best to start to monitor near close to the sensitive equipment being affected by power quality variations. Monitoring should include the utility supply locations, power conditioning equipment outputs and each feeder should be monitored. Power distribution unit should be also monitored.

3.4.2 Preprocessing

Preprocessing is a precondition for any computerized the power quality analysis. It is whereby preprocessing stage involves signals de-noising, detection and normalization of the power quality events.

3.4.3 Post-preprocessing

The post processing for variations and events is different. For variations the first step is calculation of such characteristics as rms voltage, the frequency, the spectrum. The first steps in the calculation of events are rms voltage and comparing it with the threshold (typically 90% for voltage dip event and 10% for interruption). Further processing is calculation of indices as duration and magnitude.

3.4.4 Signal processing theory

The processing of power quality monitoring data is described by block diagram in figure 3.2 Data consists of sampled voltage and current waveforms. Signal-processing tools play an essential role in power quality monitoring. To extract the information of power quality monitoring, signal processing tools and power system knowledge are well needed. Signal processing theory performs extraction of characteristics and information from the measured digital signals. The application of its methods on the voltage and current waveforms is considered. In the thesis the results from the signal processing are analyzed on the basis of power system knowledge (Bollen et al, 2006:13).

Data are available in the form of sampled voltage and current waveforms. From these waveforms the information is extracted (dips, duration of the dips, etc). Signal processing tools play an essential role in this step. To extract the knowledge from the information (type and location of the fault that causes the voltage dip) both processing methods and tools and power system knowledge are needed.

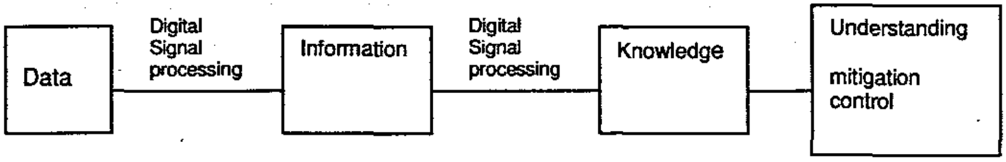

Figure3.2: Signal processing steps in extraction information from the power quality data

3.5 Signal processing requirements towards the monitoring process

The power quality monitoring process involves a number of steps that require signal processing. The requirements towards the operation of the monitoring system can be listed as (Bollen and Gu, 2006:17):

- The systems should characterize steady state variation of power quality as well as disturbances.
- Events should be characterized with complete both voltage and current waveform for evaluating interaction issues.
- Distinguish between variation and event.
- Categorize each event according to its underlying causes from the extracted features
- Proper determination of the data sampling period

Different type of signal processing method can be applied to extract and estimate the nature and parameters of the quality disturbances.

3.5.1 Decomposition of the signal processing methods.

"Decomposition of the signal processing methods can be categorized into two classes which means first class is a transform or sub band filter based methods and second one is model-based methods" (Bollen et al,2006:18).

1) **Data Decomposition Based on Transforms:** Based on Frequency-Domain Analysis and Time-Frequency Analysis.

- **Frequency-Domain Analysis:** The Frequency-Domain decomposition of the data is regularly desirable, if the measurements data are stationary. It is whereby a standard and commonly preferred method is the Discrete Fourier Transform (DFT) or its fast algorithm, the fast Fourier transforms (FFT). Frequency-domain analysis is closely correlated to the wavelet transform.

- **Time-Frequency Domain Analysis:** The commonly method is the short-time Fourier transform to obtain the time-frequency representation data. The STFT can be explained equivalently by a set of bandpass filters with an equal bandwidth. The bandwidth is determined by the selected window and the size of the window. Another way to implement time-frequency representation of data is to use time-scale analysis by discrete *wallet filters. This is mostly done by successively applying wavelet transforms to* decompose the low-pass-filtered data (or the original data) into low-pass and high-pass bands. This is equivalently described by a set of bandpass filters with octave bandwidth. The advantages are the possibility to trade off between time resolution and frequency resolution given a fixed join t time-frequency resolution value constrained under the uncertainty principle.

2) **Data Analysis Using Model-Based Methods:** Signal-processing methods for power system data analysis are the model-based methods (Bollen et al, 2006:18):

- **Sinusoidal Models:** In such models, the signals are considered to be a number of harmonics. The number of harmonics is decided beforehand and their amplitudes must be estimated.
- ***Stochastic Models:*** *In stochastic models, a signal is considered linear, time invariant* with white noise as the input. The system is then modelled using poles or poles and zeros. (Bollen et al, 2006:18).

3.6 Conclusion

This chapter gives short overview of the monitoring process, and the steps should be followed to monitor the power quality. For example how to monitor, monitoring location, etc. A monitoring system can detect problem conditions right through the system before even equipment damage occurs. The standards to power quality measurements and power quality protection and application is presented in the next chapter.

CHAPTER FOUR

STANDARDS FOR POWER QUALITY MEASUREMENTS AND POWER QUALITY PROTECTION AND APPLICATION

4.1 Introduction

Power quality monitoring is based on the measurement campaign, so that the minimum numbers of monitoring points are used. This allows to obtain the figures and reliable information related with the distribution system to be analyzed.

4.2 The reasons for carrying out (making) power quality measurements:

- To determine the different kinds of power quality disturbance.
- To define the exact origin of the disturbances.
- To get the statistical information and performance of the supply.
- Power quality monitoring produces do not require anymore measurement for troubleshooting.
- To analyze the data that is obtained from power quality monitoring that led to an interruption.

The power quality monitoring also involves lot of issues like classification and characterization of electrical power disturbances.

4.3 Power Quality Measurement Methods

The power quality methods for measurement are based on the existing standards.

4.3.1 IEC 61000-4-30 Standard for Measurement.

This IEC 61000-4-30 standard actually defines the measurement methods for 50HZ and 60HZ power quality instruments.

Measurement methods make it possible to obtain reliable, repeatable and comparable results. *The IEC 61000-4-30 standards also define two classes of performance*, which are class A and class B.

Class A

In terms of requirements, are stricter. Ensure that any two instruments that meet the requirements and when are connected to the same signals, produce the same results. Devices for class A are basically for contractual applications and verification with standards.

Class B

For class B performance requirements the meters will produce useful results. But not necessary accurate results. The devices are used for statistical surveys and troubleshooting is not *important*.

IEC 61000-4-30 includes some verification procedures which are more useful for information. It also ensures that the different power quality instruments use the same definitions and measurements techniques for sags, dips, swells frequency, harmonics, flickers etc (Mohd et al, 2009:2).

4.3.2 Measurement Chain

All power quality measurements have to be done according to the requirements of the standard. The connection of the meter to the real signal is done according to the so called measurement chain, Figure 4.1

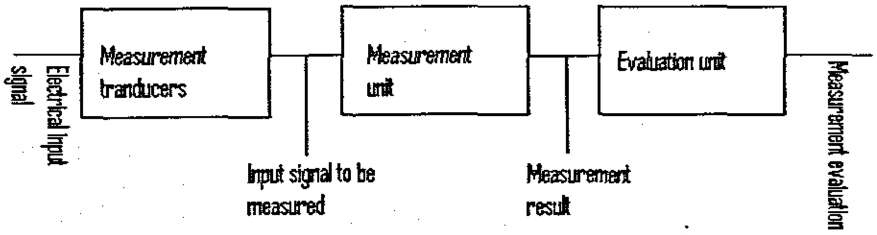

Figure 4.1: Diagram of Chain measurement (Mohd et al, 2009:2).

The measurement instrumentation covers the whole chain between the electrical input signal and the measurement evaluations.

4.4 IEC 61000-4-7 standard for harmonics and interharmonic measurements

IEC 61000-4-7 describes testing and measurement strategies for the following: harmonics measurements and instrumentation, power supply systems and equipment connected to the system. Part of IEC 61000-4-7 standard is applicable to instrumentation aimed at measuring spectral components in the frequency range up to 9 kHz which are superimposed on the fundamental of the power supply systems at 50Hz and 60Hz. In practice, this standard distinguishes between harmonics, interharmonics and other components above the harmonic frequency range, (up to 2.5 kHz in this case).

This standard defines the measurement instrumentation used for testing individual items of equipment according to limits given in specific standards such as harmonic current limits given in IEC 61000-3-2. The standard also defines measurement instrumentation for the measurement of *harmonic currents and voltages in actual supply systems* (Ghulmi, 2006:46).

4.4.1 Requirements for harmonic measurement according to IEC 61000-4-7

According to Ghulmi (2006:46), IEC 61000-4-7 suggests a standardized configuration for the instrument measuring harmonics and interharmonics in the power system. According to the IEC 61000-4-7 only instruments using the Discrete Fourier Transform (DFT) are likely to be used, normally using a fast algorithm called FFT (Fast Fourier Transform).

The main instrument incudes:

- Input circuitry with anti-aliasing filter.
- A/D- converter including sample and hold unit.
- Synchronization and window-shaping-unit if necessary.
- DFT- processor providing the Fourier transforms.

The window width shall be 10 periods (cycles) in our 50 Hz (50 periods or cycles/s) system case. The time between the leading edge of the first window sampling pulse and the last window sampling pulse shall be equal to the duration of the specified number of cycles of the power system with a maximum permissible error of (± 0,03%)

A further output shall provide in addition the active power P, evaluated over the same time window for harmonics, which must not include any possible contribution due to a DC component.

- *Instrument must measure the harmonic emission and interharmonic emission as well.* Harmonic measurements can be performed only on stationary signals; fluctuating signals (varying with time) cannot be described correctly by their harmonics only.
- Frequencies outside the measuring range of the instrument (normally 0 to 2 or 2.5 kHz)

shall be attenuated so as not to affect the results using an anti-aliasing low pass filter with a -3dB frequency above the measuring range (Ghulmi, 2006:46).

The configuration of the procedures to be implemented in the measurement instrument is shown in Figure 4.2

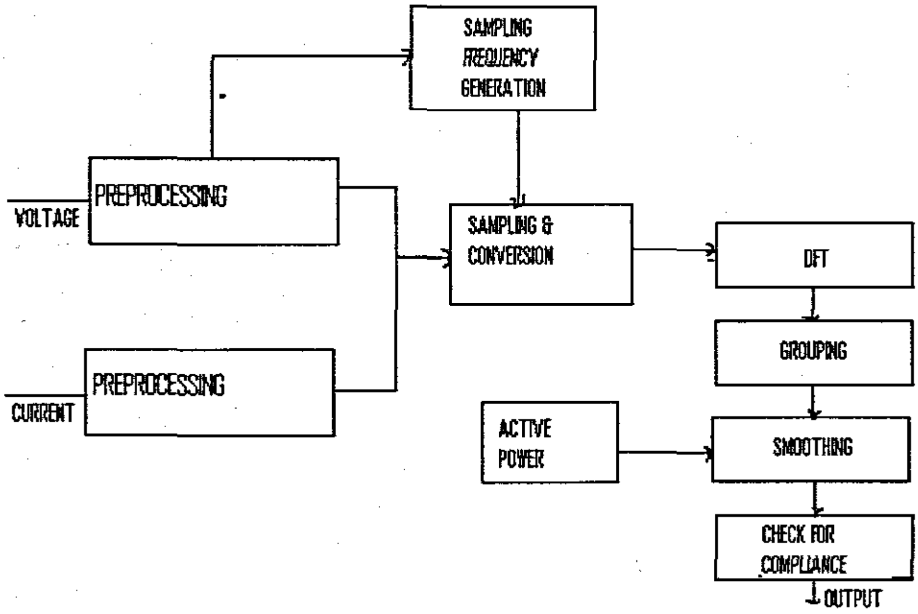

Figure 4.2: Suggested configuration of the measurement instrument for calculation of harmonics (Ghulmi, 2006:46).

4.4.2 Assessment of harmonic emissions:

The Fourier transform analysis assumes that the signal is not changing. Since the voltage amplitude of the power system may fluctuate, spreading out the energy of the harmonic components to adjacent interharmonic frequencies, IEC 61000-4-7 suggests a grouping method to improve the assessment accuracy of the voltage through grouping. Grouping of the output components of the Discrete Fourier Transform algorithm is done according to the following equations:

$$C^2_{n-200ms} = \sum_{k=-1}^{1} C^2_{10n+k} \text{....(Harmonic groups, n=0,., 63)} \qquad (4.1)$$

$$C^2_{ng-200ms} = \sum_{i=2}^{8} C^2_{10ng+i} \text{..}\textit{(Interharmonic groups (Harmonics groups), ng=0,.,63)} \qquad (4.2)$$

The following distortion factors are recommended to be evaluated:

$$\text{THD} = \sqrt{\sum_{n=2}^{40}\left(\frac{C_{10n}}{C_{10}}\right)^2} \quad \text{Total Harmonic Distortion} \qquad (4.3)$$

$$\text{THDG} = \sqrt{\sum_{n=2}^{40}\left(\frac{C_{ng}}{C_{1g}}\right)^2} \quad \text{Group Total Harmonic Distortion} \qquad (4.4)$$

$$\text{THDS} = \sqrt{\sum_{n=2}^{40}\left(\frac{C_{ns}}{C_{1s}}\right)^2} \quad \text{Sub-Group Total Harmonic Distortion} \qquad (4.5)$$

Ghulmi (2006:47) states that aggregations are to be performed using the square root of the mean of the squared input values (RMS). Generally, for harmonics, the data for 200ms or 10cycles (50 Hz) generally aggregated.

4.4. 3 Smoothing of harmonic groups

IEC 61000-4-7 harmonic emission testing standard requires smoothing of the groups and subgroups by using a digital first order filter with a time constant of 1.5 s:

$$C_{aver}(n) = 0.882C_{aver}(n-1) + 0.118C_{10}(n) \qquad (4.6)$$

Where C_{aver} is the 1.5 s average value and C_{10} is the 10 cycle value.

According to Ghulmi, (2006:48) there is a discrepancy between IEC 61000-4-7 and IEC 61000-4-30 regarding this issue. This is because the two standards are aimed at different goal,so 61000-4-7 is a testing standard describing current measurement procedure to equipment under test, whereas the IEC 61000-4-30 is a voltage quality standard defining the procedure to quantify the voltage distortion in an existing system. However, grouping scheme is however in both standards with the 10-min average excluding smoothing of groups. Smoothing is only used for the purpose of instantaneous measurements and display on the screen.

4.5 IEC Electromagnetic Compatibility Approach

International community in IEC standards formed by technical committee 77 accepted the electromagnetic compatibility approach. So the IEEE standard 1159 uses the electromagnetic compatibility approach to describe the power quality phenomena. (Collins and McEachern, 2003:3)

4.6 IEC 61000-4-15 Method

Short term flicker is measured and calculated by the flickermeter model. The model is divided into three parts which perform these tasks namely: Scaling the input voltage, simulation of the response of the lamp-eye-brain and statistical analysis of the flicker signal (Alencar et al,2009-05-11:2).The following block diagram describes the function of the flickermeter, Figure 4.3

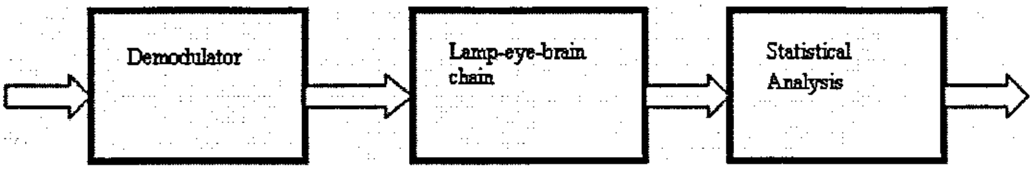

Figure 4.3: Diagram of IEC Flickermeter

Demodulator covers the whole part of input voltage. Lamp-eye-brain chain block models the lamp and the way our brain observes the fluctuations. The statistical block represents the way our brain interprets severity of the light intensity fluctuations. Revision of flickermeter standard IEC 61000-4-15 uses lamp models, these models are 60-W, 230-V and 60-W, 120-V incandescent lamp.

These modifications are really based on the values of the transfer function (Tf) coefficients. The transfer function links the fluctuations in voltage and steady-state flicker level. The transfer function is:

$$F(s) = \frac{kw_1 s}{s^2 + 2\lambda s + w_1^2} \times \frac{1 + s/w_2}{(1 + s/w_3)(1 + s/w_4)} \tag{4.7}$$

where **s** is the Laplace complex variable and indicative

4.6.1 Incandescent lamps

Incandescent lamp consists of a coiled tungsten filament of some highly resisting material prepared from carbonized paper or bamboo and enclosed in a glass bulb. The current flowing through tungsten varies when the voltage fluctuates, consequently a voltage fluctuation produces light intensity.

4.6.2 Statistical Analysis

The statistical analysis is made by subdividing the amplitude of the flicker level signal into a suitable number of classes. The IEC standard requires at least 64 classes for the classifier. After several tests, the number of classes set for the designed flickermeter was 128, which led to a higher accuracy and minimum memory requirements, thus reducing the computer minimum requirements, what makes the program portable. From this the cumulative probability function the flicker levels is obtained, then the short-term flicker severity can be calculated.

Short-term Flicker Evaluation

The short-term flicker severity P_{st} is measured based on an observation period of 10 min and can be calculated as in (4.2).

$$P_{st} = \sqrt{0{,}0314P_{0{,}1} + 0{,}0525P_{1s} + 0{,}0657P_{3s} + 0{,}28P_{10s} + 0{,}08P_{50s}} \qquad (4.8)$$

The suffix s in (1) indicates that the smoothed value should be used; these are obtained using (2)

$$\begin{aligned} P_{50s} &= (\ P_{30} + P_{50} + P_{80})/3 \\ P_{10s} &= (\ P_6 + P_8 + P_{10} + P_{13} + P_{17})/3 \\ P_{3s} &= (\ P_{2{,}2} + P_3 + P_4)/3 \\ P_{1s} &= (\ P_{0{,}7} + P_1 + P_{1{,}5})/3 \end{aligned} \qquad (4.9)$$

Where P_{st} is a short-term flicker severity. It is measured based on an observation period of 10 min. And the percentiles $P_{0,1}$, P_1, P_3, P_{10} and P_{50} are the flicker levels exceeded for 0,1; 1; 3; 10 and 50% of the time during the observation period.

The 0.3 s memory time-constant in the flickermeter ensures that they cannot change abrupty and no smoothing is needed for percentile (Alencar et al, 2006:3).

4.7 EN/IEC 6100-3-2

EN/IEC 61000-3-2 is a frequency harmonic current emissions standard that has been the subject of considerable controversy. The recently published amendment 14 to this standard makes many important changes and attempts to eliminate some of the controversy surrounding this standard. It changes the classification of many products, the way limits are computed for class C and class D, and the way that harmonic are measured and compared against the limits for all classes.

Although amendment 14[2] is clearly advantageous to a large number of manufacturers, so far most test equipment manufactures have not responded with product modifications that will allow testing to the new specifications. How the requirements changed, how these changes will impact harmonic emissions testing, and what is expected from test equipment manufacturers are explained in the standard (Mathieu et al, 2001:1).

4.8 Power Quality Standards for Power Quality responsibilities of the power energy produces

Electrical power has a set of approved standards. These standards give guidelines for contractors and consultants dealing with electrical power quality, covering up areas of frequency, balance, range, voltage level and disturbances. Power quality standards clarify normal and abnormal operation condition which can provide terminology for effective communication in the industry and minimize some problems by explicitly putting limitations on electrical equipment design and implementation.

These standards clarify the responsibilities of electrical power producers and customers in maintaining high-quality electrical service.

4.8.1 The purpose of Power Quality Standards

The purpose of power quality standards is to make sure that utility and end-user equipment are well protected from failing or mis-operating when the current, voltage diverge from normal. There are protection settings measurable limits provided by power quality standards to how far the current, voltage can diverge from normal. Utilities and their customers are helped by limits of the power quality standard so that an agreement for acceptable and unacceptable levels of service can be reached. Power quality standards are in demand on both of utilities and their customers. Standards help utilities to keep electrical power disturbances from their equipment and homeholds equipment by the utility side of a meter. Users just need standards that keep user-created electrical disturbances from affecting the operational equipment hold by utility and other end-users on the side of end-user meter.

4.9 Conclusion

This chapter discusses the importance of measurement and the power quality measurement standards. Measurements make it possible to obtain the most reliable and comparable results depending on the instrument being used.

Power quality standard defines the measurement methods should be used or considered. Measurement instrumentation is intended for testing individual items of equipment in accordance with limits given in certain standards. The measurements taken on the CPUT distribution network are done according to requirements of the IEC 61000-4-30 with 10min sampling interval. Data collection presented in the next chapter.

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CHAPTER FIVE

DATA COLLECTION

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5.1 Introduction

Data collection can be defined as the term that can be used to illustrate the collection, preparation and processing of data. An intention of collecting data is to get hold of information to keep on records, and use if it needs important issues to be improved or make decisions about it. It is often formalized through a data collection plan. It contains the following activities:

- Sorting analysis
- Target data
- Goals
- Methods

This chapter discusses the data collection where measurements were taken in substations at Cape Peninsula University of Technology at Bellville campus in order to check the power quality disturbances.

5.2 Power Quality Data Collection

There are some organizations used to collect data around the world. Such organizations are Electrical Power Research Institute (EPRI), Norwegian Electric Power Research Institute, and Canadian Electrical Association. By now it is very important that each and every institution should monitor the power quality. This is very also important for the universities because at tertiary institutions there are many electronic devices used.

The data required to monitor power quality are usually voluminous. Hence, software must be used to automatically characterize measured events and store the results in a well-defined database. It will be economical to integrate the data collected from power quality and in-plant monitoring with electric power instrumentation, site descriptions and event information (Sastry and Sarma, 2008:21).

5.2.1 Data Collection Plan

The institution is facing some problems concerning with electrical power system, so the purpose is to monitor or measure the power quality disturbances in Cape Peninsula University of Technology Bellville campus distribution network. The process for monitoring and taking measurements started in 2008. Then only the meter called DMK40 Lovato was used for measurements. In 2009 year three instrumental power quality meters were used, ImpedoGraph, ProvoGraph and DMK40 Lovato. These instrumental meters were connected in parallel to each other for the purpose of getting enough information about power quality disturbances. These instrumental power quality meters were placed in some of the substations around Bellville campus in order to get the data and analyze it.

5.3 Methods of Data Collection

The methods of data collection can provide quantitative data throughout the structured data collection process. These methods that are used during the data collection at the Bellville campus are as follows:

5.3.1 Interviews:

By listening and talking to people data can be collected and some characteristics of load behaviour can be understood.

5.3.2 Observation and recording:

Observing the structures of substations and recording special trends and events.

5.3.3 Survey:

Taking measurements of the power quality disturbances, i.e. Harmonics, voltage unbalance, flicker, etc.

5.3.4 Analyzing Records:

Saving data in a database. History of trends and events analyzes

5.4 Description of the Cape Peninsula University of Technology (CPUT) Bellville campus reticulation network.

The actual load data for the Cape Peninsula University of Technology(CPUT) Bellville campus were used to evaluate the effectiveness of the models .The CPUT reticulation network at Bellville campus is 11KV ring connected reticulation network.13 Substations actually feeding residential buildings, educational buildings and as well as the Sport Field. The network has11kV step down to 400V, 1000kVA ×5 and 1× 1600kVA used as 1000kVA, fuses of 90A×6, PILC 11kV cable(1x3C $70mm^2$) and 11kV step down to 400V, 8×500kVA, fuses of 50A×7, PILC 11kV cable(1x3C $70mm^2$).Measurement were taken at the main in-intake substation (*labelled as pentech in Figure 5.1*).The main focus is on power quality disturbances, so the measurements were taken on the following substations: IT centre, Mechanical engineering, MGR residence, Sport hall.

This is Cape Peninsula University of Technology Electrical Reticulation network layout at Bellville campus shown bellow in Figure 5.1

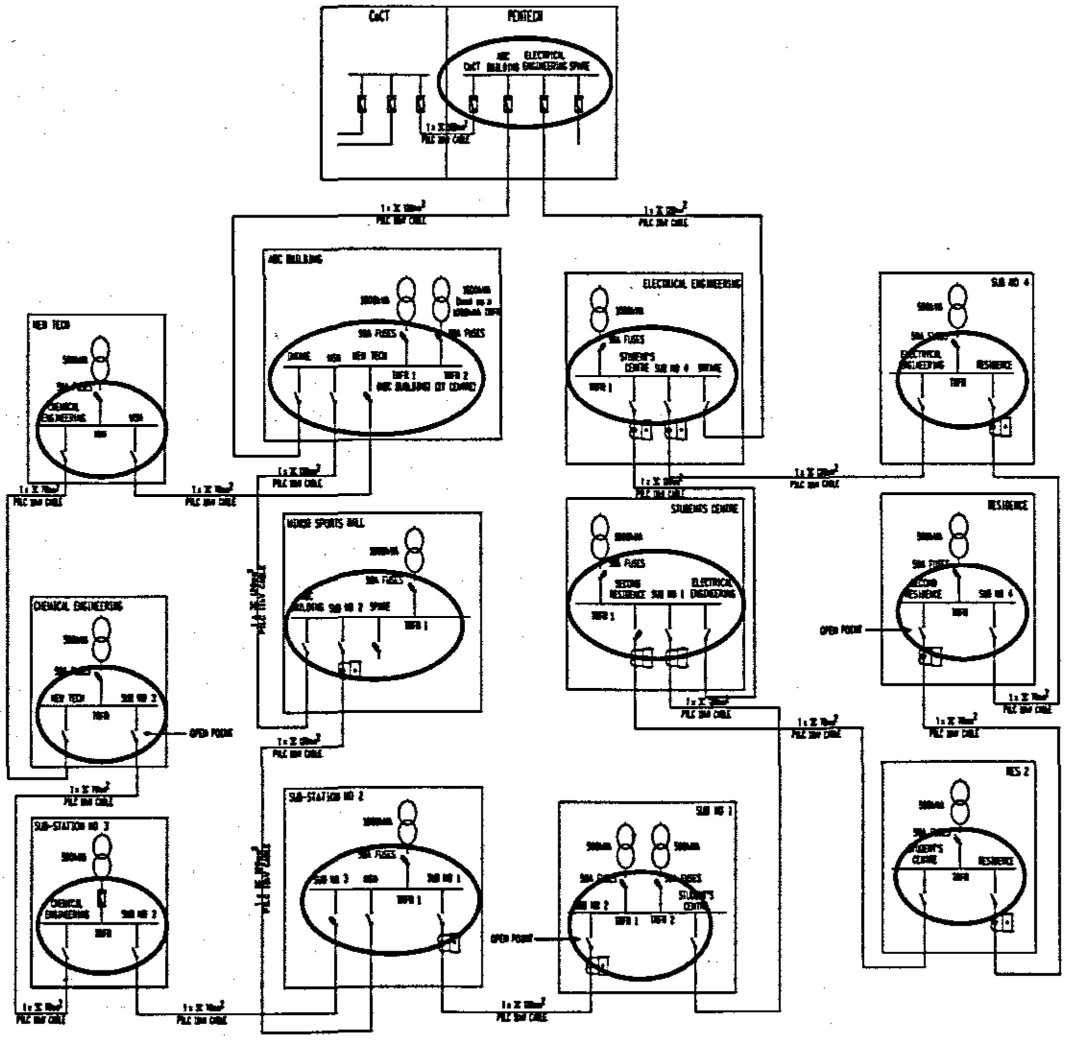

Figure 5.1: CPUT Electrical Reticulation network layout at Bellville campus

5.5 Selection of points of measurements

Table 5.1: Description of Substation

IT (Information Technology) Substation	Mechanical Substation	MGR (Mathew Goniwe Residence) Substation	Sport Hall Substation
IT substation is supplying IT building. There are many labs with many electrical equipments and electronic devices such as computers, scanners, printers etc. in the IT building	Mechanical substation supplies mechanical engineering department. There are many heavy machines which can need a lot of power such as induction motors. arc welders, computers etc, in the labs of this department.	Mathew Goniwe Residence (MGR) supplies two residences. There are cafeterias which have many cooking machines and many geysers for residence in these residences.	Sport hall is the substation which supplies sport hall and gymsium. Gymsium has many electrical heavy machines.

At Cape Peninsula University of Technology the points of measurement are selected according to the power quality measurement standard of IEC 61000-4-30 requirements. The measurement methods state that it is possible to obtain reliable, repeatable and comparable data.

The Points of common couplings (PCC) can be located maybe at the primary side or secondary side of the service transformer. They depend on which side of the transformer multiple customers are being supplied. It means if the multiple customers are served from the primary side of the transformer, the PCC is located at the primary side. The Figure 5.2 below shows points of common couplings used as selection pf the location of measurement.

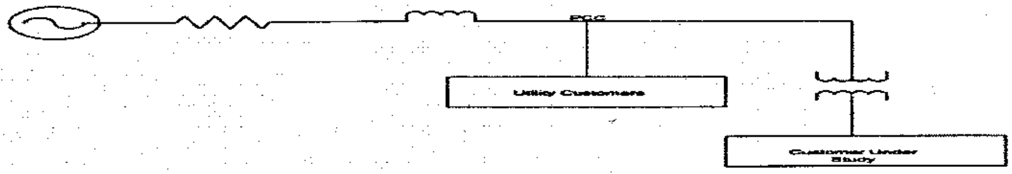

Figure 5.2: Points of common couplings

5.6 Meters and types of measurement.

There were three power quality meters used to collect the data. These instrumental power quality meters are ImpedoGraph, ProvoGraph, DMK40 Lovato

5.6.1 Description of power quality meters

The Table 5.2: below summarises the meters characteristics and gives the specifications of each meter. Pictures of the used meters are given in Figure 5.3

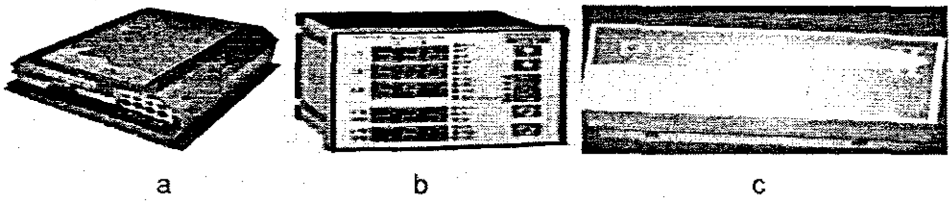

Figure 5.3: **Power Quality instrumental meters, a)ImpedoGraph, b)DMK40 Lovato, c)ProvoGraph**

Table 5.2: Description of Meters

DMK40 Lovato	ImpedoGraph	ProvoGraph
The DMK40 is the three phase multimeter that contains excellent features, including powerful and easy-to-use data logger. It can measure and display more than 246 parameters e.g. Harmonics, Voltage unbalance, current, single phase voltage, three phase voltage, frequency, power factor, real power, reactive power, apparent power. DMK40Lovato specifications are:RS232/RS485 converter drive, 220-240VAC.PC-4 PX1 connecting cable (1.80m long), DMK40-PC connecting cable (1.80m long), PC-Modern connecting cable (1.80m long).	ImpedoGraph is a three phase power quality monitoring instrument and was designed to comply with the latest international power quality standards. The phase and diagnostic information is used to calculate flicker and harmonic in certain network configurations. The measured data also available through dedicated RS485/RS232 telemetry interface. This instrument measures harmonics, flicker, voltage unbalance, Vrms, voltage, current. ImpedoGraph specifications are: number of channels 4x differential voltage inputs, status inputs 8x Differential voltage inputs, 4x current inputs, 4x current transducer inputs, 0-300 Vrms, accuracy 0.1% on reading(50-300Vrms), resolution 20m Vrms, serial ports RS232(direct) and RS232(modem).	ProvoGraph is a smaller version of the VectoGraph voltage quality recorder, it records the following parameters: Vrms profiles and Voltage Unbalance. This instrument is very reliable and highly accurate. The ProvoGraph specifications are: 30-300VRMS accuracy 0.2% of 58-62 Hz, 4 wire analog to digital converter with resolution 12 bit memory. Communications Ports type is RS232, mordem support is 3 wire modem interface, isolation is opto-isolated (1kV), baud rate is 9600 band. Ac voltage input range is 85-135 VRMS and 170-270 Vrms (50/60Hz).

5.6.2 DMK40 Measurements

Table 5.3: DMK40 Lovato meter measurements.

Duration time	Substation	Variables measured	Variables calculated
11/08/2008 to 18/08/2008	Information Technology(IT) Centre	1Phase Voltage and 3Phase Voltage, Current, Real Power, Reactive Power, Apparent Power.	Voltage harmonics, current harmonics, total harmonics distortion in voltage, total harmonics distortion in current. Power factor, Frequency
01/09/2008 to 29/09/2008	Mechanical Engineering	1Phase Voltage and 3Phase Voltage, Current, Real Power, Reactive Power, Apparent Power.	Voltage Harmonics, current harmonics, total harmonics distortion in voltage, total harmonics distortion in current. Power factor, Frequency
29/09/2008 to 23/10/2008	Sport Hall	1Phase Voltage and 3Phase Voltage, Current, Real Power, Reactive Power, Apparent Power.	Voltage harmonics, current harmonics, total harmonics distortion in voltage, total harmonics distortion in current. Power factor, Frequency
23/10/2008 to 13/11/2008	Mathew Goniwe Residence (MGR)	1Phase Voltage and 3Phase Voltage, Current, Real Power, Reactive Power, Apparent Power.	Voltage harmonics, current harmonics, total harmonics distortion in voltage, total harmonics distortion in current. Power factor, Frequency

5.6.3 Parallel measurement

Parallel measurement, it is whereby two or more meters are connected in parallel in one point, so that the meters can give enough information of power quality parameters. For example each meter can measure ten parameters, then the combination of two meters can give twenty *parameters. The ProvoGraph is used to give simple, cheap measurement of the voltage. The* data is used for estimation of some of the power quality disturbances. The calculated by ImpedoGraph harmonics is used for validation of the results from the estimation with data received from the ProvoGraph or DMK40 Lovato meters. The Figure 5.4 below is a single line diagram of a distribution substation network and two meters connected in parallel

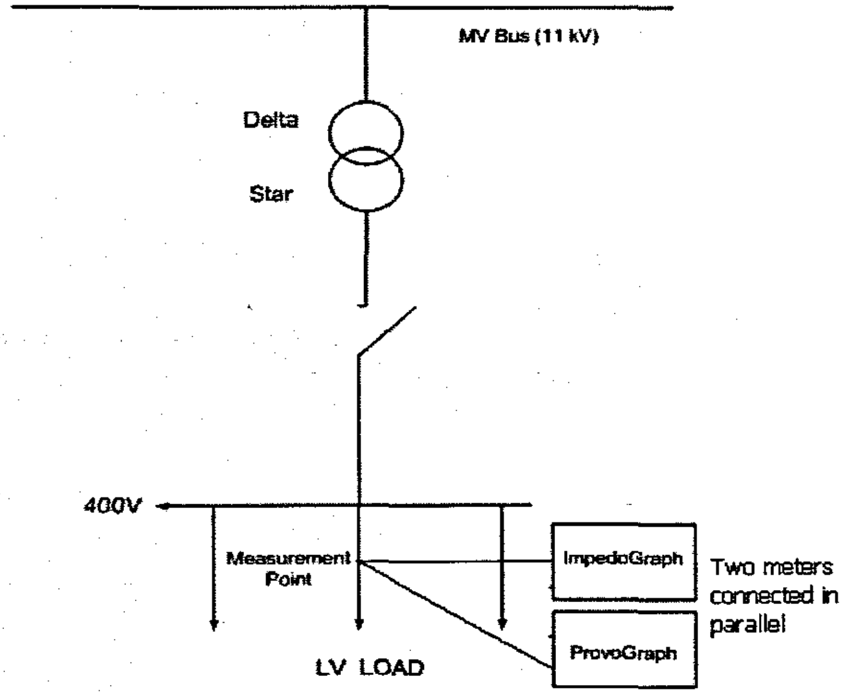

Figure 5.4: Two meters connected parallel in distribution substation network

5.6.3.1 Measurements from meters connected in parallel

Table 5.4: Parallel Measurements.

Mechanical Engineering Substation				
Meter	**Duration time**	**Substation**	**Variables Measured**	**Variables calculated**
DMK40	03/04/2009 to 19/04/2009	Mechanical Eng	1Phase Voltage and 3Phase Voltage, Current, Real Power, Reactive Power, Apparent Power.	Voltage Harmonics, current harmonics, total harmonics distortion in voltage, total harmonics distortion in current. Power factor, Frequency
ImpedoGraph	03/04/2009 to 19/04/2009	Mechanical Eng	1Phase Voltage and 3Phase voltage, Current, Reactive Power, Apparent power, Active power, Power angle.	Dip type Y, voltage swell, over-voltage, Vrms, Voltage Unbalance, voltage harmonics, current harmonics. Crest factor, Power factor, Flicker
ProvoGraph	03/04/2009 to 19/04/2009	Mechanical Eng	1Phase Voltage and 3Phase voltage, current	Vrms, Voltage Unbalance.
Admin Building				
Meter	**Duration time**	**Substation**	**Variables Measured**	**Variables calculated**
DMK40	24/03/2009 to 31/03/2009	Admin Building	1Phase Voltage and 3Phase Voltage, Current, Real Power, Reactive Power, Apparent Power.	Voltage Harmonics, current harmonics, total harmonics distortion in voltage, total harmonics distortion in current. Power factor, Frequency
ImpedoGraph	24/03/2009 to 31/03/2009	Admin Building	1Phase Voltage and 3Phase voltage, Current, Reactive Power , Apparent power, Active power, Power angle	Dip type Y, voltage swell, over-voltage, Vrms, Voltage Unbalance, voltage harmonics, current harmonics. Crest factor, Power factor, Flicker
ProvoGraph	24/03/2009 to 31/03/2009	Admin Building	1Phase Voltage and 3Phase voltage, current	Vrms, Voltage Unbalance.

IT Centre

Meter	**Time**	**Substation**	**Variables Measured**	**Variables calculated**
ImpedoGraph	1/05/2009 to 21/05/2009	Admin Building	1Phase Voltage and 3Phase voltage, Current, Reactive Power , Apparent power, Active power, Power angle	Dip type Y, voltage swell, over-voltage, Vrms, Voltage Unbalance, voltage harmonics, current harmonics. Crest factor, Power factor, Flicker
ProvoGraph	1/05/2009 to 21/05/2009	Admin Building	1Phase Voltage and 3Phase voltage, current	Vrms, Voltage Unbalance.

5.7 Data obtained from the measurement.

5.7.1 Information Technology (IT) Centre.

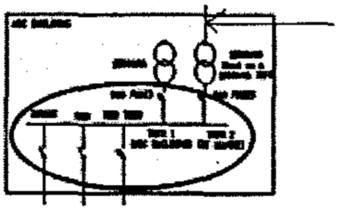

Figure 5.5: IT Centre

These measurements are records measured from 11-08-2008, time start at 10:58 till 18-08-2008, time end at 08:22 in August 2008. The sampling time 15 minutes, where $\frac{15\text{ minutes}}{60}$ =0.25 hour, the sampling period is 96 points are equivalent to 24 hours. DMK40 Lovato meter was used for measurements.

5.7.1.1 Single Phase Voltages

Plot of the voltage measurement data for the separate phases is given in Figure 5.6.The first graph is for voltage phase 1, second graph for voltage phase 2 and third graph for voltage phase 3.

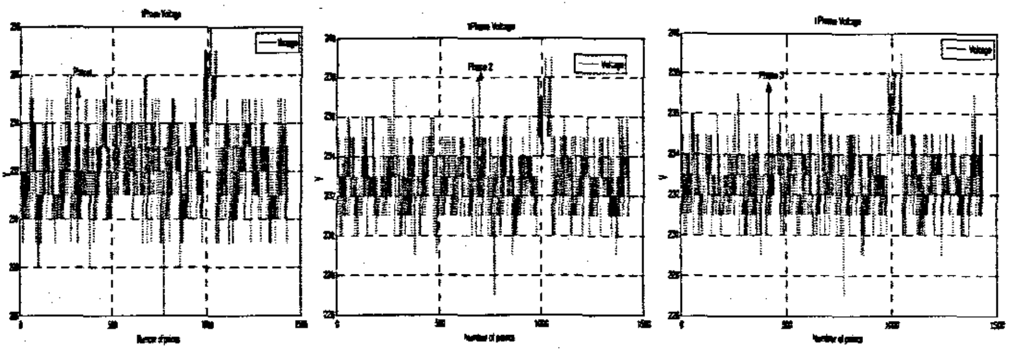

Figure 5.6: Single Phase Voltage fluctuation graph.

By looking at the records measurement, the voltage is still in the prescribed limitations because the voltage standard in South Africa is 230V ±5% which means the voltage should be not over 241.5V or less than 218.5V, Figure 5.6 above. The number of data points is 1436, the sampling interval for measurements is 15 minutes. The measurements are done first separately for every phase and then for all three phases.

5.7.1.2 Three Phase Voltages

A Plot of the three phase voltage measurement data for the separate phases is given in Figure 5.7. The first graph is for voltage phase 1, second graph for voltage phase 2, third graph for voltage phase 3 and fourth graph for neutral.

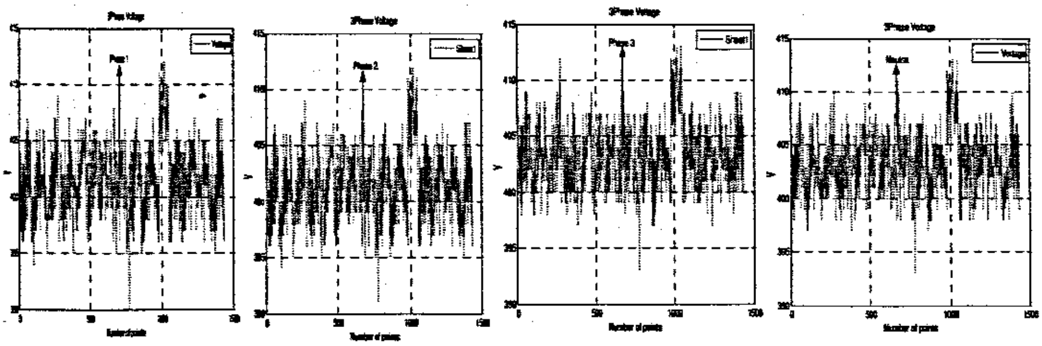

Figure 5.7: Three Phase Voltage fluctuation graph.

Three phase lines and the neutral together give a three-phase 4-wire supply with a rms voltage of $230\sqrt{3}$=398.4. By looking at the records measurement, the three phase voltage is still in the prescribed limitations because the voltage standard in South Africa is 400V ±5% which means the voltage should be not over 420V or less than 395V.

5.7.1.3 Current

A plot of the current data is shown in Figure 5.8

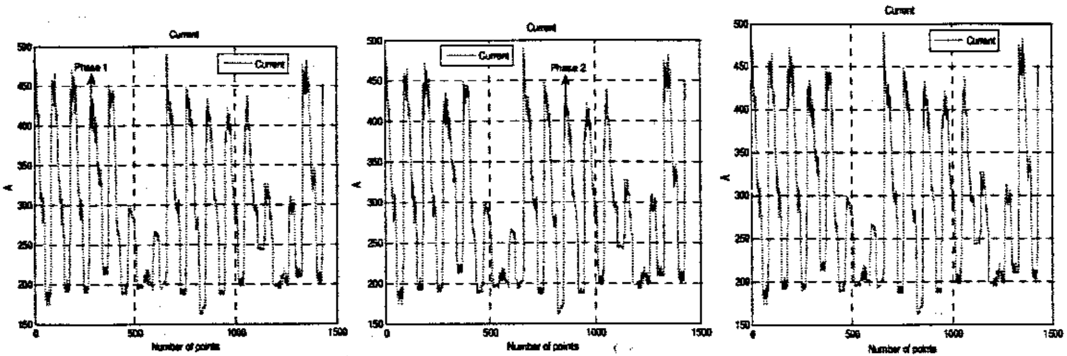

Figure 5.8: Current

The time start at 10:58 till 18-08-2008, time end at 08:22 in August 2008. The sampling time 15 minutes, where $\frac{15\text{ minutes}}{60}$=0.25 hour, the sampling period is 96 points are equivalent to 24 hours.The data shows that the current rises up to 410A from 08:00 till 21:00. It is because students are switching on computers in the labs and using all the equipments in the labs such as printers, scanners etc. From 21:00 to 23:58 drops little bit to 280A because some students are going back their residences. As from 00:00 till 07:50 the current drops down to 181A because labs are closed. It is necessary to limit the high current in power systems to protect the electrical equipments.

5.7.1.4 Real power, Reactive power and Apparent power

Apparent, Real, Reactive power is already defined in the previous chapters. The data for the three types of power are plotted in Figure 5.9 where the notations are: VA is the apparent power, W is the real power and VAR is the reactive power. The number of data points is 673, the sampling interval for measurements is 15 minutes.

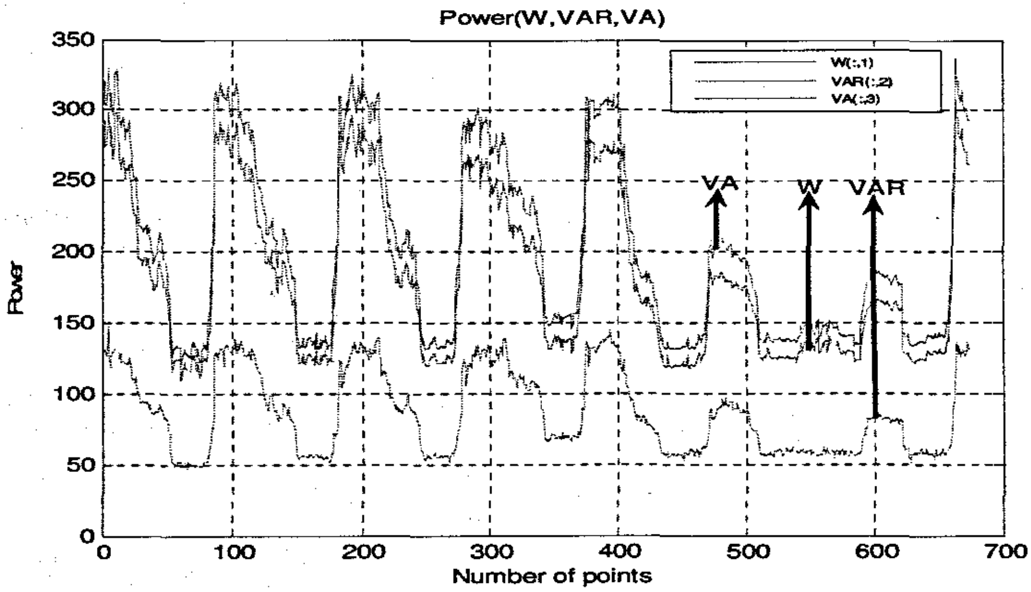

Figure 5.9: Real power, Reactive power and Apparent power

The level of power is under prescribed limitations because the transformer did not trip on overload protection, and starting drop round about 23:50 to 07:50 because labs are closed.

5.7.1.5 Frequency (Hz)

Frequency is the number of cycles per unit of time and is measured in hertz. The data of frequency is plotted in Figure 5.10. The number of data points is 673, the sampling interval for measurements is 15 minutes.

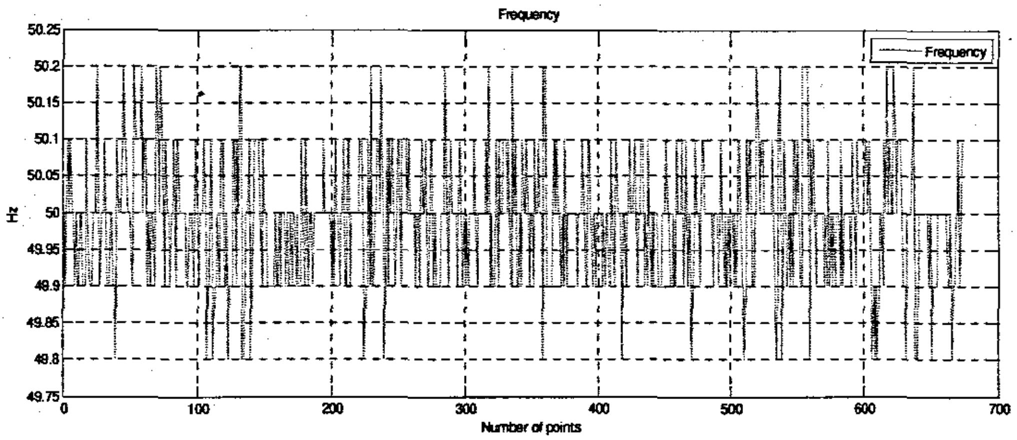

Figure 5.10: Frequency (Hz)

The frequency is still in the prescribed limitations because it is between 49.7 and 50.2.

5.8 Power Quality Disturbances calculated by the meter and standard for harmonics

This Table 5.5 is the NRS 048-2 standard for harmonics to check if the harmonics are on prescribed limitations (Kock et al, 2007-09-27).

Table 5.5: NRS 048-2 Standard for Harmonics

Odd harmonics							Even harmonics
Non-multiples of 3			Multiples of 3				
H	Magnitude %		h	Magnitude %		h	Magnitude %
	LV MV	HV EHV		LV MV	HV EHV		
5	6	3	3	5	2.5	2	2
7	5	2.5	9	1.5	-	4	1
11	3,5	1,7	15	0,5	-	6	0,5
13	3	1,7	21	0,3	-	8	0,5

The meter DMK40 Lovato can calculate (estimate) some of the power quality disturbances, as follows.

5.8.1 Voltage and Current Harmonics

It is important to take measurements in a building which contains a lot of electronic devices or equipment. Especially some electronic devices have a solid state electronic device which contains poor power supply such as computers, Laser printer, and copy machines. The effects of harmonics are heating of neutral conductor, overheating transformers and motors, cause high neutral to ground voltages at ends loads and also distorted voltages.

Measurements were obtained in August 2008 at IT (Information Technology) building. The harmonics calculated by the meter are shown in Figure 5.11

5.8.1.1 Voltage Harmonics

Event graph of current harmonics is shown in Figure 5.11, where in the data used data (1-3.H VL1)(:,1) is the third harmonic in voltage line 1, (1-3.H VL2)(:,2) is the third harmonic in voltage line 2, (1-3.H VL3) (:,3) is the third harmonic in voltage line 3, (1-5.H VL1)(:,4) is the fifth harmonic voltage line 1, (1-5.H VL2)(:,5) is the fifth harmonic in voltage line 2, (1-5.H VL3)(:,6) is the fifth harmonic in voltage line 3, (1-7.H VL1)(:,7) is the seventh harmonic in voltage line 1, (1-7.H VL2)(:,8) is the seventh harmonic in voltage line 2, (1-7.H VL3)(:,9) is the seventh harmonic in voltage line 3. The x axis describes the number of points and y axis describes the harmonic (%).

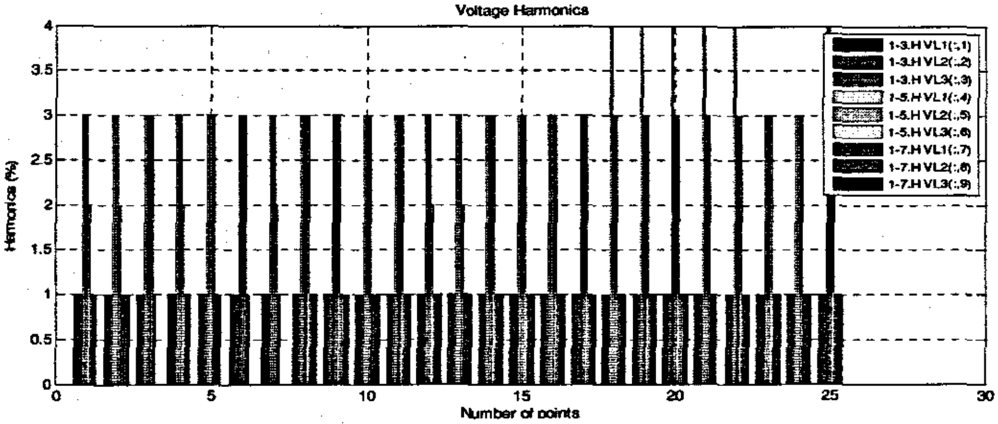

Figure 5.11: Voltage Harmonics part of all points of calculation

According table 5.5 above, the harmonics are still fine on Figure 5.11 because harmonics only reach 4%. According NRS 048-2 harmonics standard the 3rd harmonic shall not exceed than 5%

magnitude, while 5th harmonic shall not exceed than 6% magnitude and also 7th harmonic shall not exceed than 5% magnitude. Therefore neglecting the effect of voltage harmonic and considering no load losses caused by the fundamental voltage component will only give the rise to an insignificant error.

5.8.1.2 Current Harmonics

Event graph of current harmonics is shown in Figure 5.12, where in the data used data (1-3.H CL1)(:,1) is the third harmonic in current line 1, (1-3.H CL2)(:,2) is the third harmonic in current line 2, (1-3.H CL3) (:,3) is the third harmonic in current line 3, (1-5.H CL1)(:,4) is the fifth harmonic in current line 1, (1-5.H CL2)(:,5) is the fifth harmonic in current line 2, (1-5.H CL3)(:,6) is the fifth harmonic in current line 3, (1-7.H CL1)(:,7) is the seventh harmonic in current line 1, (1-7.H CL2)(:,8) is the seventh harmonic in current line 2, (1-7.H CL3)(:,9) is the seventh harmonic in current line 3. The x axis describes the number of points and y axis describes the harmonic (%).

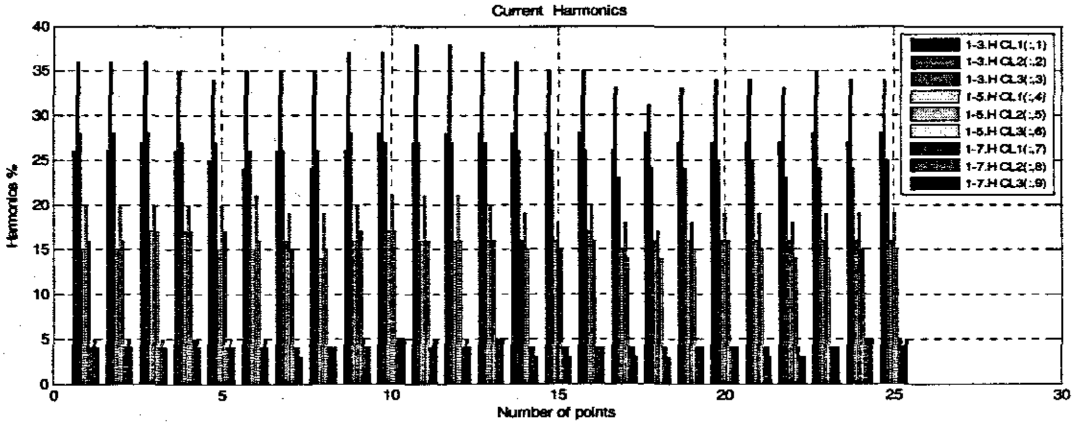

Figure 5.12: Current Harmonics part of all points of calculation

The flow of the current harmonics in a network produces two main effects, one of the effects is *the additional transmission loss caused by the increased rms value of current waveform.* The second one effect is the creation of harmonic voltage drops across circuit impedances. The reason why there are harmonics in IT centre because there is a lot of electronic devices.

5.8.1.3 Total Harmonic Distortion in Voltage

The total harmonic distortion in voltage calculated by the meter is shown in Figure 5.13 where in the data used (1-THD VL1)(:,1) total harmonic distortion in voltage line 1, (1-THD VL2)(:,2) total harmonic distortion in voltage line 2, (1-THD VL3)(:,3) total harmonic distortion in voltage in voltage line 3, The x axis describes the number of points and y axis describes the total harmonic distortion (%).

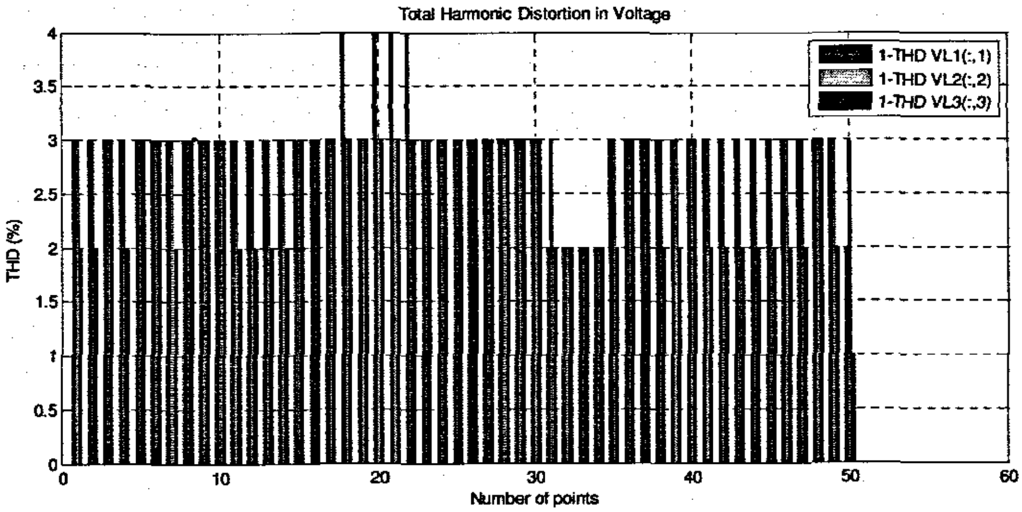

Figure 5.13: Total Harmonic Distortion in voltage part of all points of calculation

The total harmonic distortion (THD) of voltage is equal to the effective value of all the harmonics and divided by the effective value of the fundamental. The minimum waveform requirement for total harmonic distortion in medium voltage and low voltage is 8% and for high voltage and extra high voltage is 4%. There is no more difference between voltage harmonics and total harmonic distortion in voltage.

5.8.1.4 Total Harmonic Distortion in Current

The calculated by the meter THD in current is shown in Figure 5.14 for the three phases.

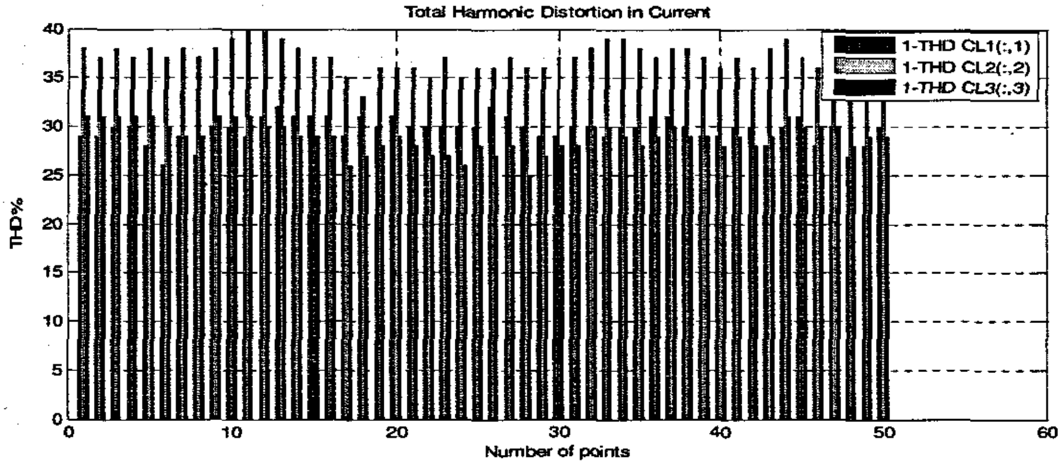

Figure 5.14: Total Harmonic Distortion in current part of all points of calculation

The total harmonic distortion (THD) of current is equal to the effective value of all the harmonics divided by the effective value of the fundamental. The highest percentage is 40% in total harmonic distortion.

5.8.1.5 Power factor

Power factor can be defined as the ratio of the real power to the apparent power, which means power factor $(pf) = \frac{kW}{kVA}$. The data of power factor is plotted in Figure 5.15.

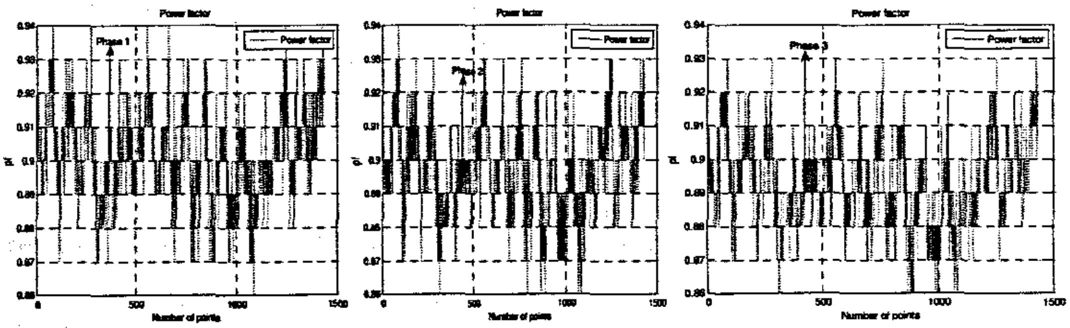

Figure 5.15: Power factors

All phases for power factor shows that the power factor is around 0.8 and 0.98. If the power factor 0.8 and 0.98 which means it consumes on 960 watts, so the kW capacity of the UPS will be reached before the kVA limit.

5.8.2. Mathew Goniwe Residence (MGR) Substation

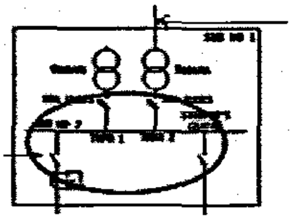

Figure 5.16: MGR Residence point of measurement.

MGR substation- is the substation feeding the education faculty and MGR residence. The point measurement is as shown in Figure 5.16 by an arrow. The period of measurement is from 23-10-2008, time start at 10:19 till 05-11-2008, time end at 09:50, where $\frac{15\text{ minutes}}{60}$ =0.25 hour, the sampling period is 96 points are equivalent to 24 hours. DMK 40 Lovato was used for measurements.

5.8.2.1 Single Phase Voltages

Plot of single phase voltages measured by the meter is shown in Figure 5.17.

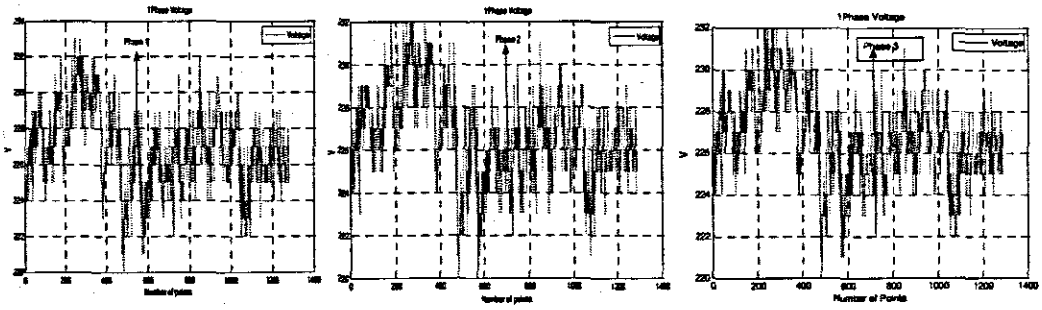

Figure 5.17: 1Phase Voltage

By looking at the records measurement, the voltage is still in the prescribed limitations because the voltage standard in South Africa is 230V ±5% which means the voltage should be not over 241.5V or less than 218.5V, figure 5.17 above. The number of data points is 1287. The measurements are done first separately for every phase and then for all three phases.

5.8.2.2 Three Phase Voltages

Plot of the three phase voltages is shown in Figure 5.18.

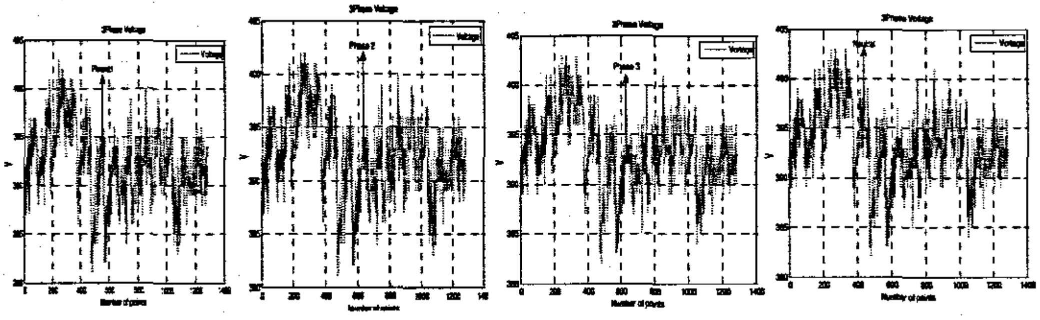

Figure 5.18: 3Phase Voltage

Three phase lines and the neutral together give a three-phase 4-wire supply with a rms voltage of 230$\sqrt{3}$=398.4. By looking at the records measurement, the three phase voltage is still in the prescribed limitations because the voltage standard in South Africa is 400V ±5% which means the voltage should be not over 420V or less than 395V. The number of data points is 1287, the sampling interval for measurements is 15 minutes.

5.8.2.3 Current

The current is measured separately in three phases. Plot of the current data is shown in Figure 5.19.

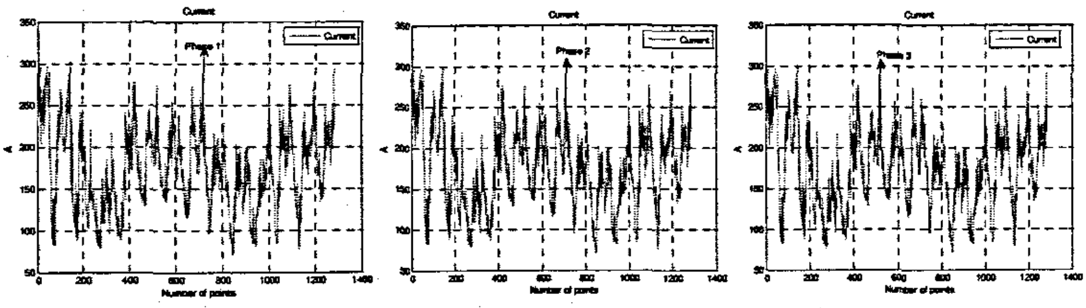

Figure 5.19: Current

The data shows that the current rises up to 234A from 08:00 till 23:40. It is because students and cafeterias are cooking. From 00:10 to 01:00 drops little bit to 130A because some students sleep during that time. As from 01:00 till 07:50 the current drop down to 95A because cafeterias are closed and students sleeping. It is necessary to limit the high current in power systems to protect the electrical equipments.

5.8.2.4 Power (Real, Reactive, Apparent)

The data for the three types of power are plotted in Figure 5.20 where the used notations are: VA is the apparent, W is the real power, VAR is the reactive power.

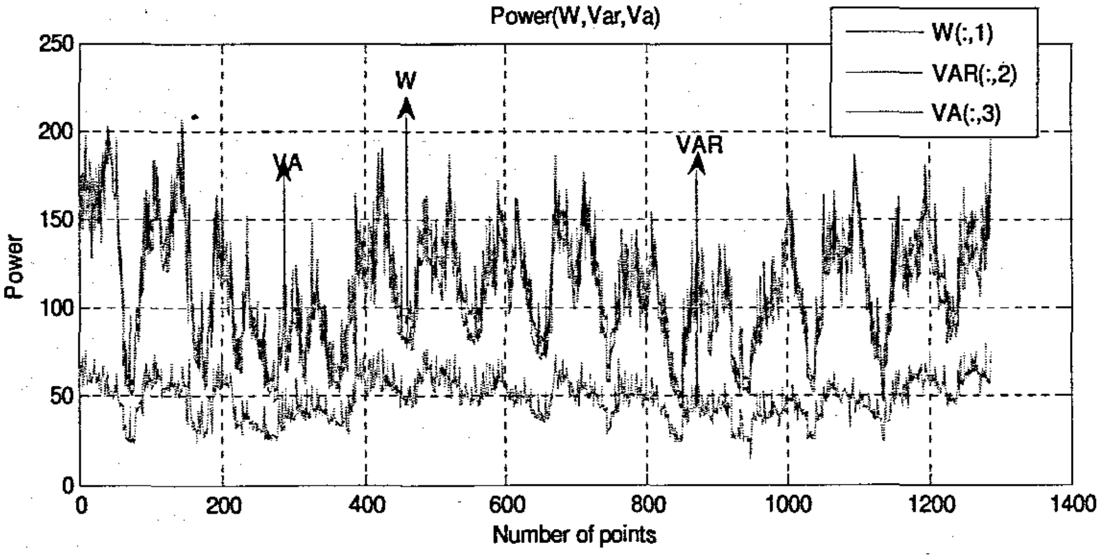

Figure 5.20: Power (Real, Reactive, Apparent)

The power rises up very high around about 08:00 to 23:40 because too much power is needed to be used that time. It starts dropping around 23:50 to 07:50 because cafeterias were closed.

5.8.2.5 Power Factor

Plot of power factor measurement data is given in Figure 5.21.

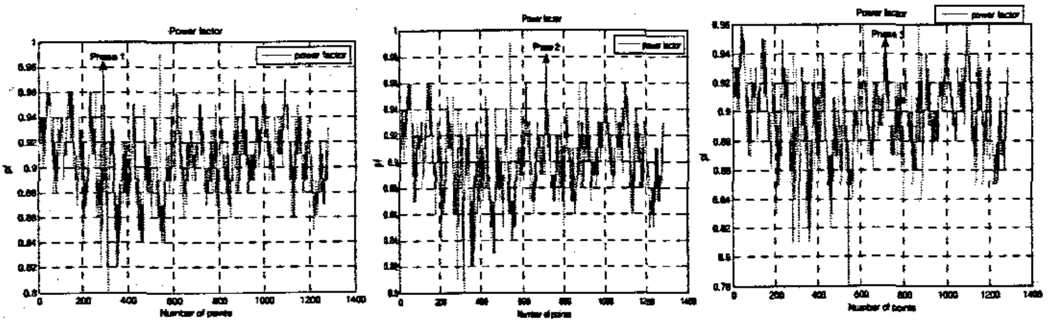

Figure 5.21: Power factor

All phases for power factor shows that the power factor is around 0.8 and 0.98. If the power factor 0.8 and 0.98 which means it consumes on 960 watts. so the kW capacity of the UPS will be reached before the kVA limit.

5.8.2.6 Frequency

Plot of frequency measurement data is given in Figure 5.22.

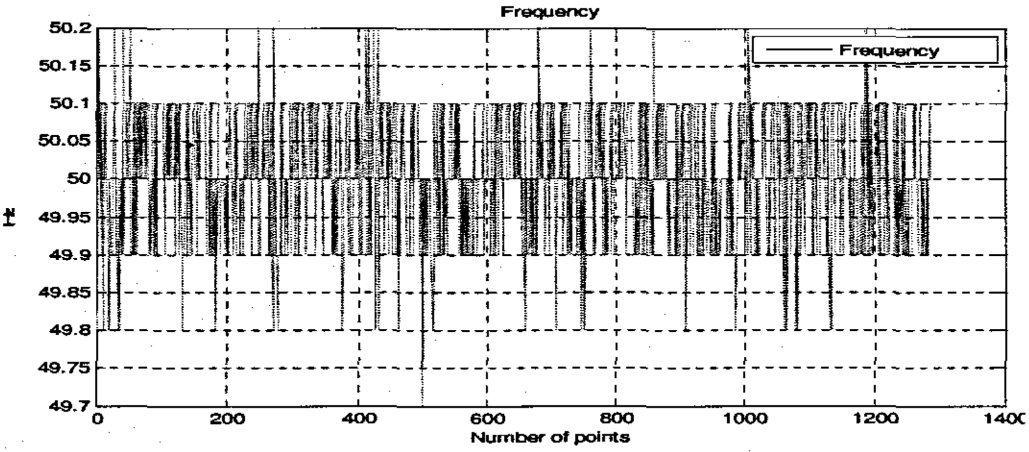

Figure 5.22: Frequency

The frequency is still in the prescribed limitations because it is between 49.7 and 50.2.

5.8.2.7 Current Harmonics

Event graph of current harmonics is shown in Figure 5.23, where in the data used (1-3.H VL1)(:,1) is the third harmonic in voltage line 1, (1-3.H VL2)(:,2) is the third harmonic in voltage line 2, (1-3.H VL3) (:,3) is the third harmonic in voltage line 3, (1-5.H VL1)(:,4) is the fifth harmonic voltage line 1, (1-5.H VL2)(:,5) is the fifth harmonic in voltage line 2, (1-5.H VL3)(:,6) is the fifth harmonic in voltage line 3, (1-7.H VL1)(:,7) is the seventh harmonic in voltage line 1, (1-7.H VL2)(:,8) is the seventh harmonic in voltage line 2, (1-7.H VL3)(:,9) is the seventh harmonic in voltage line 3. The x axis describes the number of points and y axis describes the harmonic (%).

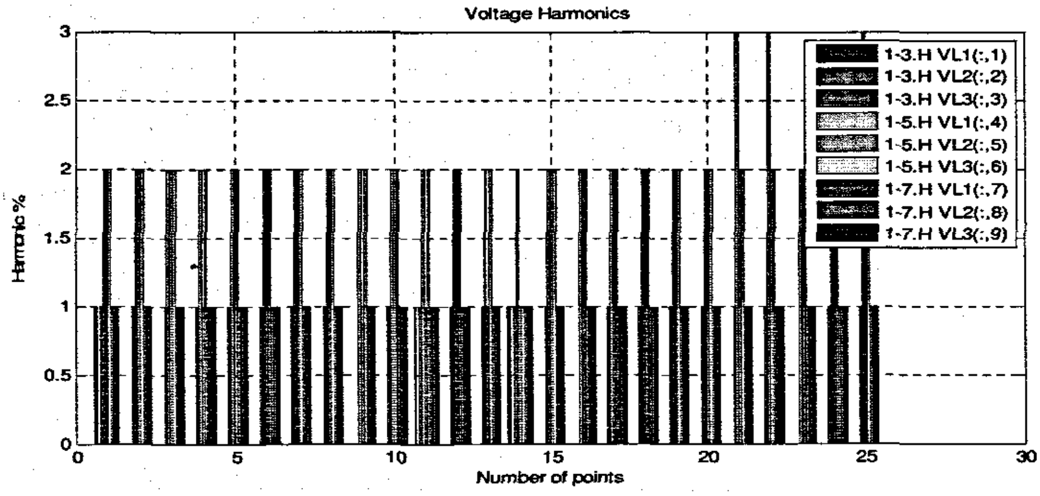

Figure 5.24: Voltage Harmonics part of all points of calculation

According Table 5.5 NRS 048-2 harmonics standard above, the harmonics are still fine on Figure 5.24 because harmonics did not even exceed 3%. According NRS 048-2 standard the 3rd harmonic shall not exceed than 5% magnitude, while 5th harmonic shall not exceed than 6% magnitude and also 7th harmonic shall not exceed than 5% magnitude. Therefore neglecting the effect of voltage harmonic and considering no load losses caused by the fundamental voltage component will only give the rise to an insignificant error.

5.8.2.9 Total Harmonic Distortion In Voltage

The total harmonic distortion in voltage calculated by the meter is shown in Figure 5.25 *where in* the data used (1-THD VL1)(:,1) total harmonic distortion in voltage line 1, (1-THD VL2)(:,2) total harmonic distortion in voltage line 2, (1-THD VL3)(:,3) total harmonic distortion in voltage in voltage line 3, The x axis describes the number of points and y axis describes the total harmonic distortion (%).

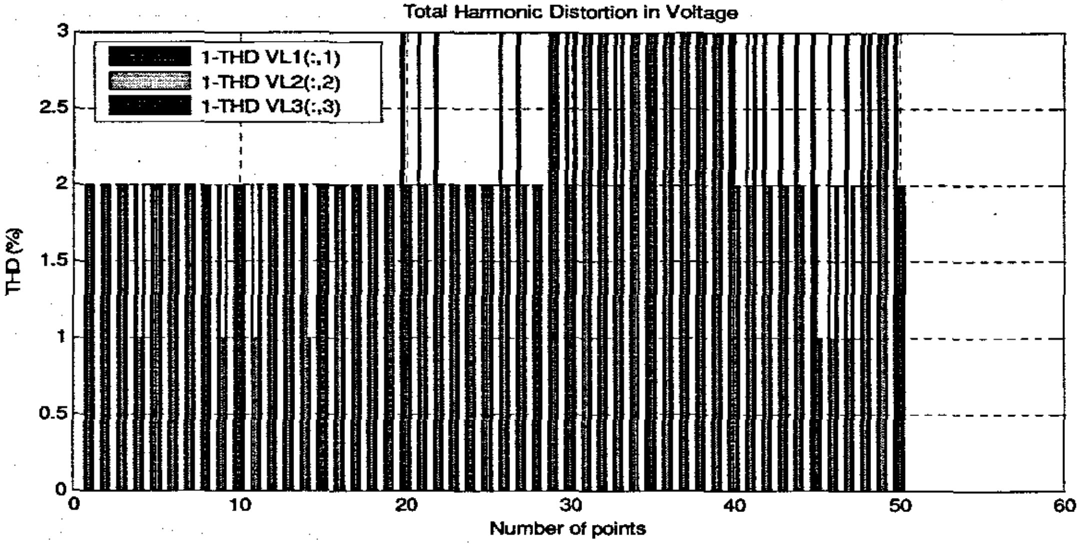

Figure 5.25: Total Harmonic Distortion in voltage part of all points of calculation

The total harmonic distortion (THD) of voltage is equal to the effective value of all the harmonics and divided by the effective value of the fundamental. The minimum waveform requirement for total harmonic distortion in medium voltage and low voltage is 8% and for high voltage and extra high voltage is 4%. There is no more difference between voltage harmonics and total harmonic distortion in voltage.

5.8.2.10 Total Harmonic Distortion in Current

The total harmonic distortion in current calculated by the meter is shown in Figure 5.26 where in the data used (1-THD CL1)(:,1) total harmonic distortion in current line 1, (1-THD CL2)(:,2) total harmonic distortion in current line 2, (1-THD CL3)(:,3) total harmonic distortion in current line 3, The x axis describes the number of points and y axis describes the total harmonic distortion (%).

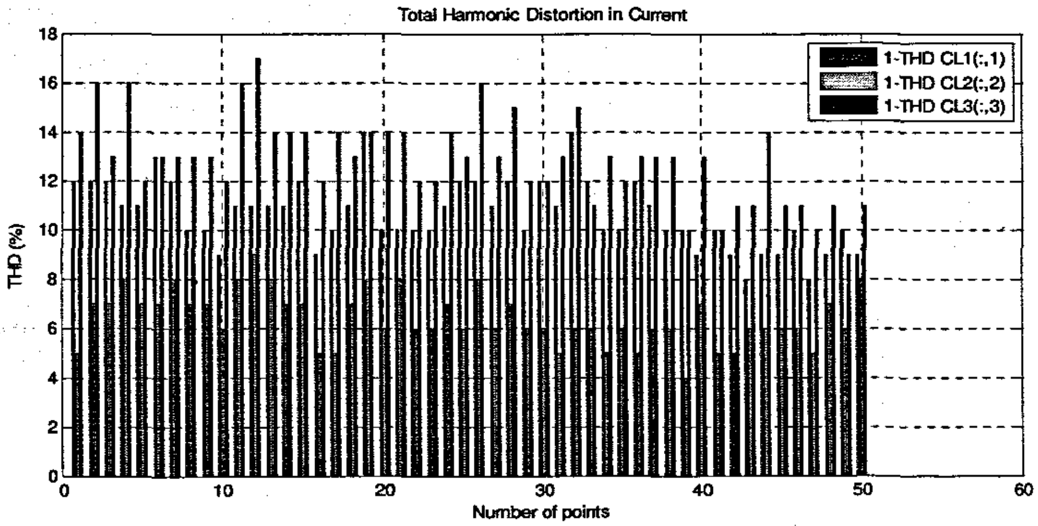

Figure 5.26: Total Harmonic Distortion in Current part of all points of calculation

The total harmonic distortion (THD) of current is equal to the effective value of all the harmonics and divided by the effective value of the fundamental. The highest percentage is 17% in total harmonic distortion.

5.8.3 Sport Hall Substation

Sport Hall substation- is a substation feeding the ABC building and IT centre. Then IT centre also feeds substation 1 and substation 2.The measurements are done from 29-09-2008, time start at 10:23 till 23-10-2008, time end at 09:11, where $\frac{15\text{ minutes}}{60}$=0.25 hour, the sampling period is 96 points are equivalent to 24 hours. The number of data points is 2230. The point of measurement for the sport hall is shown in Figure 5.27.

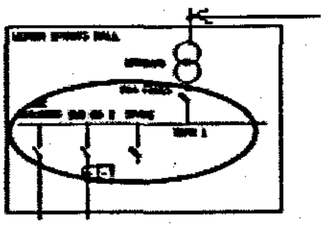

Figure 5.27: Sport Hall substation

5.8.3.1 Single Phase Voltages

The measurements are done first separately for every phase and then for all three phases, Figure 5.28 below.

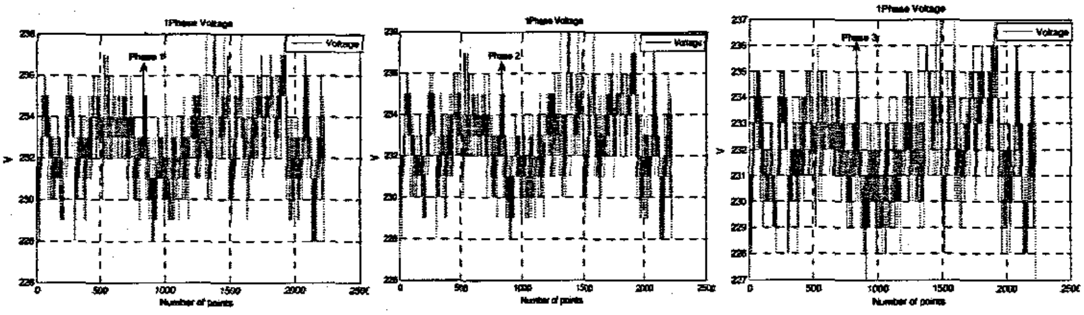

Figure 5.28: Single phase voltage

By looking at the records measurement, the voltage is still in the prescribed limitations because the voltage standard in South Africa is 203V ±5% which means the voltage should be not over 241.5 or less than 218.5.

5.8.3.2 Three Phase Voltages

Plot of the three phase voltages is shown in Figure 5.29.

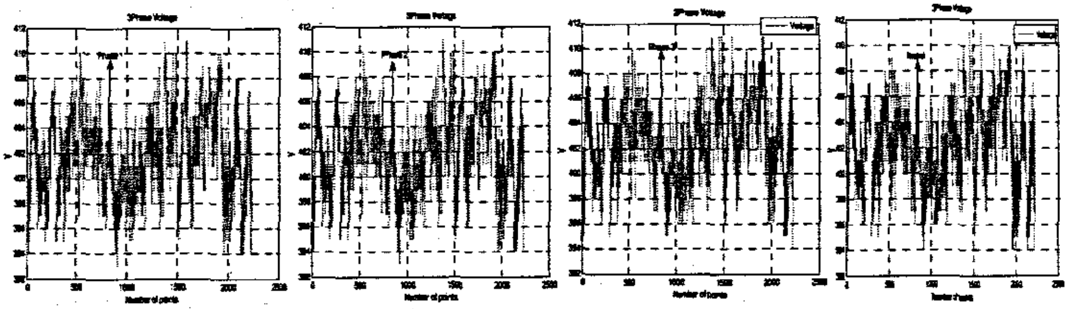

Figure 5.29: Three phase voltage

Three phase lines and the neutral together give a three-phase 4-wire supply with a rms voltage of $230\sqrt{3}$=398.4. By looking at the records measurement, the three phase voltage is still in the prescribed limitations because the voltage standard in South Africa is 400V ±5% which means the voltage should be not over 420V or less than 395V.

5.8.3.3 Current

The current is measured separately in three phases. Plot of the current data is shown in Figure 5.30.

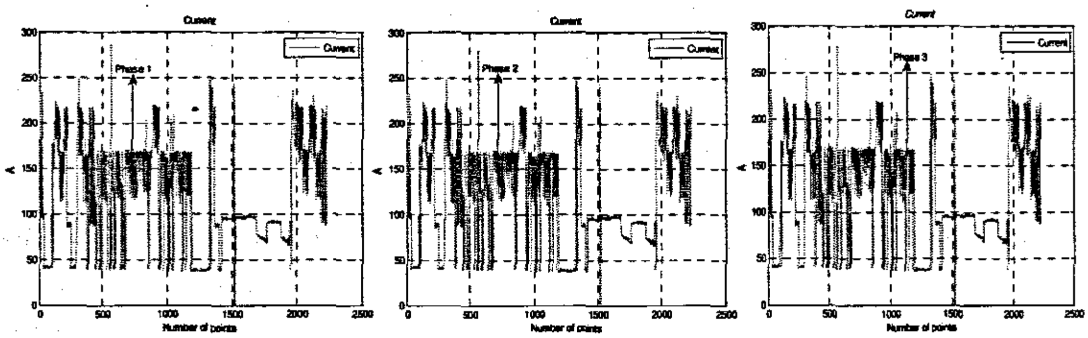

Figure 5.30: Current

At sport hall, the data shows that the current rise up only if there is an event in sport hall. It is necessary to limit the high current in power systems to protect the electrical equipments.

5.8.3.4 Power (Real, Reactive, Apparent)

The data for the three types of power are plotted in Figure 5.31 where the used notations are: VA is the apparent, W is the real power, VAR is the reactive power.

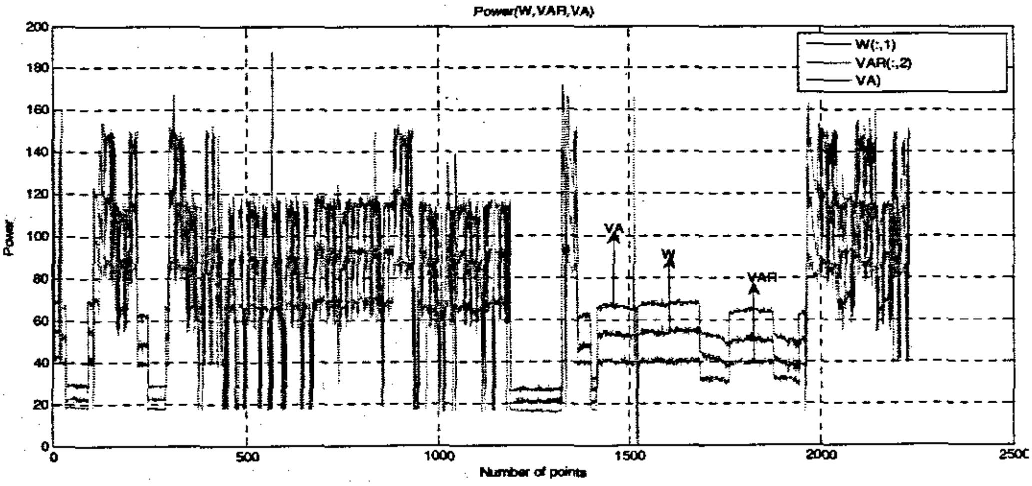

***Figure 5.31:** Real power, Reactive power, apparent power*

The power is not used all the time in the sport hall. It actually depends on many sport events taking place that is why most of the time the power drops.

5.8.3.5 Power Factor

Plot of power factor measurement data is given in Figure 5.32.

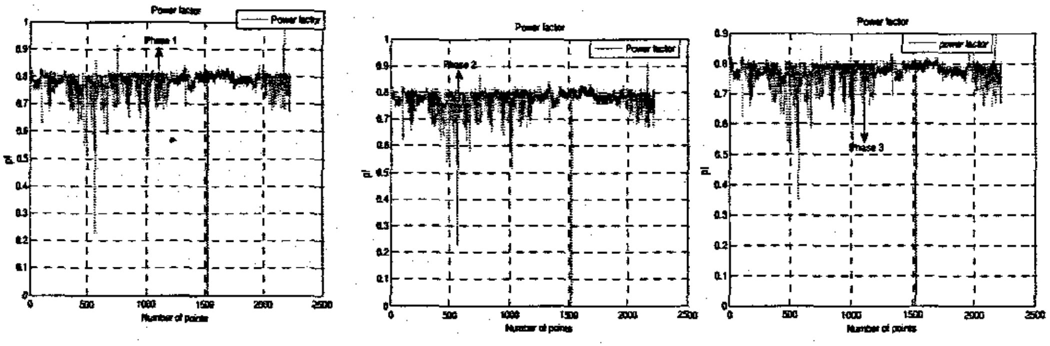

Figure 5.32: Power factor

The power factor at sport hall drops from 0.9 to 0.1. There are some equipments that make the poor power factor such as inductor motor, arc welders, induction heating equipment etc

5.8.3.6 Frequency

Plot of frequency measurement data is given in Figure 5.33

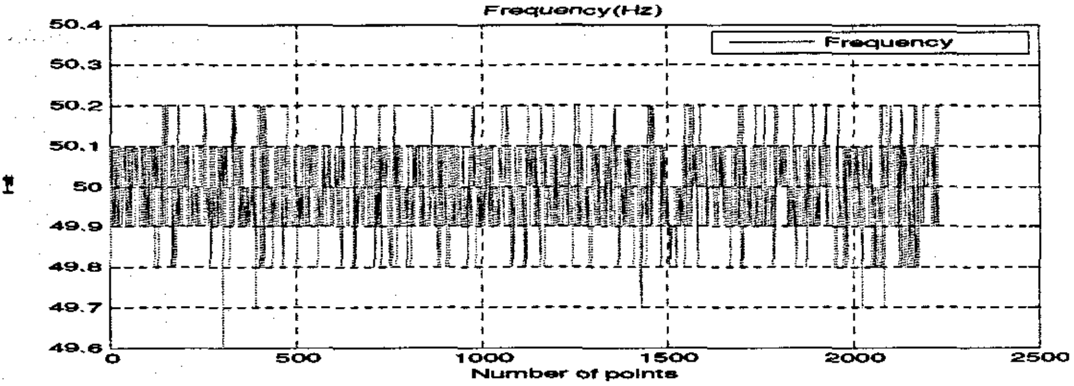

Figure 5.33: Frequency

The frequency is still in the prescribed limitations because it is between 49.6 Hz and 50.2Hz.

5.8.3.7 Total Harmonic Distortion in Voltage

The total harmonic distortion in voltage calculated by the meter is shown in Figure 5.34 where in the data used (1-THD VL1)(:,1) total harmonic distortion in voltage line 1, (1-THD VL2)(:,2) total harmonic distortion in voltage line 2, (1-THD VL3)(:,3) total harmonic distortion in voltage line 3, The x axis describes the number of points and y axis describes the total harmonic distortion (%).

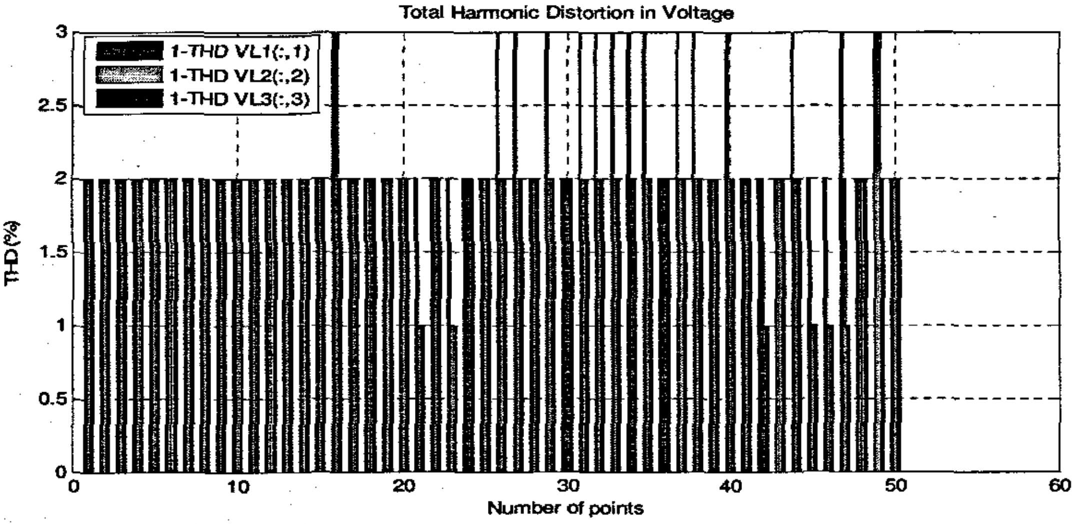

Figure 5.34: Total Harmonic Distortion in Voltage part of all points of calculation

The minimum waveform requirement for total harmonic distortion in medium voltage and low voltage is 8% and for high voltage and extra high voltage is 4%. There is no more difference between voltage harmonics and total harmonic distortion in voltage.

5.8.3.8 Total Harmonic Distortion in Current

The total harmonic distortion in current calculated by the meter is shown in Figure 5.35 where in the data used (1-THD CL1)(:,1) total harmonic distortion in current line 1, (1-THD CL2)(:,2) total harmonic distortion in current line 2, (1-THD CL3)(:,3) total harmonic distortion in current line 3, The x axis describes the number of points and y axis describes the total harmonic distortion (%).

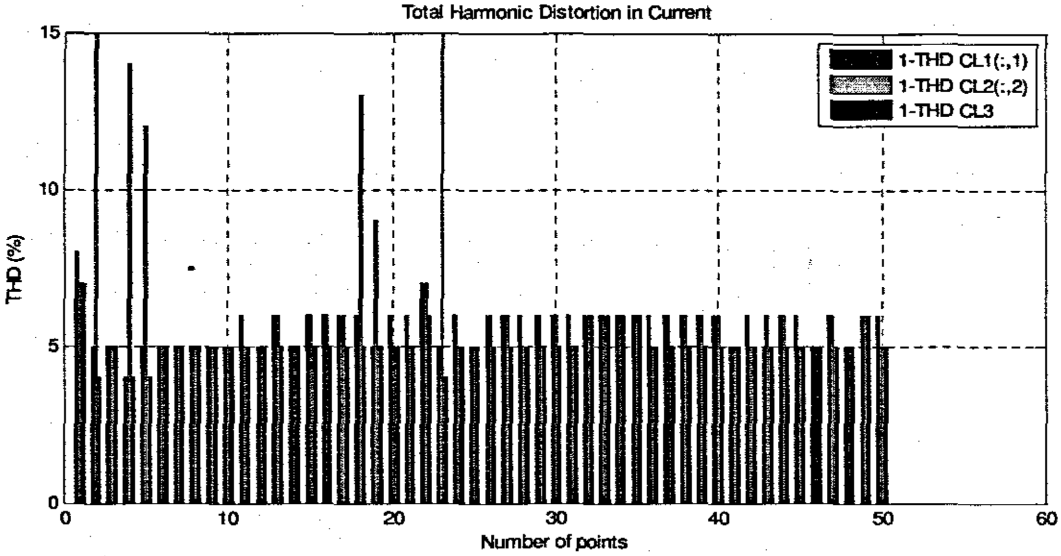

Figure 5.35: Total Harmonic Distortion in Current part of all points of calculation

. The highest percentage is 15% in total harmonic distortion.

5.8.3.9 Voltage Harmonics

Event graph of current harmonics is shown in Figure 5.36, where in the data used data (1-3.H VL1)(:,1) is the third harmonic in voltage line 1, (1-3.H VL2)(:,2) is the third harmonic in voltage line 2, (1-3.H VL3) (:,3) is the third harmonic in voltage line 3, (1-5.H VL1)(:.4) is the fifth harmonic voltage line 1, (1-5.H VL2)(:,5) is the fifth harmonic in voltage line 2, (1-5.H VL3)(:,6) is the fifth harmonic in voltage line 3, (1-7.H VL1)(:,7) is the seventh harmonic in voltage line 1, (1-7.H VL2)(:.8) *is the seventh harmonic in voltage line 2, (1-7.H VL3)(:,9) is the seventh harmonic* in voltage line 3. The x axis describes the number of points and y axis describes the harmonic (%).

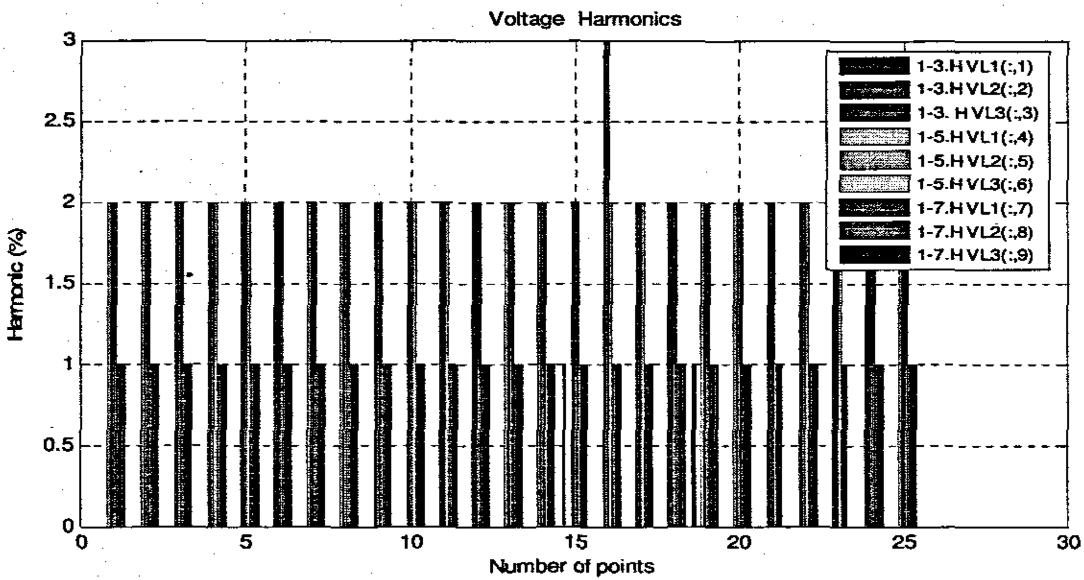

Figure 5.36: Voltage Harmonics part of all points of calculation

In sport hall, according to Table 5.5 above, the harmonics are still fine on Figure 5.36 above, because harmonics did not even exceed 3%. According NRS 048-2 standard the 3rd harmonic *shall not exceed than 5% magnitude, while 5th harmonic shall not exceed than 6% magnitude* and also 7th harmonic shall not exceed than 5% magnitude. Therefore neglecting the effect of voltage harmonic and considering no load losses caused by the fundamental voltage component will only give the rise to an insignificant error.

5.8.3.10 Current Harmonic

Event graph of current harmonics is shown in Figure 5.37. where in the data used (1-3.H CL1)(:,1) is the third harmonic in current line 1, (1-3.H CL2)(:,2) is the third harmonic in current line 2, (1-3.H CL3) (:,3) is the third harmonic in current line 3, (1-5.H CL1)(:,4) is the fifth harmonic current line 1, (1-5.H CL2)(:,5) is the fifth harmonic in current line 2, (1-5.H CL3)(:,6) is the fifth harmonic in current line 3, (1-7.H CL1)(:,7) is the seventh harmonic in voltage line 1, (1-7.H CL2)(:,8) is the seventh harmonic in current line 2, (1-7.H CL3)(:,9) is the seventh harmonic in current line 3. The x axis describes the number of points and y axis describes the harmonic (%).

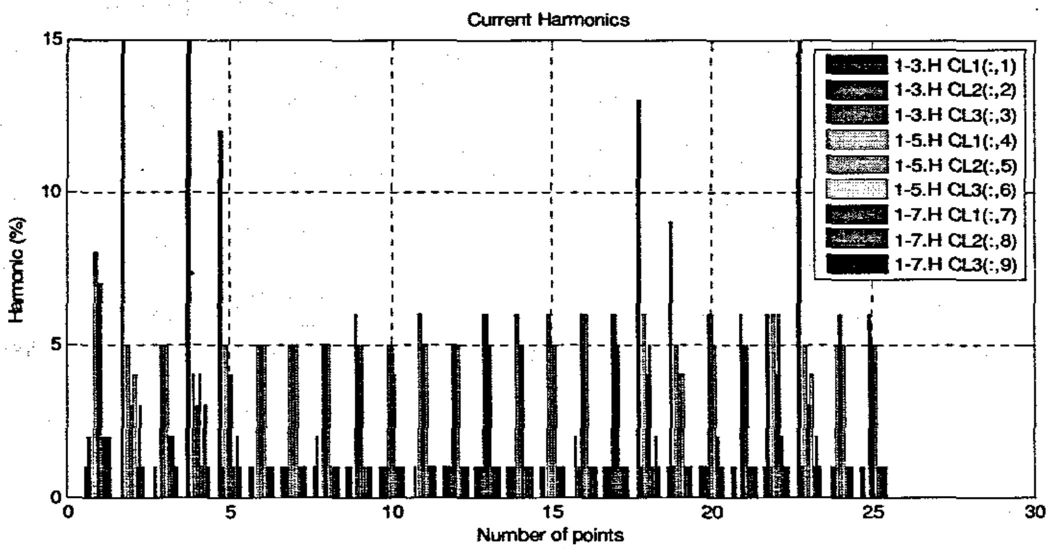

Figure 5.37: Current Harmonics part of all points of calculation

The flow of the current harmonics in a network produces two main effects, one of the effects is the additional transmission loss caused by the increased rms value of current waveform. The second one effect is the creation of harmonic voltage drops across circuit impedances.

5.8.4 Mechanical Engineering Substation

Mechanical Engineering substation is feeding substation number 4 and De Beers residence. The data are records measured from 1-09-2008, time start at 09:47 till 10-09-2008, time end at *09:34, where* $\frac{15\text{ minutes}}{60}$*=0.25 hour, the sampling period is 96 points are equivalent to 24* hours. DMK40 Lovato meter was used for measurements. The number of data points is 905. The point of measurement for the Mechanical Engineering substation is shown in Figure 5.38.

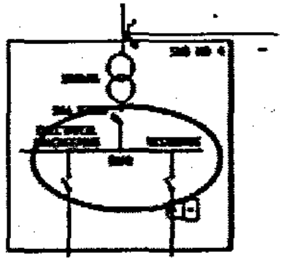

Figure 5.38: Mechanical Engineering Substation

5.8.4.1 Single Phase Voltages

The number of data points is 905, the sampling interval for measurements is 15 minutes. The measurements are done first separately for every phase and then for all three phases.

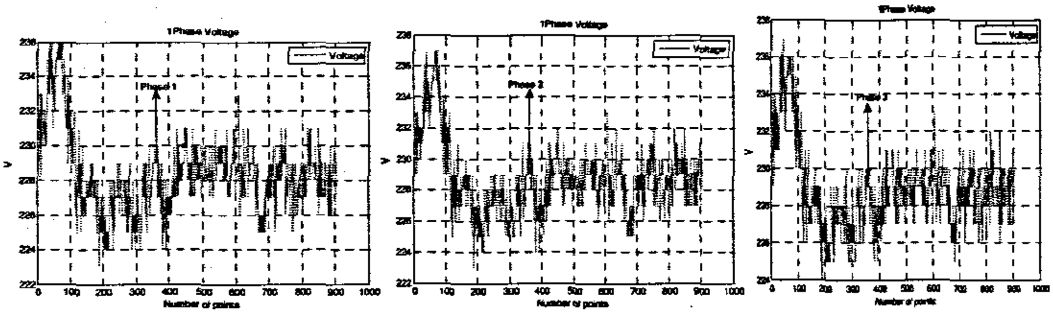

Figure 5.39: Single phase Voltage

By looking at the records measurement, the voltage is still in the prescribed limitations because the voltage standard in South Africa is 203V ±5% which means the voltage should be not over 241.5 or less than 218.5, so it is still fine because the low voltage is around 223, figure 5.39 above.

5.8.4.2 Three Phase Voltages

Plot of the three phase voltages is shown in Figure 5.40.

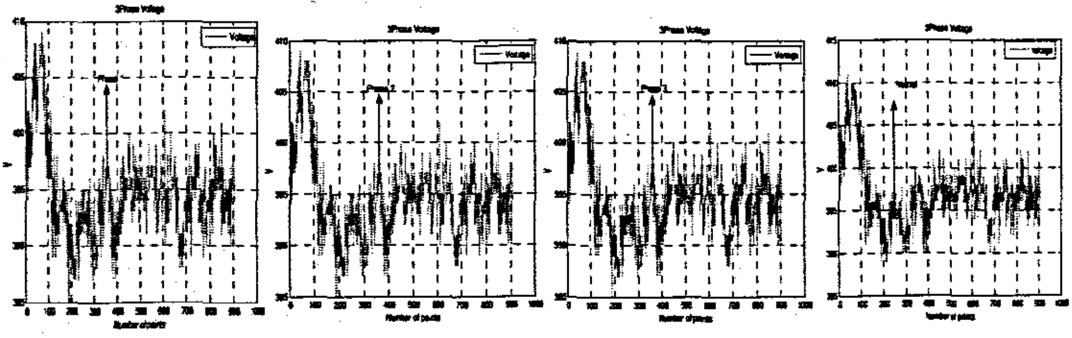

Figure 5.40: Three phase voltage

Three phase lines and the neutral together give a three-phase 4-wire supply with a rms voltage of $230\sqrt{3}=398.4$. By looking at the records measurement, the three phase voltage is still in the prescribed limitations because the voltage standard in South Africa is 400V ±5% which means the voltage should be not over 420V or less than 395V.

5.8.4.3 Current

The current is measured separately in three phases. Plot of the current data is shown in Figure 5.41

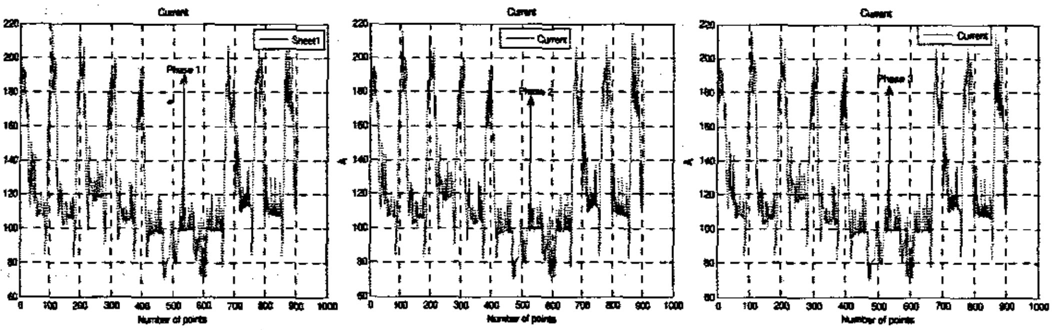

Figure 5.41: Current

The data shows that the current rises up to 218A from 08:00 till 16:00. It is because students are switching on the computers and machines in mechanical engineering labs. As from 16:00 till 07:50 the current drop down to 95A because no students at labs.

5.8.4.4 Power (Real, Reactive, Apparent)

The data for the three types of power are plotted in Figure 5.42 where the used notations are: VA is the apparent, W is the real power, VAR is the reactive power.

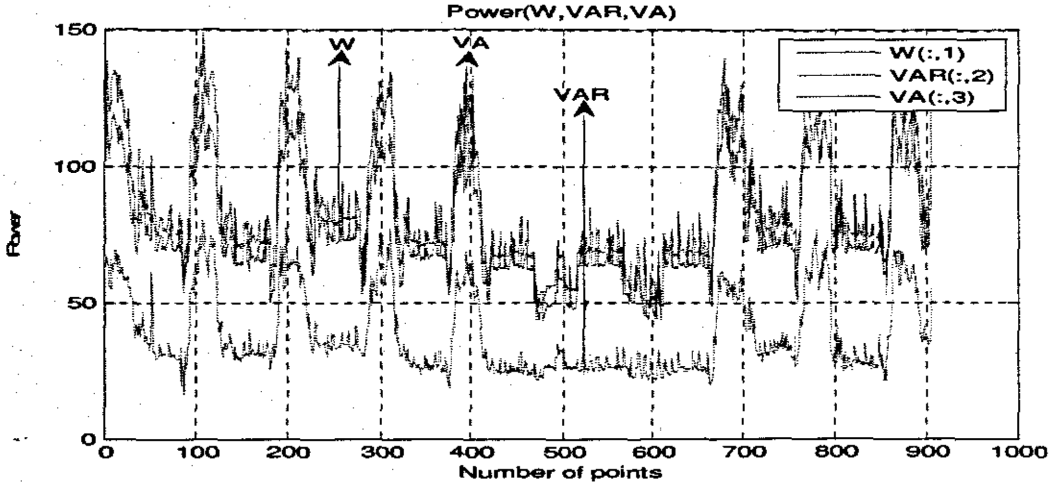

Figure 5.42: Power (Real, Reactive, Apparent).

The power rise up very high around about 08:00 to 23:40 because too much power needed to be used by many machines and starting drops around about 23:50 to 07:50 because labs were closed.

5.8.4.5 Power factors

Plot of power factor measurement data is given in Figure 5.43.

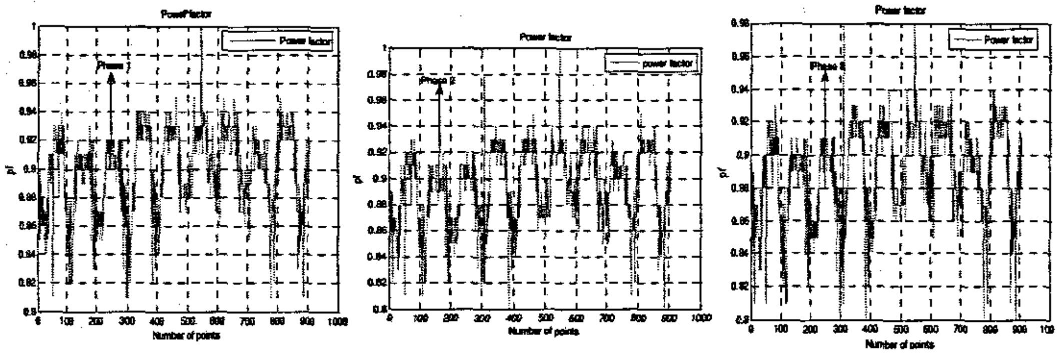

Figure 5.43: Power factor.

All phases for power factor shows that the power factor is between 0.8 and 1. Because of the value of 1, it is not under prescribed limitations. It needs to be improved.

5.8.4.6 Frequency

Plot of frequency measurement data is given in Figure 5.44

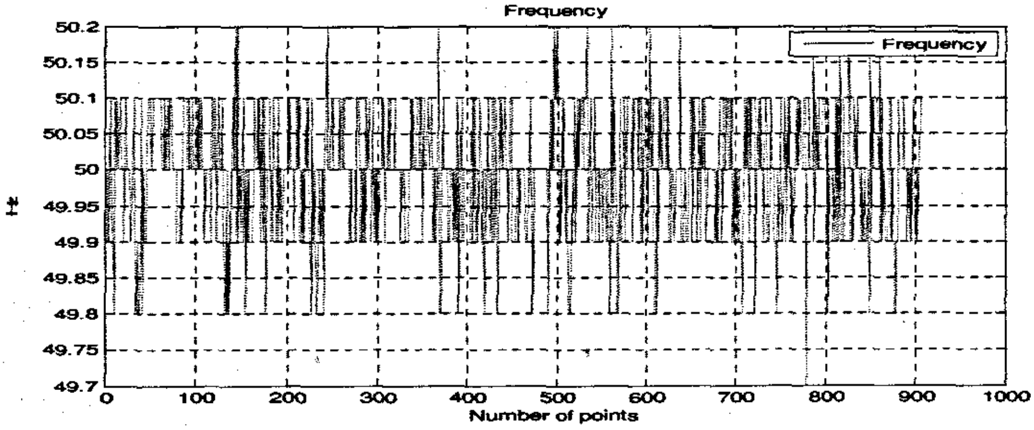

Figure 5.44: Frequency

The frequency is still in the prescribed limitations because is between 47.6 Hz and 50.2Hz.

5.8.4.7 Voltage Harmonics

Event graph of current harmonics is shown in Figure 4.45, where in the data used (1-3.H VL1)(:,1) is the third harmonic in voltage line 1, (1-3.H VL2)(:,2) is the third harmonic in voltage line 2, (1-3.H VL3) (:,3) is the third harmonic in voltage line 3, (1-5.H VL1)(:,4) is the fifth harmonic voltage line 1, (1-5.H VL2)(:,5) is the fifth harmonic in voltage line 2, (1-5.H VL3)(:,6) is the fifth harmonic in voltage line 3, (1-7.H VL1)(:,7) is the seventh harmonic in voltage line 1, (1-7.H VL2)(:,8) is the seventh harmonic in voltage line 2, (1-7.H VL3)(:,9) is the seventh harmonic in voltage line 3. The x axis describes the number of points and y axis describes the harmonic (%).

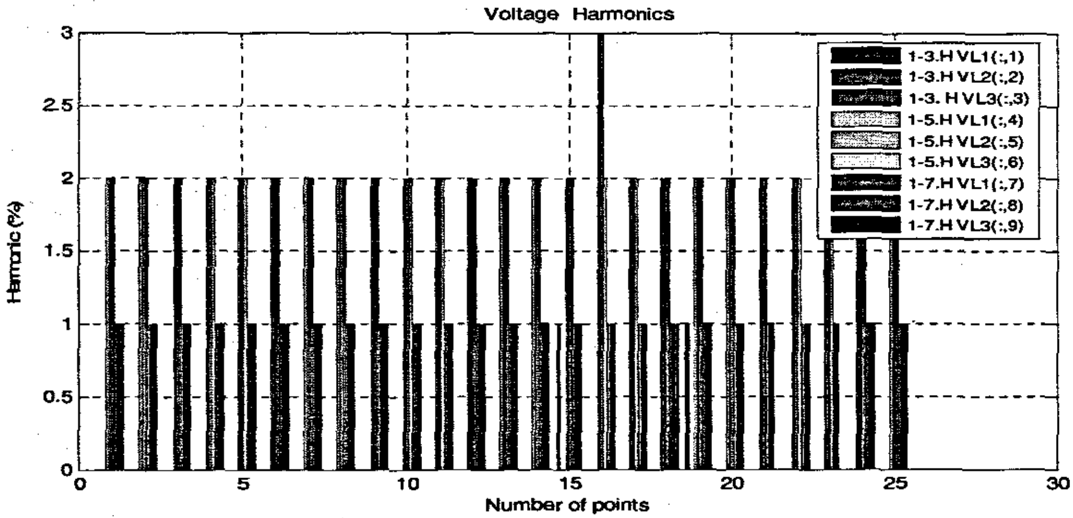

Figure 5.45: Voltage Harmonics part of all points of calculation

In mechanical substation, according table 5.5 above, the harmonics are still fine on Figure 5.45 above, because harmonics did not even exceed 3%.

5.8.4.7 Current Harmonics

Event graph of current harmonics is shown in Figure 5.46, where in the data used (1-3.H CL1)(:,1) is the third harmonic in current line 1, (1-3.H CL2)(:,2) is the third harmonic in current line 2, (1-3.H CL3) (:,3) is the third harmonic in current line 3, (1-5.H CL1)(:,4) is the fifth harmonic current line 1, (1-5.H CL2)(:,5) is the fifth harmonic in current line 2, (1-5.H CL3)(:,6) is the fifth harmonic in current line 3, (1-7.H CL1)(:,7) is the seventh harmonic in voltage line 1, (1-7.H CL2)(:,8) is the seventh harmonic in current line 2, (1-7.H CL3)(:,9) is the seventh harmonic in current line 3. The x axis describes the number of points and y axis describes the harmonic (%).

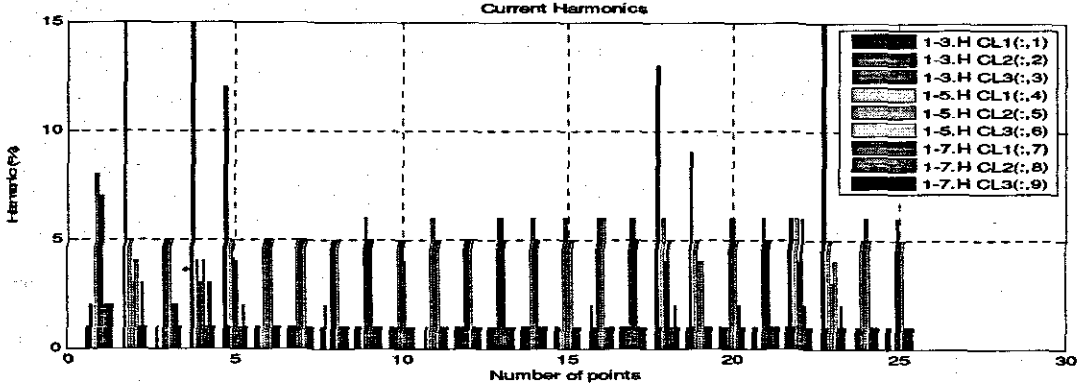

Figure 5.46: Current Harmonics part of all points of calculation

The current harmonics only reach 15% in mechanical engineering department

5.8.4.8 Total Harmonic Distortion in Voltage

The total harmonic distortion in voltage calculated by the meter is shown in Figure 5.47 where in the data used (1-THD VL1)(:,1) total harmonic distortion in voltage line 1, (1-THD VL2)(:,2) total harmonic distortion in voltage line 2, (1-THD VL3)(:,3) total harmonic distortion in voltage in voltage line 3. The x axis describes the number of points and y axis describes the total harmonic distortion (%).

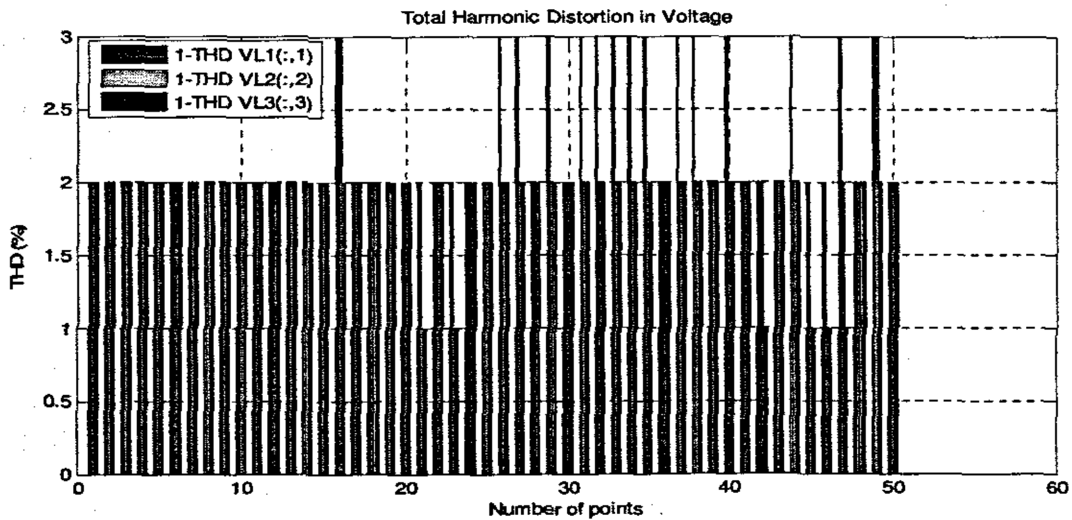

Figure 5.47: Total Harmonic Distortion in Voltage part of all points of calculation

The total harmonic distortion only reaches 3%.

5.8.4.9 Total Harmonic Distortion in Current

The total harmonic distortion in current calculated by the meter is shown in Figure 5.48 where in the data used data (1-THD CL1)(:,1) total harmonic distortion in current line 1, (1-THD CL2)(:,2) total harmonic distortion in current line 2, (1-THD CL3)(:,3) total harmonic distortion in current line 3, The x axis describes the number of points and y axis describes the total harmonic distortion (%).

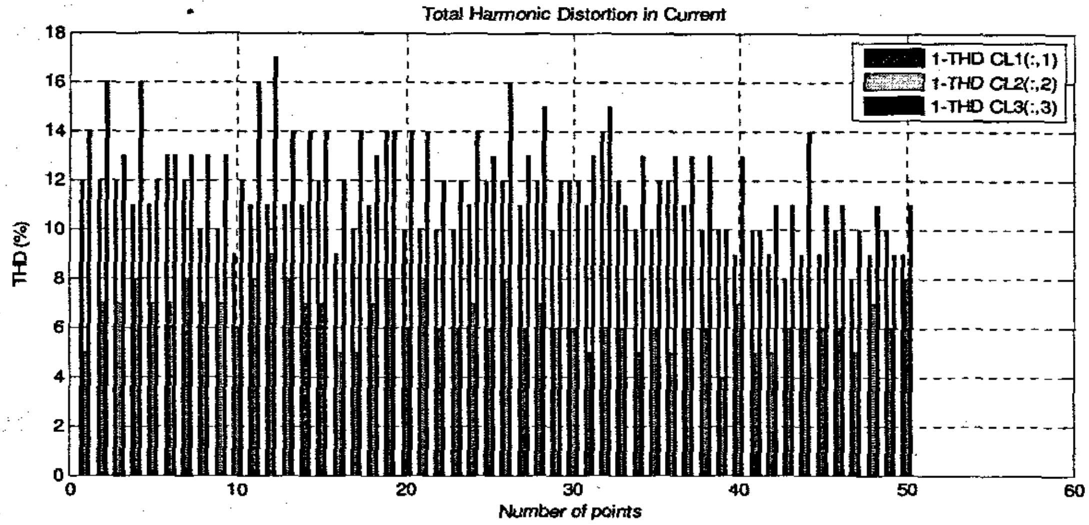

Figure 5.48: Total Harmonic Distortion in Current part of all points of calculation

Total harmonic distortion reaches 17%

5.9 Parallel Connection

5.9.1 Measurements in 2009

Early in 2009 two meters which are the ImpedoGraph and the ProvoGraph were connected in parallel to different points for measurements on the low voltage side of substations. The Table 5.6 below shows data recorded by ImpedoGraph meter. The table contains the data events for power quality disturbances for the Admin building. As discussed in previous chapter 2 that Short duration variations are divided into instantaneous, momentary, and temporally ones and the voltage disturbance characterizing them are swells, sags and dips. Long duration variations are voltage variations that are preceding longer than or take longer time than a minute and are over-voltage, under-voltage, interruption, etc. Some of these disturbances appeared during the period of measurements from 24-03-2009 till 31-03-2009. The table shows two types of starting time scheduled for every five hours with duration of one hour and event start time with different lengths. The measurements are taken with a sampling period of 10 minutes.

Table 5.6: Events from ImpedoGraph Meter

Meter Point	Start Date	Start Time [h]	Category	Phases	Duration time	Residual Voltage	Description
Admin Building	Tue 24 Mar 2009	50:00.0	Scheduled Recording	....	59.996	100.00%	Scheduled recording
Admin Building	Fri 27 Mar 2009	57:47.1	Dip type Y	1,2	0.08	74.20%	170.6 Volt minimum
Admin Building	Sun 29 Mar 2009	51:18.5	Voltage Swells	3	0.73	110.00%	253.1 Volt maximum
Admin Building	Sun 29 Mar 2009	51:19.5	Over-voltage	2,3	10.439	110.20%	253.5 Volt maximum
Admin Building	Sun 29 Mar 2009	51:30.3	Over-voltage	2,3	18.339	110.20%	253.5 Volt maximum
Admin Building	Sun 29 Mar 2009	00:00.5	Voltage Swells	3	0.05	110.00%	253.0 Volt maximum
Admin Building	Sun 29 Mar 2009	00:00.9	Voltage Swells	3	0.22	110.00%	253.1 Volt maximum
Admin Building	Sun 29 Mar 2009	00:01.3	Voltage Swells	3	0.07	110.00%	253.0 Volt maximum
Admin Building	Sun 29 Mar 2009	00:02.3	Voltage Swells	3	0.13	110.00%	253.0 Volt maximum

Admin Building	Sun 29 Mar 2009	00:02.5	Voltage Swells	3	0.879	110.00%	253.1 Volt maximum
Admin Building	Sun 29 Mar 2009	00:03.6	Voltage Swells	3	0.18	110.00%	253.0 Volt maximum
Admin Building	Sun 29 Mar 2009	00:04.0	Over-voltage	3	13.56	110.20%	253.5 Volt maximum
Admin Building	Tue 31 Mar 2009	54:33.3	Over-voltage	3	0.01	110.00%	253.1 Volt maximum

5.9.1.1 Voltage Unbalance

ImpedoGraph was used to collect data for voltage unbalance. This data in Figure 5.49 was collected in Sacco substation which is feeding administration, Sacco cafeteria and Sacco residence. Voltage unbalance is considered as a power quality disturbance of important concern at electrical distribution. 2% is the compatibility level for the unbalance in three- phase networks. So in places with predominance of two-phase custormers, the assessed unbalance may be up to 3%.

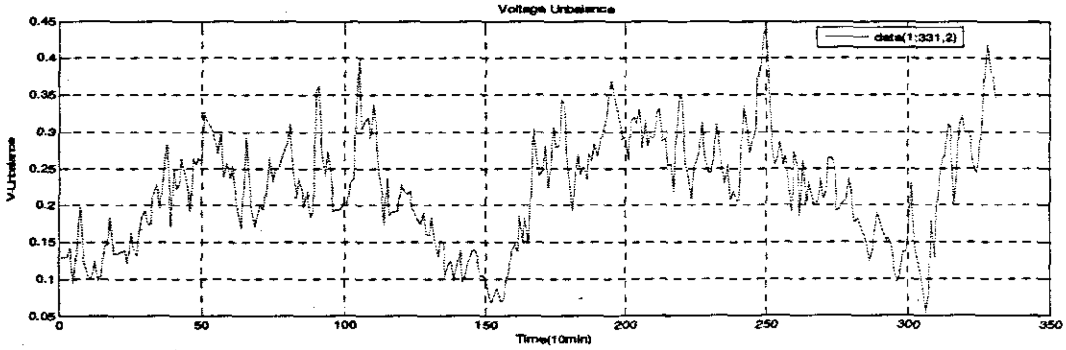

Figure 5.49: Voltage Unbalance

The data show that around 1:50AM till 6:30AM the voltage is in limits because the unbalance is around 0.1 to 0.2. The peak hours starts from 7:00AM to 10:00AM because that time the students are preparing for breakfast, taking showers and the cafeteria is cooking. Actually according to the graph, during the time when the students are at residence, peak hours start and stop when they are sleeping.

5.9.1.2 RMS Voltage

Figure 5.50 shows the voltage root mean square (rms) obtained by the ImpedoGraph for Sacco substation from 02-06-2009 till 03-06-2009. The VRMS is presented in percentages.

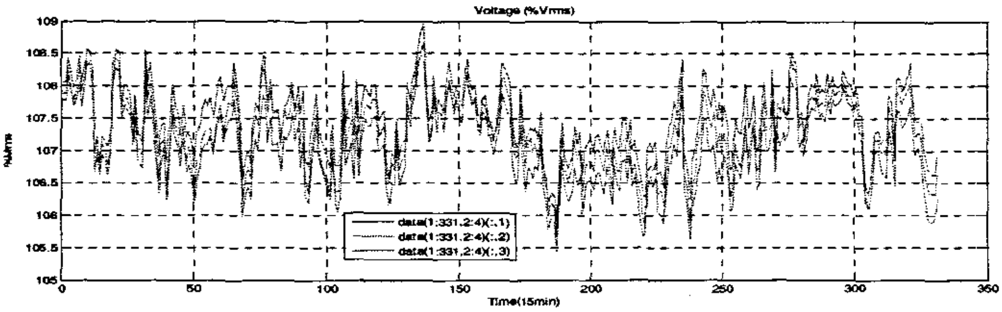

Figure 5.50: RMS Voltages by ImpedoGraph meter

Trends data represent the characteristics of power quality variations that are usually slow and continuous in time in comparison to data. Reactive power can play an important part to compensate the problem for voltage RMS variations.

5.10 ProvoGraph Meter

5.10.1 RMS Voltage

Figure 5.52 shows the voltage root mean square (rms) obtained by the ProvoGraph meter

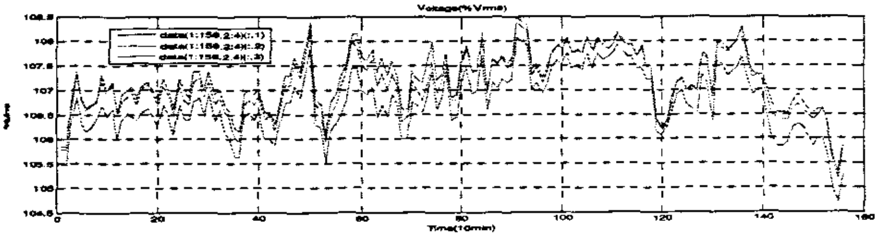

Figure 5.51: VRMS Voltages

Reactive power can play an important part to compensate the problem for voltage RMS variations.

5.11 Discussion of the results

According to the measurements taken, there are some power quality disturbances like swells, crest factor, harmonics etc. Current harmonics are in high percentage although they are not so dangerous for the equipment. Voltage harmonics are not important because they do not even reach 5%.

5.12 Conclusion

All power quality disturbances are calculated by the meters DMK40 lovato, ImpedoGraph and ProvoGraph In chapter six, MySQL data base and MATLAB are used to plot graphs. Comparison of measured parameters and calculated parameters/indicators of power quality are presented in the next chapter.

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CHAPTER SIX

CALCULATION OF POWER QUALITY PARAMETERS (INDICATORS)

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6.1 Introduction

All measured data is stored (exported) to MySQL DB manager database, where data then is easily to be imported to software MATLAB via ODBC communication protocol. MySQL database allows the users to store and use data. The comparison is done by using MySQL and MATLAB to calculate the disturbances and compare them with the data from the meter's calculations. The measured data from Information Technology (IT) building was used to calculate different parameters of power system quality and compare with the measured or calculated by the meter ones. The following parameters are calculated: power factor, real power, active power, apparent power, crest factor, voltage unbalance.

6.2 Algorithm for calculations

An algorithm for calculation of the power quality disturbances and indicators is shown in Figure 6.1.

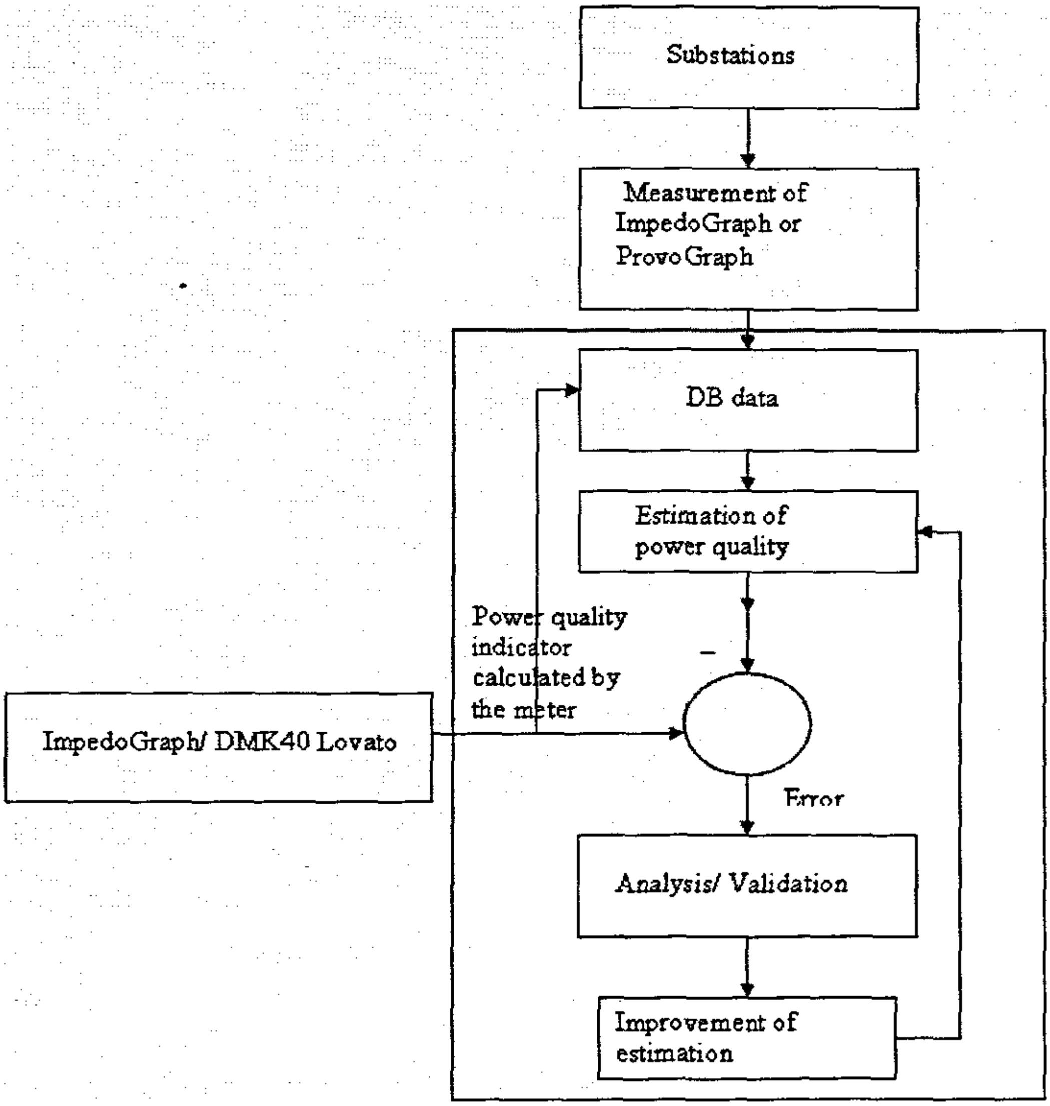


Figure 6.1: Algorithm for Measurement, data storage and disturbances estimation

6.3 Power Quality parameters

6.3.1 Power Factor

As already defined on the previous chapter power factor is the ratio of the real power flowing through the system to the apparent power.

The alternating current (AC) is characterized with three power components which are apparent power, real power and reactive power. In electrical power system, real power is considered to be the work producing power measured in watts (W) or kilowatts (kW) (Ed Kwiatkowski, 2009-10-

06). Reactive power is the quality which is normally only classified for alternating current in electrical systems. Apparent power can be defined as the product of root mean square voltage and the root mean square current that delivered in an alternating current circuit, whereby there is no account being taken of the phase difference between voltage and current.

The formula for the power factor can be expressed as follows:

$$\text{Power factor} = \frac{\text{Real power (P)}}{\text{Apparent power(S)}} \qquad (6.1)$$

It is where the $\text{Apparent power} = \sqrt{(\text{Real Power})^2 + (\text{Reactive Power})^2}$

$$= \sqrt{P^2 + Q^2} \qquad (6.2)$$

where S is the magnitude of apparent power, P is the magnitude of the active power, and Q is the magnitude of the reactive power.

The Real power is calculated as:

$$\text{Real Power} = \text{V} \times \text{I} \times \cos\boldsymbol{\theta} \qquad (6.3)$$

Where V is the voltage, I is the current, $\boldsymbol{\theta}$ is the angle between them

The apparent power is calculated as $\text{Apparent power} = \text{Vrms} \times \text{Irms}$ (6.4)

Where $\boldsymbol{Vrms}$ is the root mean square voltage, $\boldsymbol{Irms}$ is the mean square current.

$$\text{Power factor} = \frac{\text{VI}\cos\boldsymbol{\theta}}{\text{VI}} \qquad (6.5)\text{a}$$

$$\text{Power factor} = \cos\boldsymbol{\theta} \qquad (6.5)\text{b}$$

The formula of Equation 6.1 was used to calculate the power factor on the bases of measured data.

A vector diagram representing the power factor is given on Figure 6.2 shown below

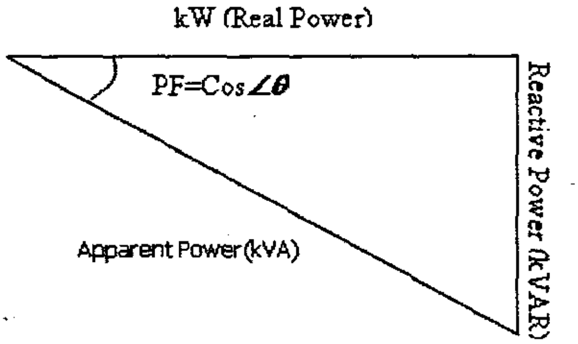


Figure 6.2: Vector diagram for Calculation of the Power Factor

6.3.1.1 Causes of Poor Power Factor

The poor power factor can creates some considerable cost and the performance consequences for power system. The causes of poor power factor are following below:

- *The welding machines.*
- Induction motors.
- The induction heating equipment.
- Solenoids.
- *The poorly designed equipment.*

6.3.1.2 Improving or correcting the power factor

In order to eliminate the power factor penalty that is charged by the utility. Some measures can be provided as:

- Use high power factor lighting ballasts.
- Use of the capacitor banks.

6.3.1.3 Calculated Power Factor and Measured Power Factor

There is data measured from substations around the Cape Peninsula University of Technology and the data saved in MySQL. This data is used to perform calculations of the power quality disturbances/ *indicator and to do comparison between these calculations and the calculations* done by the meters. In this case the measured active power and apparent power are used for calculations of the power factor. The calculated power factor by the meter is used for comparison. This is done for every substation and every phase. The errors between the *calculated and measured* (calculated by the ImpedoGraph) values are calculated, according to: $ePF = PFc - PFm$,

where PFc is the calculated power factor value and PFm is the measured power factor value. The data from IT building is measured for a week with sampling period of 10 minutes. The data *is stored in* MySQL. *The following Table* 6.1 *shows* that there is very small difference between calculated power factor and measured power factor. Only few values are displayed in the table to show the results. A MATLAB program using data from MySQL to perform calculations *mysql power factor (whole).m* is shown in Appendix E

Table 6.1: Calculated Power Factor and Measured Power Factor for IT building.

Calculated Power Factor1 Fundamental	Calculated Power Factor2 Fundamental	Calculated Power Factor3 Fundamental	Measured Power Factor1 Fundamental	Measured Power Factor2 Fundamental	Measured Power Factor3 Fundamental	Error between calculated and Measured Power factor1. 10^{-6}	Error between calculated and Measured Power factor2. 10^{-6}	Error between calculated and Measured Power factor3. 10^{-6}
0.9543	0.9921	0.9384	0.9543	0.9921	0.9384	-0.2580	-0.3147	0.1999
0.9543	0.9921	0.9384	0.9543	0.9921	0.9384	-0.2580	-0.3147	0.1999
0.9538	0.9921	0.9376	0.9538	0.9921	0.9376	-0.2520	-0.1146	-0.2393
0.9513	0.9914	0.9322	0.9513	0.9914	0.9322	0.2258	0.4491	-0.4474
0.9493	0.9905	0.9281	0.9493	0.9905	0.9281	-0.0804	0.1041	0.2123
0.9495	0.9907	0.9274	0.9495	0.9907	0.9274	0.3703	0.1983	-0.1916
0.9531	0.9922	0.9367	0.9531	0.9922	0.9367	-0.2252	0.2014	-0.4048
0.9527	0.9925	0.9369	0.9527	0.9925	0.9369	0.2833	-0.1350	0.2301
0.9525	0.9922	0.9362	0.9525	0.9922	0.9362	0.2872	0.0089	-0.0454
0.9481	0.9906	0.9278	0.9481	0.9906	0.9277	0.2783	0.1284	0.3878

Graphs of the calculated power factor for a period of week are given in Figure 6.3 for the three phases, where sampling period is 10 minutes and the number of sampling points are 350.

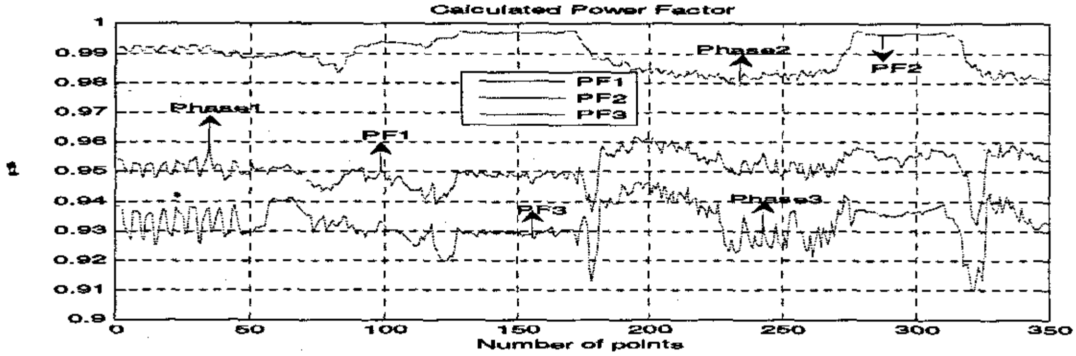


Figure 6.3: Power Factor Graph.

6.3.1.4 The Difference between Calculated and Measured Power Factor

The calculated active power and apparent power values were exported to software MySQL during the process of saving of data and called again in order to calculate the power factors and compare with measured power factors. Calculated and measured power factors graph were printed in order to compare them. There is no difference between the calculated and measured power factor in these graphs. In figure 6.4, it can be seen that the two graphs are very close. The software for calculation *mysql power factor (whole).m* is given in appendix E

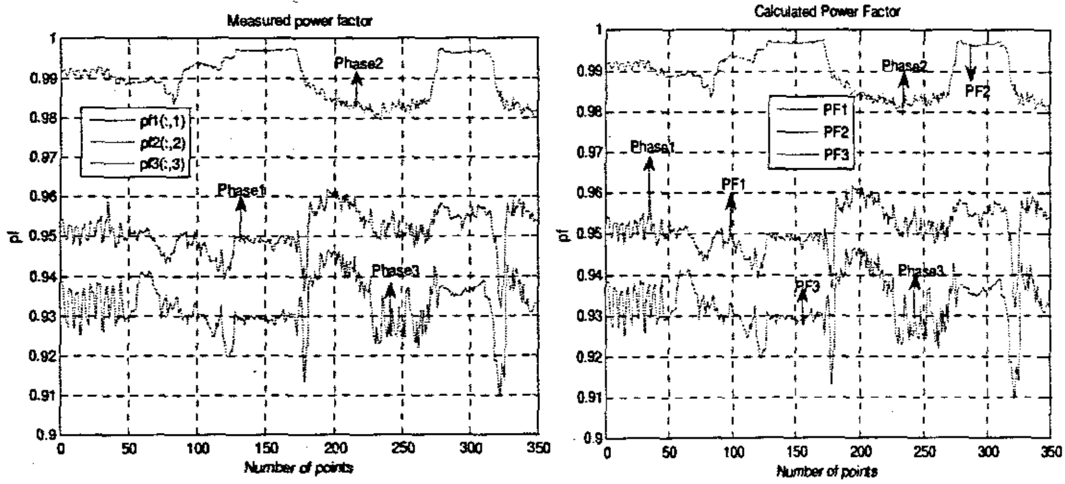


Figure 6.4: Calculated and Measured Power Factor

6.5.1.5 The Error between Calculated and Measured Power Factor

The error is calculated by the program *mysql power factor (whole).m*, Appendix E. The obtained graph is shown in figure 6.5(a).

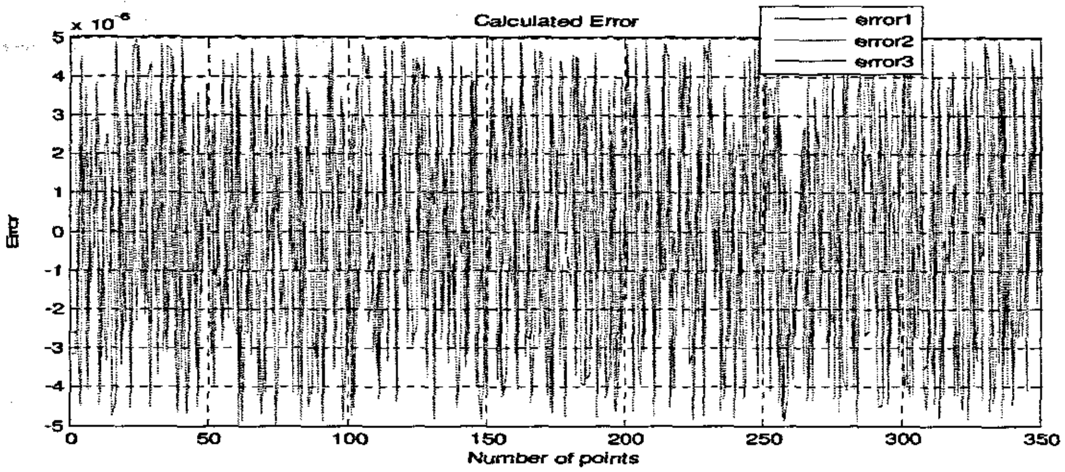
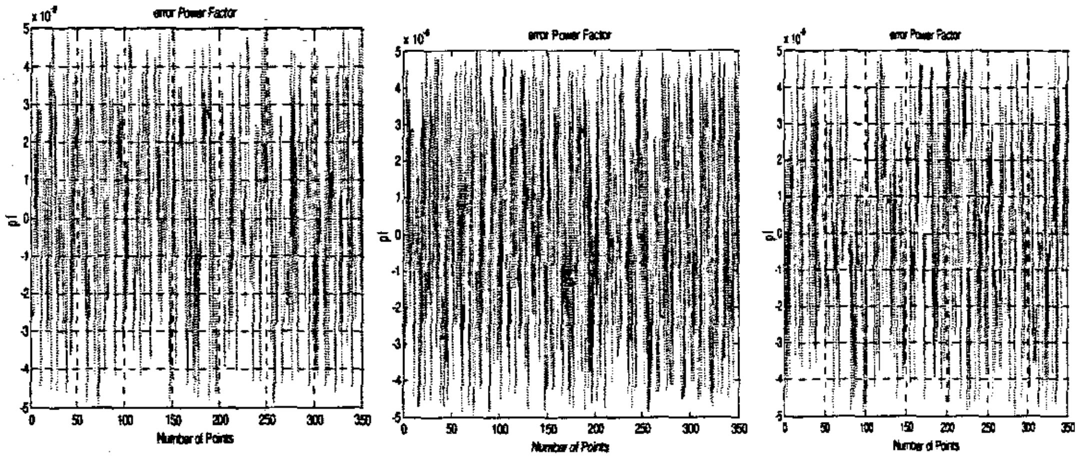


Figure 6.5(a): Error between Calculated and Measured power factors.

It can be seen that the error is very small in the range of 10^{-6}. The figure 6.5(b) below, shows the error splitted into three phases, which is phase 1, phase 2, and phase 3.



Phase 1 Phase 2 Phase 3

Figure 6.5(b): Error between Calculated and Measured power factors in the Separate Phases.

6.3.2 Real Power /Active Power

Power can be determined by measuring the voltage and current of a system. Power consumed by the system or delivered by the system is measured in terms of real, reactive, apparent power and power factor.

Real power or active power is defined as the time average of the instantaneous product of voltage and current: $P = V \times I \times \cos\theta$. When there are data from measurement for some period of time the active power can be calculated by averaging the powers at the sampling points (K. Mohan,2009-10-12:3). This can be given as:

$$P = \{\sum_{i=1}^{i=n} P(i)\}/n$$

$$= \{P(1) + P(2) + P(3) + \dots\dots\dots + P(n)\}/n$$

$$\{[V(1) \times I(1)] + [V(2) \times I(2)] + [V(3) \times I(3)] + \dots\dots\dots + [V(n) \times I(n)]\}/n \qquad (7.6)$$

where **n** is the number of the samples. The following Table 6.2 shows the small difference between the calculated and measured active or real powers for the IT building.

6.3.2.1 The Difference between Calculated and Measured Active Power

The data is taken from IT substation only for one week, sampling period of 10 minutes and the number of sampling points are 350. The program *active power.m* using MySQL and MATLAB is developed, see the Appendix F, Calculated and measured graphs are given in Figure 6.7 as well as calculated error graphs in Figure 6.8(a). The active power is calculated using the formula $P = V \times I \times \cos\theta$. Only few values of the calculation are shown in the Table 6.2.

Table 6.2: Calculated Active power and Measured Active Power.

Calculated Active power(w)	Calculated Active power(w)	Calculated Active power(w)	Measured Active Power(w)	Measured Active Power(w)	Measured Active Power(w)	Error between calculated and Measured Active Power(w)	Error1 between calculated and Measured Active Power(w)	Error2 between calculated and Measured Active Power(w)
55013.00	30944.00	33440.00	55039.00	30974.00	33465.00	-26.0758	-30.1539	-24.9414
55013.00	30944.00	33440.00	55039.00	30974.00	33465.00	-26.0758	-30.1539	-24.9414
54890.00	30851.00	33381.00	54914.00	30887.00	33404.00	-24.7148	-35.3547	-22.4770
53248.00	29937.00	31924.00	53269.00	29950.00	31928.00	-20.9734	-12.9174	-3.3120
52366.00	29103.00	30969.00	52393.00	29139.00	30998.00	-26.7256	-35.9903	-28.6236
52680.00	29325.00	30985.00	52710.00	29349.00	31006.00	-29.7435	-24.3282	-21.8144
54463.00	30782.00	33259.00	54492.00	30815.00	33280.00	-28.9312	-33.1466	-20.7257
55020.00	31211.00	33440.00	55057.00	31231.00	33606.00	-36.9536	-20.3240	-26.9887
54561.00	30558.00	33440.00	54581.00	30576.00	32981.00	-19.9244	-17.5241	-7.7905
52512.00	29210.00	33381.00	52538.00	29237.00	30940.00	-26.7851	-26.7768	-20.9577

The graphs of the calculated and measured active powers are shown in figure 6.6. It can be seen that the two graphs are very close.

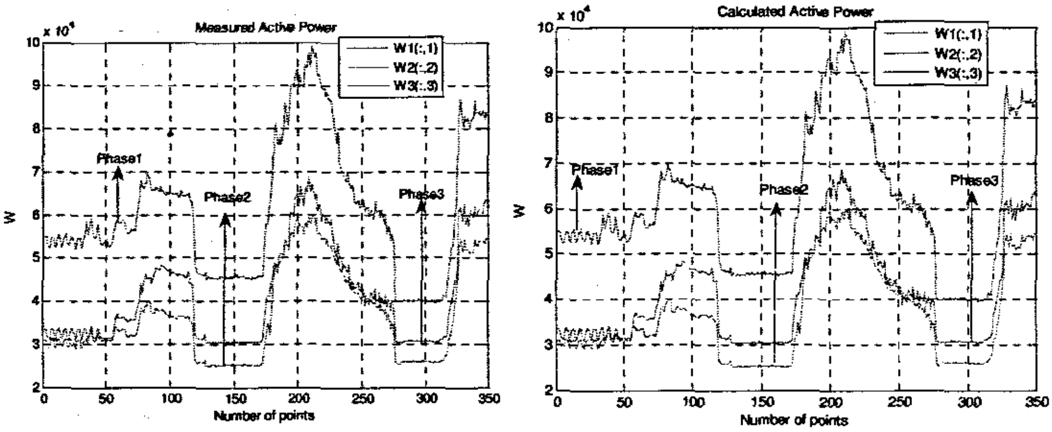


Figure 6.6: Calculated and Measured Active Power Graph

6.3.2.2 The Error between Calculated and Measured Active Power

The errors between the calculated and measured active powers are shown in Figure 6.7(a).

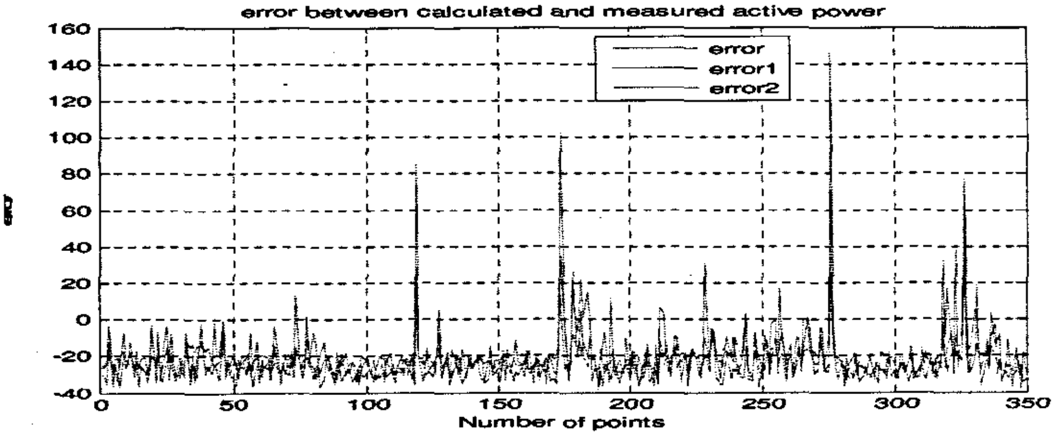
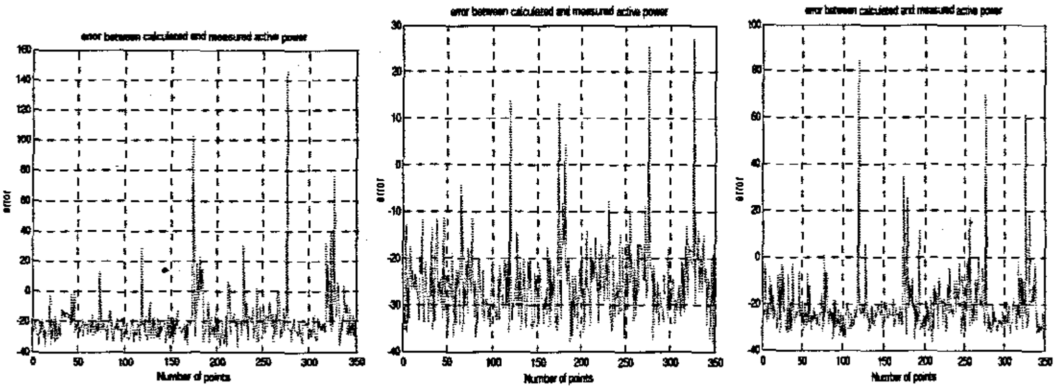


Figure 6.7(a): Error between Calculated and Measured Active Power.

It can be seen that there are some big errors at some moments of time. The graphs of the errors in different phases are shown in Figure 6.7(b). It can be seen that the smallest errors are obtained for phase 1 and the biggest ones for phase 2.



Phase 1 Phase 2 Phase 3

Figure 6.7(b): Errors between Calculated and Measured Active Power in Phases

6.3.3 Apparent Power

The three phase apparent power is not invariant in the power system. Its value depends on how the voltage and currents are defined or measured. The source phase voltage can have different RMS values and can even have different harmonic contents, sometimes from the centre of the load and sometimes from an artificial source (Malengret et al, 2009, 2).

6.3.3.1 The Single-Phase Sinusoidal Situation

The apparent power is defined as the product of the rms values of the voltage and the current ($S = |V||I|$).

It can readily be seen that this is the maximal power that can be realized by a given sinusoidal voltage and a current of given rms value (which corresponds to given line losses). This quantity is characteristic for the cost of the equipment for the power transfer, since the rms value of the current characterizes the required conductor size and the rms value of the voltage characteristics the insulation. The square of the active power and the square of the reactive power ($Q = |V||I|\sin(\varphi)$), determines the square of the apparent power:

$$S^2 = P^2 + Q^2$$

$$S = \sqrt{P^2 + Q^2} \qquad (6.7)$$

Other formula also can be used to calculate apparent power is:

$$S = VrmsIrms \tag{6.8}$$

For sinusoidal single-phase systems the apparent power can hence be defined in various equivalent ways:

- The apparent power is the product of the rms values of voltage and current and characterizes the cost of the equipment (with respect to conductor size and insulation).
- The apparent power is the square root of the sum of the squares of active and reactive power and can be seen as the composition of active (useful) and reactive (non-useful) power;
- The apparent power is the maximal active (useful) power that can be delivered by the given voltage with the given current magnitude (or the same losses in the conductor) (Willems et al, 2003:2).

6.3.3.2 The Difference between Calculated and Measured Apparent Power

The data is taken from IT substation only for one week, sampling period of 10 minutes and the number of sampling points are 640. The program *apparent power work.m* using the MySQL and MATLAB, see the Appendix M is developed for apparent power calculation, plotting of measured and calculated graphs as well as error graphs. Some extract of the calculated and measured apparent power values and of the errors between them is shown in Table 6.3.

Table 6.3: Calculated Apparent power and Measured Apparent Power.

Calculated Apparent Power(w)	Calculated Apparent Power(w)	Calculated Apparent Power(w)	Measured Apparent Power(w)	Measured Apparent Power(w)	Measured Apparent Power(w)	Error1 between calculated and Measured Apparent Power(w)	Error2 between calculated and Measured Apparent Power(w)	Error3 between calculated and Measured Apparent Power(w)
0.6157	3.4416	3.7872	0.6157	3.4416	3.7872	0.0021	-0.0037	0.0016
0.6157	3.4416	3.7872	0.6157	3.4416	3.7872	0.0021	-0.0037	0.0016
0.6150	3.4354	3.7826	0.6150	3.4354	3.7826	-0.0027	-0.0012	-0.0048
0.6003	3.3548	3.6578	0.6003	3.3548	3.6578	0.0015	0.0017	0.0013
0.5928	3.2830	3.5764	0.5928	3.2830	3.5764	-0.0017	-0.0019	0.0001
0.5961	3.3050	3.5809	0.5961	3.3050	3.5809	-0.0010	0.0014	0.0050
0.6115	3.4342	3.7775	0.6115	3.4342	3.7775	-0.0013	-0.0009	-0.0003
0.6172	3.4717	3.8087	0.6172	3.4717	3.8087	-0.0041	-0.0000	0.0000
0.6123	3.4079	3.7478	0.6123	3.4079	3.7477	-0.0015	-0.0009	0.0031
0.5946	3.4416	3.5681	0.6157	3.2912	3.5681	-0.0034	-0.0001	-0.0019

The graphs of the calculated and measured active powers are shown in Figure 6.8.

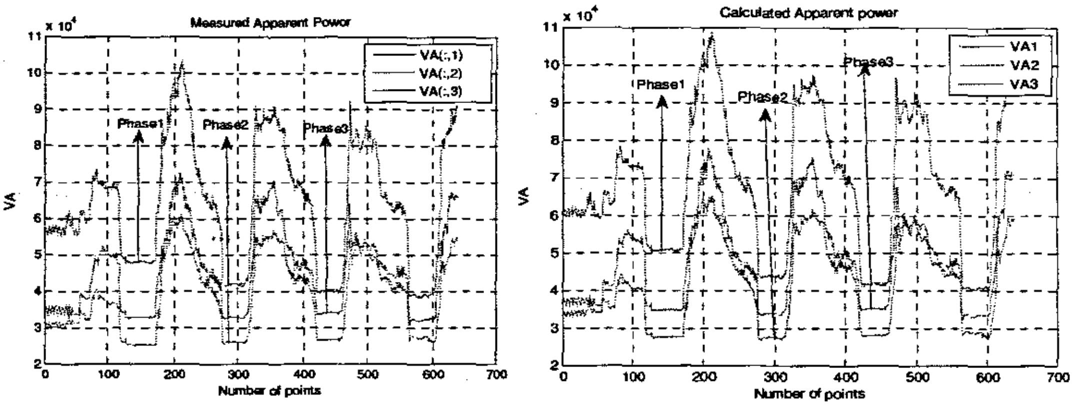


Figure 6.8: Measured and Calculated Apparent power Graph

It can be seen that the two graphs are very close.

6.3.3.3 The Error between Calculated and Measured Apparent Power

The error between the calculated and measured apparent power are shown in figure 6.9

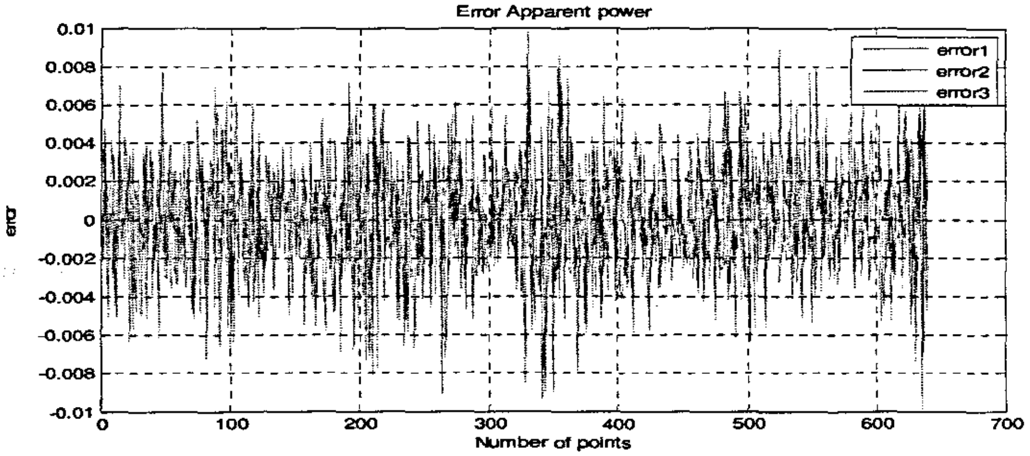
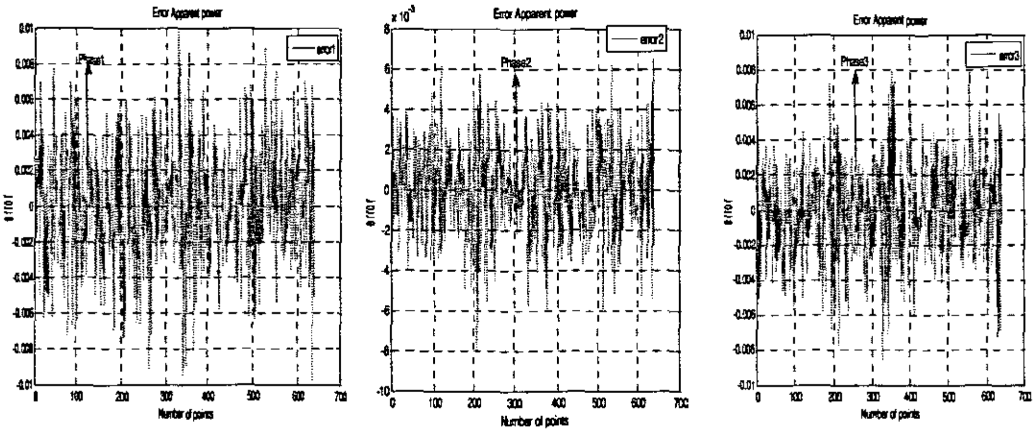


Figure 6.9(a): Error between Calculated and Measured Apparent Power.

The figure 6.9(b) below, shows the errors splitted into three phases, which is phase 1, phase 2, and phase 3. It can be seen that the error is very small its average value is $\bar{e} = \frac{\sum_{i=1}^{n} eAP}{n}$, where n is the number of data points the obtained average value for every of the phases is $\bar{e}_1 = \bar{e}_2 = \bar{e}_3$. The smallest error is for the phase 2 and the biggest one is for phase 1and phase 3



Phase 1 Phase 2 Phase 3

Figure 6.9(b): Error between Calculated and Measured Apparent power in Phases.

6.3.4 RMS Voltage

In electronics, ac voltages typically are specified with a value equal to a dc voltage that is capable of doing the same amount of work. For sinusoidal voltages, this value is $\frac{1}{\sqrt{2}}$ times the peak voltage (V_0) and is called the root mean square or rms voltage (Vrms), given by

$$V_{rms} = \frac{V_0}{\sqrt{2}} = (0.707)V_0 \qquad (6.8)$$

Household line voltages are specified according to rms values. This means that a 230V ac line would actually have a peak voltage that is $\sqrt{2}$ (or 1.414) times greater than the rms voltages. The true expression for the voltage would be $230.\sqrt{2}\ \cos(\omega t)$ (Paul Scherz, 2007:21).

The measured voltage for the IT building obtained by the ImpedoGraph is shown in Figure 6.10

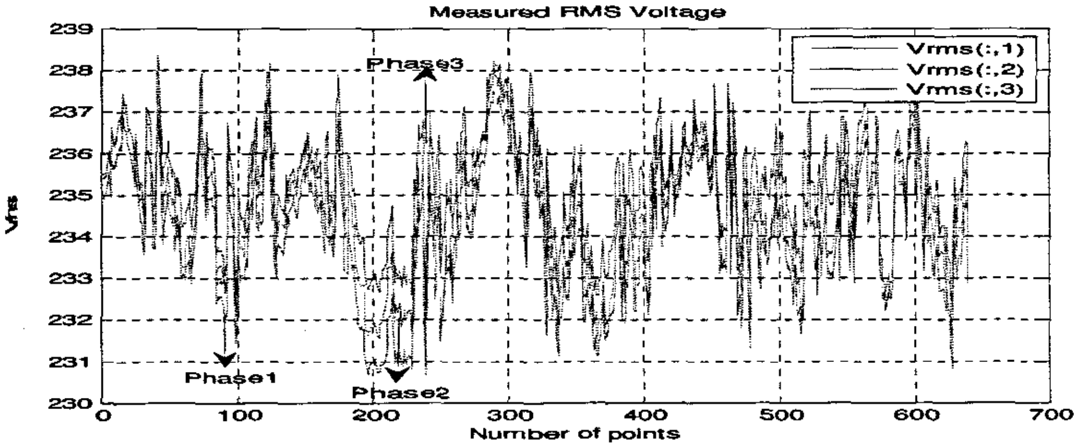


Figure 6.10: Measured Voltage RMS

The data for RMS voltage is used further for calculation of the Crest Factor and the Apparent Power.

6.3.5 Crest Factor

Crest factor is the ratio of the peak value of a sinusoidal waveform to its RMS value. Crest factor can be used as an indicator to quantify the harmonic distortion. The crest factor cannot be related to the commonly used magnitude spectrum; *instead a time-domain approach is needed.* One may distinguish between a low-frequency crest factor and a high-frequency crest factor. The high-frequency crest factor is a measure of the effect of the waveform on insulation aging. The low-frequency crest factor of the current is a measure of the effective loading of electronic series components. Note again that also the crest factor does not directly quantify the impact of the waveform distortion. For this needs to be multiplied by the rms value of the voltage or current. It could be more appropriate to use the voltage or current magnitude estimated from the peak values (Bollen, et el,2006:207).The formula for crest factor is:

$$\text{Crest factor (cf)} = \frac{\text{Peak Value}}{\text{RMS Value}} \tag{6.9}$$

6.3.5.1 The Difference between Calculated and Measured Crest Factor

The data is taken from IT substation, sampling period of 10 minutes and the number of sampling points are 640. The program *crest factor.m* using the MySQL and MATLAB see the appendix K is developed for crest factor calculation, plotting of measured and calculated graphs as well as error graphs. Some extract of the calculated and measured crest factor values and of the errors between them is shown in Table 6.4.

Table 6.4: Crest Factor Calculations

Calculated Crest Factor1	Calculated Crest Factor1	Calculated Crest Factor1	Measured RMS Voltage1	Measured RMS Voltage2	Measured RMS Voltage3	Calculated Voltage Peak 1	Calculated Voltage Peak 2	Calculated Voltage Peak 3	Error between measured and calculated crest factor 1.e-006	Error between measured and calculated crest factor 1.e-006	Error between measured and calculated crest factor 1.e-006
1.9981	2.0936	1.9247	234.9948	235.4868	235.3687	469.5430	493.0151	453.0141	0.2125	0.1424	0.1567
1.9981	2.0936	1.9247	234.9948	235.4868	235.3687	469.5430	493.0151	453.0141	0.2125	0.1424	0.1567
1.9998	2.094	1.9269	234.9160	235.4868	235.3687	469.7851	493.1093	453.5319	-0.0988	0.1200	0.2465
2.0152	2.1146	1.9444	235.0538	235.5459	235.4474	473.6804	498.0852	457.8040	0.1181	0.0988	-0.0302
2.0244	2.1274	1.9518	235.5262	235.9198	235.9591	476.7991	501.8957	460.5450	0.1616	0.2118	0.1672
2.0235	2.138	1.9537	235.5065	236.0576	236.0575	476.5473	504.6911	461.1857	0.1785	-0.1556	-0.1908
2.0104	2.1079	1.9354	234.9357	235.5065	235.6246	472.3148	496.4241	456.0278	-0.1644	-0.0505	-0.1128
2.0039	2.1076	1.9282	235.8607	236.4905	236.6086	472.6413	498.4275	456.2288	0.0714	-0.1180	-0.1252
2.0015	2.0996	1.9225	235.6049	236.1363	236.1756	471.5631	495.7917	454.0477	0.1583	0.1842	-0.1359
2.0121	2.1184	1.9416	235.8214	236.3921	236.3331	474.4962	500.7731	458.8643	-0.0484	0.0397	0.0767

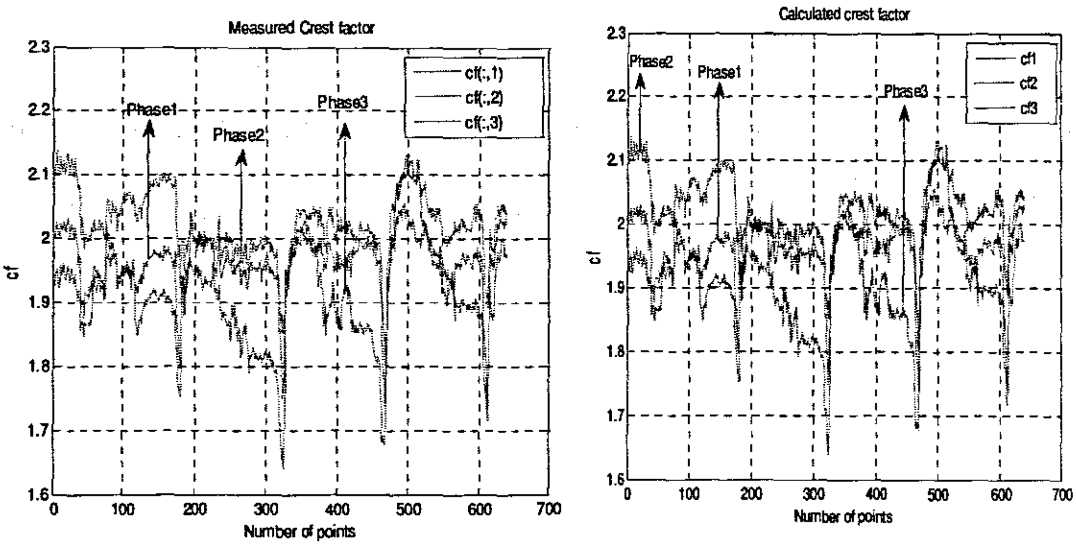


Figure 6.11: The Comparison between Calculated and Measured crest factor in Phases.

It can be seen that the two graphs are very close.

6.3.5.2 The Error between Calculated and Measured Crest factor

The error between the calculated and measured crest factor are shown in figure 6.11(a)

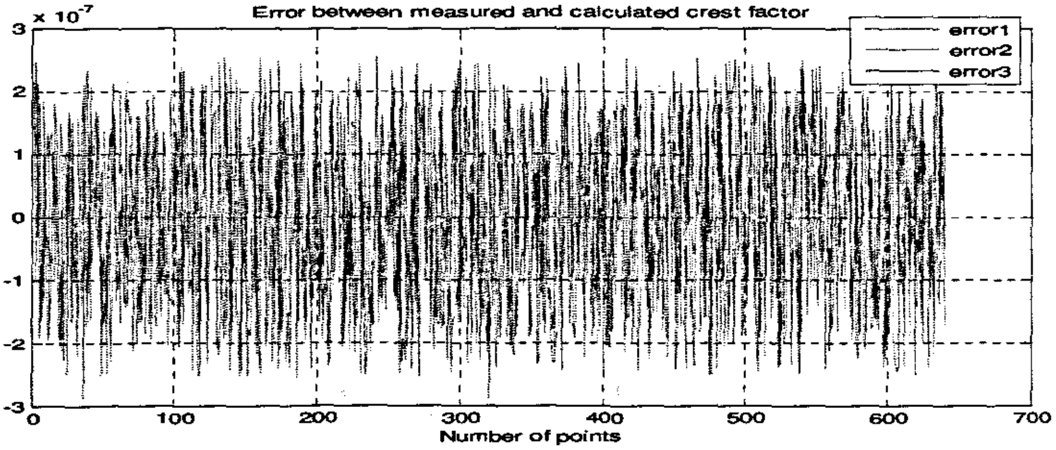


Figure 6.11(a): Error between Calculated and Measured crest factor

It can be seen that the error is very small in the range of 10^{-7}. The figure 6.11(b) below, shows the errors are splitted into three phases, which is phase 1, phase 2, and phase 3.

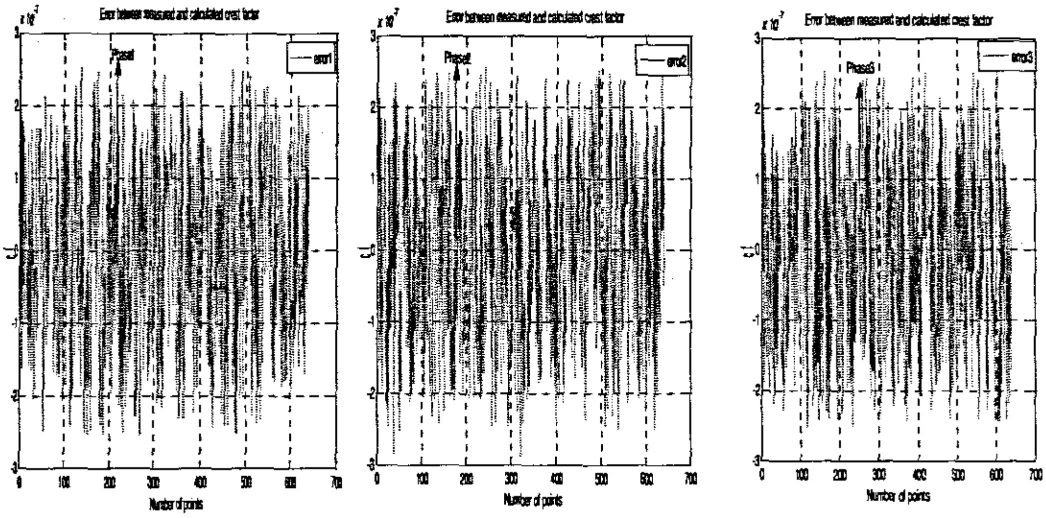


Figure 6.13(b): Error between Calculated and Measured crest factor in Phases.

6.3.6 Voltage Peak

Peak voltage is the highest of voltages given from alternating current. Peak voltage is actually measured from 0V baseline to either the positive peak or the negative peak, and while peak to peak voltage is measured from the positive peak to the negative peak (+Vp to –Vp).

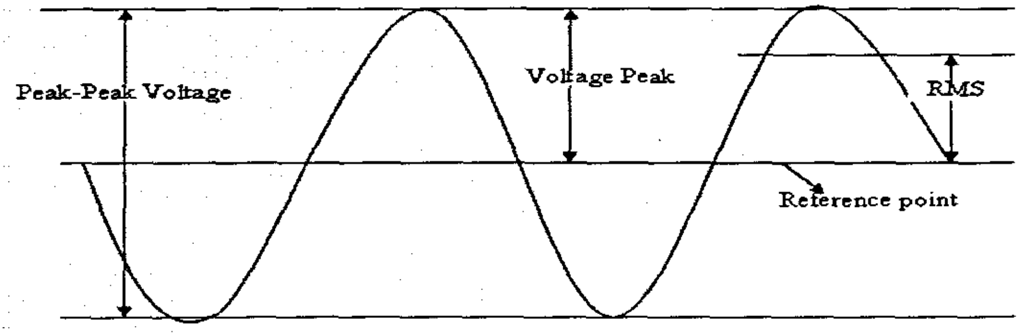


Figure 6.14: Sine Wave with Peak-Peak, Peak Voltage and RMS Voltage.

Due to the fact that crest factor and root mean square (rms) voltage are measured data, then formula can be used to calculate the voltage:

$$\text{Voltage Peak} = \text{Crest factor} \times \text{rms voltage} \tag{6.9}$$

This data also is taken from IT substation only for one week, sampling period of 10 minutes and the number of sampling points is 640. The program *(vpeak)whole.m* using MySQL and MATLAB is developed for the calculations, see Appendix G. Part of the calculated voltage peaks for every phase are shown in Table 6.5. Plot of the calculated peaks for all data points is given in Figure 6.15

Table 6.5: Voltage Peak Calculations

Measured Crest Factor1	Measured Crest Factor1	Measured Crest Factor1	Measured RMS Voltage1	Measured RMS Voltage2	Measured RMS Voltage3	Calculated Voltage Peak 1	Calculated Voltage Peak 2	Calculated Voltage Peak 3
1.9981	2.0936	1.9247	234.9948	235.4868	235.3687	469.5430	493.0151	453.0141
1.9981	2.0936	1.9247	234.9948	235.4868	235.3687	469.5430	493.0151	453.0141
1.9998	2.094	1.9269	234.9160	235.4868	235.3687	469.7851	493.1093	453.5319
2.0152	2.1146	1.9444	235.0538	235.5459	235.4474	473.6804	498.0852	457.8040
2.0244	2.1274	1.9518	235.5262	235.9198	235.9591	476.7991	501.8957	460.5450
2.0235	2.138	1.9537	235.5065	236.0576	236.0575	476.5473	504.6911	461.1857
2.0104	2.1079	1.9354	234.9357	235.5065	235.6246	472.3148	496.4241	456.0278
2.0039	2.1076	1.9282	235.8607	236.4905	236.6086	472.6413	498.4275	456.2288
2.0015	2.0996	1.9225	235.6049	236.1363	236.1756	471.5631	495.7917	454.0477
2.0121	2.1184	1.9416	235.8214	236.3921	236.3331	474.4962	500.7731	458.8643

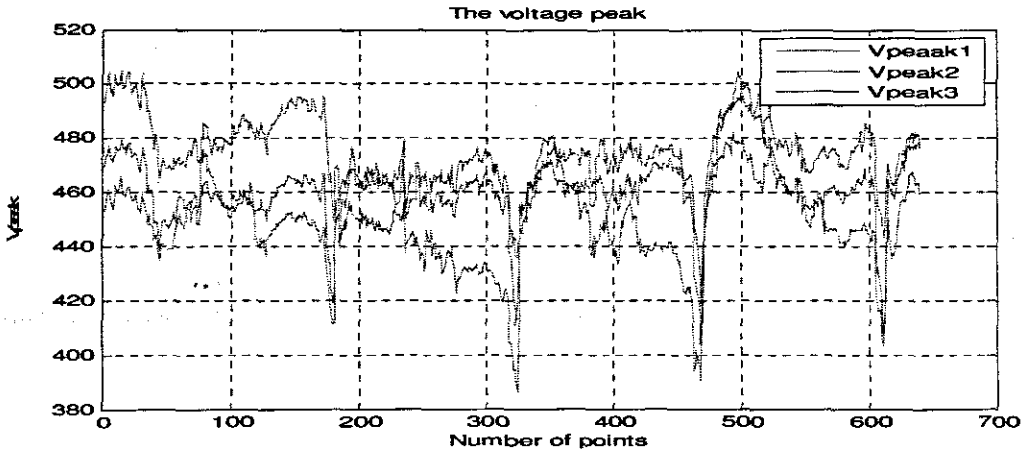


Figure 6.15: Calculated Voltage Peak

The graphs of the calculated voltage peak and the measured crest factor are showing approximately the same type of behaviour.

The voltage peak is giving information for the power quality disturbance. The calculated values can be used to see if some sensitive equipment is used properly. Some high values and low values points are observed on the graphs.

6.3.7 Voltage Unbalance.

Voltage unbalance is considered as a power quality disturbance of important concern at electrical distribution. Because of unbalance voltage, the distribution system sustains a lot (more) of losses. Heating effects and low stability of the system are also some of the consequences. Voltage unbalanced is harmful to the equipment like adjustable speed drives (ASD), induction motors. Uneven distribution of the single phase loads which changes across the distribution system causes unbalance voltages.

6.3.7.1 Causes of Unbalanced Voltages.

- Faults in the power transformer.
- Unbalanced transformers tap settings.
- Open delta connections.
- Unbalanced or unequal single-phase loads.
- Welders.
- Unbalanced incoming utility supply.

6.3.7.2 Definition of voltage unbalance.

Voltage unbalance defined as a considered as a power quality disturbance of the significant concern at electrical power distribution level. Three phases in the Figure 6.16. The algorithm for calculation of voltage unbalance can be written as:

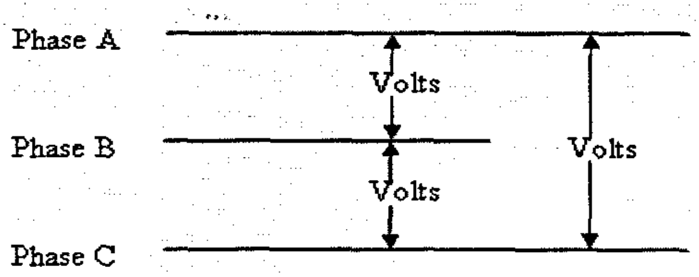


Figure 6.16: Phases in Voltage

Zero step: Take the measurements of the phase voltages $V1, V2, V3$.

First step: Add the voltage readings together.

Second step: Find the voltage average. Voltage Avg = $\frac{V_1+V_2+V_3}{3}$ (6.10)

Third step: Subtract the voltage average from one of the voltages that indicates the greatest *voltage difference.*

Fourth step: Divide the greatest voltage difference by voltage average.

$$\text{Voltage Unbalance}(\%) = \frac{\text{Maximum Deviation from the Average}}{\text{Voltage Average}} 100\% \qquad (6.11)$$

The voltage unbalance caused by a load connected only between two phases may be calculated as:

$$\text{Voltage Ubalance} = \frac{\text{Single phase load (MVA)} \times 100\%}{\text{Three - phase short circuit level (MVA) at the point}}. \qquad (6.12)$$

The data is taken from IT substation only for one week, sampling period of 10 minutes and the number of sampling points is 640. The program *voltage unbalance.m* using MySQL and MATLAB *for calculation of voltage unbalance according to equations* 6.10, 6.11 is developed Appendix H. Some of the calculated values are shown in Table 6.6.

Table 6.6: Voltage Unbalance

Measured Voltage1	Measured Voltage2	Measured Voltage3	Calculated Voltage Unbalance (%)
234.9948	235.4868	235.3687	0.1227
234.9948	235.4868	235.3687	0.1227
234.9160	235.4868	235.3687	0.1450
235.0538	235.5458	235.4474	0.1254
235.5262	235.9198	235.9591	0.1169
235.5065	236.0576	236.0576	0.1558
234.9357	235.5065	235.6246	0.1784
235.8607	236.4905	236.6086	0.1943
235.6049	236.1363	236.1756	0.1557
235.8214	236.3921	236.3331	0.1227

The plot of the voltage unbalance is shown in Figure 6.17.

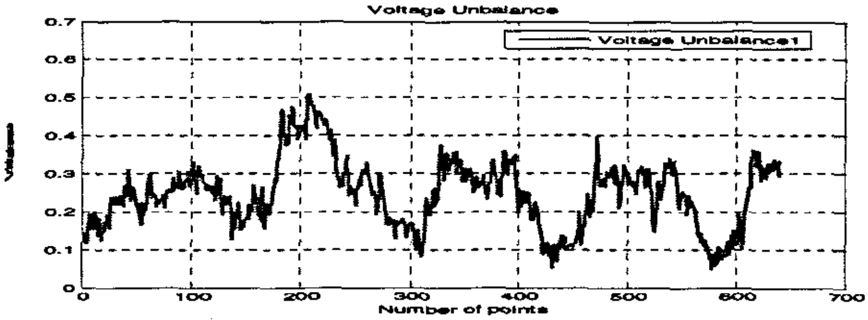


Figure 6.17: Voltage Unbalance Graph.

Reduction of Unbalance

- *Connection of distribution loads to a different supply points*
- Rearrangement of phase connections of one or more loads
- Connection of distribution load at a higher voltage level
- Provision of phase balancing or filtering equipment (Abu Dhabi,2005:5).

6.4 Discussion of the Results Obtained for IT building

The measured power quality disturbances parameters/ indicators obtained at IT building are compared with the calculated power quality disturbances parameters, the results for calculated and measured parameters are very close. The calculated parameters are power factor, crest factor, active power, apparent power, voltage peak, voltage unbalance.

6.5 Conclusion

The chapter calculates some of the power quality characteristic parameters using the measured and saved in MySQL database data from Cape Peninsula University of Technology reticulation network. MATLAB.programs to communicate with the database and calculate the disturbances and power quality parameters are developed. The calculated results are very close to the measured data.

This chapter also shows the importance of capturing the power quality data around CPUT Bellville campus. The data indicates clearly what types of power quality disturbances need to be sorted out. The next chapter describes the importance of Fourier analysis and calculations of harmonic spectrum.

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CHAPTER SEVEN

FOURIER ANALYSIS AND HARMONICS

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7.1 Introduction

Fourier analysis is the method of decomposing the periodic function into essential sine and cosine waves. Fourier analysis also helps to understand the behaviour of signals and systems. Many waveforms consist of a sum of variables, (for example power (energy)) at the multiples of the fundamental frequency (harmonics) and also at the fundamental frequency (harmonics), where the relative size of power (energy) at the fundamental and of harmonics determines the shape of the wave. The wave function can be expressed as the sum of sine functions and cosine functions and it is called Fourier series.

7.2 IEC Standard Method: IEC 6100-4-30, IEC 61000-4-7

Harmonic and Interharmonic measurement has been proposed by IEC. So the Discrete Fourier Transform is performed over a rectangular window with determined length.

7.2.1 IEC 61000-4-30

IEC 61000-4-30 defines the way the voltage quality should be measured. According to IEC 6100-4-30 standard, the basic measurement window used to calculate the unbalance is the same as for voltage magnitude and harmonic distortion: 10 cycles in a 50Hz system, 12 cycles in a 60Hz system, about 200ms in each case. Next to the negative-sequence unbalance, a " zero-sequence" may be calculated as the ratio between zero-sequence and positive-sequence voltage (Umar Naseem Khan, 2009-09-20)

7.2.2 IEC 61000-4-7

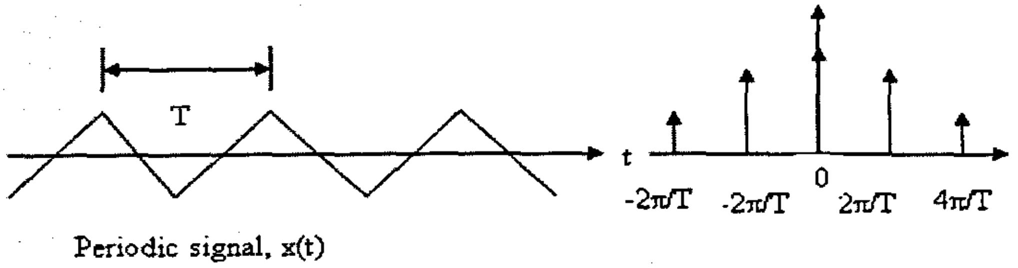
The IEC 61000-4-7 standard actually defines the way in which the harmonic current distortion should be measured. The assessment of harmonics up to 9kHz is performed by the application of the Fourier transform, using a rectangular window whose width is equal to 10 cycles (50Hz system). Since the Fourier algorithm assumes that the analyzed signal is stationary, to improve the assessment accuracy, IEC 61000-4-7 requires the application of grouping, which consists in the summation of harmonic components of neighboring frequencies. The analytical relations used in the present analysis to describe the grouping methodology for integer harmonic, interharmonics and higher frequency harmonics are given in (Tentzerakis et al, 2009-09-20).

7.3 FREQUENCIES-DOMAIN ANALYSIS AND SIGNAL TRANSFORM:

7.3.1 Continuous and Discrete Fourier Series

7.3.1.1 Continuous-Time Periodic Signals

The continuous-time periodic signals are the signals that satisfy the condition for periodicity to be determined for $-\infty < t < \infty$. And also it is important to note that if this condition is satisfied for a given period T, it is also satisfied for all integer multiplies of T. So the smallest **T** which satisfies this condition is called a period of the periodic signal. The frequency formula of the periodic signal is $f=\frac{1}{T}$ and $T=\frac{1}{f}$. Angular frequency is $\omega=2\pi f$ or $\omega=\frac{2\pi}{T}$ [rad]. The graphical presentation of an periodic signal is given in Figure 7.1a),b)



a)Time domain representation b)Frequency representation

Figure 7.1: Representation of a Periodic Signal.

A continuous-time periodic signal with period T can be decomposed into an infinite sum of complex exponentials, multiplied by Fourier coefficients (Andrew E. Yagle, 2009:2):

$$x(t)=\sum_{-\infty}^{\infty} x_k e^{j\frac{2\pi}{T}kt} \qquad (7.1)$$

where x_k are the coeffierents and *x(t)* can also be represented in this form:

$$x(t)=x_0+x_1e^{j\frac{2\pi}{T}t}+x_2e^{j\frac{4\pi}{T}t}+x_3e^{j\frac{6\pi}{T}t}+x_4e^{j\frac{8\pi}{T}t}+\ldots\ldots$$

$$+x_1 e^{-j\frac{2\pi}{T}t} + x_2 e^{-j\frac{4\pi}{T}t} + x_3 e^{-j\frac{6\pi}{T}t} + x_4 e^{-j\frac{8\pi}{T}t} + \ldots.. \qquad (7.2)$$

In order to get the coefficients x_k the following formula is applied:

$$x_k = \frac{1}{T}\int_{-\frac{T}{2}}^{\frac{T}{2}} x(t)e^{-j\frac{2\pi}{T}k.t}dt \qquad (7.3)$$

7.3.1.2 Discrete-Time Periodic Signals

Discrete-time signals are signals which are represented by their values at discrete moments of time. One illustration of a discrete time signal is shown in Figure 7.2, where **n** is the discrete time.

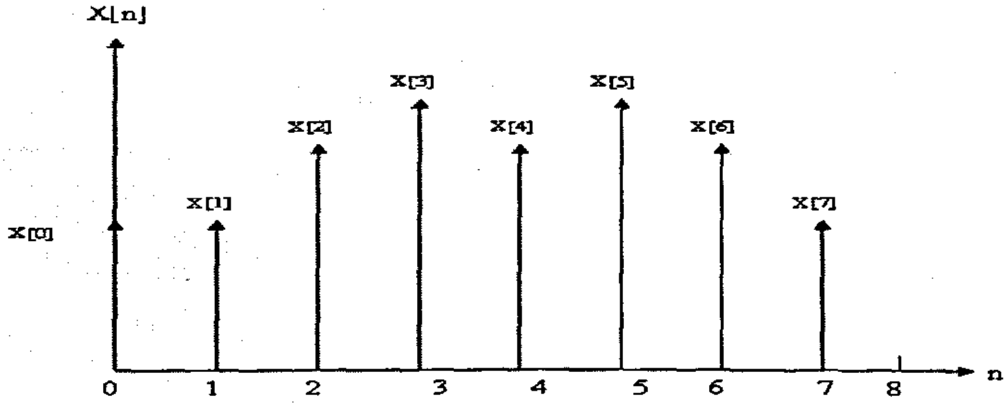


Figure 7.2: Data points (X [0], X [1], X [2], X [3]...) represent the signal.

The periodic sequence *x(n)* can have a period N. It is where *x(n)=x(n+N)* for all n. Fourier series actually represents *x(n)* which consists of N harmonically related exponential functions:

$$W_N = e\frac{-j2\pi kn}{N} \text{ where } k = 0,1,2......N-1 \qquad (7.5)$$

The discrete periodic signal *x(n)* can be calculated using the Fourier formula

$$x(n) = \sum_{k=0}^{N-1} x_k e^{\frac{j2\pi kn}{N}} \qquad (7.6)$$

In an extended form:

$$x[n] = x_0 + x_1 e^{j\frac{2\pi}{N}n} + x_2 e^{\frac{j4\pi}{N}n} + x_3 e^{j\frac{6\pi}{N}n} + x_{\frac{(N-1)}{2}} e^{j\pi\frac{N-1}{N}n}$$

$$+x_1 e^{-j\frac{2\pi}{n}n} + x_2 e^{-j\frac{4\pi}{N}n} + x_3 e^{-j\frac{6\pi}{N}n} + x_{\frac{(N-1)}{2}} e^{-j\pi\frac{N-1}{N}n}$$

$$x[n] = x_0 + x_1 e^{j\frac{2\pi}{N}n} + x_2 e^{\frac{j4\pi}{N}n} + x_3 e^{j\frac{6\pi}{N}n} + x_{\frac{(N-1)}{2}} e^{j\pi\frac{N-1}{N}n} \tag{7.7}$$

The coefficients x_k are computed using the following formula, which is the N-point DFT

$$x_k = \frac{1}{N}\sum_{n=0}^{N-1} x(n) e^{\frac{-j2\pi kn}{N}} \tag{7.8}$$

where x_k are the coefficients in the series representation. x_k represent the amplitude and phase associated with the frequency components $e^{\frac{j2\pi kn}{N}}$.

7.4 Discrete Fourier Transform

Discrete Fourier Transform is a discrete type of Fourier transform, used in Fourier analysis. Discrete Fourier Transform always allows using a finite-length window of data. The finite-length window of data has to be periodical in a way that a finite length signal is the element of the related periodic signal. Finite-length consists of **N** samples, where the samples are taken at the moments t_n:

$$t_n = n\Delta t = \frac{nT}{N} \quad \text{where } \Delta t = \frac{T}{N} \quad n = 0,1,2.......N-1 \tag{7.9}$$

N is the number of samples within the measurement window T. The windows with the sampling period N(T) is given in Figure 7.3.

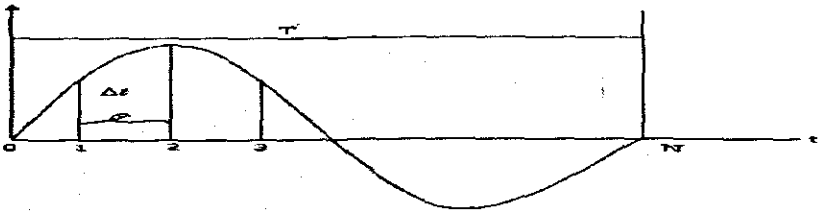


Figure 7.3: Window with length equal to the period T

The DFT is often used in harmonic measurement because the measured data is always available in the form of a sampled time function. The sampled time function is represented by a time series of points of known magnitude separated by fixed time intervals of limited duration. Fourier analysis can be done by DFTs. The DFTs are often calculated by the use of fast Fourier transform (FFT) algorithm. FFT techniques are very fast methods for performing the DFT calculations (7.10) and (7.11):

$$x[k] = \frac{1}{N}\sum_{n=0}^{N-1} x[n]e^{-j\frac{2\pi}{N}k.n} \tag{7.10}$$

$$x[n] = \sum_{k=0}^{N-1} x[k]e^{j\frac{2\pi}{N}k.n} \tag{7.11}$$

where $k,n = 0,1......,N-1$.

which allow the evaluation of a large number of functions. There are a number of available FFT algorithms that can be easily used in harmonic analysis (Chang & Ribeiro 2009-09-08). The research work in the thesis requires development of an algorithm for studying of the power quality harmonics by their calculation and analysis. The application of campus data for this purpose is not possible because of a variable meters can not store data measured with small sampling period. On the basis of above the investigation is done using generated voltage periodic signals.

7.4.1 Analysis and Synthesis of Discrete Signals, DFT, the Sampling Theorem and Phenomena Aliasing.

The meters used for measurement can calculate harmonics on the basis of 200 milliseconds windows but they are not made to save the data from these windows. That is why in order to provide some investigations with DFT or FFT is necessary to design a test signal which can be considered as a real one. Such signal can be generated in Simulink.

MATLAB has a toolbox called Simulink. Simulink offers a set of commands for analyzing and synthesizing same basic discrete signals: Square wave, sine wave etc. Some of the complex signals can be analyzed and synthesized by the combination of the basic signals. In Figure 7.4, sine wave and uniform random numbers are summed to produce complex sine wave. The addition of uniform random noise in sine wave can generate noise. The purpose of building Simulink model is to generate a data that can be used for analysis with DFT or FFT.

The data for Simulink function, summed with Uniform Random Number function with parameters, minimum=-10, maximum=10, initial seed=0, sample time=0.002 is generated. The sine wave, parameters are: amplitude = 10, bias=0, frequency=100, phase=0. The parameters of the function To workspace are: decimation=1, sample time=0.002. The frequency of the sine function is $\omega = 2\pi f$,then $f = \frac{\omega}{2\pi}$ and, the period is $T = \frac{1}{f}$. The sampling $\Delta t = \frac{T}{N}$ time between data points, where N is the number of point is taken in the window equal to the value of the period.

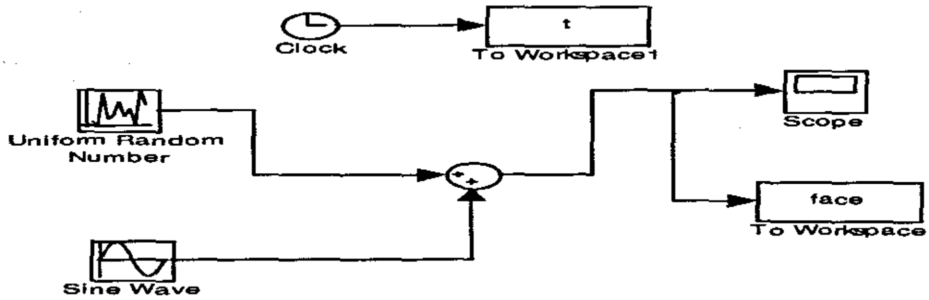


Figure 7.4: Sine Wave and Uniform Random number in Simulink

The Uniform Random Number block generates uniformly distributed random numbers over a specifiable interval with a specifiable starting seed. The seed is reset each time a simulation starts. The generated sequence is repeatable and can be produced by any Uniform Random Number block with the same seed and parameters [http://www.oit.uci.edu/dcslib/MATLAB (2009-11/2:50 PM)].

Sine Wave block gives a sinusoidal waveform and it operates either in continuous or in discrete mode.

The Uniform Random Number and Sine Wave block were built in Simulink and added together to make a data. The purpose of adding those signals together is to make sometimes the sample point at the positive peak to move unpredictably up and down from its correct value. In figure 7.5 below, the waveform of noise have small spikes with zero crossings occurring at irregular intervals. The data can be used to calculate the harmonics.

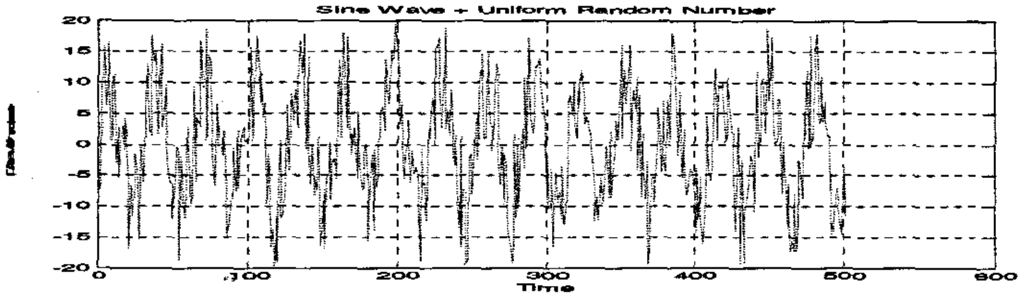


Figure 7.5: Generation of the distorted signal in Simulink

7.4.1.1 Calculations Using Discrete Fourier Transform

The Simulink model in Figure 7.4 is simulated to create a data which is used in DFT, considering the discrete-time periodic signal. The noise signal has period T=0.02 and is sent to MATLAB work space in the file *face*. The window selected for the example calculation is:

face = {.......*-5.6208 -7.0724 7.4715 9.2324*......}

The number of points in the period T = 0.02, is N=4 and Discrete Fourier Transform (DFT) is computed using the following formulas for the coefficients of the Fourier series:

$$x_k = \frac{1}{N}\sum_{n=0}^{N-1} x[n]e^{-j\frac{2\pi}{N}k.n}, \quad k = 0,1,2,3 \tag{7.12}$$

Which applied to the considered example is:

$$face_k = \frac{1}{4}\sum_{n=0}^{3} x[n]e^{-j\frac{2\pi}{N}k.n}, \quad k = 0,1,2,3 \tag{7.13}$$

The equations below were used to calculate discrete Fourier transform or fast Fourier transform.

$$face_0 = \frac{1}{4}(x[0] + x[1]e^{-j0} + x[2]e^{-j0} + x[3]e^{-j0}) = 1.0027$$

$$face_1 = \frac{1}{4}(x[0] + x[1]e^{-j\frac{2\pi}{4}} + x[2]e^{-j\frac{4\pi}{4}} + x[3]e^{-j\frac{6\pi}{4}}) = -3.2731 + 4.0762j$$

$$face_2 = \frac{1}{4}(x[0] + x[1]e^{-j\frac{4\pi}{4}} + x[2]e^{-j\frac{8\pi}{4}} + x[3]e^{-j\frac{12\pi}{4}}) = -0.3093 - 0.0000j$$

$$face_3 = \frac{1}{4}(x[0] + x[1]e^{-j\frac{6\pi}{4}} + x[2]e^{-j\frac{12\pi}{4}} + x[3]e^{-j\frac{18\pi}{4}}) = -13.0923 - 16.3048j$$

The obtained coefficients are used further for calculation of the inverse Fourier transform.

7.4.1.2 DFT/ FFT MATLAB Program

Now it is wise to prove the hand writing calculations by programming using MATLAB software. The calculations for **facek** coefficients and **X(n)** follow:

Discrete Fourier Transform (DFT) program

The software implements the formula for the DFT

$$x_k = \frac{1}{N}\sum_{n=0}^{N-1} x[n]e^{-j\frac{2\pi}{N}k.n} \qquad k = 0,1,2,3 \tag{7.14}$$

```
% Discrete Fourier Transform
% This function generates the coefficients for a signal face(k)
% Number of samples =N
% Perform summation

face=[-5.6208  -7.0724   7.4715   9.2324]      % define a sequence length
N = length(face);
for k=0:N-1;
   facen=0;                                    % summation
  for n=0:N-1;
     facen=facen+face(n+1)*exp(-i*(2*pi/N)*n*k);
  end
  facen1(k+1,1)=facen;
  facek=facen1/N;
 end
```

The results from the running of the above software is

```
facek =
   1.0027
  -3.2731 + 4.0762i
```

```
 -0.0773 - 0.0000i
-3.2731 - 4.0762i
```

It can be seen that the results from the manual calculation and the software calculations are the same.

In order to prove that the calculated coefficients are right ones to generate the data the Inverse Discrete Fourier Transform (IDFT) is used. The calculations are done according to the formula:

$$x[n]=\sum_{k=0}^{N-1} x[k]e^{j\frac{2\pi}{N}k.n}$$

which can be written in the following way.

$$X[n]=1.0027+(-3.2731+4.0762i)e^{j\frac{2\pi}{4}n}+(-0.0773)e^{j\frac{4\pi}{4}n}+(-3.2731-4.0762i)e^{\frac{6\pi}{4}n}$$

MATLAB program used for calculating the values of the data samples are as follows:

```
x=facek;
N=length(x);
 for n=0:N-1;
   sum=0;
 for k=0:N-1;
     sum=sum+x(k+1)*exp(i*(2*pi/N)*n*k);
  end
  sum1(n+1,1)=sum;
  Xn=sum1/1;
 end
```

The result for the four samples of data is

```
Xn =
   -5.6208 - 0.0000i
   -7.0724 - 0.0000i
    7.4715
    9.2324 - 0.0000i
```

The result shows that face = Xn, or the result verifies that the program in MATLAB performs well.

7.5 Calculation of the Harmonics Created in Simulink Model

7.5.1 Application of the developed software

In the power system, the definition of a harmonics can be stated as: A sinusoidal component of a periodic wave having a frequency that is an integral multiple of the fundamental frequency. Thus for a power,.system with fundamental frequency, the frequency of the *h*-th order of harmonic is hf_0. Harmonics are often used to define distorted sinewaves associated with currents and voltages of different amplitudes and frequencies (Chang et al,2009-10:2).

The data for Simulink function, on Uniform Random Number the parameters are: minimum=-10, maximum=10, initial seed=0, sample time=0.02. On the sine wave, amplitude = 10, bias=0, frequency=50, phase=0 and to workspace, decimation=1, sample time=0.02. The following data created in Simulink is considered, Figure 7.7

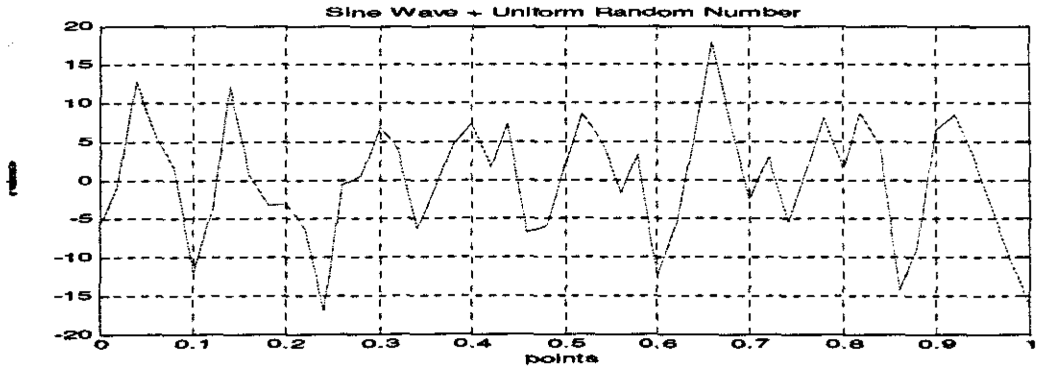


Figure 7.7: Data generated by the Simulink model.

The calculation of the coefficients for the whole period is performed in MATLAB in the same way as in the example above. The array of the absolute values of obtained coefficients is plotted following harmonics, Figure 7.9.MATLAB program *Harmonics example.m* for harmonics see Appendix I. Table 7.1 is for estimated data and coefficients of facek

Table 7.1: Estimated data and coefficients of facek(Xk) from Simulink

face	Inverse Fourier Transform (Xn)	Coefficients of facek(Xk) in FFT
-5.6208	-5.6208 - 0.0000i	0.0859
-0.7541	-0.7541 + 0.0000i	-0.8290 +0.5755i
12.8294	12.8294 + 0.0000i	-0.1656 - 0.0549i
5.5882	5.5882 + 0.0000i	0.2385 - 1.0760i
1.6724	1.6724 - 0.0000i	-0.7579 - 0.4262i
-12.1545	-12.1545 + 0.0000i	-0.7961 - 0.1898i
-3.5352	-3.5352 - 0.0000i	0.2252 - 0.1232i
12.0729	12.0729 - 0.0000i	-1.0379 - 0.5333i

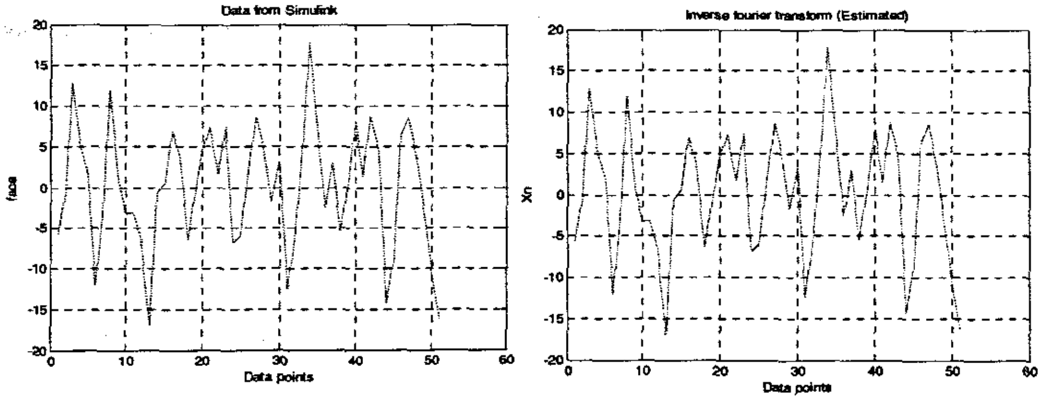


Figure 7.8: Data from Simulink and Estimated data

It can be seen that data from Simulink and estimated data are the same to prove that calculations are right.

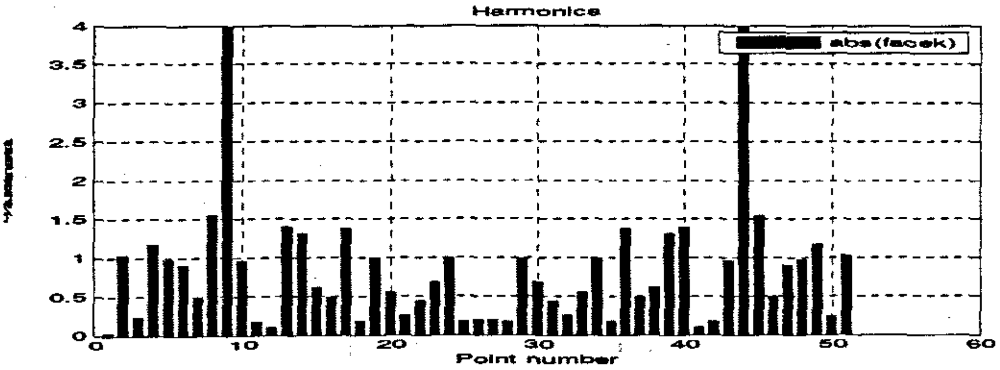


Figure 7.9: Harmonics.

When the signal is periodic with fundamental frequency, frequencies composing this signal are integer multiples of (Hz), example 1fHz, 2fHz, 3fHz, 4fHz. These frequencies represents harmonics, so the first harmonic is 1fHz, second harmonic is 2fHz etc.

7.5.2 Error between Original data and Estimated Signal

MySQL and MATLAB program *Harmonics example.m* for error between original data and estimated signal is in Appendix I. To compare the original data with the estimated signal by the inverse FFT, the error between is calculated the following way: err=face-Xn

The results are shown in Figure 7.10

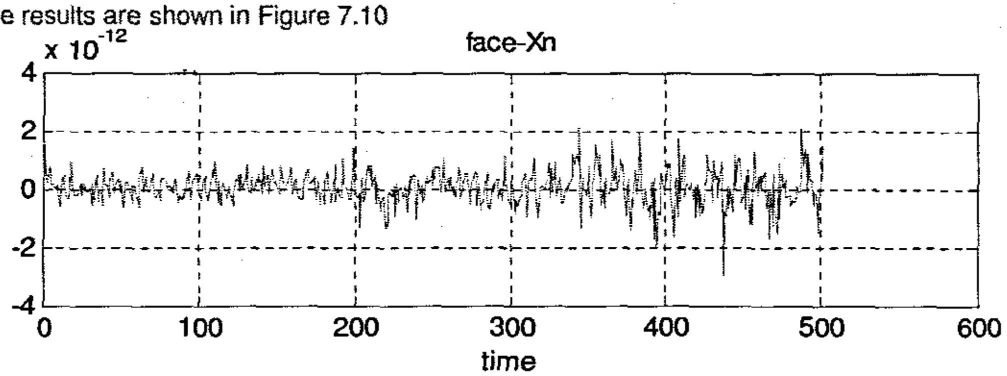


Figure 7.10: Error in the Calculation of the Coefficients of the harmonics.

It can be seen that the values of the errors for every moment is in the range of 10^{-12}, which shows that the estimated signal is very close to the original data.

7.5.3 Calculations of separate Harmonics

In Figure 7.11, the inverse Fourier transform is applied, *but it applied only for one of the multiple* frequencies. See Appendix I

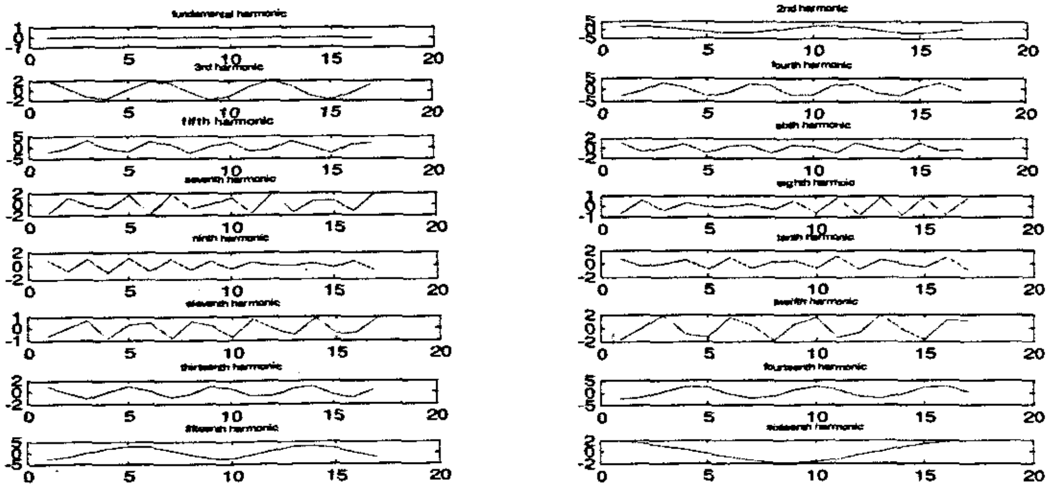


Figure 7.11: Graphs of the separate harmonics

7.6 Harmonics signal generation using ImpedoGraph meter.

The ImpedoGraph meter has capability to sample the real signal and prescribes values of the sampling interval.

This meter however has not capability to save the measured waveforms. One way to overcome this difficulty is to use an injector as input to the ImpedoGraph and to generate the required waveforms.

Voltage and current were injected from the injector using ImpedoGraph meter in order to compute harmonics using FFT in MATLAB. The following Figure 7.12 shows the voltage square waveform generated by the injector. The configuration template for the time of square wave form is to produce signal for 0.5s (half a second) every one minute for the period of 25 minutes.

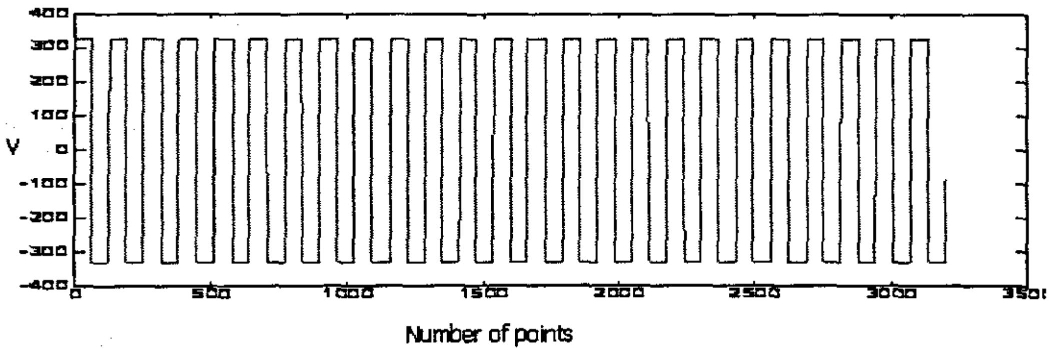


Figure 7.12: Voltage Square Wave form from the Injector

The ImpedoGraph produces three phase voltages. These signals are used for calculation of DFT and then Inverse Fourier transform is applied. The voltage data and the data obtained by the calculations are compared to find the error of the estimation. Some of the results are shown in Table 7.2. The absolute value of the harmonics is show in Figure 7.13

Table 7.2: Measured Voltages and Coefficients of Xk

Measured Voltage1	Measured Voltage2	Measured Voltage3	Inverse Fourier Transform (Xn)	Inverse Fourier Transform (Xn)	Inverse Fourier Transform (Xn)	Coefficients of Voltage_1k (Xk) in FFT	Coefficients of Voltage_2k (Xk) in FFT	Coefficients of Voltage_3k (Xk) in FFT
328.1267	328.1070	328.4219	328.13	328.11	328.42	0.8734	0.9764	0.9807
329.1304	329.2682	329.2682	329.13	329.27	329.27	0.0067	0.0066	0.0066
329.1501	329.3076	329.3272	329.15	329.31	329.33	0.0007	0.0007	0.0011
329.1895	329.3469	329.3469	329.19	329.35	329.35	0.0490	0.0479	0.0493
329.2092	329.3469	329.3666	329.21	329.35	329.37	0.0579	0.0566	0.0582
329.2092	329.3666	329.3666	329.21	329.37	329.37	0.0282	0.0274	0.0282
329.2289	329.3666	329.3863	329.23	329.37	329.39	0.0340	0.0333	0.0343
329.2289	329.3863	329.3863	329.23	329.39	329.39	0.0322	0.0313	0.0325
329.2289	329.3863	329.3863	329.23	329.39	329.39	0.0292	0.0285	0.0293
329.2682	329.3863	329.4060	329.27	329.39	329.41	0.0416	0.0410	0.0421
						THD(Xk)	THD(Xk)	THD(Xk)
						0.1221	0.1068	0.0119

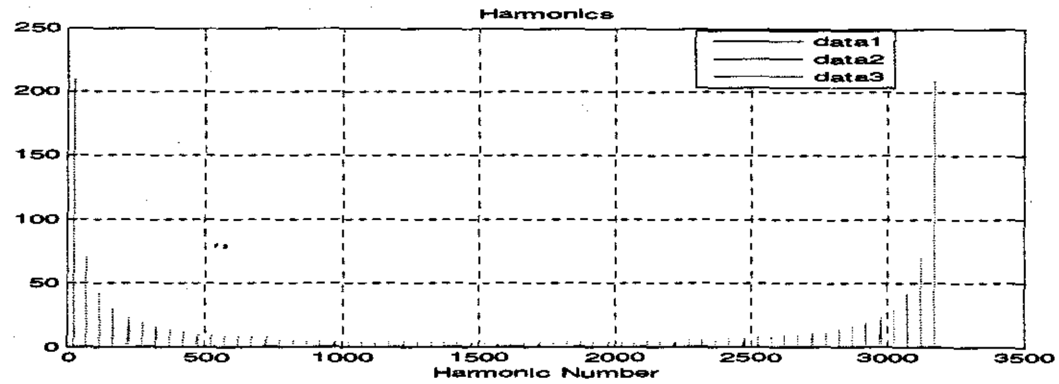


Figure 7.13: Calculated Harmonics

The Fast Fourier Transform (FFT) is done on the single 50Hz cycle of data. Then 3200 point FFT is performed. It gives decomposition into 1600 harmonics. MySQL and MATLAB program *harmonics.m* for harmonics calculations is shown in Appendix J2

7.6.1 Error between Measured voltages and Inverse Discrete Fourier Transform data.

In Figure 7.14 below the graph of the error between measured voltages and inverse discrete Fourier transform data (Xn) to check how close estimated signal is to the original data is shown Table 7.2, MATLAB and MySQL program *Error.m* for calculations see appendix J4.

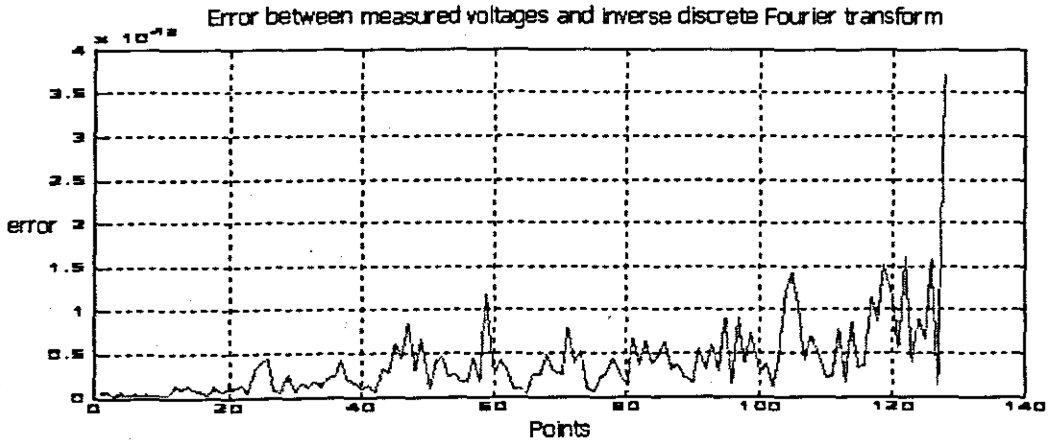


Figure 7.14: Error between Measured voltages and Coefficients of Xn

To compare the injected data with the estimated signal by the inverse FFT, the error is calculated the following way: error=measured voltages-Inverse Fourier transform (Xn). It can be seen that the values of the errors for every moment are in the range of 10^{-12}, which shows that the estimated signal is very close to the original data.

7.6.2 Calculations of separate harmonics

These graphs are plotted in each phase, Figure 7.15. The following graphs are the graphs from the injected data, these graphs were plotted to check the fundamentals, second harmonics, third harmonics etc.

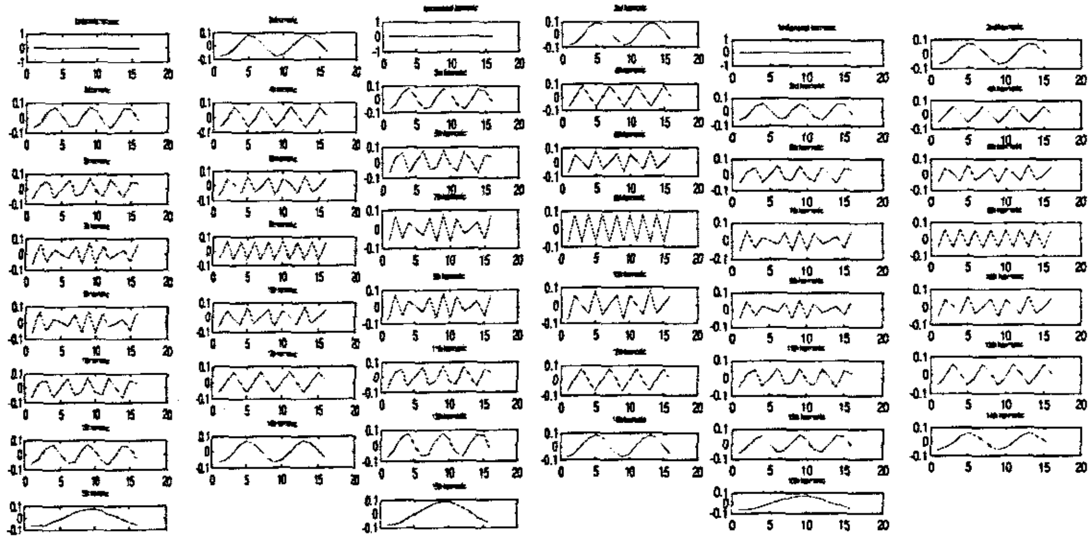


Figure 7.15: Graphs of the separate harmonics in each phase

7.7 Conclusion

In harmonic studies, the fundamental concepts are Fourier series and Fourier analysis. Distorted sinusoidal signals are considered where the frequencies composing the signal are the integer multiplies of fundamental one f(Hz), and the signals with these frequencies are called harmonics.

Uniform Random Number and Sine Wave block were built in Simulink and added together to make data. The data from the simulink model used to calculate the harmonics.

ImpedoGraph is used to measure the voltage and current injected by the injector to generate the required waveforms. 3200 points data is used in FFT. It gives decomposition into 1600 harmonics. The next chapter describes the conclusions and future direction of research.

CHAPTER EIGHT

CONCLUSIONS AND FUTURE DIRECTION OF RESEARCH

8.1 Project aim and objectives

Power quality (PQ) has become a significant issue for both power suppliers and customers. So it becomes more important to precisely measure and monitor it and identify the causes of power quality corruption and try to come up with solution of power quality corruption. The main research problem of the project is to investigate the power quality of a distribution network by selection of proper measurement, applying and developing the existing classic and modern signal conditioning methods for power disturbance's parameters extracting and monitoring.

8.2 Project deliverables

8.2.1 Literature Overview, analysis of power quality and its application

8.2.1.1 Literature Overview

Review of different modern papers that analyse some power quality disturbances and propose effective solutions. The following criteria are considered:

- What type of system is investigated
- Type of power quality disturbance analyzed
- Signal processing methods used
- Real-time implementation performed
- Methods of charactering the considered disturbance.

8.2.1.2 Analysis of power quality and its application

An analysis of the definitions and description of power quality disturbances is done, paying attention to the following points:

- Symptoms of poor power quality
- Power quality disturbances
- Detecting and classifying power quality disturbances.
- Characterizing power quality disturbances
- Source of these power quality disturbances

- Load sensitive: Electrical equipment affected by poor power quality
- Studying equipment sensitivity during power quality disturbances
- Solutions for improving power quality

8.2.1.3 Analysis of the existing standards for power quality measurements, data collection and monitoring.

The following important points were considered

8.2.1.3.1 Measurements

The measurements results for power quality disturbances obtained from substations in the distribution network.

- The reasons for carry out(making) power quality measurements
- Power quality measurements methods
- IEC 61000-4-7 standard
- IEC Electromagnetic Compatibility approach
- IEC 61000-15-15 method
- EN/IEC 61000-3-2 standard

8.2.1.3.2 Monitoring

- Importance of monitoring power quality
- The methodology of power quality monitoring
- Monitoring process

8.2.1.4 Data Collection and Simulation

- Power quality data collection
- Methods of data collection
- Description of the Cape Peninsula University of Technology (CPUT) Bellville Campus reticulation network.
- Algorithm for measurement and harmonic estimation
- Parallel connection

8.2.2 Implementation of Algorithms for Calculation of power quality disturbances/ indicators.

The different types of measured data are used to calculate some of the power quality disturbances or indicators. The algorithms are based on the relationship between the power network variables. The following indicators and disturbances are calculated:

1) Power factor

- MySQL and MATLAB softwares are used in order to calculate power factor, on the basis of the measured data for power.
- Comparison of calculated and measured power factor is performed.
- The error between calculated and measured values was calculated.

2) Apparent Power

- Vrms and Irms were the measured data used to calculate the apparent power and MySQL and MATLAB software was developed.
- Comparison of calculated and measured apparent power was done.
- The error between calculated and measured values was calculated.

3) Voltage Peak

- Vrms and Crest factor were used to calculate voltage peak.

4) Voltage Unbalance

- Measured voltages are used to calculate voltage unbalance.

5) Crest factor

- Vrms and Voltage peak were the measured data used to calculate the apparent power and MySQL and MATLAB software was developed.
- Comparison of calculated and measured apparent power was done.
- The error between calculated and measured values was calculated.

8.2.3 Implementation of a Simulink model for generation of deteriorated by harmonics periodic signal

- *In Simulink model, sine wave and Uniform random number sequence were added* together to create a distorted wave form. The waveform has small spikes with zero crossings occurring at irregular intervals. The data can be used to calculate the harmonics.,

8.2.4 Implementation of an algorithm for application of Fast Fourier transform for calculated coefficients of the harmonics.

The coefficients are calculated for the data generated by the Simulink model.

8.2.5 Implementation of an Algorithm for application of Inverse Fourier transform

- In order to prove that the calculated coefficients can generate back the used data the inverse discrete Fourier transform is used.

8.2.6 Generation of deteriorated by *harmonics periodic signal using an injector*

Voltage and current were injected from the injector using ImpedoGraph meter in order to generate data for application of FFT and inverse FFT

8.3 Implementation of software

A set of programs developed in MATLAB to calculate the disturbances/ indicators of power quality are summarized in Table 8.1.

Table 8.1: Programs used for power quality calculation

Software environment	**Purpose**	**M-File/ Name of the program**
MATLAB and MySQL	Power factor calculation	Power factor(whole).m
MATLAB and MySQL	*Active power calculation*	*Active power .m*
MATLAB and MySQL	Voltage Peak calculation	(Vpeak).whole.m
MATLAB and MySQL	Voltage Unbalance calculation	Voltage Unbalance.m
MATLAB and MySQL	Crest factor calculation	Crest factor.m
MATLAB and MySQL	*Apparent power calculation*	*Apparent power work.m*
MATLAB	Harmonics coefficient	Harmonics example.m
MATLAB and MySQL	Harmonics coefficients	Harmonics.m

8.4 Application of the results

- The investigation and results can be applied for education purposes.
- The results form a base for providing different research investigations.
- The results can be applied in distribution network for the design of power systems control and monitoring systems.

8.5 Future Research

The research has shown that FFT/DFT is viable option to be considered for prediction of power quality disturbances like harmonics because these methods propose the simplest way to estimate the signal frequency. The literature research and other sources with bigger experience in the field of harmonics indicate that FFT is the best solution.

In terms of the power quality standards, the researchers always recommended the IEC standard 6100-4-30.

Further research can be developed for creation of data acquisition and monitoring system as a bases for design and implementation of control action for improvement of the power quality status of a given distribution network.

8.6 Publications

Nduku, N., Tzoneva. R. 2009. "Development of Methods for Distribution Network Power Quality Variation Monitoring",SAIEE research journal (Submitted to the journal).

Nduku, N., Tzoneva, R. 2009." Power Quality Harmonics estimation" PAC magazine (Submitted to the journal).

APPENDICES

List of appendices

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APPENDIX B: Settings and Programming a DMK 40 Lovato.

APPENDIX C: Settings and Programming of ImpedoGraph and ProvoGraph

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APPENDIX E: MySQL and MATLAB Program on Comparison of Calculated and Measured Disturbances for power factor.

APPENDIX F: Calculate Active Power on the basis of measurements of the current and voltage.

APPENDIX G: To calculate Voltage Peak

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APPENDIX J2:MATLAB and MySQL program harmonics to coefficients of voltage_1k (Xk) and plotting the absolute values of the harmonics graphs.

APPENDIX J3: Inverse Fourier Transform (Xn) are used to check that the calculated coefficients are right one to generate the data

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APPENDIX K: To calculate Crest factor

APPENDIX M: To calculate Apparent power

APPENDIX A

Single line diagram for the 11kV reticulation network layout.

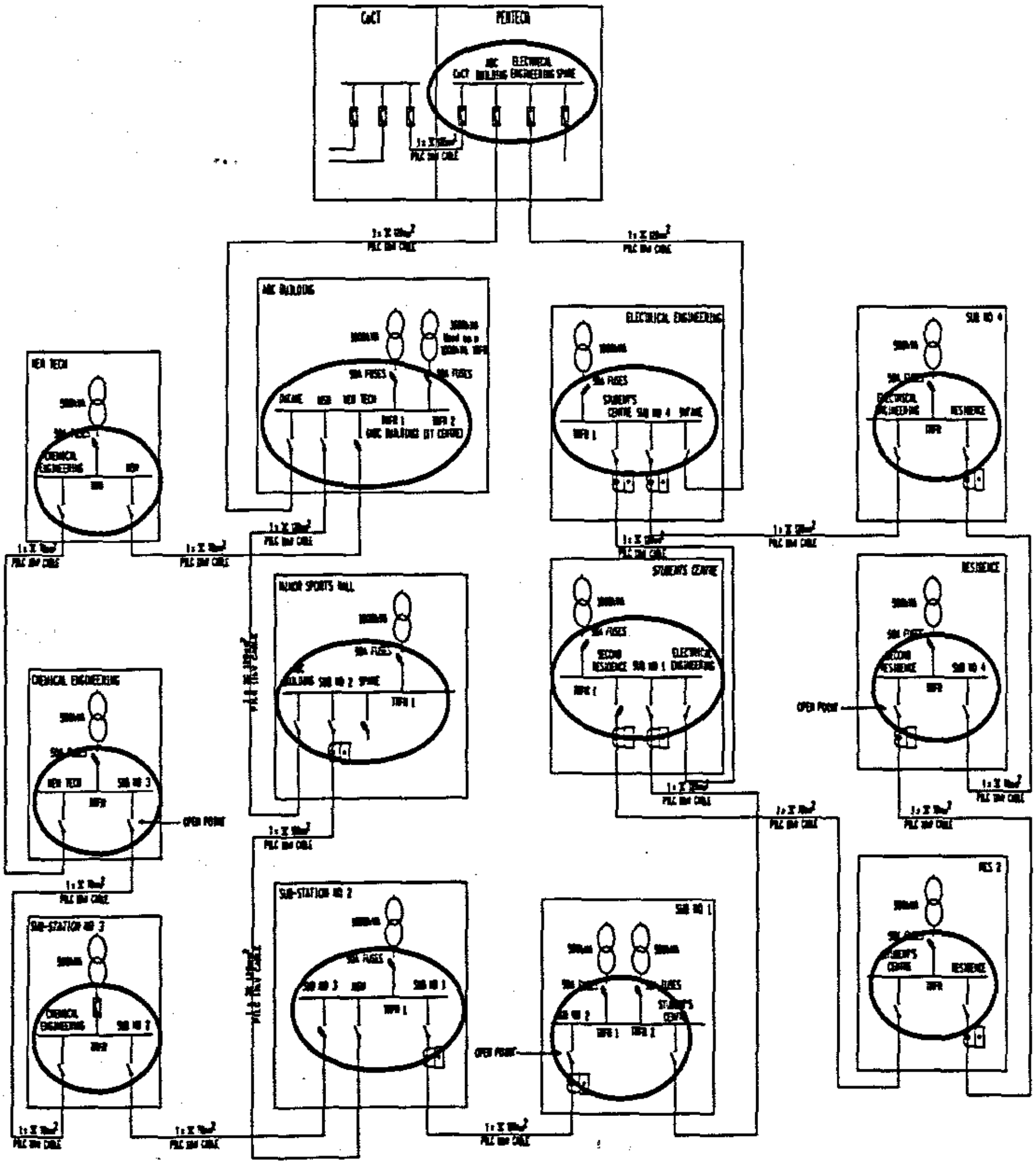


Figure A1: CPUT Electrical Reticulation network layout at Bellville campus

APPENDIX B

Settings and Programming a DMK 40 Lovato.

1. Installation of Software

The software is on CD with two different installation procedures.

Setup1:

- Close all applications running
- Insert the CD in the drive
- From the setup 1 directory, start the setup.exe program
- Press the button with the PC icon to start the installation procedure.
- A window is displayed asking the user to specify the directory in which the user to install the program
- Follow the instructions

Setup 2:

- Close all applications running
- Insert the CD in the drive
- From the setup 2 directory, start the Dmk.msi program
- A window is displayed asking the user to specify the directory in which the user to install the program
- Follow the instructions

These different procedures, first setup used in Window 95 and 98 operating systems, second setup contains new installation procedure for window 98 and 2000 operating system. DMK 40 multimeters and the PC should be able to exchange data on the serial link. Connect the Rs232/Rs485 converter to the PC. The configuration-options-General serial port settings window must match with programmed port of the PC used.

2. Principles

Make sure that the data logging system is correctly connected and settings must be transferred to the network of multimeters connected in the RS485 network.

3. DMK40 Main Page

The main menu of the meter is shown on Figure B1.

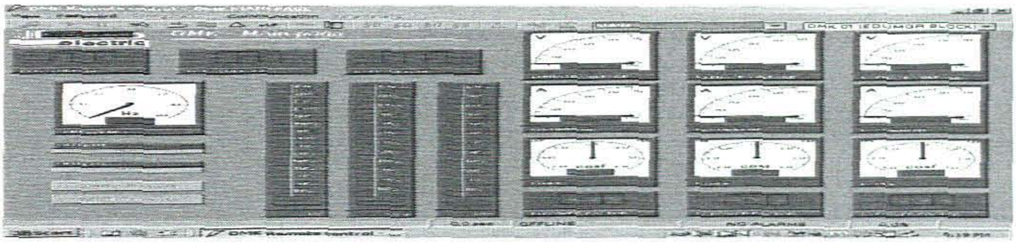


Figure B1: DMK40 Main menu

4. Password

No password is required during the installation.

The required password is only for resetting and re-programming the meter. On the main menu of Lovato, click on *password* and type in *Lovato*

Figure B2: Password

5. Options

From configuration, click *data log*

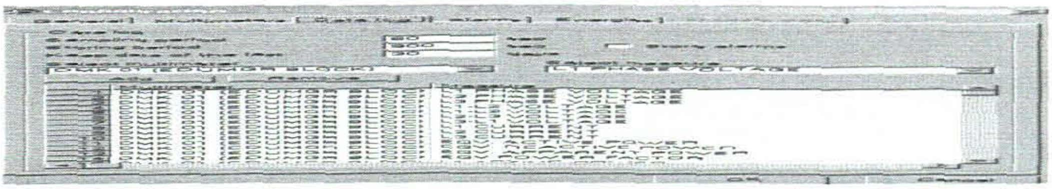


Figure B3: Settings of Power Quality disturbances

On this window user can select the measurement he/she wants to be done and then clicks ok.

6. Data log

Click *view* from the main menu, and then click *data log*. Figure B4 below will appear.

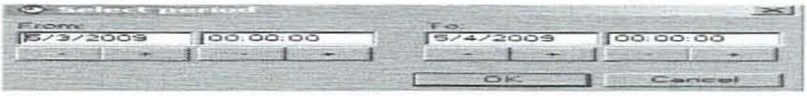
	Date	Time	01-VL1[V]	01-VL2[V]	01-VL3[V]	01-VL1-L2[V]	01-VL1-L2[V]	01-VL2

Figure B4: Data log

This window is to view all the recoded data.

7. Time and Date Settings.

On this window below, the user selects the period that you wants to take the measurements.



From: 5/3/2009 00:00:00

To: 5/4/2009 00:00:00

Figure B5: Settings of Time and Date

Then click *ok.*

8. Uploading Recoded Data

Click to *view all*, then all the recorded data will be displayed and click to Export to save to Excel spread sheet.

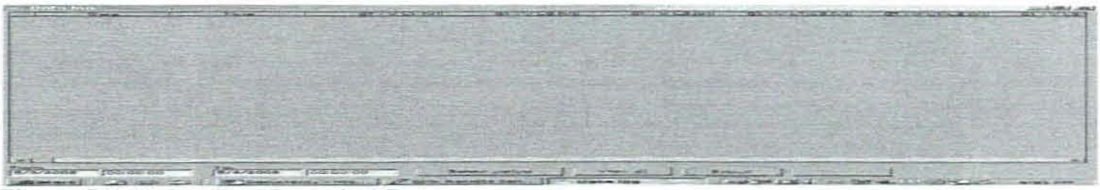


Figure B6: Uploading Recoded Data

9. Alarm Events

Date	Time	Type	Event
5/3/2009	6:18:53 PM	Event	REMOTE CONTROL STARTED
5/3/2009	6:18:55 PM	Event	DMK 01 (EDUMGR BLOCK) - OFFLINE
5/3/2009	6:20:47 PM	Event	REMOTE CONTROL STOPPED
5/3/2009	6:20:59 PM	Event	REMOTE CONTROL STARTED
[illegible]	[illegible]	Event	[illegible]

Select view: (view all)

Select multimeter: (all multimeters)

From: 5/3/2009 00:00:00

To: 5/4/2009 00:00:00

Figure C7: Alarm Events

APPENDIX C

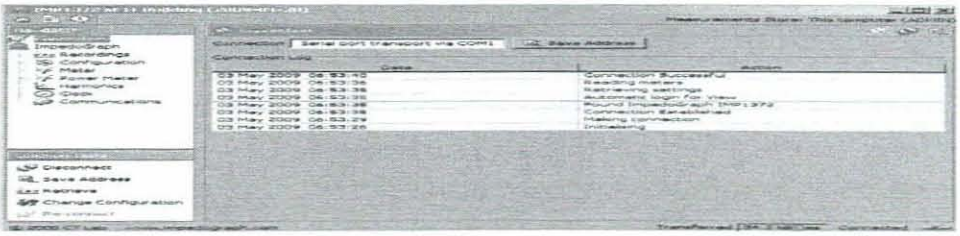
Settings and Programming of ImpedoGraph and ProvoGraph

1. Software Installation.

To install the software, it requires Windows 2000/XP/ Vista with Java installed. Install and launch the software by clicking on *java web start*. On subsequent launches Power Quality Recorder Manager (PQRM) will be automatically updated from the internet via Java web start. No is password required to install the software.

2. ImpedoGraph Main Page

On this window below the user chooses by himself if he wants to view the harmonics or all the recordings.

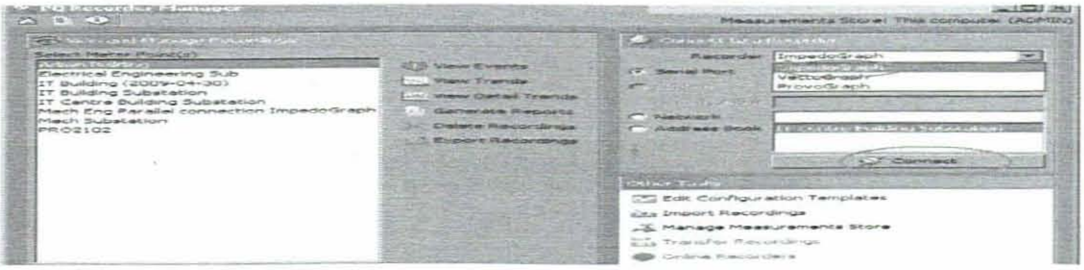


Connection: Serial port transport via COM1

Figure C1: ImpedoGraph Main Page

3. Connection

On this window below the user chooses which meter he/she want to be connected. If he/she chooses ImpordoGraph, then he/she has to click to *serial port* and to press *connect*.



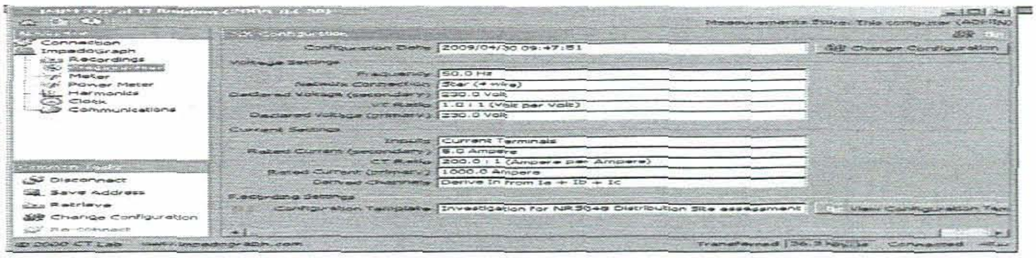
Electrical Engineering Sub
IT Building (2009-04-30)
IT Building Substation
IT Centre Building Substation
Mech Eng Parallel connection ImpedoGraph
Mech Substation
PRO2102

Recorder: ImpedoGraph

Figure C2: Connection

4. Settings

The user can press *configuration* to set dates, frequency, CT ratio etc



Configuration Date: 2009/04/30 09:47:51

Voltage Settings

Frequency: 50.0 Hz

Network Connection: Star (4 wire)

Declared Voltage (secondary): 230.0 Volt

VT Ratio: 1.0 : 1 (Volt per Volt)

Declared Voltage (primary): 230.0 Volt

Current Settings

Inputs: Current Terminals

Rated Current (secondary): 5.0 Ampere

CT Ratio: 200.0 : 1 (Ampere per Ampere)

Rated Current (primary): 1000.0 Ampere

Derived Channels: Derive In from Ia + Ib + Ic

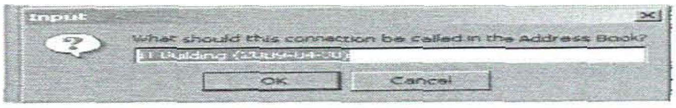
Recording Settings

Configuration Template: Investigation for NRS048 Distribution Site assessment

Figure C3: Settings

5. Save Address

Click on the *save address*, to change configuration.



What should this connection be called in the Address Book?

Figure C4: Saving Address

6. Recordings

In this window below, the user can view if all the recordings are on the meter.

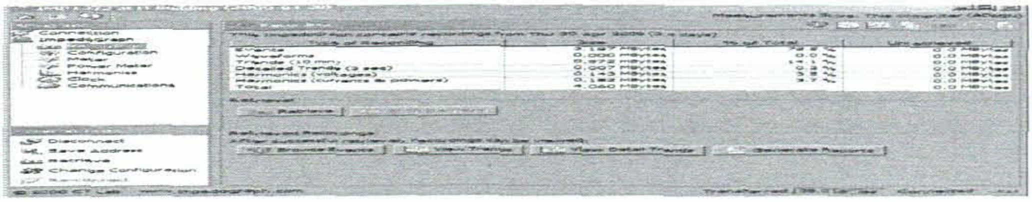


Figure C5: Recordings

7. Retrieve data

In this window below, user should press recordings and press *retrieve* in order to retrieve the data

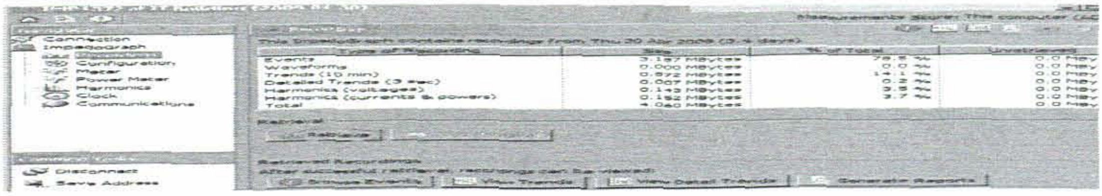


Figure C6: Retrieving data

Click to *retrieve*, then after successful retrieval the user can be able to view the records.

8. Uploading Recoded Data

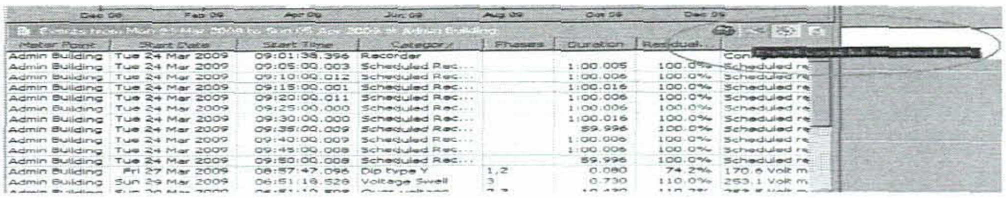
Click to Export to save data to Excel spread sheet

IT Building (2009-04-30)
IT Building Substation
IT Centre Building Substation
Mech Eng Parallel connection ImpedoGraph
Mech Substation
PRO2102

Address Book: IT Centre Building Substation

Figure C7: Uploading the data

Click to excel node in order to export the event list to spreadsheet



Meter Point	Start Date	Start Time	Category	Phases	Duration	Residual...	Con
Admin Building	Tue 24 Mar 2009	09:01:38.396	Recorder				
Admin Building	Tue 24 Mar 2009	09:05:00.003	Scheduled Rec...		1:00.005	100.0%	Scheduled re
Admin Building	Tue 24 Mar 2009	09:10:00.012	Scheduled Rec...		1:00.006	100.0%	Scheduled re
Admin Building	Tue 24 Mar 2009	09:15:00.001	Scheduled Rec...		1:00.016	100.0%	Scheduled re
Admin Building	Tue 24 Mar 2009	09:20:00.011	Scheduled Rec...		1:00.006	100.0%	Scheduled re
Admin Building	Tue 24 Mar 2009	09:25:00.000	Scheduled Rec...		1:00.006	100.0%	Scheduled re
Admin Building	Tue 24 Mar 2009	09:30:00.000	Scheduled Rec...		1:00.016	100.0%	Scheduled re
Admin Building	Tue 24 Mar 2009	09:35:00.009	Scheduled Rec...		59.996	100.0%	Scheduled re
Admin Building	Tue 24 Mar 2009	09:40:00.009	Scheduled Rec...		1:00.006	100.0%	Scheduled re
Admin Building	Tue 24 Mar 2009	09:45:00.008	Scheduled Rec...		1:00.006	100.0%	Scheduled re
Admin Building	Tue 24 Mar 2009	09:50:00.008	Scheduled Rec...		59.996	100.0%	Scheduled re
Admin Building	Fri 27 Mar 2009	08:57:47.096	Dip type Y	1,2	0.080	74.2%	170.6 Volt m
Admin Building	Sun 29 Mar 2009	06:51:18.528	Voltage Swell	3	0.730	110.0%	253.1 Volt m

Figure C8: To Export to Spreadsheet.

APPENDIX D

Data Storage to MySQL

1 MySQL database

MySQL is the most reliable and very easy software to be used and it performs very fast. MySQL database allows users to create a relational database structure on a web-sever in order to store data.

2 MySQL Database Manager

The MySQL Database Manager is a controlling tool whereby it tolerates users to create, administer and manage MySQL databases on users website.
Within fixed support for MySQL, DBF tables, MsAccess, MssQL server, Sybase, ODBC database engines. It includes GUI that actually lets flavored database administrators to work quickly and professionally. The features of DB Manager are:

- Import or export data easily from another source.
- *Diagram designer/ Populate tables*
- Work group
- Management for databases, tables.
- Database comparer and database control version system.

It runs on windows:

- Windows 98
- Windows ME
- Windows NT4
- Windows 2003
- Windows XP

3 Creating a database

To create a database select the server that will be used for the database, by clicking on the *create database* icon in the tool bars. Then start writing the database name in the Alias ground *(Field) and click ok, as shown In Figure D1*

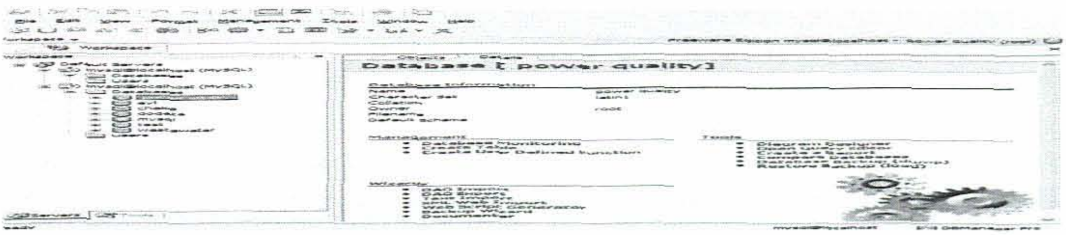
Server: mysql@localhost (MySQL)

Creating a New Database
For databases which support external files you must choose the file name or the database folder. In these cases you can link a database previously created by other engines. I.E. MSAccess.

Name or Alias: Power Quality
Character Set: latin1

Figure D1: Overview of DBManager Professional, how to create a database.

The new created database appears in the workspace window in the Figure D2 below



Database [power quality]

Name: power quality
Character Set: latin1
Owner: root

Figure D2: Overview of DBManager for new created database.

4. Creating a Table

- In DBManager Professional, select the database into which user want to add the table
- Click the *manage* database button
- Enter field name under the column name, press *enter* button in the keyboard to enter the next field name.
- *Click the save button to save* the database table, Figure D3

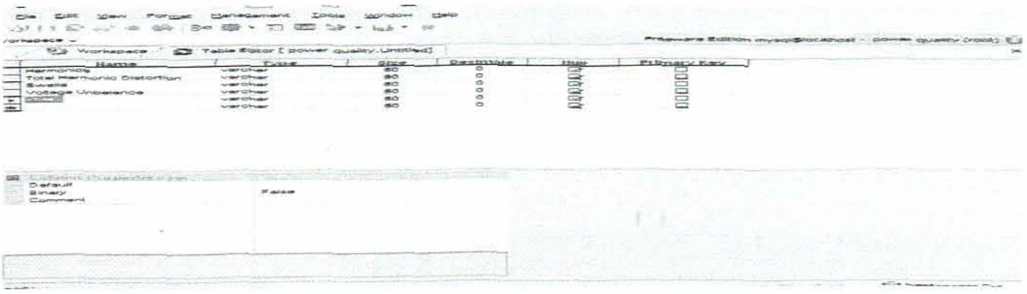


Table Editor [power quality.Untitled]

Name	Type	Size	Decimals	Null	Primary Key
Harmonics	varchar	60	0	☑	☐
Total Harmonic Distortion	varchar	60	0	☑	☐
Swells	varchar	60	0	☑	☐
Voltage Unbalance	varchar	60	0	☑	☐

Binary: False

Figure D3: To create a table

The figure D4 below, shows the table name on MySQL.

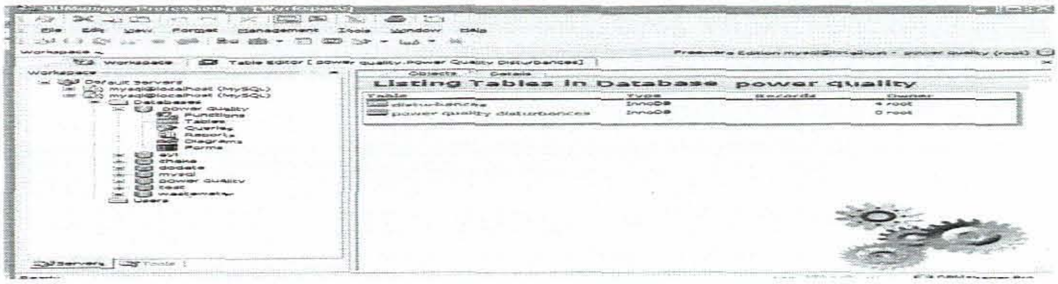
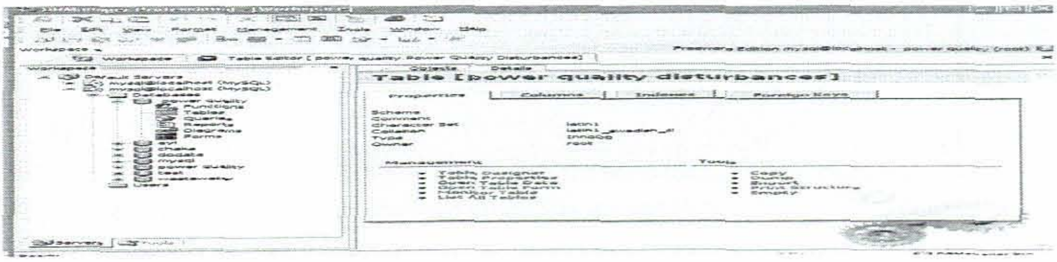


Table	Type	Records	Owner
disturbances	InnoDB		4 root
power quality disturbances	InnoDB		0 root

Figure D4: The Table name.

5. Entering Data in the Table.

Click on the *workspace* after saving the table, select the created database. The created list of tables, will be shown on the details window. Click on the created table called *Power Quality disturbances*. Figure D5 below



Schema
Comment
Character Set latin1
Collation latin1_swedish_ci
Type InnoDB
Owner root

Figure D5: Entering data in the table.

Click *open table* data under management in the toolbar of the DB Manager Professional spall

6. Importing Text File

To import data from Excel data to MySQL, the Excel data should be saving as a csv file. Then just check the saved file using a text editor such as Notepad. Open the Notepad file to see how looks like, for example to see what delimiter was used.

The figure D6 below shows that the user must click to Tools, then to Data Management and click again to Import Text wizard.

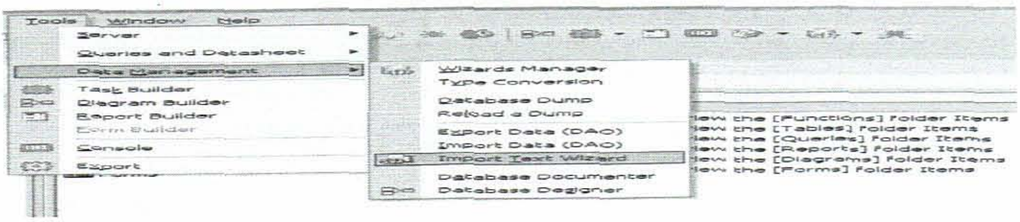
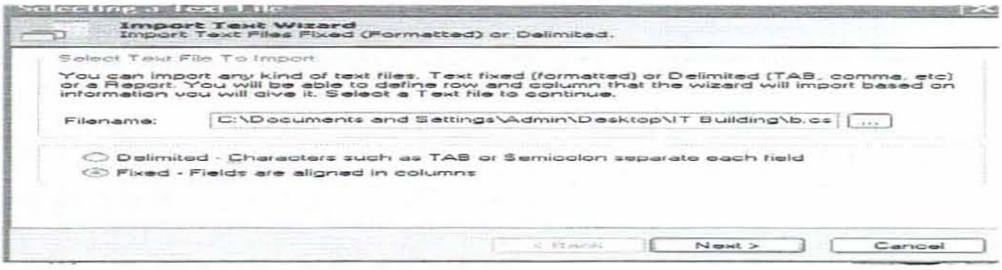


Figure D6: Importing Text File to MySQL.

The DBManager Professional has the capabilities to import text files, MSAccess as well as Excel files. This figure D7 (a), (b) below shows the steps in importing the Excel file


Import Text Wizard
Import Text Files Fixed (Formatted) or Delimited.

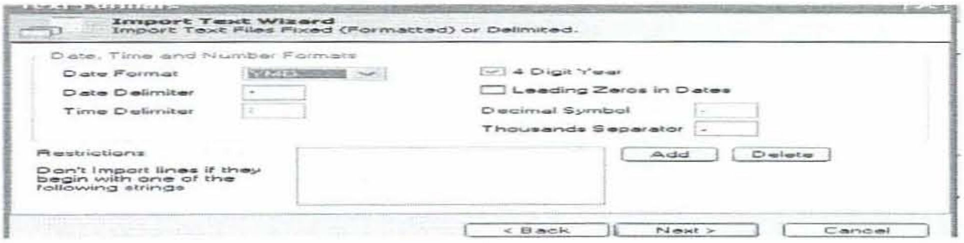
Select Text File To Import

You can import any kind of text files. Text fixed (formatted) or Delimited (TAB, comma, etc) or a Report. You will be able to define row and column that the wizard will import based on information you will give it. Select a Text file to continue.

Filename: C:\Documents and Settings\Admin\Desktop\IT Building\b.cs

○ Delimited - Characters such as TAB or Semicolon separate each field
● Fixed - Fields are aligned in columns

Figure D7 (a): Importing Excel spred sheet file into MySQL.


Import Text Wizard
Import Text Files Fixed (Formatted) or Delimited.

Date, Time and Number Formats

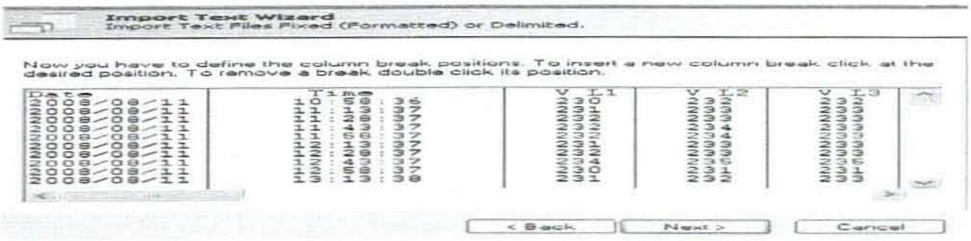
Date Format: YMD
Date Delimiter: -
Time Delimiter: :
☑ 4 Digit Year
☐ Leading Zeros in Dates
Decimal Symbol: .
Thousands Separator: ,

Restrictions

Don't Import lines if they begin with one of the following strings

Figure D7 (b): Importing Excel speed sheet file into MySQL.

The Figure D8 below, shows the stored recorded data saved in MySQL.

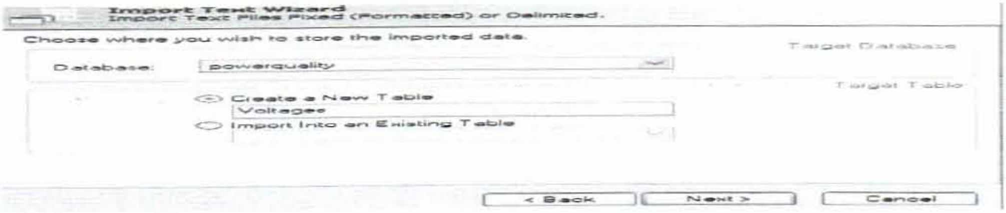

Import Text Wizard
Import Text Files Fixed (Formatted) or Delimited.

Now you have to define the column break positions. To insert a new column break click at the desired position. To remove a break double click its position.

Date	Time	V L1	V L2	V L3
2008/08/11	10:58:36	230	232	232
2008/08/11	11:13:37	231	233	233
2008/08/11	11:28:37	232	233	233
2008/08/11	11:43:37	232	234	233
2008/08/11	11:58:37	232	234	233
2008/08/11	12:13:37	231	233	233
2008/08/11	12:28:37	232	233	233
2008/08/11	12:43:37	234	235	235
2008/08/11	12:58:37	230	231	231
2008/08/11	13:13:38	231	232	233

Figure D8: The stored data into MySQL

In Figure D9 below, the user selects the database and selects to create a new table or Import into an Existing Table by the shown radio buttons. *Click Next.*


Import Text Wizard
Import Text Files Fixed (Formatted) or Delimited.

Choose where you wish to store the imported data.

Target Database

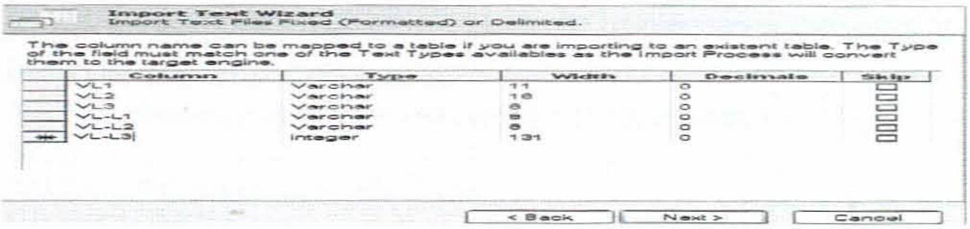
Database: powerquality

Target Table

● Create a New Table
Voltages
○ Import Into an Existing Table

Figure D9: To create a new table or Import into an Existing Table radio button.

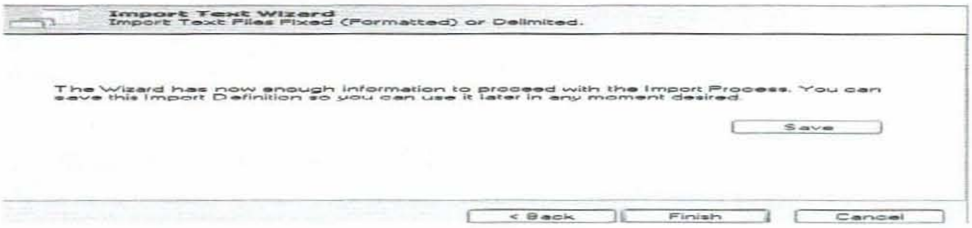
The figure D10(a),(b), shows the data stored in mySQL database.



The column name can be mapped to a table if you are importing to an existent table. The Type of the field must match one of the Text Types availables as the Import Process will convert them to the target engine.

Column	Type	Width	Decimals	Skip
VL1	Varchar	11	0	☐
VL2	Varchar	18	0	☐
VL3	Varchar	8	0	☐
VL-L1	Varchar	8	0	☐
VL-L2	Varchar	8	0	☐
VL-L3	integer	131	0	☐

Figure D10(a): Stored data in mySQL database.



The Wizard has now enough information to proceed with the Import Process. You can save this Import Definition so you can use it later in any moment desired.

Figure D10 (b): Stored data in mySQL database.

APPENDIX E

E. 1: MATLAB script file – mysql power factor (whole).m

MySQL and MATLAB Program Power_factor for Comparison of Calculated and Measured Disturbances

Aim : To calculate power factor and compare with measured power factor

```
%M-file- mysql power factor (whole).m
%Author: N. Nduku
%Institution: Cape Peninsula University of Technology
%Date: 2009


%Clearing the screen and memory
clc
clear
tic;
```

CONNECTING TO THE DATABASE:

```
% conn - connects a MATLAB session to a database via the specified ODBC driver
% returns a connection object
% database - MATLAB function used to connect to an ODBC/JDBC database
% exec - returns the cursor object to the variable "curs"
% fetch - imports data from the cursor
% curs.Data - returns the data at the cursor object

% establishing the connection to the DB and extracting the required data
% Inserting the username and password to access the DB
% importing the required data from ImpedoGraph into MATLAB using SQL Syntax from a table named powerfactor.
```

Phase1 Power Factor Fundamental

```
conn = database('industrial','root','Admin');%connects a MATLAB session to a database via an ODBC driver
cursor = exec(conn,'SELECT pfund from ayi.pfund');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
%Pfund = cursor.Data;
pfund = cursor.Data;
 pfund = pfund(:,1);


conn = database('industrial','root','Admin');%connects a MATLAB session to a database via an ODBC driver
cursor = exec(conn,'SELECT qfund from ayi.qfund');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
%Pfund = cursor.Data;
```

```
qfund = cursor.Data;
 qfund = qfund(:,1);


% Calculation of PF1
a = length(pfund);

 PF =[];
for i=1:a;
PF1(i)= pfund(i)/(sqrt(pfund(i)^2+qfund(i)^2));
end
PF1';

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

Phase2 Power Factor Fundamental

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

conn = database('industrial','root','Admin');%connects a MATLAB session to a database via an
ODBC driver
cursor = exec(conn,'SELECT pfund1 from powerquality.pfund1');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
%Pfund = cursor.Data;
pfund1 = cursor.Data;
 pfund1 = pfund1(:,1);


conn = database('industrial','root','Admin');%connects a MATLAB session to a database via an
ODBC driver
cursor = exec(conn,'SELECT qfund1 from powerquality.qfund1');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
%Pfund = cursor.Data;
qfund1 = cursor.Data;
 qfund1 = qfund1(:,1);


% Calculation of PF2
a = length(pfund1);

 PF2 =[];
for i=1:a;
PF2(i)= pfund1(i)/(sqrt(pfund1(i)^2+qfund1(i)^2));
end
PF2';
```

Phase3 power factor fundamental

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

```
conn = database('industrial','root','Admin');%connects a MATLAB session to a database via an
ODBC driver
cursor = exec(conn,'SELECT pfund2 from powerquality.pfund2');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
pfund2 = cursor.Data;
 pfund2 = pfund2(:,1);


conn = database('industrial','root','Admin');%connects a MATLAB session to a database via an
ODBC driver
cursor = exec(conn,'SELECT qfund2 from powerquality.qfund2');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
%Pfund = cursor.Data;
qfund2 = cursor.Data;
 qfund2 = qfund2(:,1);


% Calculation of PF3
a = length(pfund2);

 PF =[];
for i=1:a;
PF3(i)= pfund2(i)/(sqrt(pfund2(i)^2+qfund2(i)^2));
end
PF3';

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

Plotting all phases of power factors in one Graph

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

i=1:a;
plot(i,PF1)
title('Calculated Power Factor');
xlabel('time');
ylabel('pf');
grid
hold on

i=1:a;
plot(i,PF2)
title('Calculated Power Factor');
xlabel('time');
ylabel('pf');
grid
hold on

i=1:a;
```

```
plot(i,PF3)
title('Calculated Power Factor');
xlabel('time');
ylabel('pf');
grid
```

Calculation of the Error between calculated power factor and measured power factor

```
conn = database('industrial','root','Admin');%connects a MATLAB session to a database via an
ODBC driver
cursor = exec(conn,'SELECT pffund from ayi.pffund');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
%Pfund = cursor.Data;
pffund = cursor.Data;
 pffund = pffund(:,1);



 conn = database('industrial','root','Admin');%connects a MATLAB session to a database via an
ODBC driver
cursor = exec(conn,'SELECT pffund1 from powerquality.pffund1');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
%Pfund = cursor.Data;
pffund1 = cursor.Data;
 pffund1 = pffund1(:,1);


 conn = database('industrial','root','Admin');%connects a MATLAB session to a database via an
ODBC driver
cursor = exec(conn,'SELECT pffund2 from powerquality.pffund2');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
%Pfund = cursor.Data;
pffund2 = cursor.Data;
pffund2 = pffund2(:,1);


error1 = PF1'-pffund;
error2 = PF2'-pffund1;
error3 = PF3'-pffund2;


a=350;
 i=1:a;
plot(i,error1)
title('Calculated error');
xlabel('time');
ylabel('error');
grid
```

```
hold on

i=1:a;
plot(i,error2)
title('Calculated error');
xlabel('time');
ylabel('error');
grid
hold on

i=1:a;
plot(i,error3)
title('Calculated error');
xlabel('time');
ylabel('error');
grid
```

APPENDIX F

F.1:MATLAB Script file- Active Power.m

```
% m-file:Active Power.m
1. Aim of the program: Is to calculate active power on the basis of measurements of the
current and voltage
%Clearing the screen and memory
clc
clear
tic;

% Import data from MySQL database for phases
% establishing the connection to the DB and extracting required data
% Inserting the username and password to access the DB
% importing the required data from ImpedoGraph into MATLAB using SQL Syntax from a table
named activepower.


Active Power


conn = database('industrial','root','Admin');%connects a MATLAB session to a database via an
ODBC driver
cursor = exec(conn,'SELECT current_fun from activepower_fun.current_fun');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
%Pfund = cursor.Data;
current_fun = cursor.Data;
 current_fun = current_fun(:,1);

conn = database('industrial','root','Admin');%connects a MATLAB session to a database via an
ODBC driver
cursor = exec(conn,'SELECT pfactor_fund from activepower_fun.pfactor_fund');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
%Pfund = cursor.Data;
pfactor_fund = cursor.Data;
 pfactor_fund = pfactor_fund(:,1);


conn = database('industrial','root','Admin');%connects a MATLAB session to a database via an
ODBC driver
cursor = exec(conn,'SELECT voltage_fund from activepower_fun.voltage_fund');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
%Pfund = cursor.Data;
voltage_fund = cursor.Data;
voltage_fund = voltage_fund(:,1);


 % Calculation of the active power for phase 1
```

```
a = length(current_fun);

 Activep =[];
for i=1:a;
Activep(i)= current_fun(i)*pfactor_fund(i)*voltage_fund(i);
end
Activep';


% Power Factor

conn = database('industrial','root','Admin');%connects a MATLAB session to a database via an
ODBC driver
cursor = exec(conn,'SELECT current_fun1 from activepower_fun.current_fun1');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
%Pfund = cursor.Data;
current_fun1 = cursor.Data;
 current_fun1 = current_fun1(:,1);


conn = database('industrial','root','Admin');%connects a MATLAB session to a database via an
ODBC driver
cursor = exec(conn,'SELECT pfactor_fund1 from activepower_fun.pfactor_fund1');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
%Pfund = cursor.Data;
pfactor_fund1 = cursor.Data;
pfactor_fund1 = pfactor_fund1(:,1);


 conn = database('industrial','root','Admin');%connects a MATLAB session to a database via an
ODBC driver
cursor = exec(conn,'SELECT voltage_fund1 from activepower_fun.voltage_fund1');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
%Pfund = cursor.Data;
voltage_fund1 = cursor.Data;
voltage_fund1 = voltage_fund1(:,1);

% Calculation of the active power for phase 2

 a = length(current_fun1);

 Activep1 =[];
for i=1:a;
Activep1(i)= current_fun1(i)*pfactor_fund1(i)*voltage_fund1(i);
end
Activep1';


% Voltage fundamental
```

```
conn = database('industrial','root','Admin');%connects a MATLAB session to a database via an
ODBC driver
cursor = exec(conn,'SELECT voltage_fund2 from activepower_fun.voltage_fund2');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
%Pfund = cursor.Data;
voltage_fund2 = cursor.Data;
voltage_fund2 = voltage_fund2(:,1);


conn = database('industrial','root','Admin');%connects a MATLAB session to a database via an
ODBC driver
cursor = exec(conn,'SELECT current_fund2 from activepower_fun.current_fund2');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
%Pfund = cursor.Data;
current_fund2 = cursor.Data;
current_fund2 = current_fund2(:,1);


conn = database('industrial','root','Admin');%connects a MATLAB session to a database via an
ODBC driver
cursor = exec(conn,'SELECT pfactor_fund2 from activepower_fun.pfactor_fund2');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
%Pfund = cursor.Data;
pfactor_fund2 = cursor.Data;
 pfactor_fund2 = pfactor_fund2(:,1);


% Calculation of the active power for phase 3
a = length(voltage_fund2);

 Activep2 =[];
for i=1:a;
Activep2(i)= current_fund2(i)*pfactor_fund2(i)*voltage_fund2(i);
end
Activep2';

%Plotting

a=350;
i=1:a;
plot(i,Activep)
title('Active Power')
xlabel('Number of Points')
ylabel('W')
grid
hold on

plot(i,Activep1)
```

```
title('Active Power')
xlabel('Number of Points')
ylabel('W')
grid
hold on

plot(i,Activep2)
title('Active Power')
xlabel('Number of Points')
ylabel('W')
grid




% ERROR Calculation

conn = database('industrial','root','Admin');%connects a MATLAB session to a database via an
ODBC driver
cursor = exec(conn,'SELECT activefund from activepower_fun.activefund');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
%Pfund = cursor.Data;
activefund = cursor.Data;
activefund = activefund(:,1);


conn = database('industrial','root','Admin');%connects a MATLAB session to a database via an
ODBC driver
cursor = exec(conn,'SELECT activefund1 from activepower_fun.activefund1');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
%Pfund = cursor.Data;
activefund1 = cursor.Data;
activefund1 = activefund1(:,1);


conn = database('industrial','root','Admin');%connects a MATLAB session to a database via an
ODBC driver
cursor = exec(conn,'SELECT activefund2 from activepower_fun.activefund2');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
%Pfund = cursor.Data;
activefund2 = cursor.Data;
activefund2 = activefund2(:,1);


error =Activep'-activefund
error1 =Activep1'-activefund1
error2 =Activep2'-activefund2

a=350;
i=1:a;
```

```
plot(i,error)
title('error between calculated and measured active power')
xlabel('Number of Points')
ylabel('error')
grid
hold on

plot(i,error1)
title('error between calculated and measured active power')
xlabel('Number of Points')
ylabel('error')
grid
hold on


plot(i,error2)
title('error between calculated and measured active power')
xlabel('Number of Points')
ylabel('error')
grid
```

APPENDIX G

G.1:MATLAB Script- (Vpeak)whole.m

%m-file: (Vpeak)whole.m
1. **Aim of the model:** Is to calculate Voltage Peak

```
%Clearing the screen and memory
clc
clear
tic;
% establishing the connection to the DB and extracting required data
% Inserting the username and password to access the DB
% importing the required data from Impedograph into MATLAB using SQL Syntax from a table
named vpeak.
```

Program

```
conn = database('industrial','root','Admin');%connects a MATLAB session to a database via an
ODBC driver
cursor = exec(conn,'SELECT v_rms from ayi.v_rms');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
v_rms = cursor.Data;
v_rms = v_rms(:,1);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

conn = database('industrial','root','Admin');%connects a MATLAB session to a database via an
ODBC driver
cursor = exec(conn,'SELECT cr_factor from ayi.cr_factor');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
cr_factor = cursor.Data;
cr_factor = cr_factor(:,1);


% Calculation of the Voltage Peak for phase 1

 a = length(cr_factor);
  Vpeak1 =[]';
for i=1:a;
Vpeak1(i)= cr_factor(i)*v_rms(i);
end
Vpeak1';

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% The second phase voltage peak

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

```
conn = database('industrial','root','Admin');%connects a MATLAB session to a database via an
ODBC driver
cursor = exec(conn,'SELECT v_rms2 from powerquality.v_rms2');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
v_rms2 = cursor.Data;
v_rms2 = v_rms2(:,1);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

conn = database('industrial','root','Admin');%connects a MATLAB session to a database via an
ODBC driver
cursor = exec(conn,'SELECT cr_factor2 from powerquality.cr_factor2');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
cr_factor2 = cursor.Data;
cr_factor2 = cr_factor2(:,1);


% Calculation of the Voltage Peak for phase 2

 a = length(cr_factor2);
  Vpeak2 =[]';
for i=1:a;
Vpeak2(i)= cr_factor2(i)*v_rms2(i);
end
Vpeak2';

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% The third phase voltage peak

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

conn = database('industrial','root','Admin');%connects a MATLAB session to a database via an
ODBC driver
cursor = exec(conn,'SELECT v_rms3 from powerquality.v_rms3');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
v_rms3 = cursor.Data;
v_rms3 = v_rms3(:,1);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

conn = database('industrial','root','Admin');%connects a MATLAB session to a database via an
ODBC driver
cursor = exec(conn,'SELECT cr_factor3 from powerquality.cr_factor3');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
cr_factor3 = cursor.Data;
cr_factor3 = cr_factor3(:,1);
 % Calculation of the Voltage Peak for phase 3
```

```
 a = length(cr_factor3);
  Vpeak3 =[]';
for i=1:a;
Vpeak3(i)= cr_factor3(i)*v_rms3(i);
end
Vpeak3'

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% Plotting  all voltage Peak in one graph

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

i=1:a
plot(i,Vpeak1);
title('The voltage peak');
xlabel('Number of Points');
ylabel('Vpeak');
grid
hold on

i=1:a
plot(i,Vpeak2);
title('The voltage peak');
xlabel("Number of Points");
ylabel('Vpeak');
grid
hold on

i=1:a
plot(i,Vpeak3);
title('The voltage peak');
xlabel("Number of Points");
ylabel('Vpeak');
grid
```

APPENDIX H

H.1:MATLAB Script- Voltage Unbalance.m

```
%m.file: Voltage Unbalance.m
1 Aim of the model : To calculate the Voltage Unbalance

%Clearing the screen and memory
clc
clear
tic;
% establishing the connection to the DB and extracting required data
% Inserting the username and password to access the DB
% importing the required data from ImpedoGraph into MATLAB using SQL Syntax from a table
named VoltageUnbalance.


conn = database('industrial','root','Admin');%connects a MATLAB session to a database via an
ODBC driver
cursor = exec(conn,'SELECT rms_vol_avg from voltageunbalance.rms_voltage_avg');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
%Pfund = cursor.Data;
rms_vol_avg = cursor.Data;
 rms_vol_avg = rms_vol_avg(:,1);

 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

 conn = database('industrial','root','Admin');%connects a MATLAB session to a database via an
ODBC driver
cursor = exec(conn,'SELECT rms_voltage_avg1 from voltageunbalance.rms_voltage_avg1');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
%Pfund = cursor.Data;
rms_voltage_avg1 = cursor.Data;
 rms_voltage_avg1 = rms_voltage_avg1(:,1);

 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

 conn = database('industrial','root','Admin');%connects a MATLAB session to a database via an
ODBC driver
cursor = exec(conn,'SELECT rms_voltage_avg2 from voltageunbalance.rms_voltage_avg2');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
%Pfund = cursor.Data;
rms_voltage_avg2 = cursor.Data;
rms_voltage_avg2 = rms_voltage_avg2(:,1)

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Calculation of voltage unbalance
Vt=3;
n = length(rms_vol_avg);
```

```
% Vavg1=[];
Vunbalance=[];
for i = 1:n;
Vavg = (rms_vol_avg(i)+rms_voltage_avg1(i)+rms_voltage_avg2(i))/Vt;

Vavg1= max([Vavg-rms_vol_avg(i),Vavg-rms_voltage_avg1(i),Vavg-rms_voltage_avg2(i)]);

% Voltage Unbalance= (Maximum Deviation from the Average)/Average*100%

Vunbalance(i) = ((Vavg1)/Vavg)*100;
end
Vunbalance'

n=640
i=1:n
plot(i,Vunbalance)
title('Voltage Unbalance')
xlabel('Number of points')
ylabel('Vunbalance')
grid
```

APPENDIX I

I.1:MATLAB Script- Harmonics example.m

% m.file:Harmonics example.m
1. **Aim of the model:** Is to calculate Harmonics from Simulink
%Clearing the screen and memory
clc
clear
tic;

```
sim('Tyokie44')
N=length(face)';
 for k=0:N-1;
    facen=0;
  for n=0:N-1;
      facen=facen+face(n+1)*exp(-i*(2*pi/N)*n*k);
  end
  facen1(k+1,1)=facen;
  facek=facen1/N;
 end
 plot(abs(facek));
 title('Harmonics');
 xlabel('Harmonic Number');
 grid;
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
x=facek;
N=length(x);
 for n=0:N-1;
    sum=0;
 for k=0:N-1;
      sum=sum+x(k+1)*exp(i*(2*pi/N)*n*k);
  end
  sum1(n+1,1)=sum;
  Xn=sum1/1;
 end
facek;
Xn;
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
err=face-Xn
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

n=1:N;
plot(n,facek)
title('Fast Fourier Transform and Sine+random noise');
xlabel('time');
ylabel('Xk');
grid
hold on

n=1:N;
```

```
plot(n,Xn)
title('Fast Fourier Transform and Sine+random noise')
xlabel('time')
ylabel('Xn')
grid
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

hold off
n=1:N;
plot(n,err)
title('face-Xn')
xlabel('time')
ylabel('err')
grid
```

% Calculations of separate harmonics.

```
  sim('Tyokie445')
N=length(face)';
 for k=1:N-1;
    facen=0;
  for n=0:N-1;
      facen=facen+face(n+1)*exp(-i*(2*pi/N)*n*k);
  end
  facen1(k+1,1)=facen;
  facek=facen1/N;
 end

N=length(facek)';
for k=1:N-1;
for n=1:N;
 xh(n,k)=facek(k)*exp(i*(2*pi/N)*(n-1)*k);
end
end

n=1:N;
figure(1)
subplot(10,2,1);plot(n,xh(:,1));title('fundamental
harmonic');subplot(10,2,2);plot(n,xh(:,2))
subplot(10,2,3);plot(n,xh(:,3));subplot(10,2,4);plot(n,xh(:,4))
subplot(10,2,5);plot(n,xh(:,5));subplot(10,2,6);plot(n,xh(:,6))
subplot(10,2,7);plot(n,xh(:,7));subplot(10,2,8);plot(n,xh(:,8))
subplot(10,2,9);plot(n,xh(:,9));subplot(10,2,10);plot(n,xh(:,10))
subplot(10,2,11);plot(n,xh(:,11));subplot(10,2,12);plot(n,xh(:,12))
subplot(10,2,13);plot(n,xh(:,13));subplot(10,2,14);plot(n,xh(:,14))
subplot(10,2,15);plot(n,xh(:,15));subplot(10,2,16);plot(n,xh(:,16))
```

APPENDIX J

Appendix J1

To call the data from MySQL

J.1:MATLAB Script-Harmonics.m

```
%m-file:harmonics.m
Aim of the model: Is to calculate Harmonics produced with the help of the injector and
ImpedoGraph
%Clearing the screen and memory
clc
clear
tic;


    conn = database('industrial','root','Admin');%connects a MATLAB session to a database
    via an ODBC driver
    cursor = exec(conn,'SELECT voltages_1 from harmonics.voltages_1');
    setdbprefs('DataReturnFormat','numeric');
    cursor = fetch(cursor);
    voltages_1 = cursor.Data;
    voltages_1 = voltages_1(:,1)


    conn = database('industrial','root','Admin');%connects a MATLAB session to a database
    via an ODBC driver
    cursor = exec(conn,'SELECT voltages_2 from harmonics.voltages_2');
    setdbprefs('DataReturnFormat','numeric');
    cursor = fetch(cursor);
    voltages_2 = cursor.Data;
    voltages_2 = voltages_2(:,1)


    conn = database('industrial','root','Admin');%connects a MATLAB session to a database
    via an ODBC driver
    cursor = exec(conn,'SELECT voltages_3 from harmonics.voltages_3');
    setdbprefs('DataReturnFormat','numeric');
    cursor = fetch(cursor);
    voltages_3 = cursor.Data;
    voltages_3 = voltages_3(:,1);
```

Appendix J2

MATLAB and MySQL program to coefficients of voltage_1k (Xk) and plotting the absolute values of the harmonics graphs.

J2.1:MATLAB Script-Harmonics.m

```
%m-file:harmonics.m

conn = database('industrial','root','Admin');%connects a MATLAB session to a database
via an ODBC driver
cursor = exec(conn,'SELECT voltages_1 from harmonics.voltages_1');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
voltages_1 = cursor.Data;
voltages_1 = voltages_1(:,1);

N=length(voltages_1);
for k=0:N-1;
 voltages_1n=0;
  for n=0:N-1;
  voltages_1n=voltages_1n+voltages_1(n+1)*exp(-i*(2*pi/N)*n*k);
end
voltages_1n1(k+1,1)=voltages_1n;
 voltages_1k=voltages_1n1/N;
 end
 voltages_1k;


conn = database('industrial','root','Admin');%connects a MATLAB session to a database
via an ODBC driver
cursor = exec(conn,'SELECT voltages_2 from harmonics.voltages_2');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
voltages_2 = cursor.Data;
voltages_2 = voltages_2(:,1);

N=length(voltages_2);
 for k=0:N-1;
   voltages_2n=0;
 for n=0:N-1;
    voltages_2n=voltages_2n+voltages_2(n+1)*exp(-i*(2*pi/N)*n*k);
 end
  voltages_2n1(k+1,1)=voltages_2n;
  voltages_2k=voltages_2n1/N;
 end
 voltages_2k;


conn = database('industrial','root','Admin');%connects a MATLAB session to a database
via an ODBC driver
cursor = exec(conn,'SELECT voltages_3 from harmonics.voltages_3');
```

```
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
voltages_3 = cursor.Data;
voltages_3 = voltages_3(:,1);

N=length(voltages_3);
 for k=0:N-1;
   voltages_3n=0;
for n=0:N-1;
  voltages_3n=voltages_3n+voltages_3(n+1)*exp(-i*(2*pi/N)*n*k);
 end
 voltages_3n1(k+1,1)=voltages_3n;
 voltages_3k=voltages_3n1/N;
 end
 voltages_3k;


plot(abs(voltages_1k))
 title('Harmonics')
 xlabel('Harmonic Number')
 hold on
grid
 plot(abs( voltages_2k))
  title('Harmonics')
 xlabel('Harmonic Number')
hold on
grid


plot(abs( voltages_3k))
  title('Harmonics')
 xlabel('Harmonic Number')
 grid
```

% Calculations of separate harmonics

```
conn = database('industrial','root','Admin');%connects a MATLAB session to a
database via an ODBC driver
cursor = exec(conn,'SELECT voltage1 from harmonics.voltage1');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
%Pfund = cursor.Data;
voltage1 = cursor.Data;
voltage1 = voltage1(:,1);

N=length(voltage1)';
 for k=1:N-1;
    voltage1n=0;
  for n=0:N-1;
      voltage1n=voltage1n+voltage1(n+1)*exp(-i*(2*pi/N)*n*k);
```

```
   end
  voltage1n1(k+1,1)=voltage1n;
   voltage1k=voltage1n1/N;
  end

N=length(voltage1k)';
for k=1:N-1;
for n=1:N;
 xh(n,k)=voltage1k(k)*exp(i*(2*pi/N)*(n-1)*k);
end
end

n=1:N;
figure(1)
subplot(10,2,1);plot(n,xh(:,1));title('fundamental
harmonic');subplot(10,2,2);plot(n,xh(:,2))
subplot(10,2,3);plot(n,xh(:,3));subplot(10,2,4);plot(n,xh(:,4))
subplot(10,2,5);plot(n,xh(:,5));subplot(10,2,6);plot(n,xh(:,6))
subplot(10,2,7);plot(n,xh(:,7));subplot(10,2,8);plot(n,xh(:,8))
subplot(10,2,9);plot(n,xh(:,9));subplot(10,2,10);plot(n,xh(:,10))
subplot(10,2,11);plot(n,xh(:,11));subplot(10,2,12);plot(n,xh(:,12))
subplot(10,2,13);plot(n,xh(:,13));subplot(10,2,14);plot(n,xh(:,14))
subplot(10,2,15);plot(n,xh(:,15))

conn = database('industrial','root','Admin');%connects a MATLAB session to a
database via an ODBC driver
cursor = exec(conn,'SELECT voltage2 from harmonics.voltage2');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
%Pfund = cursor.Data;
voltage2 = cursor.Data;
voltage2 = voltage2(:,1);


N=length(voltage2)';
 for k=1:N-1;
    voltage2n=0;
  for n=0:N-1;
     voltage2n=voltage2n+voltage2(n+1)*exp(-i*(2*pi/N)*n*k);
  end
  voltage2n1(k+1,1)=voltage2n;
  voltage2k=voltage2n1/N;
 end

N=length(voltage2k)';
for k=1:N-1;
for n=1:N;
 xh(n,k)=voltage2k(k)*exp(i*(2*pi/N)*(n-1)*k);
end
end

n=1:N;
figure(1)
subplot(10,2,1);plot(n,xh(:,1));title('fundamental
harmonic');subplot(10,2,2);plot(n,xh(:,2))
subplot(10,2,3);plot(n,xh(:,3));subplot(10,2,4);plot(n,xh(:,4))
subplot(10,2,5);plot(n,xh(:,5));subplot(10,2,6);plot(n,xh(:,6))
subplot(10,2,7);plot(n,xh(:,7));subplot(10,2,8);plot(n,xh(:,8))
```

```
subplot(10,2,9);plot(n,xh(:,9));subplot(10,2,10);plot(n,xh(:,10))
subplot(10,2,11);plot(n,xh(:,11));subplot(10,2,12);plot(n,xh(:,12))
subplot(10,2,13);plot(n,xh(:,13));subplot(10,2,14);plot(n,xh(:,14))
subplot(10,2,15);plot(n,xh(:,15))


conn = database('industrial','root','Admin');%connects a MATLAB session to a
database via an ODBC driver
cursor = exec(conn,'SELECT voltage3 from harmonics.voltage3');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
%Pfund = cursor.Data;
voltage3 = cursor.Data;
voltage3 = voltage3(:,1);


N=length(voltage3)';
 for k=1:N-1;
    voltage3n=0;
  for n=0:N-1;
      voltage3n=voltage3n+voltage3(n+1)*exp(-i*(2*pi/N)*n*k);
  end
  voltage3n1(k+1,1)=voltage3n;
  voltage3k=voltage3n1/N;
 end

N=length(voltage3k)';
for k=1:N-1;
for n=1:N;
 xh(n,k)=voltage3k(k)*exp(i*(2*pi/N)*(n-1)*k);
end
end

n=1:N;
figure(1)
subplot(10,2,1);plot(n,xh(:,1));title('fundamental
harmonic');subplot(10,2,2);plot(n,xh(:,2))
subplot(10,2,3);plot(n,xh(:,3));subplot(10,2,4);plot(n,xh(:,4))
subplot(10,2,5);plot(n,xh(:,5));subplot(10,2,6);plot(n,xh(:,6))
subplot(10,2,7);plot(n,xh(:,7));subplot(10,2,8);plot(n,xh(:,8))
subplot(10,2,9);plot(n,xh(:,9));subplot(10,2,10);plot(n,xh(:,10))
subplot(10,2,11);plot(n,xh(:,11));subplot(10,2,12);plot(n,xh(:,12))
subplot(10,2,13);plot(n,xh(:,13));subplot(10,2,14);plot(n,xh(:,14))
subplot(10,2,15);plot(n,xh(:,15))
```

Appendix J3

Aim: Inverse Fourier Transform (Xn) are used to check that the calculated coefficients are right one to generate the data

J3.1:MATLAB Script-(Xn).m

```
%m-file:(Xn).m

conn = database('industrial','root','Admin');%connects a MATLAB session to a database
via an ODBC driver
cursor = exec(conn,'SELECT voltages_1 from harmonics.voltages_1');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
voltages_1 = cursor.Data;
voltages_1 = voltages_1(:,1);

N=length(voltages_1);
 for k=0:N-1;
  voltages_1n=0;
for n=0:N-1;
   voltages_1n=voltages_1n+voltages_1(n+1)*exp(-i*(2*pi/N)*n*k);
 end
voltages_1n1(k+1,1)=voltages_1n;
voltages_1k=voltages_1n1/N;
 end
 voltages_1k;


 x=voltages_1k;
N=length(x);
 for n=0:N-1;
   sum=0;
 for k=0:N-1;
   sum=sum+x(k+1)*exp(i*(2*pi/N)*n*k);
end
 sum1(n+1,1)=sum;
  Xn1=sum1/1;
end

conn = database('industrial','root','Admin');%connects a MATLAB session to a database
via an ODBC driver
cursor = exec(conn,'SELECT voltages_2 from harmonics.voltages_2');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
voltages_2 = cursor.Data;
voltages_2 = voltages_2(:,1);

N=length(voltages_2);
 for k=0:N-1;
  voltages_2n=0;
```

```
 for n=0:N-1;
 voltages_2n=voltages_2n+voltages_2(n+1)*exp(-i*(2*pi/N)*n*k);
  end
  voltages_2n1(k+1,1)=voltages_2n;
 voltages_2k=voltages_2n1/N;
end
voltages_2k;


 xb=voltages_2k;
N=length(xb);
 for n=0:N-1;
   sum=0;
 for k=0:N-1;
  sum=sum+xb(k+1)*exp(i*(2*pi/N)*n*k);
  end
  sum1(n+1,1)=sum;
  Xn2=sum1/1;
 end

 conn = database('industrial','root','Admin');%connects a MATLAB session to a database
via an ODBC driver
cursor = exec(conn,'SELECT voltages_3 from harmonics.voltages_3');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
voltages_3 = cursor.Data;
voltages_3 = voltages_3(:,1);

N=length(voltages_3);
 for k=0:N-1;
voltages_3n=0;
  for n=0:N-1;
voltages_3n=voltages_3n+voltages_3(n+1)*exp(-i*(2*pi/N)*n*k);
end
  voltages_3n1(k+1,1)=voltages_3n;
 voltages_3k=voltages_3n1/N;
end
voltages_3k;


 xc=voltages_3k;
N=length(xc);
 for n=0:N-1;
   sum=0;
 for k=0:N-1;
sum=sum+xc(k+1)*exp(i*(2*pi/N)*n*k);
 end
sum1(n+1,1)=sum;
Xn3=sum1/1;
 end
```

Appendix J4

Error

Aim: To calculate error which is used to check how close the estimated signal is to the original data

J.1:MATLAB Script-Error.m

```
%m-file:Error.m

conn = database('industrial','root','Admin');%connects a MATLAB session to a database
via an ODBC driver
cursor = exec(conn,'SELECT voltages_1 from harmonics.voltages_1');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
voltages_1 = cursor.Data;
voltages_1 = voltages_1(:,1);

N=length(voltages_1);
 for k=0:N-1;
voltages_1n=0;
for n=0:N-1;
  voltages_1n=voltages_1n+voltages_1(n+1)*exp(-i*(2*pi/N)*n*k);
 end
  voltages_1n1(k+1,1)=voltages_1n;
 voltages_1k=voltages_1n1/N;
 end
 voltages_1k;


 x=voltages_1k;
N=length(x);
 for n=0:N-1;
    sum=0;
 for k=0:N-1;
  sum=sum+x(k+1)*exp(i*(2*pi/N)*n*k);
  end
  sum1(n+1,1)=sum;
  Xn1=sum1/1;
 end

  error1=Xn1-voltages_1

conn = database('industrial','root','Admin');%connects a MATLAB session to a database
via an ODBC driver
cursor = exec(conn,'SELECT voltages_2 from harmonics.voltages_2');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
voltages_2 = cursor.Data;
voltages_2 = voltages_2(:,1);
```

```
N=length(voltages_2);
 for k=0:N-1;
  voltages_2n=0;
 for n=0:N-1;
  voltages_2n=voltages_2n+voltages_2(n+1)*exp(-i*(2*pi/N)*n*k);
end
voltages_2n1(k+1,1)=voltages_2n;
 voltages_2k=voltages_2n1/N;
end
 voltages_2k;


 xb=voltages_2k;
N=length(xb);
 for n=0:N-1;
   sum=0;
for k=0:N-1;
sum=sum+xb(k+1)*exp(i*(2*pi/N)*n*k);
 end
 sum1(n+1,1)=sum;
Xn2=sum1/1;
 end

error2=Xn2-voltages_2


conn = database('industrial','root','Admin');%connects a MATLAB session to a database
via an ODBC driver
cursor = exec(conn,'SELECT voltages_3 from harmonics.voltages_3');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
voltages_3 = cursor.Data;
voltages_3 = voltages_3(:,1);

N=length(voltages_3);
for k=0:N-1;
   voltages_3n=0;
for n=0:N-1;
 voltages_3n=voltages_3n+voltages_3(n+1)*exp(-i*(2*pi/N)*n*k);
 end
 voltages_3n1(k+1,1)=voltages_3n;
 voltages_3k=voltages_3n1/N;
end
 voltages_3k;



xc=voltages_3k;
N=length(xc);
 for n=0:N-1;
 sum=0;
for k=0:N-1;
sum=sum+xc(k+1)*exp(i*(2*pi/N)*n*k);
```

```
  end
sum1(n+1,1)=sum;
Xn3=sum1/1;
 end
Xn1;
 Xn2;
Xn3;
error3=Xn3-voltages_3
```

APPENDIX K

K:MATLAB Script- Crest factor.m

%m-file: **Crest factor.m**

1. **Aim of the model:** Is to calculate Crest factor.m

%Clearing the screen and memory

clc

clear

tic;

% establishing the connection to the DB and extracting required data

% Inserting the username and password to access the DB

% importing the required data from Impedograph into MATLAB using SQL Syntax from a table named crest factor.

Crest Factor

```
conn = database('industrial','root','Admin');%connects a MATLAB session to a
database via an ODBC driver
cursor = exec(conn,'SELECT vpeak from crestfactor.vpeak');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
%Pfund = cursor.Data;
vpeak = cursor.Data;
 vpeak = vpeak(:,1);

conn = database('industrial','root','Admin');%connects a MATLAB session to a
database via an ODBC driver
cursor = exec(conn,'SELECT vrms from crestfactor.vrms');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
%Pfund = cursor.Data;
vrms = cursor.Data;
 vrms = vrms(:,1);

a = length(vpeak);
cf =[];
for i=1:a;
cf(i)= vpeak(i)/vrms(i);
end
cf'

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
conn = database('industrial','root','Admin');%connects a MATLAB session to a
database via an ODBC driver
cursor = exec(conn,'SELECT vpeak2 from crestfactor.vpeak2');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
%Pfund = cursor.Data;
vpeak2 = cursor.Data;
vpeak2 = vpeak2(:,1);

%%%%%%%%%%%%%%%%%%%
```

```
conn = database('industrial','root','Admin');%connects a MATLAB session to a
database via an ODBC driver
cursor = exec(conn,'SELECT vrms2 from crestfactor.vrms2');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
%Pfund = cursor.Data;
vrms2 = cursor.Data;
 vrms2 = vrms2(:,1);

a = length(vpeak2);
cf2 =[];
for i=1:a;
cf2(i)= vpeak2(i)/vrms2(i);
end
cf2'


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
conn = database('industrial','root','Admin');%connects a MATLAB session to a
database via an ODBC driver
cursor = exec(conn,'SELECT vpeak3 from crestfactor.vpeak3');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
%Pfund = cursor.Data;
vpeak3 = cursor.Data;
vpeak3 = vpeak3(:,1);

%%%%%%%%%%%%%%%%%%%%%

conn = database('industrial','root','Admin');%connects a MATLAB session to a
database via an ODBC driver
cursor = exec(conn,'SELECT vrms3 from crestfactor.vrms3');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
%Pfund = cursor.Data;
vrms3 = cursor.Data;
 vrms3 = vrms3(:,1);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
a = length(vpeak3);
 cf3 =[];
for i=1:a;
cf3(i)= vpeak3(i)/vrms3(i);
end
cf3'

i=1:a;
plot(i,cf)
title('crest factor');
xlabel('Number of points')
ylabel('cf')
grid
hold on

i=1:a;
plot(i,cf2)
title('crest factor');
xlabel('Number of points')
ylabel('cf')
```

```
grid
hold on

i=1:a;
plot(i,cf3)
title('crest factor');
xlabel('Number of points')
ylabel('cf')
grid
```

Error

```
conn = database('industrial','root','Admin');%connects a MATLAB session to a
database via an ODBC driver
cursor = exec(conn,'SELECT vpeak from crestfactor.vpeak');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
vpeak = cursor.Data;
 vpeak = vpeak(:,1);

conn = database('industrial','root','Admin');%connects a MATLAB session to a
database via an ODBC driver
cursor = exec(conn,'SELECT vrms from crestfactor.vrms');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
vrms = cursor.Data;
 vrms = vrms(:,1);

a = length(vpeak);
cf =[];
for i=1:a;
cf(i)= vpeak(i)/vrms(i);
end
cf';

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
conn = database('industrial','root','Admin');%connects a MATLAB session to a
database via an ODBC driver
cursor = exec(conn,'SELECT vpeak2 from crestfactor.vpeak2');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
vpeak2 = cursor.Data;
vpeak2 = vpeak2(:,1);

%%%%%%%%%%%%%%%%%%%%%


conn = database('industrial','root','Admin');%connects a MATLAB session to a
database via an ODBC driver
cursor = exec(conn,'SELECT vrms2 from crestfactor.vrms2');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
vrms2 = cursor.Data;
 vrms2 = vrms2(:,1);

a = length(vpeak2);
```

```
cf2 =[];
for i=1:a;
cf2(i)= vpeak2(i)/vrms2(i);
end
cf2';


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
conn = database('industrial','root','Admin');%connects a MATLAB session to a
database via an ODBC driver
cursor = exec(conn,'SELECT vpeak3 from crestfactor.vpeak3');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
vpeak3 = cursor.Data;
vpeak3 = vpeak3(:,1);

%%%%%%%%%%%%%%%%%%%%%


conn = database('industrial','root','Admin');%connects a MATLAB session to a
database via an ODBC driver
cursor = exec(conn,'SELECT vrms3 from crestfactor.vrms3');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
vrms3 = cursor.Data;
 vrms3 = vrms3(:,1);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
a = length(vpeak3);
 cf3 =[];
for i=1:a;
cf3(i)= vpeak3(i)/vrms3(i);
end
cf3';

conn = database('industrial','root','Admin');%connects a MATLAB session to a
database via an ODBC driver
cursor = exec(conn,'SELECT crest_factor from crestfactor.crest_factor');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
crest_factor = cursor.Data;
 crest_factor = crest_factor(:,1);



%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%


conn = database('industrial','root','Admin');%connects a MATLAB session to a
database via an ODBC driver
cursor = exec(conn,'SELECT crest_factor1 from crestfactor.crest_factor1');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
crest_factor1 = cursor.Data;
 crest_factor1 = crest_factor1(:,1);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%


conn = database('industrial','root','Admin');%connects a MATLAB session to a
database via an ODBC driver
```

```
cursor = exec(conn,'SELECT crest_factor3 from crestfactor.crest_factor3');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
crest_factor3 = cursor.Data;
 crest_factor3 = crest_factor3(:,1);


 error1 = crest_factor-cf'
 error2 = crest_factor1-cf2'
 error3 = crest_factor3-cf3'

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% The ploting all crest factor
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
 i=1:a;
 plot(i,error1)
 title('Error between measured and calculated crest factor')
 xlabel('Number of points');
 ylabel('cf');
 grid
 hold on


 i=1:a;
 plot(i,error2)
 title('Error between measured and calculated crest factor')
 xlabel('Number of points');
 ylabel('cf');
 grid
hold on

 i=1:a;
 plot(i,error3)
 title('Error between measured and calculated crest factor')
 xlabel('Number of points');
 ylabel('cf');
 grid
```

APPENDIX M

K:MATLAB Script- Apparent power work.m

%m-file: **Apparent power work.m**
1. **Aim of the model:** Is to calculate Apparent power
%Clearing the screen and memory
clc
clear
tic;
% establishing the connection to the DB and extracting required data
% Inserting the username and password to access the DB
% importing the required data from Impedograph into MATLAB using SQL Syntax from a table named apparentpower.

```
conn = database('industrial','root','Admin');%connects a MATLAB session to a
database via an ODBC driver
cursor = exec(conn,'SELECT vrms1 from apparentpower.vrms1');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
vrms1 = cursor.Data;
vrms1 = vrms1(:,1);

conn = database('industrial','root','Admin');%connects a MATLAB session to a
database via an ODBC driver
cursor = exec(conn,'SELECT irms1 from apparentpower.irms1');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
irms1 = cursor.Data;
irms1 = irms1(:,1);
```

%Calculation of Apparentp'

```
a=length(vrms1);
Apparentp = [];
for i =1:a;
    Apparentp(i) = vrms1(i)*irms1(i);
end
Apparentp'

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

conn = database('industrial','root','Admin');%connects a MATLAB session to a
database via an ODBC driver
cursor = exec(conn,'SELECT vrms2 from apparentpower.vrms2');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
vrms2 = cursor.Data;
vrms2 = vrms2(:,1);

conn = database('industrial','root','Admin');%connects a MATLAB session to a
database via an ODBC driver
cursor = exec(conn,'SELECT irms2 from apparentpower.irms2');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
irms2 = cursor.Data;
```

```
irms2 = irms2(:,1);

%Calculation of Apparentp2'
a=length(vrms1);
Apparentp2 = [];
for i =1:a;
    Apparentp2(i) = vrms2(i)*irms2(i);
end
Apparentp2'

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

conn = database('industrial','root','Admin');%connects a MATLAB session to a
database via an ODBC driver
cursor = exec(conn,'SELECT vrms3 from apparentpower.vrms3');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
vrms3 = cursor.Data;
vrms3 = vrms3(:,1);

conn = database('industrial','root','Admin');%connects a MATLAB session to a
database via an ODBC driver
cursor = exec(conn,'SELECT irms3 from apparentpower.irms3');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
irms3 = cursor.Data;
irms3 = irms3(:,1);

%Calculation of Apparentp3'
a=length(vrms1);
Apparentp3 = [];
for i =1:a;
    Apparentp3(i) = vrms3(i)*irms3(i);
end
Apparentp3'

i =1:a;
plot(i,Apparentp')
title('Calculated Apparent power')
xlabel('Number of points')
ylabel('VA')
grid
hold on

i =1:a;
plot(i,Apparentp2')
title('Calculated Apparent power')
xlabel('Number of points')
ylabel('VA')
grid
hold on

i =1:a;
plot(i,Apparentp3')
title('Calculated Apparent power')
xlabel('Number of points')
ylabel('VA')
grid
```

Error Program

```
conn = database('industrial','root','Admin');%connects a MATLAB session to a
database via an ODBC driver
cursor = exec(conn,'SELECT apparentpower1 from apparentpower.apparentpower1');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
apparentpower1 = cursor.Data;
apparentpower1 = apparentpower1(:,1);

conn = database('industrial','root','Admin');%connects a MATLAB session to a
database via an ODBC driver
cursor = exec(conn,'SELECT vrms1 from apparentpower.vrms1');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
vrms1 = cursor.Data;
vrms1 = vrms1(:,1);

conn = database('industrial','root','Admin');%connects a MATLAB session to a
database via an ODBC driver
cursor = exec(conn,'SELECT irms1 from apparentpower.irms1');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
irms1 = cursor.Data;
irms1 = irms1(:,1);

a=length(vrms1);
Apparentp = [];
for i =1:a;
    Apparentp(i) = vrms1(i)*irms1(i);
end
Apparentp';

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

conn = database('industrial','root','Admin');%connects a MATLAB session to a
database via an ODBC driver
cursor = exec(conn,'SELECT apparentpower2 from apparentpower.apparentpower2');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
apparentpower2 = cursor.Data;
apparentpower2 = apparentpower2(:,1);

conn = database('industrial','root','Admin');%connects a MATLAB session to a
database via an ODBC driver
cursor = exec(conn,'SELECT vrms2 from apparentpower.vrms2');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
vrms2 = cursor.Data;
vrms2 = vrms2(:,1);

conn = database('industrial','root','Admin');%connects a MATLAB session to a
database via an ODBC driver
```

```
cursor = exec(conn,'SELECT irms2 from apparentpower.irms2');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
irms2 = cursor.Data;
irms2 = irms2(:,1);

a=length(vrms1);
Apparentp2 = [];
for i =1:a;
    Apparentp2(i) = vrms2(i)*irms2(i);
end
Apparentp2';

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
conn = database('industrial','root','Admin');%connects a MATLAB session to a
database via an ODBC driver
cursor = exec(conn,'SELECT apparentpower3 from apparentpower.apparentpower3');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
apparentpower3 = cursor.Data;
apparentpower3 = apparentpower3(:,1);

conn = database('industrial','root','Admin');%connects a MATLAB session to a
database via an ODBC driver
cursor = exec(conn,'SELECT vrms3 from apparentpower.vrms3');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
vrms3 = cursor.Data;
vrms3 = vrms3(:,1);

conn = database('industrial','root','Admin');%connects a MATLAB session to a
database via an ODBC driver
cursor = exec(conn,'SELECT irms3 from apparentpower.irms3');
setdbprefs('DataReturnFormat','numeric');
cursor = fetch(cursor);
irms3 = cursor.Data;
irms3 = irms3(:,1);

a=length(vrms1);
Apparentp3 = [];
for i =1:a;
    Apparentp3(i) = vrms3(i)*irms3(i);
end
Apparentp3';


error1=apparentpower1-Apparentp'
error2=apparentpower2-Apparentp2'
error3=apparentpower3-Apparentp3'

i =1:a;
plot(i,error1')
title('Error Apparent power')
xlabel('Number of points')
ylabel('error')
grid
hold on
```

```
i =1:a;
plot(i,error2')
title('Error Apparent power')
xlabel('Number of points')
ylabel('error')
grid
hold on

i =1:a;
plot(i,error3')
title('Error Apparent power')
xlabel('Number of points')
ylabel('error')
grid
```

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