Intervention mechanisms to reduce energy consumption of air-conditioning and illumination systems for commercial buildings

by

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DECLARATION

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

Signed

Date

ABSTRACT

This study aimed to explore the cost-effective mechanisms to reduce energy demand consumption in SASOL Fuels Application Centre (SFAC) building in South Africa. It focuses on the commercial facility's total real power (kW) and reactive power (KVAR), which together contributes to high demand (KVA) spark resulting in high demand energy costs, which has a direct influence on the high electricity bills issued to commercial businesses worldwide.

The demand sparks are caused by current's instantaneous hike which as a result caused pressure to power producer. Then, the producer issues penalties in the form of demand charges resulting in a high electricity bill. The energy consumption reduction of commercial buildings can be achieved through the implementation of a power metering system to measure the total kW, KVA, KVAR and power factor.

The study presents DSM techniques as a model suitable for reduction of demand load consumptions and demonstrates a range of energy conservation options available for baseline reduction to contribute to lower total electricity consumption of SFAC. The preferred method for the study was power factor improvement aimed at correcting the current spark by discharging the set of required capacitor banks to compensate for the demand. The power simulator software model was developed to simulate the real power together with the desired power factor and the reduction of approximately 10% on electricity bill was realised.

Keywords: Electricity bill, demand saving, peak shaving, energy efficiency, consumption and power factor correction.

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To my loving family, wife and children, I wish to thank them for their affection and encouragement even during difficult times of the passing of my mother. I would not have endured the years of research and study without your constant support and love. You are all a blessing beyond description and words do not do justice to the gifts you have lavished upon me.

Finally, to the rest of the faculty and staff at the Cape Peninsula University of Technology, I express my heart-felt thanks. Your long hours spent processing library requests and application forms has made this research possible.

DEDICATION

To my lovely wife MAPASEKA INNOCENTIA LEPHUTHING

and

to my late mother PUSELETSO ALINA LEPHUTHING.

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LIST OF ABBREVIATIONS AND ACCRONYMS

SFAC	SASOL Fuels Application Centre
NEES	National Energy Efficiency Strategy
IEA	International Energy Association
GHG	Greenhouse gases
UN	United Nation
US	United State
USA	United States of America
SA	South Africa
DOE	Department of Energy
CO_2	Carbon dioxide
PF	Power factor
PFC	Power Factor Correction
EEDSM	Energy Efficiency Demand Side Management
OHS	Occupational Health and Safety
GDP	Gross Domestic Product
SG	Smart grid
AC	Air Conditioning
HVAC	Heating, Ventilation and Air Conditioning
UPS	Uninterruptible Power System
CCT	City of Cape Town
DR	Demand Response
CPP	Critical peak time pricing
RTP	Real-time pricing
DA-RTP	Day-ahead real-time pricing
TOUP	Time-of-use Pricing
TOU	Time-of-Use

FRP	Flat Rate Pricing
EDF	Electricite de France
DLC	Direct load control
KVA	Kilovolt-ampere
KVAR	Kilovolt-ampere reactive
KVARh	Kilovolt-ampere reactive per hour
VAR	Voltage-Ampere Reactive
RMS	Root mean square
pF	Pico-farad
kW	Kilowatt
kWh	Kilowatt Hour
GW	Giga-Watts
MW	Mega-Watts
DSM	Demand-side Management
LED	Light Emitting Diode
ETB	Ethiopian Birr
EEUE	Education on Efficient Usage of Energy
EES	Energy Efficient Systems
UV	Ultra-Violet
ICU	Intensive Care Unit
AC/DC	Alternating Current or Direct Current
CVR	Conservation Voltage Reduction
ANSI	American National Standards Institute
SPS	Smart power system
g CO_2/ kWh	Grams of carbon dioxide equivalent per kilowatt hour
Gt CO_2	Giga-tonnes of equivalent carbon dioxide
t CO_2e	Tonnes of Carbon Dioxide Equivalent

SSA	Southern Sahara Africa
RBS	Revised Balanced Scenario
IRP	Integrated Resource Plan
ASTM	American Society for Testing and Materials
EEI	Edison Electrical Institute
AEIC	Analytical Excellence through Industry Collaboration
HAN	Home area network
ISO	International Organization for Standardization.
RTU	Remote terminal unit
ASCII	American Standard Code for Information Interchange
TCP	Transmission Control Protocol
LPU-MV	Large Power User Medium Voltage
TOU-MV	Time-of-Use Medium Voltage
SPU	Small Power User
PFCMD	Power factor correction model design
MCCB	Moulded Cased Circuit Breaker
DOL	Direct on line
CCT	City of Cape Town

1. Chapter One: Introduction

1.1. Background

Energy in the world is the most important commodity that each country needs to grow the economy, create employment, and reduce the lack of access that exist. An inefficient power generating technology produces high toxic emissions of gases emitted to the atmosphere which has a direct impact to the health of society and poses a danger to food security. As a result of the increased population worldwide, the need to cut down on greenhouse gases (GHGs) gained momentum. Due to this, it is important for domestic use and commercial sectors to conserve energy or introduce more renewable energy mix sources (Fouejio-Tsobze, 2010).

Due to electricity supplies still running short, most of the countries in the African continent are generating electrical energy through fossil fuel technology, which contributes a huge amount of GHG (Longe et al., 2013). The power generation through coal-fired technology possesses a risk of producing emissions, which directly affect climate change (Herbst & Lalk, 2016). In 1998, the UN committed to the Kyoto protocol on the climate change to cut-off CO2 emissions (Herbst & Lalk, 2016). African researchers, institutions and businesses have intensified their efforts in renewable energy and renewable potentials in the continent.

Access to electricity is accepted as the demonstrator of socio-economic development of any country (Hammons et al., 2000). In 2012, IEA (Longe et al., 2013) reported that Sub-Saharan Africa has 589 million people and 56.9% of the population do not have access to electricity, and 67.2% rely on biomass for cooking with electrification of 43.1%. According to the IEA, in 2012 (Longe et al., 2013), in Africa the population is predicted to grow by 71% from 2009 to 2035, but there will be only a 38% increase in energy demand over the same period. This means as African population increases from 2009 (by 15%) to estimated 2035 (by 20%), then the global energy share will decline by fractionally to 5.4% over the same predicted period (Zoll, 2010). This leads to considerable benefits of investing on energy efficiency use. Increasing the supply energy bandwidth in turn leads to health and outreach benefits to the society in general.

Carbon sequestration methods and technologies can assist in rooting-out the damage caused by climate change (Fouejio-Tsobze, 2010). Carbon sequestration is described as the process of capturing carbon emission, transporting and storing waste in reservoirs, and stopping the occurrence of atmospheric carbon dioxide. High energy consumption generally contributes to air pollution which has a direct contribution to the climate change phenomenon. It is therefore sensible for commercial and industrial businesses to reduce greenhouse gases emitted to the atmosphere in order to prevent climate change.

In the late 1970s, the energy producers of the United States introduced and implemented the program purposed at changing the level and timing of energy demand among customers which called demand-side management (DSM) (Fouejio-Tsobze, 2010). They partnered together due to oil and gas price increase around the world. Fast forward in 1980s the DSM concept was disperse-out across the United States to put stop to further construction of power plants (Fouejio-Tsobze, 2010). It was found in 1999 study that US Energy producers spend $14.7 billion on DSM programs structured to influence decision making of their customers to invest in energy efficiency.

In 2005, the South African government introduced the national energy efficiency strategy (NEES) aimed to respond to the increasing demand for energy alongside a growing commitment to improving resources utilisation and cutting down on the environmental polluters (Department of Energy, 2016). The commercial sector under NEES set a reduction target of 15% by 2015. The City of Cape Town committed to lead by example and improve the energy efficiency and management of the energy consumed by council operations.

It was estimated that buildings consume 27% of energy in the city council operation. As a result, the city introduced building energy efficiency retrofit program for large buildings in the city, with the cost equating to R60million, and eventually other programs followed such as the installation of smart meters. According to the city council, this smart meter program has resulted in energy savings of approximately 1068MWh and carbon emission reductions of 1058t CO_2e.

The world 1970s crises led to a variety of energy efficiency methods such as demand side management, conservation intervention methods, and the power factor correction (PFC) method. These methods can be utilised together or in each form to achieve a decrease in energy demand consumptions which eventually leads to lower demand pressure from the power producer, which in turn, results in less carbon emissions exhausted into the atmosphere and less damage to the environment. The PFC technique is used by many studies as a method consisting of grouped capacitive load to the power line to reduce the reactive power generated from inductive loads (Karimeh et al, 2016). As a result, it reduces the demand energy required and lowers electricity cost. Therefore, this method promotes the efficient use of energy and saves on cost for commercial or industrial businesses.

The target set by the South African government on the National Energy Efficiency Strategy is to reduce demand energy by 15% in 2015 (Department of Energy, 2016). PFC methods lead to considerable benefits such as elimination of power factor penalty, lower energy consumption by reducing losses and increase system capacity.

1.2. Commercial sector energy consumption in South Africa

The country’s energy sector is under a tremendous pressure which is caused by the increase in population, as well as commercial and industrial businesses. In 2012, the Department of Energy (DOE) conducted research on South Africa’s national energy balances and found that mining and manufacturing consume just under two thirds of South Africa’s total electricity consumption which equates to 62% (Holdings, 2017).

According to the DOE figure below, residential sectors consume 20% of energy, while the industrial and commerce and public services together comprises an average of 30% of the total electricity consumption. Furthermore, the mining and quarrying consumes 16%, whereas iron and steel is responsible for 11%.

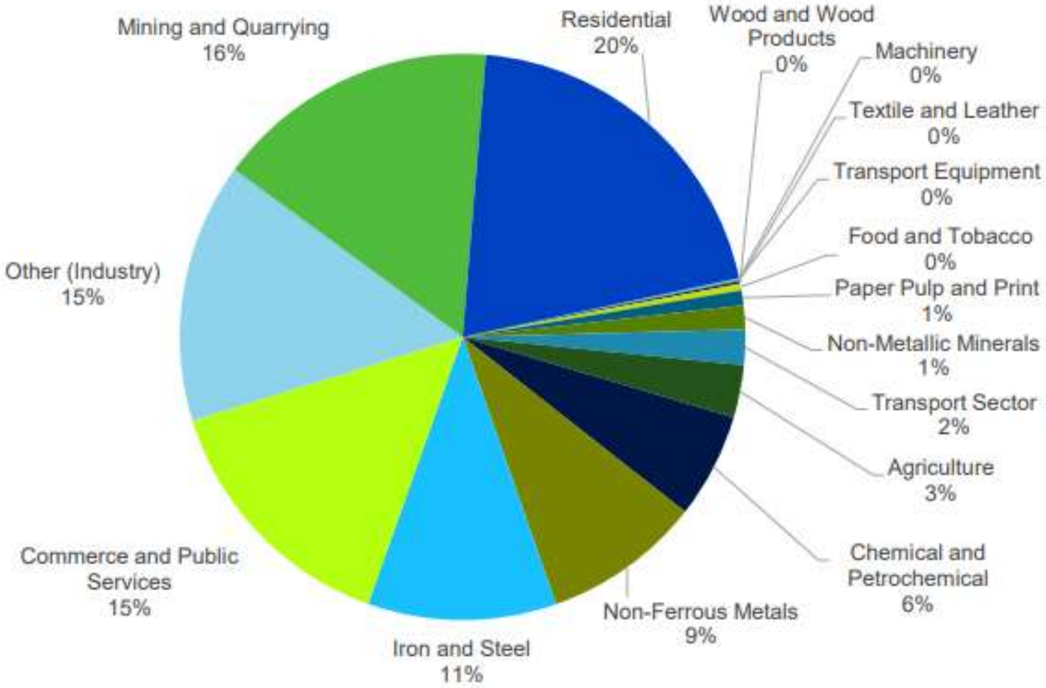
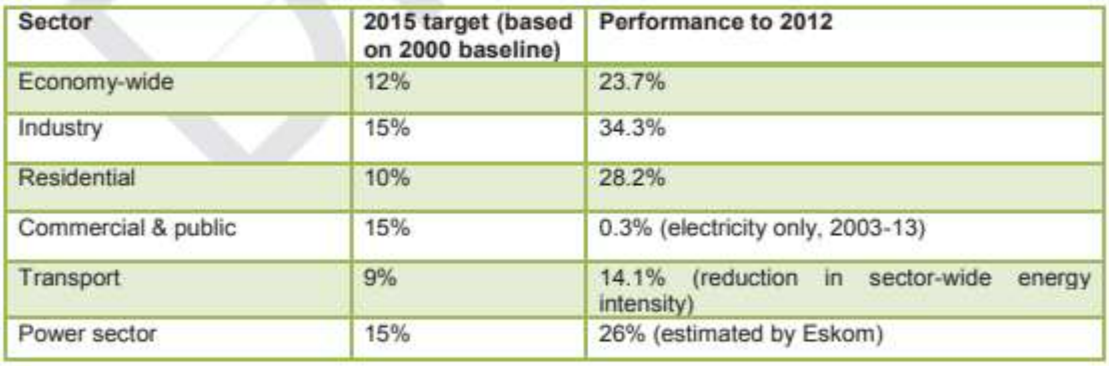


Figure 1: South Africa’s energy consumption of Survey of 2012 (Holding, 2017).

The notion of the South African government and DOE to release a NEES policy in 2005, changed the attitude of consumers in South Africa. According to Table1, the target indicates the areas where energy reduction is required such as in the case where the industrial sector in 2012 was responsible for 34.3% of total energy consumption, while the target was set to be 15% in 2015, and the commercial target was a 15% reduction of total energy consumption (Department of Energy, 2016).



Sector	2015 target (based on 2000 baseline)	Performance to 2012
Economy-wide	12%	23.7%
Industry	15%	34.3%
Residential	10%	28.2%
Commercial & public	15%	0.3% (electricity only, 2003-13)
Transport	9%	14.1% (reduction in sector-wide energy intensity)
Power sector	15%	26% (estimated by Eskom)

Table 1: Improvements and targets of energy (2000-2012) (Department of Energy, 2016).

1.3. Health of Economy in South Africa

According to the World Bank, South Africa is ranked among the upper middle-income countries, the economic structure of which mimics that of a high-income country, which typically has a dominant service sector that accords for more than 66% of national GDP (Holdings, 2017).

In the past 30 years, South Africa's economy has switched away from traditional dependency to energy-intensive mining, with manufacturing sectors having a more diverse range of service-oriented activity (Holdings, 2017). The mining, manufacturing and construction sectors accounted for almost half of the GDP, equating to 45%, however, today they produce under 30% of the GDP (Holdings, 2017).

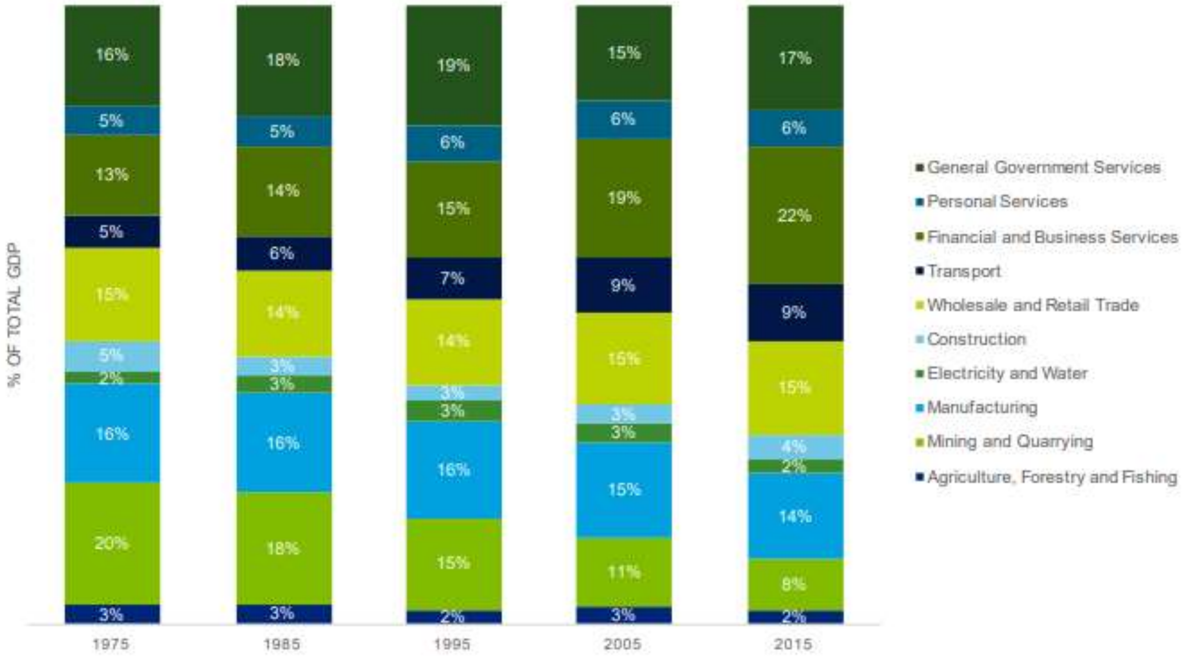


Figure 2: 1975-2015 Evolution of South African economy (Holdings, 2017).

The South African economy has a large and well-developed service sector which accounted for over 65% of the GDP in 2015, whereby mining, manufacturing and construction consumes the remaining portion (Holdings, 2017). According to Figure 2 above, financial and business services activity expanded from 13%-22% of the GDP from 1975-2015. The sector, as indicated above, is now the single largest contributor to national output. The contribution of transport services also increased notably from 5% of the GDP in 1975 to 9% in 2015.

In contrast, the mining sector's share of GDP declined from 20% in 1975 to just 8% in 2015, and also the manufacturing sector fell from 16% to 14% of GDP over the same period. Other sectors, including electricity and water, remain unchanged or constant from the period of 1975 till 2015.

However, although electricity and water does not show growth nor decline in GDP during the period, there are great benefits for potential growth of the sector since there is lack of electricity supply and water in and outside the country. IRP 2010-2030 is established by the Department of Energy to layout a proposed power generation plan of new-builds fleet for the period of 2010-2030 (Department of Energy, 2011).

1.4. Problem Statement

SASOL Fuels Application centre (SFAC) is a state-of-the-art fuels research and development facility with interventions to test the impact of its range of synthetic and crude oil derived fuels on automotive engines for performance and emissions. The facility encompasses a number of equipment, systems, processes and other specialised instruments for its specialised duties. These instruments together with office administration equipment contribute to the total consumption of electricity of the building. Due to this, the pressure builds up in the demand for energy which results in a high electricity bill. The electricity bill was such that the energy charge was quite low, but demand energy cost was very high. The facility management have previously investigated electricity bills to see similar pattern occurrence on the cost analysis of past months, however, a solution did not materialise due to the cost of electricity versus implementation of energy-efficient systems to reduce skyrocketing demand energy.

It was envisioned that with the development of an energy efficiency system that can reduce demand energy consumption relative to the electricity bill via proper control system or sequence procedure to monitor the total facility consumption, and controlling energy at non-essential systems, can lead to facility improvement. Historic metering data would make the system much clearer, providing a sense of understanding about the areas where energy is highly consumed to be able to formulate the proper mitigation and control methods to address the energy demand.

1.5. Research aim and objectives

The aim of the study is to reduce the demand energy cost for the commercial building in South Africa.

In achieving the objectives, the study will focus on the issues below:

- To analyse and implement the total SFAC building energy consumption
- To simulate and develop an energy efficiency model
- To implement the model to reduce demand energy for the facility.

1.6. Research questions

The research questions intends to address the fundamental energy saving intervention mechanism which will be investigated to bring solutions to the following:

a) Main question
  - Can energy management methods assist in reducing demand energy consumption in SFAC?

b) Sub-questions
  - How efficient are energy demand response strategies?
  - How do increases in energy consumption affect SFAC on the electricity bill?

1.7. Methodology

To explore the demand side management strategies to reduce demand power consumption cost for commercial business in the South Africa. To achieve that the need to design simulator software tool that can be used to simulate different scenarios of demand energy consumption, to enable efficient reduction of demand power for the facility.

To deal with the objectives set, the model simulation design will incorporate power factor improvements and the electricity tariff structure features which could efficiently reduce the demand power. The tariff structures used in the study are derived from local power supplier (City of Cape Town). The success of the model will lead to demonstration and approval for implementation of technology to SFAC facility.

1.8. Delineation of the research

The study is limited to the SFAC facility in Cape Town in the Western Cape Province of the Republic of South Africa wherein the facility's total energy consumption is been analysed and model to transform the cost of electricity bill.

- The outcome of this study is to develop an energy efficient model which industries can utilise to achieve efficient energy usage.

However, the study does not cover or include the implementation of the model.

1.9. Significance of the research

The outcome of this study is to develop an energy efficient model which industries can utilise to achieve efficient energy usage, as well as to support the government and DOE on their commitment to the national energy efficient strategy policy.

The commercial or industrial business can expect electricity bill reduction, as the results will be reduced carbon emission, which posed a risk to atmospheric space.

1.10. Thesis structure and sequence of chapters

This section provides the thesis layout in a systematic sequence with chapters labelled accordingly from introduction to the conclusion. Figure 3 below is a graphical presentation thereof.

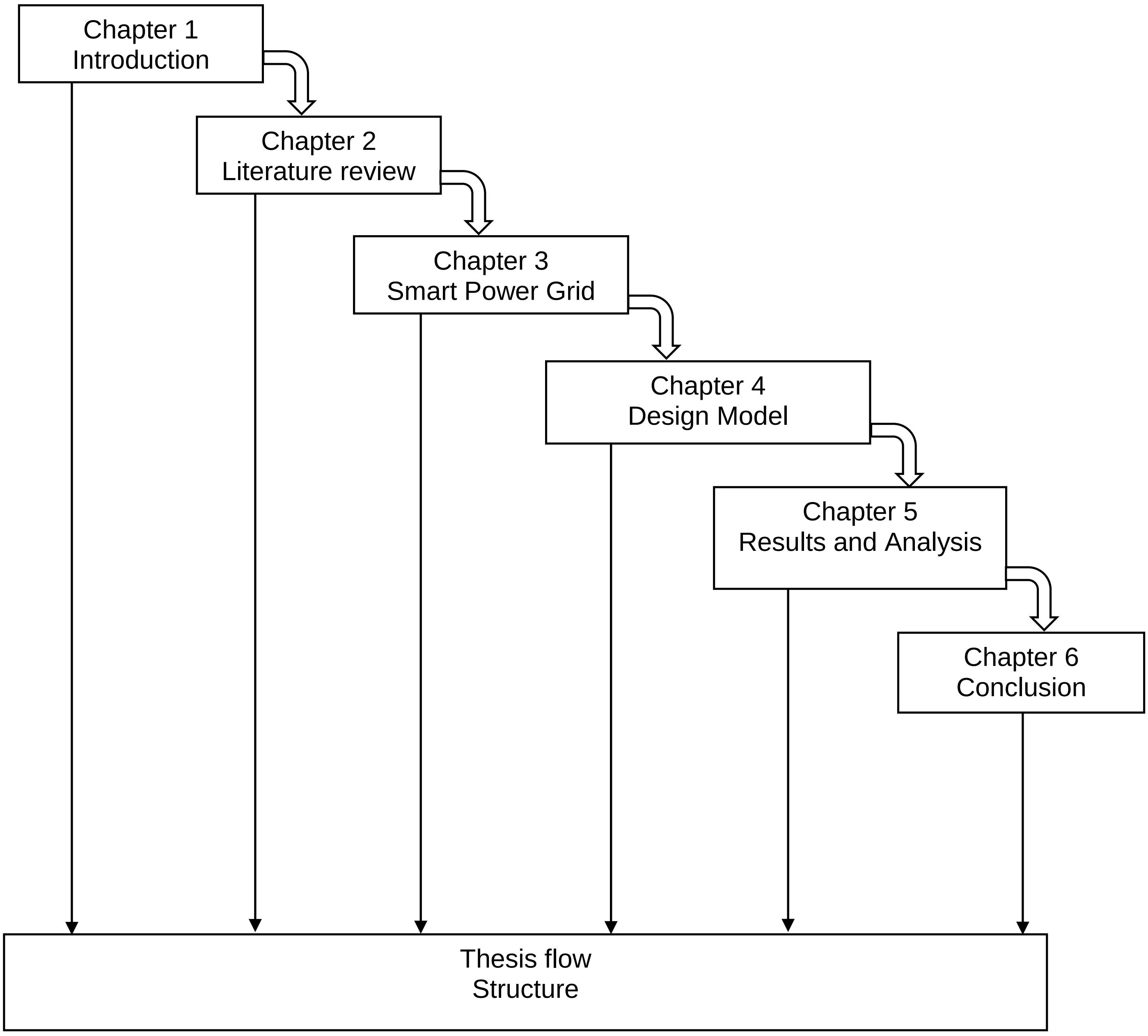


Figure 3 : Thesis Structure and Sequence

Chapter 1: Introduction

A brief background is provided on the state of energy consumption in South Africa, specifically the commercial and industrial sectors, mentioning interventions initiated by government to drive energy efficient strategies around the country. The chapter covers the problem statement, objectives of the research, research questions, limitations, as well as the importance of the study.

Chapter 2: Literature Review

This chapter discusses the energy consumption reduction techniques and demand side management in the commercial sector. It reflects on state-introduced interventions to deal with the energy situation. The history of energy from past to present is inclusive to formulate the understanding of the study, therefore, previous research related to the study were conducted and discussed.

Chapter 3: Smart Power metering

The chapter discusses the smart power metering systems together with pros and cons of these technology developments. It further deals with architecture to reflect the design structure. Lastly, the chapter explains and demonstrates the communication protocols and associated smart devices capability of delivering the smart commercial sector.

Chapter 4: Design Model

The chapter illustrates the proposed model design simulator software which clearly shows perfect energy improvement technique for energy consumption. The model includes mathematical expressions of energy to assist the energy end-user with decision making in order to implement an energy efficient system. Furthermore, types of electricity tariffs for commercial sectors are highlighted as well as objectives of these tariff structures to consumers and energy producers. The chapter covers the comparison among existing tariffs within the sector. The model also discusses and demonstrates its cost benefit on the facility electricity bill.

Chapter 5: Results and Analysis

The chapter discusses the results generated from the model design simulator and analyses energy performance according to tariff structures and power factor. The reductions of energy cost before and after power factor correction are also discussed.

Chapter 6: Conclusion

The chapter concludes with discussions and findings about the model and states recommendations vital for the advancement of the topic in the future. The improvement the facility needs to implement for energy reduction and efficiency is also suggested.

1.11. Chapter summary

The section covered the state of energy in the world and statistical standing of energy in some of the African countries with results showing that indeed there is a huge shortage of electricity in Africa. Similarly, South Africa is among these countries and the economy is interconnected with the energy sector. Previous studies revealed that industrial and commercial sectors are deemed to be high consumers, therefore, the need to reduce the consumption is of high priority.

The study outlined the research origin in the problem statement and also derived detailed scope of work which included the research objective and questions. It further highlighted the research limitations and importance of the study. Lastly, the systematic structure of research chapters was presented.

2. Chapter Two: Literature Review

2.1. Introduction

Electricity management in the commercial and industrial sectors intends to be an effective method of reducing the energy consumption of businesses and improving power supply reliability. Energy management is to limit the quantity of energy demand during expensive peaks or high demand periods to reduce total operating cost. This involves energy conservation or demand reduction mechanisms. This chapter reviews the literature on energy efficient interventions and demand side management systems, focusing primarily on mechanisms associated with energy reduction of commercial businesses.

Electricity demand is directly influenced by the climate parameters, the high potentials caused by countries improved standard of living, and the introduction of technologies in the industries (Majumdar et al., 2013). It was revealed by Bhattacharyya et al. (2004) that weather conditions have a high influence on energy consumption, and increases demand sensitivity to climate change. It was also stated that demand response control is a good choice for contributing to the balance of grid power, which is an attempt from the user side (Zhou et al., 2016). The same study indicated that building load changes frequently at times, the peak load takes place for a short period and management of the building is important for the load balance.

2.2. Demand side management

The electricity supply grid is faced with a challenge of covering up the ever-increasing demand sourced from commercial, industrial and residential consumers (Longe et al., 2017). Demand side management programs have been praised and gained popularity as an intelligent program to optimise features of electricity consumption reference to the overall consumption picture, time profile, and other parameters in order to achieve savings in electricity charges (Majani, 2011). The supply and demand load should be constantly balanced to avoid interference in supply systems or causing extremely high demand.

In 2002, Ashok and Banerjee identified demand side management (DSM) functions as a benefit for energy efficiency and load management (Majani, 2011). The DSM technique helps to improve the performance of supplying energy to the facility, while increasing the number of customers.

In 2010, the South African Department of Energy issued a report stating that the country's estimated potential energy efficiency are conservatively between 20-30% across many segments (Department of Energy, 2010). The department introduced the EEDSM policy through legislative provisions under section 15(1), (u), which require license holder to comply with energy efficiency standards and demand side management (Department of Energy, 2010). As noted, the available energy resources have to be assigned efficiently in order to derive greater benefit for the nation's economy as well as relief to consumers.

In 2014, it was revealed that commercial sector HVAC systems are the main focal point of energy management and conservation, due to the high proportion of total energy it consumed (Keshtkar et al., 2014). Additionally, the study noted that HVAC systems are main load which during peak load can result in a serious outage. It can be noted that HVAC in commercial businesses or industries gained popularity due to increase in office occupants and climate change conditions that create a greater demand for comfort. Other reasons that boosted its popularity was the OHS act and building regulations.

However, it should be noted that most industries and commercial companies have not succeeded to execute energy audit to understand their current operation (Saini, 2004). The purpose of DSM is to reduce energy inefficient systems and promote consumption methods to lower demand. These reasons influence consumer's decision to utilise DSM for the benefit of reducing the electricity bill and peak demand (Saini, 2004).

The DSM technique application differ by industry to industry. For example, it presents to consumers as opportunity to reduce demand load consumptions, as a results reduce electricity bill, lower production cost and increase systems capacity. The proper implementation of energy conservation and energy efficient system can lead to more efficient energy consumption.

Building lighting, air-conditioning and ventilation systems operate independently of one another, but sometimes could be triggered at the same time, which results in a bulk of demand power consumption which occurs simultaneously (Nghiem et al., 2011). The same study argued that most industry energy structures find themselves exposed to a demand price 200 times higher than nominal power rate, which could be extremely expensive and lead to inefficient energy consumption.

However, commercial buildings consumed 40% of total energy and 50% of that energy is consumed by systems responsible for heating and cooling of the building (Wang et al., 2014). The same study stated that in Hong Kong, the commercial buildings consume 60% of total electricity and 50% comes from Air Conditioning (AC) systems. In 2012, another study indicated the importance of understanding the AC load profile characteristic as a fundamental factor of saving power (Qi, et al., 2012). The energy savings demand responses of industry can be achieved by energy efficiency systems, improving building management system envelop and optimisation of control AC systems at the building (Wang et al., 2014). Passive building design and control of systems are important aspects of improving energy efficiency while also achieving energy saving or cost.

Building structures can play a vital role in load balancing regulation and grid operation systems such as the thermal load storage and considering demand load control e.g. load shifting and peak demand limit/set-point (Wang et al., 2014). It was revealed that load shifting and load shedding are not the correct approaches to balance power consumption, as it does not aid in de-correlating energy sinks (Nghiem et al., 2011). It is also indicated that demand response and load control play an important role in switching off/on loads supply that are non-essential during peak and off-peak times (Aksanli et al., 2013).

Energy conservation became a big challenge to many countries worldwide. The consumers suffer the effect of the high cost of energy due to lack of knowledge on energy efficient usage, and energy policy makers are challenged with investigating and executing the best method that supports efficient usage of energy by end-users (Majani, 2011). In South Africa, Eskom had previously extended its hand to educated end-users about the use of energy and times that are less expensive for consumption.

Studies have been carried out to examine the reasons behind these measures as using the DSM technique is different for the different groups involved. For example, in the energy generating sector, the reduction of consumer's electrical power needs could simply mean avoiding the production of extra generating power at all. However, these avoidance tactics would result in extra electricity price to be financed by other customers (Riaz et al., 2017).

However, for other groups, the DSM technique aids the consumers to reduce their electricity bill though conservation consideration and demand efficiency, while industrial consumers aid to lower production costs and provide a more competitive market. Lastly, domestic users reduce energy cost and save for other household use (Riaz et al., 2017). In fact, DSM techniques help the end-users or utilities to run at higher efficiency while addressing both environmental pollution issues and electricity costs.

2.3. Types of DSM techniques

Demand side management (DSM) techniques has been preached in the country and the world to encourage consumers to apply for efficient use of energy, which could relieve both producers and consumers from high cost of energy. This vision was achieved decades ago by the introduction of smart grid (SG) to monitored both end-user and provider's electric power system to respond to demand load (Javaid & Ahmed, 2018). Both industrial and commercial sectors are required to reduce their consumption, especially at defined peak-hour periods, and also be motivated to implement energy efficient systems and DSM programs as shown in Figure 4 below.

The world oil and gas price crises that took place in the 70s influenced electricity producers to enforce the implementation of demand side management aimed to change the timing and level of demand that consumer generates, which put strains on the distribution network (Majani, 2011).

DSM technique gives an opportunity for end-users to participate in the operation of the electric grid by shifting, load shedding or reducing their energy consumption during peak time in reply to incentive associated with response (Saad, 2016). It has the ability to reduce electricity costs in the wholesale market which, in turn, lowers retail rates. Demand response (DR) uses many methods to bring customers in the real-time base rates like real-time pricing, variable peak pricing, critical peak pricing and time of use pricing. DR aims to improve market liquidity, reduce electricity prices, and resolve transmission lines congestion and security management (Saad, 2016). It is divided into two streams such as time-based programs and incentive-based programs as indicated in Figure 4 below.

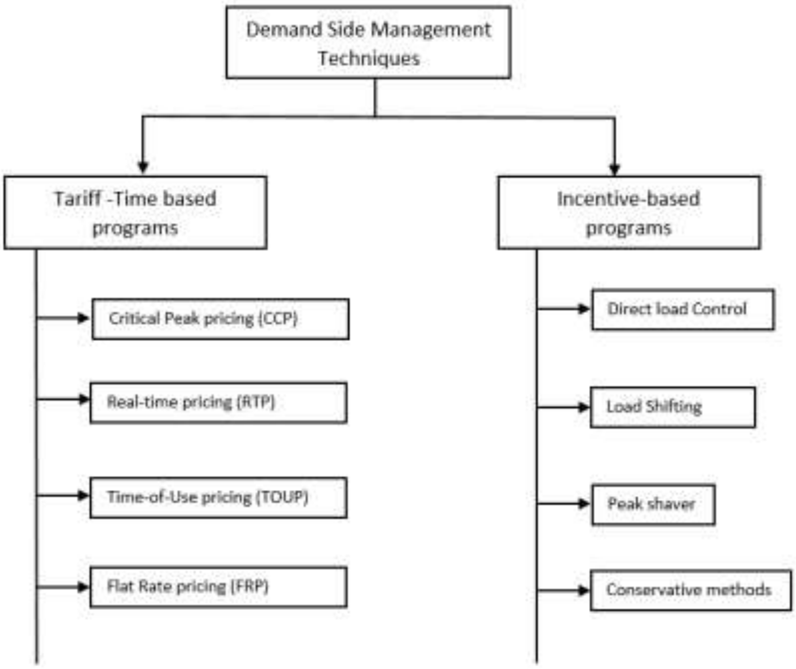


Figure 4: Types of DSM techniques (Longe et al., 2017)

The DSM techniques are fundamentally composed of both time-based strategies and incentive-based strategies, which both help to control demand load profiles (Longe et al., 2017). DSM time-based programs include the different time frames employed which turns to be static and dynamic in nature while incentive-based program deals with methods in which both users can apply for energy cost containment and efficient usage.

It is important to apply the enhanced DSM technique for peak demand reduction from an end-user point of view, due to the benefit it provides to consumers, power producers, and the environment (Longe et al., 2017). Moreover, DSM programs gives the consumer the ability to locally control its demand and bill make-up structures.

2.4. Time-based programs

Time-based programs are predominately static and dynamic pricing rates made to influence a customer's decision to operate demand energy consumption at off-peak times. The program's objective is to popularise the demand response by inflating prices during the peak times and deflating during off-peak times (Saad, 2016).

Smart grid technology has boosted traditional grid performance between end-users and producers. Today, it is possible for producers to supply end-users with electricity based on time-dependent prices which includes real time and day-ahead pricing (Javaid & Ahmed, 2018). The transition of information from the producer to consumers helps the end-user to properly plan their operation according to the pricing pattern (Javaid & Ahmed, 2018). Furthermore, the power monitoring system helps consumers to continuously make informed decisions about the consumption pattern.

The tariff rates system is to reduce system costs and consumer electricity bills by increasing prices during peak period and reducing prices during off-peak period (Cousins, 2009). These rates are inclusive of the critical peak time pricing, real-time pricing, time of use pricing and flat rate pricing as indicated in Figure 4 above.

2.4.1. Critical peak time pricing (CPP)

A critical peak time pricing is similar to time-of-use rates, especially during high critical peak price period. The critical peak time is expressed as high specified per unit rate for usage during load time. This rate occurs in the real-time of extreme system conditions and makes it a reliability based DR (Saad, 2016).

CPP provides timely information to the consumer about energy costs, especial at high energy usage periods (Javaid & Ahmed, 2018). It provides more accurate information about the cost of energy during high energy usage periods to assist consumers to make more accurate and informed decisions about their electricity consumption patterns (Javaid & Ahmed, 2018). As an example, in a CPP event , it is a fact that the cost of energy is very high, however, CPP rates offer much lower prices for electricity for events happening outside the CPP periods. This strategy definitely encourages consumers to make use of electricity for their processes outside CPP periods to avoid high cost of energy.

These CPP events normally occur during the four seasonal times in the year, with some taking place during heat waves in summer, extreme cool conditions in winter, and even during religious events such as Christmas (Javaid & Ahmed, 2018). The CPP does not have a defined range within the year. San Diego gas and electric company has the power to initiate CPP events on the condition that the need is established and consumers are informed 24 hours before the event that they temporary reduce their electricity consumption (Javaid & Ahmed, 2018).

2.4.2. Real-time pricing (RTP)

Dong & Zou (2015) proposed real-time pricing as an effective DSM to adjust the load curve in the order to achieve peak load shifting. It was also indicated that the RTP method can raise the power producer's revenue and reduce the electricity expenses of the consumers, which is described as a win-win situation (Dong & Zou, 2015).

A study by Javaid et al. (2018) proposed the day-ahead real-time pricing (DA-RTP) model as a model intended to resolve the energy management issues between producer and distribution companies by offering optimal day-ahead hourly prices using smart meters (Javaid & Ahmed, 2018). These power meters have two way communication which increases price responsive demand (Javaid & Ahmed, 2018).

The RTP strategy, according to Dong & Zou (2015) is that the physical connection between the utility and the consumer's power meters exists to allow real-time pricing and to allow the utility access to real-time information about the electricity consumption of each consumer.

In the United States, an Illinois power utility uses a day-ahead pricing (DA RTP) tariff (Doostizadeh & Ghasemi, 2012). Taking into account the current increases in energy prices, RTP caters for consumers to reduce their electricity bills by taking a reasonable opportunity of lower energy prices in some periods and reducing their consumption rate when energy prices are high.

2.4.3. Time-of-use pricing (TOUP)

Time-of-use (TOU) zonal tariffs are the most popular way to control demand power in Poland (Andruszkiewicz et al., 2015). The TOU tariff package has supplier commodity prices and distribution and transmission charges according to times and seasonal periods. France operates the most successful TOU pricing through Electricite de France (EDF) (Cousins, 2009).

The aim of tariff prices is to encourage consumers to shift part of their load during peak and off-peak periods to relieve the strains on the power producer’s distribution network and transmission lines (Andruszkiewicz et al., 2015). However, power producers see this as an opportunity to increase sales to customers in the off-peak period, when purchase prices are lower than the standard prices.

In France, one third of its population of 30 million are using TOU tariffs, which was initially introduced as an industrial tariff from 1956 and proceeded as voluntary to the residential customers in 1965 (Cousins, 2009). Since 1978, this tariff is applied permanently in California for users above 500kWas a response to the energy crises of 1973 (Cousins, 2009).

The energy producers in Poland diversified their energy prices at all voltage levels and offered a variety of price levels in two to three zones (Andruszkiewicz et al., 2015). In South Africa, electricity prices differ according to time and seasons; the voltage is supplied to the premises under TOU prices.

In South Africa, according to Cousin’s study, the TOU tariff rates are divide into two and three time periods. In the two time period TOU tariff, the consumer is charged according to time of electricity consumption, for example, in Figure 5.Peak time rate is 0.84 per kWh from 6am to 9pm weekdays and 0.22per kWh is off-peak times which start from 9pm to 6am weekdays as well as on Saturday and Sunday (Cousins, 2009). These times are called according to Eskom, nightsaver tariff.

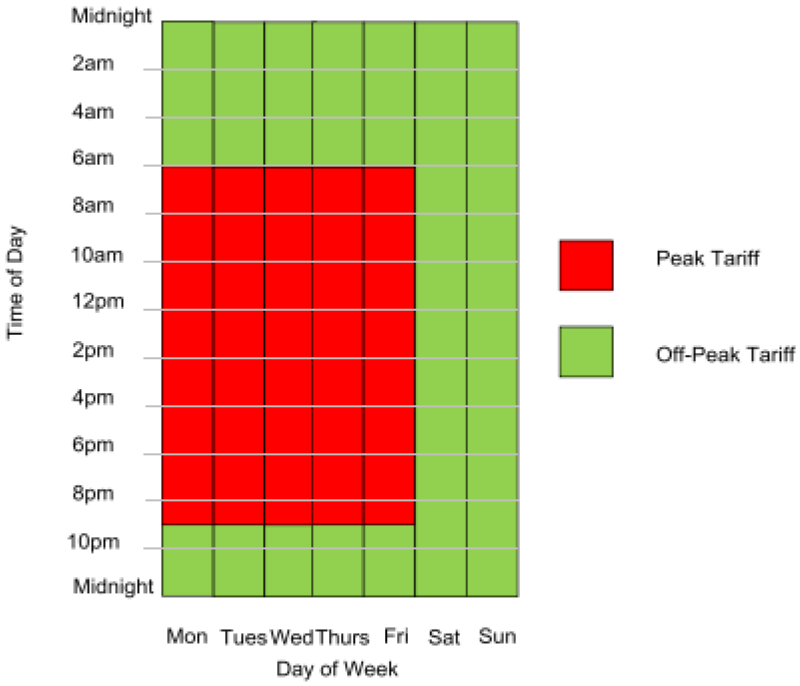


Figure 5: Two time periods tariff preferred as nightsaver (Cousins, 2009).

The three times period TOU tariff has peak, off-peak, and standard rates for weekdays, both standard and off-peak for Saturdays, with Sunday being off-peak only. Figure 6 below, indicating ESKOM's schedule of standard prices, represents Megaflex, ruralflex and miniflex with low and high demand season TOU periods.

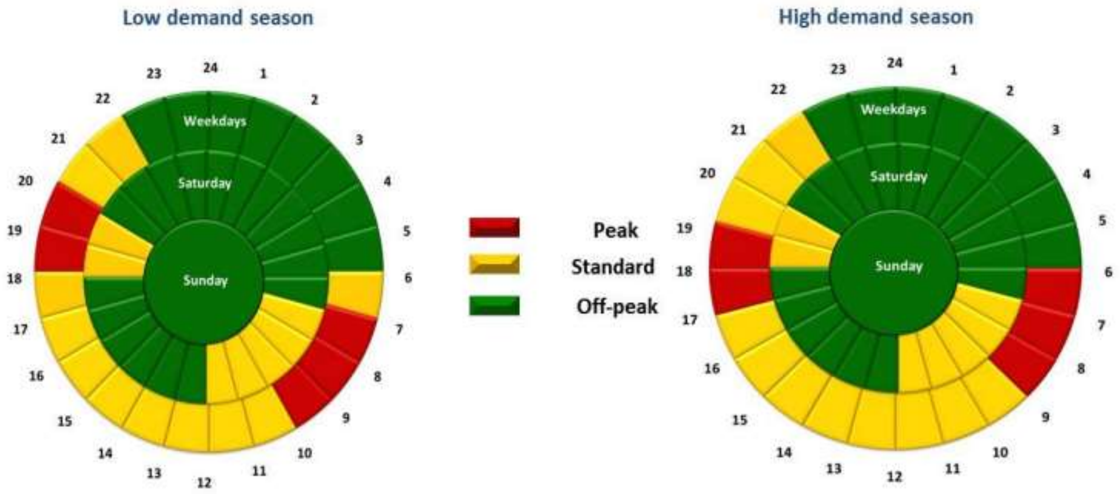


Figure 6: ESKOM schedule of standard prices for 2019/20 (ESKOM, 2019)

It is a very difficult setup because the consumer needs to schedule more load during off-peak and standard times due to lower tariff rates at both these times. This is to prevent high load during peak time in order to lower the cost of electricity during this period. The structure called Megaflex according to Eskom is currently preferred by the commercial sector.

2.4.4. Flat rate pricing (FRP)

The flat rate pricing refers to as the strategy wherein utilities charge consumers a fixed prices for all periods. This strategy has become too dangerous to both consumers and producers (Javaid & Ahmed, 2018). For example, small businesses who use the FRP strategy decide to maximize their productivity for that period which can apply strains to utility distributions and transmission lines.

According to Longe et al. (2017), the FRP DSM strategy is static in nature, with single tariff or pricing applied though a 24-hour period and it can only be altered in summer and winter to accommodate the high demand period. The strategy is commonly applied in the rural and informal settlement of the Republic of South Africa and in some developing countries such as Nigeria (Longe et al., 2017).

During the program, the producer sets a supply limit to the consumer’s total energy consumption, which, once reached the producer disconnects the supply. In India, FRP ranges from 60 to 200INR/month, which in Bihar accounts for 7 to 10% of a household’s monthly income (Rao et al., 2015). In Ethiopia, consumers making of more or less 25kWh are charged at a FRP of 0.273 ETB/month (Euro 0.02) while those who exceed the 26-50kWH range are charged 0.34 ETB/Month (Euro 0.02) (Ethiopia Energy Situation, 2017).

2.5. Risk impact on consumer and producer tariff

Cousins’s study indicated the number of risks associated with these time-based programs (Cousins, 2009). It is evident in Cousins’s (2009) study that the tariff prices could have disadvantages and advantages to consumers as well as the power producer. Figure 7 below indicates the risk that both consumers and producers are exposed to in relation to tariff categories.

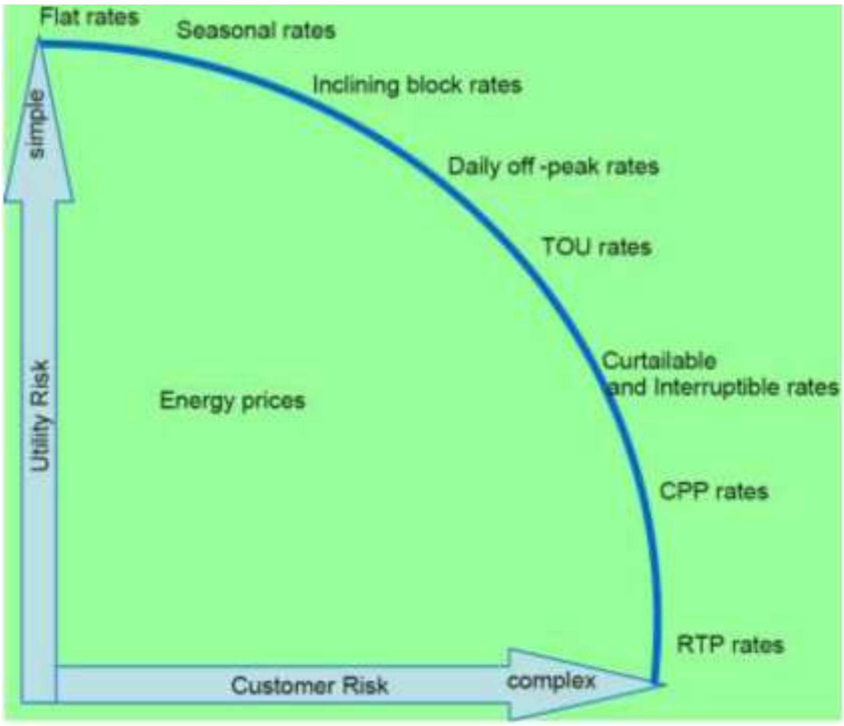


Figure 7: Consumer-producer’s risk against tariff rates (Cousins, 2009).

For instance, the consumers experience flat rate as their best tariff rate, whereas the power producer experience a loss due to the high cost of energy generation (Cousins, 2009). However, according to the figure, TOU rate is shown to be the appropriate rate for both consumers and producers.

2.5.1. Cost to premium

Flat rate consumption appears very expensive compared to consumption based tariff, due to hedging costs associated with the premium, whereas, real time pricing (RTP) has both high risks and rewards according to Hunt Alcott’s (2016) study which states that Australian households are able to save energy to the amount of 1-2% of the yearly electrical expenditure by switching to a tariff that applies RTP.

However, the RTP scheme works correctly with smart grid for efficient operation, as a results the cost of operating are higher due to smart grid systems cost and infrastructure (Hunt Alcott’s, 2011). For this reason, India and Nepal encouraged the use of flat rate pricing tariffs.

2.5.2. Cross-subsidization

The flat rate pricing program is unintended cross-subsidizing, which means certain consumers within FRT pays for the cost of other high consumers during the program (Faruqui et al., 2010). What makes matters worse is the fact that flat rate users are often those in the lower income levels of society (Faruqui et al., 2010). It was indicated in several studies that flat rate pricing can save more money compared to others, however, in this instance the outcome differed, which could results in deterrent of RTP at the moment (Mohsenian-Rad & Leon-Garica, 2010).

Summary: Analysis of best time-based programs

Now, looking at all above mentioned time-based programs, each tariff pricing is configured differently according to individual tariff structure assigned. There are advantage and disadvantage which are important for selection of the cost efficient structure as indicated in table 2.

Time- based programs	**Advantages**	**Disadvantages**
Critical peak pricing	Tariff is a dynamic pricing scheme	Not as economically efficient as RTP
	Utility make profit during CPP	More economically efficient than TOU
Real-time pricing	Tariff is ideal pricing scheme	Implementation is difficult yet due to technical limitations of demand side
Time of use	Tariff Is a static pricing scheme	Rate are high during periods of system stress
Flat rate pricing	Flat rate to all consumers	Utility losses on High consumer

Table 2: demonstrate the best tariff selection

Refer to the above advantages and disadvantages together with related information about time-based programs, time of use pricing is presented as cost efficient tariff structure due to different time rates which can be used to reduce the cost of energy. The risk impact of the consumer versus utility shows that time of use tariff as better tariff among the time-based programs.

2.6. Incentive-based programs

The smart power systems and controllers have made DSM techniques prosper in recent times due to two reasons (1) increase in the cost of energy and popularised benefits associated with the time-based and incentive-based programs, (2) increase in demand load during peak periods and critical events which applies strain to distribution and transmission networks.

Reddy et al. (2017) study reflects on incentive-based schemes or programs as a better service scheme options compared to time-based programs for demand side. These programs are inclusive of the direct load control (DLC), load shifting, peak shaver and conservative methods as indicated in the figure 7 above.

2.6.1. Direct load control (DLC)

Load control methods can be implemented in two different ways to control the load from the consumer-side during peak and critical events. The first method is for the utility to control a group of systems from the consumer’s location by dropping load demand during peak times to lower the supply to consumers. The second method is to convey a power information to the consumer and inform about the plan to implement curtailment within a stipulated time.

Direct load control, according to Stenner et al. (2017), is described as the ability to allow the utility access to specific household appliances or equipment to switch on and off during the peak period. This DLC program requires intensive involvement of the utility for accurate installation of the DLC systems such as a radio control device that allows the utility to permanently perform consumer loads control, which includes switching the system on and off during peak periods and critical events (Stenner et al., 2017).

Once the control is made, the utility compensates or rewards the associated consumers by way of a financial incentive such as once-off payment, recurring annual payments, electricity bill discounts or free hardware installation (Stenner et al., 2017). This action gained the attraction for network and system operators by assisting with more accurate planning for future investment in capacity (Stenner et al., 2017).

The variable payments to responsive load were also realised through a dynamic incentive approach designed by load serving entity through direct load control (Kiani & Annaswamy, 2014). Longe et al. (2017) indicated that DLC implementation has become unpopular as consumers prefer the price responsiveness DSM program it gives the consumers local control over the demand and bill.

Mathieu et al. (2015) investigated the optimal scheduling of responsive loads to maximise cost savings through arbitraging intraday wholesale prices. The study alluded that DLC technology existed for decades since the 1970s and was not well accepted and adopted by residential consumers (Cappers et al, 2010).

In the US, for example, a 2012 survey by the Federal Energy Regulatory commission reported that customer enrolment of the DLC program ranged from 0.11% in the Texas Reliability Entity region and up to 14.54% in the Florida reliability coordinating council region (Federal Energy Regulatory Commission, 2012).

2.6.2. Energy Conservation (EC)

Energy conservation is a DSM technique under incentive-based programs that is objectively designed to prevent the waste of energy resources due to inefficiently operating electric machinery and process systems. The intended objective of energy conservation can be achieved by two important applications (1) education on efficient usage of energy (EEUE) and (2) implementation of energy efficient systems (EES).

Majani's study explained EEUE as a method that help to teach consumers to use energy well in order to reduce demand load (Majani, 2011). The study proceeds to emphasize that the program should be spread from households, schools, and business communities within industries and commercial sectors. This initiative extends to advertisements, showing the importance of energy conservation. The South African, DOE 2010 report emphasized that energy conservation programs are a critical part of a contingency plan for the industrial sector to conserve energy in the event that an electricity load-shedding risk materialised (Department of Energy, 2010).

The EEUE program is a behaviour-based method to build a positive image about energy use. During load shedding, Eskom introduced the program to encourage end-users to save power especially at peak hour; it was advertised on national television.

Most industries fail to conserve power due to the lack of conservation programs that teach employees to be conscious of energy use. This resulted in both high electricity bills and high strains on ESKOM.

2.6.2.1. Energy efficient systems (EEC)

According to the South African DOE, energy efficiency potentials are between 20-30% across many segments, and are not utilized to its full potential to date (Department of Energy, 2010). Therefore, as indicated in the previous sections, the DOE introduced the new regulatory framework specifically to address the energy efficiency potentials that exist (Department of Energy, 2010).

Dmitrijs et al. (2017) described energy efficiency as a method of consuming less energy to provide the same or even improved level of service to consumers in an economically efficient way. A study proceeded to state that the efficient usage of energy brings a positive impact to the grid reliability, lowers cost of grid extensions, and reduces CO2 gas emissions (Dmitrijs et al., 2017).

2.6.2.1.1. Lighting

An energy efficient lighting system is an important component of energy demand particularly at the time of peak demand. It was noted by Matenda’s study that light constitutes a significant portion of energy consumed in residential buildings (Matenda, 2014). Observable measure of energy saving includes retrofit of lighting bulbs, as well as fitting and switches which will encourage natural lighting. This may include building modifications.

Khalid W. et al. indicated that light retrofitting is the best and a quicker method of minimizing the load of generation capacity, which ranges from 60-70% of existing building energy consumption (Khalid et al., 2015). Fluorescent lamps can reduce a significant amount of energy consumption in the lamp wattage while retaining the same intensity of illumination.

Lights have passed many generations and have varied from incandescent to fluorescent lamps, Ultra-Violet (UV) light, Infrared, and Light Emitting Diodes (LED) (Matenda, 2014). These generations of lighting were improved to enhance efficiency, be competitive, and reduce environmental impact. Today, light is an important part of the electrical organ that affects other fields such as entertainment, security, production, hospital (ICU) and more. Matenda (2014) suggested that due to that increase of investment on the advancement of lightings, it would be appropriate to achieve expected results such as the invention of X-ray, laser lamp and so on.

Since 2001, Brazil reduced their energy consumption by producing a policy that encouraged conservation and efficient use of electricity (Braga et al., 2014). This was driven by experience as the Brazilian energy sector was exposed to an energy crisis resulting in serious concern. The plan aimed to produce Brazilian incandescent lamps which were imported to the market. Since then, a series of incandescent lamps were manufactured from 150W (2012), 100W (2013), 60W (2014) and 45W (2015).

Fluorescent lamps are extensively used in the modern indoor lighting application and mostly used with a ballast as power converter AC/DC to supply the lamp (Debanka et al., 2016). LEDs are perhaps the most cost-effective energy saving products compared to other lights and Matenda (2014) stated that it is often called the light of the future, also owing to its compact, tiny, and efficient design structure.

2.6.2.1.2. Heating and cooling systems

Efficient use of energy in the building mostly originates from air conditioning systems, as a result of heating during winter and cooling during summer times. Today, air-conditioning systems are part of smart systems, which are designed to regulate the consumption efficiently during operations.

The popular remedy according to Khalid W et al. (2015) is to initiate an energy audit, which is inclusive of electricity bill analysis and all building equipment (such as air-conditioner, chillers, computers and other building equipment),concluding with direction for mitigation which at the time are retrofit or re-configuration.

Utilising a central-based air conditioning system can assist building a management system to better control the heating and cooling processes in building offices. This provides the ability to set the temperature to an approved building temperature, which in some instances can be 22 ̊C, as well as the ability to set the speed and start and stop schedule of the week according to trading hours. Benefits of this concept includes lower energy consumption and maintenance costs. Khalid et al. (2015) study shows that during winter, buildings can use an electric resistance heater due to its lower energy consumption rate.

However, another remedy is to decentralise air conditioning systems, which can achieve efficient energy use by involving smart air-conditioning systems to form a network structure of air-conditioning systems in the building. This method gives ability to set the individual air-conditioning systems according to requirements of each office it supplies. Furthermore, it gives the controller unlimited range of operational optimisation and energy consumption efficiency.

2.6.2.1.3. Conservation Voltage reduction

Conservation voltage reduction (CVR) method contributes to the DSM program that gives the power producer power or access to lower supply voltage that is distributed through distribution to consumer, and that lower voltage should not damage equipment or affect the equipment’s performance output.

According to Kampezidou & Wiegman (2017) the conservation voltage reduction is the reduction of energy consumption resulting from reducing the feeder voltage. The sole objective is for energy savings due to the reduction in the level of voltage supplied to consumer, which reduces peak demand (Kampezidou & Wiegman, 2017). The CVR can be applied in the short or long peak load interval reduction for energy savings (Kampezidou & Wiegman, 2017). This action poses a disadvantage to the power producer which will experience a loss in investment income due to this strategy. The equation 1 below demonstrates the quantity efficiency of applying the CVR sensitivity method (Kampezidou & Wiegman, 2017).

$$\text{CVR (power)} = (\Delta P\,\%)/(\Delta V\,\%) \qquad \text{Eq. 1}$$

The Sen et al. (2016) elaborated on a conservation voltage reduction technique study which indicates that American National Standards Institute (ANSI) standard C84.1 of 2006 is a landmark document, which was developed and constructed since 1960s as a basis for CVR discussions for high quality power supply to consumers. The study emphasized the standard that under normal operating conditions, the supply voltage to the consumers' premises must be limited to ±5% of its normal value (Sen et al., 2016).

$$Vs = Vn\ (1 \pm 0.05) \qquad \text{Eq. 2}$$

Where,

Vs - Voltage at the secondary terminal of the transformer
Vn - Nominal value of voltage.

In the instance where the nominal voltage is 240V, the transformer terminal voltage will vary between 240*0.95 and 240*1.05, which translate to 228V and 252V. The benefits of the CVR program to consumer lies on demand response measure through both lower electricity rates and reduced electricity bills (Kampezidou & Wiegman, 2017). However, it is noted that the utility might lose revenues from this DSM program. The global benefit of CVR can result in the reduction of greenhouse gases, increase the life expectancy of consumer's appliances, and reduce transformer losses due to the use of the reduced voltage program (Majani, 2011).

The CVR efficiency depends on the load's sensitivity to voltage. The fluctuation nature of load power makes the CVR operate much more efficiently. However, constant load power results in the CVR performance being limited, while constant impedance results in a much greater CVR factor (Kampezidou & Wiegman, 2017). The losses of transmission lines might increase by order 0.1%, when the voltage is reduced for constant power loads, but this is stated the same in the case of constant impedance or current loads (Sen et al., 2016).

In the United States of America (USA), it is a common practice to set the voltage to the higher end of the bandwidth (Sen at el., 2016). Now, the CVR strategy guides us in reducing the voltage at the consumer metering point to lower end, but within the ANSI standard so that energy could be saved.

2.6.3. Load Shifting

Load Shifting is another incentive-based DSM program which directly provides consumers with access and control of the load in their premises to move load around during high demand time. These programs succeed with the implementation of a smart power system (SPS), which manages and monitors the load profile and baseline. Today, the world has a number of intelligent power controllers that could be used to help consumers schedule load consumptions and process systems to avoid high peak demand occurrence within their premises. Furthermore, proper management of load in-line with utility off-peak periods have potential to reduce electricity bill, greenhouse gases and distribution and transmission lines.

Load shifting techniques uses time-independency characteristics of some electrical appliances and shifts their usage from peak time to off-peak time (Longe et al., 2017). The study proceeds to characterise this technique as an effective load management in the distribution network (Longe et al., 2017).

In 2003, England introduced restructured electrical usage for wholesalers and retailers to shape the demand consumption patterns of end-users (Tracey et al., 2003). It was alluded that retails explore methods of shifting the energy usage from peak-hours to off-peak-hours to avoid high pressure on the demand load and embrace the cost reduction and greenhouse gases philosophy.

On the other hand, the commercial sectors were forced to shift the load by switching off non-essential systems such as air-conditioning and lights. Additionally, another study in 2017 indicated that in commercial buildings, batteries smooth the load and provide the backup service. These batteries are 100kWh, which is slightly smaller and would need replacements after their specified lifespan (Shi et al., 2017).

2.6.4. Peak Shaver

The peak shaver technique is based on the consumer having to manage and control their load profile at the specific period to reduce peak demand and save money. This is achieved by the application of the peak demand shaver to avoid the occurrence of instantaneous peak or sparks caused by high peak demand generated at consumer’s premises. This is unlike peak clipping technique, which utility uses to reduce peak demand at consumer’s load profile at specific period by direct control of equipment or the use of tariffs (Longe et al., 2017).

Malinowski & Kaderly (2004) indicated the methods of peak shaving in commercial offices by modifying and changing the HAVC into energy efficient configurations and also incorporating automated lighting systems which would be controlled by motion.

The study stated the need for knowing or understanding peak-time and sessions that demand energy increases. There are a number of electricity sources such as renewable energy sources, uninterrupted power supply and fuels generators that are capable of producing electrical energy for peak demand as required by load management system. These systems are discussed in the section below.

2.6.4.1. Fuel generators

An active peak shaving strategy is to use generators, which can help to reduce peak demand by supplying when the energy set-point is reached. Malinowski & Kaderly (2004) indicated in a peak shaving study methods of using diesel generator to supply a facility HVAC with energy to feed cooled-air into the building. The study also states that a generator was set-up such that the load monitor system pick-up the power usage increase towards a set-point and then the generator start command can be initiated.

The focus is intensively on industrial generator utilisation to shave peak load. These are very different generators from residential models as they withstand extreme usage for extended periods in less than ideal conditions. The important part of an electric power system is three-phase AC generator and almost are synchronous type (Lupsa-Tataru, 2009). Making the perfect selection for right type of generator is vital for maximum usage intended. These different types can easily run from diesel, petrol and natural gas.

2.6.4.1.1. Potential benefits and barriers of generators

a) Lower cost of electricity bill

Consumers are expected to pay their peak demand charges consumed in the form of kW (Chua et al., 2017). The consumer pays for the maximum demand charge recorded during the month. Therefore, even if for only 0.5 hours of the month’s ±720 hours the demand charge is 100 KVA, and the rest of the 719.5 hours it is 10 KVA, the consumer will pay for 100 KVA demand charge at the end of the month/billing time.

b) Fuels Storage

Standby generators fundamental function is meant to produce electric power during emergency outage periods. They are capable of supplying constant power for about 24 hours of outage (Chua et al., 2017). Due to the expectation of the generator to produce energy during outage, the fuels storage becomes an important component to ensure enough capacity is there for consumption during outage otherwise the demand cannot match (Chua et al., 2017).

c) Fuel price volatility

Fuel prices in South Africa are influenced by local and international markets, which leads to price adjustments. The international market factor is the crude oil price while the local factor is the exchange rate of the rand in relation to the US-dollar (Motiang & Nembahe, 2017). Figure 8 below shows the Brent crude oil relationship with the exchange rate.

Figure 8: Illustrates the Brent crude oil verse exchange rate (Motiang & Nembahe, 2017).

The graphical presentation indicates the volatility of Brent crude oil against the exchange rate which caused by speculation of production frozen by the international oil producers (OPEC) meeting held in September 2016 at Algeria (Motiang & Nembahe, 2017). These factors lead to fuel price being adjusted every month over a year (Motiang & Nembahe, 2017).

d) Air pollution or emissions

The use of diesel/natural gas generators increases fuel consumption which translates to increased pollution and emissions to the atmosphere. According to the study of Chua et al. (2017), the average CO_2 emissions from electricity generation for coal, natural gas, and diesel are 1035 g CO_2 per kWh, 400 g CO_2 per kWh, and 725 g CO_2 per kWh, respectively.

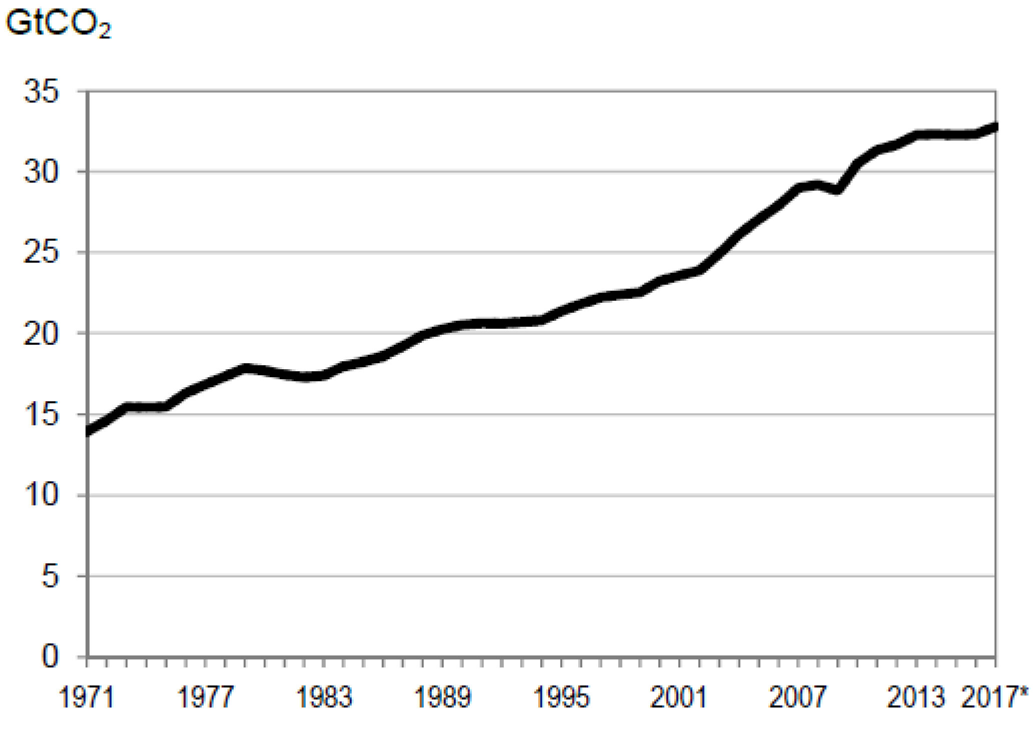


Figure 9: The CO2 emission increase over time (IEA, 2018).

However, the global CO2 emissions from fuel combustion were 32.31GtCo2 similar to 2015 of 32.28Gtco2, which shows more than double since the seventies, and these increase around 40% since 2000 which is linked to general increases to economic output (International Energy Agency, 2018). The graphical presentation in figure 9 indicates that the CO2 emissions increase above the 32 GtCo2 constantly from 2013 till 2016 (International Energy Agency, 2018).The figure indicated the increase in Co2 emissions over years, which contributes to air pollution and climate change.

2.6.4.2. Renewable energy sources

Renewable energy sources as alternative usages have increased worldwide to reduce peak demand energy in commercial industries. The energy storage is a fundamental organ of renewable energy, such as Solar PV, which utilises an energy buffer system when peak power demand increases (Services & Electric, 2013). The same study of Services & Electric (2013) indicated that the PV system is used to reduce the peak load demand.

Africa has an abundance of renewable energy resources which have not been exploited fully such as wind, sun, water; heat, to mention a few. (Hammons et al., 2000). In 2014, a study guessed that the continent has 1.750TWH hydroelectric potentials and 14000MW of geothermal potentials (Zoll, 2010). The continent of Africa is regarded as a giant in solar power due to amount of solar irradiation and it also has wind in the very dry desert and coastal regions (Zoll, 2010).

2.6.4.2.1. Solar Energy

One of the renewable energy sources that Africa has in abundance is the opportunity for solar energy, which studies indicated to be at the coastal and very dry desert regions on the continent. African countries lack access to electricity, due to the traditional technology of fossil fuel being too expensive. Extensions of the electricity grid to remote areas is also too costly. Today's world energy demand increases as population increases which puts stress on the supply load and as a result the need for renewable energy source increases (Temaneh-nyah & Mukwekwe, 2015).

The study revealed that the population is expected to increase to 8 billion over the next 25 years, while electricity demand will double in 2050 (Temaneh-nyah et al., 2015). Although Africa has an abundance of renewable energy potentials, it contributes 3.5% of renewable energy compared to Europe with 28%. In Namibia, for instance, the population doubled from 1987-1990 (power was 0.54GW) and the power demand increased by double to 1.1GW.

There are fundamental benefits of PV energy that can be utilised for the development of struggling countries in Africa, eradication of poverty, improved living condition of the population, as well as economic benefits and environmental friendliness according to the study by Longe et al. (2013). The economic benefit of its application in African countries will grow economic (GDP) while changing the lives of ordinary citizens.

These renewables are sustainable with zero greenhouse gases and will reduce the electricity and maintenance costs for households or industries. A benefit of off-grid is that it saves cost by not spending money on transmission network for rural areas. Solar energy is a sustainable energy source that is not harmful to the environment; it is environmentally friendly and does not produce any greenhouse gases.

However, there are challenges that exist with solar energy source which is intermittent in nature according to the study by Buchan & Ustun (2015). Weather was also found to be one of the barriers that can effectively disturb the efficient operating of technology. Other barriers are that procuring the technology is expensive and that it uses a lot of space.

A study indicated that Sub-Saharan Africa receives the highest solar irradiation which averaged to 6 – 8 kWh/m2/day of solar irradiation. For example, Namibia is one of the highest solar potentials, but currently produces 0.216MW, which is 1% of Namibian power generation according to the study by Temaneh-nyah et al. (2015).

2.6.4.2.2. Wind Energy

Another renewable energy source that Africa has in abundance is wind energy. The highest wind potential areas are found at east, west and Sub-Saharan Africa according to (Longe et al., 2013). It is directly competitive with traditional energy sources. The Africa wind atlas with climatological data shows the following countries as having the best wind resources in SSA: These comprise of the southern region (South Africa, Lesotho, Madagascar and Mauritius); eastern region (Djibouti, Eritrea and Somalia); and western region (Cape Verde and Mauritania) as well as Chad in Central Africa according to (Longe et al., 2013).

As an example in the southern region, the South African government has committed to wind energy generation in its RBS and IRP scheduled to 2030 and committed to produce a total 36% of renewable electricity capacity in 2030, according to Department of Energy (2011).

Similarly, wind energy source as a renewable has fundamental benefits to consumers such as clean fuel source; cost-effective application, and job creation opportunities. However, there are challenges confronting renewables such as the intermittent nature of wind and solar energy according to the study done by Buchan & Ustun (2015). The most significant negative environmental impact of wind turbine technology is wildlife (birds and bats crashed by turbine blades), noise caused by blades and visual change the viewshed Saidur et al (2011) & Masden et al (2012). It was found in Saidur et al (2011) study that birds are one of the largest victim groups in mortality collision with wind turbine.

2.6.4.2.3. Hydropower resource

Water energy is another opportunity as a renewable energy source that Africa has in abundance, the highest potentials of which can be found at the central region of Sub-Saharan Africa (Hammons et al., 2000). Africa houses the largest rivers including the Congo, Nile, Zambezi and Niger, as well as Lake Victoria which is the world’s second largest river. However, Africa is the second driest continent in the world after Australia, and millions of Africans still suffer from water shortages throughout the year (Ilupeju et al., 2015).

Hydro-electric energy is an source that is clean and renewable which can be used to manage power supply or demand load, as well as engage in reducing the emissions of greenhouse gases according to the study of Rosenqvist et al., (2003). However, the problem is African is a water challenged continent; Arab countries in the northern and southern region, and South Africa suffers from water shortages (Rosenqvist et al., 2003).

2.6.4.2.4. Bioenergy energy resource

Biomass is a primary energy source for a significant proportion of Sub-Saharan Africa society especially in rural areas of Africa. The study revealed that an estimated 80% of cooking and house warming in the subcontinent comes from wood biomass resulting in 0.7% deforestation, which is unsustainable (Shuma et al., 2015).

In southern Africa, governments have established policies that mandate a biofuel industrial strategy to promote production for biomass fuels as one source of energy generation and increases the production of bioenergy which has advantages such as improved lives of the people and socio-economic development of the region (Agwa-Ejon et al., 2016). Bioenergy has challenges to food security in Sub-Saharan Africa.

2.6.4.2.5. Geothermal energy resource

Geothermal energy is a renewable energy that can generate electricity with the reduction of CO2 emissions and effects of greenhouse gases. Geothermal energy is the heat contained within our planet earth, which is recyclable, clean, sustainable and economically beneficial to the country in use (Kheshti & Kang, 2015).

The same study above emphasized the source of geothermal as energy that comes from the core of the plant’s layers and that the core temperature is about 6650˚C. However, the temperature increases by 3 ˚C in normal areas, whereas in the case of volcanic activities, the rate is higher than 3 ˚C normal values (Kheshti & Kang, 2015).

This energy source is an alternative energy source free of greenhouse gases and require only a small piece of land to perform efficiently. Its disadvantages include high construction costs, but the short time return on investment overwrites the disadvantage (Kheshti & Kang, 2015).

Kheshti, M. et al. indicated that China began the exploitation of geothermal resources since the 1970’s. It is further stated that Chinese states such as Beijing and Tianjin regions exploited 40-70 ˚C of geothermal water from 1000m depth (Kheshti & Kang, 2015). In 2005, China’s total geothermal energy was 12604.6GWh with installed capacity of 3687MW, which positioned China as the third in the globe with renewable energy (Kheshti & Kang, 2015).

2.6.4.3. Uninterrupted Power Supply (UPS)

The UPS is a commonly used alternative or backup source of power connecting the mains power and critical loads in emergency situations. UPS works as energy storage system perform functionality such as generator output stabilisation, frequency control, peak shaving and load shedding.

It provides back-up power during the absence of main supply energy and protects the sensitive loads against the line frequency variations (Milad & Darwish, 2014). A second method for reducing peak demand energy could be through an uninterrupted power supply system. Ma & Wang (2015) study indicated that the UPS can be utilised for power shaving to cut off the peak power demand, in order to decrease energy consumption and electricity bills. The other important part of the method is that power shaving needs UPS storage (batteries) with calculated capacity, according to (Ma & Wang, 2015).

2.6.4.4. Power factor Correction

Power factor correction is a DSM technique developed under the incentive program to deal with the high demand load produced by consumer’s consumption. PFC technique is used by many studies as a method consisting of grouped capacitive load to the power line to reduce the reactive power generated from inductive loads (Karimeh et al., 2016). It was also indicated that the phase shifting between current and voltage generates misalignment between real dissipated power and apparent, as a results increase power costs (Karimeh et al., 2016).

The same study revealed the power factor (PF) as power that generates work done over the paid power (Kabir et al., 2017). Most industrials have installed the huge sized inductive electrical load causing a lagging PF, which results in a high electricity bill. Therefore, it became important to use all paid power and translate into working by cutting-off the gap between apparent and real powers.

$$\textbf{Power factor (PF)} = \frac{Real\ Power(kW)}{Apparent\ Power(KVA)} \qquad \text{Eq.3}$$

Power factor is defined as the ratio between the actual load power (kW) and apparent load power (KVA) as indicated in equation 3. It is primary utilised to measure the efficiency of load current to be converted into useful work output (Kabir et al., 2017). An electrical network operating at unity power factor represents a system at 100% efficiency. However, anything lesser than unity simply means that extra power is required to achieve the actual demand power. The equation below defines power factor.

2.6.4.4.1. Power triangle relationship

The triangle below indicates three important power characteristics that exist in the power system and the relationship thereof.

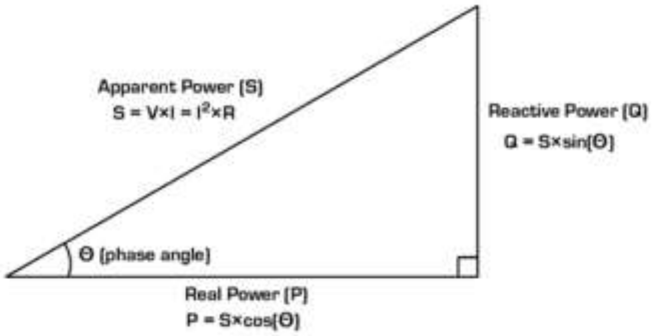


Figure 10: illustration of power triangle (Dhameliya et al., 2017).

The equation defines power factor as:

$$\boldsymbol{PF} = \frac{(P)\quad (expresses\ real\ power)}{(S)\quad (expresses\ apparent\ power)}$$

Eq. 4

Where: P – defined in the power triangle as real power measured in kW

S –defined in the power triangle as apparent power measured in KVA

The low power factor also means a significant phase difference between current and voltage at the load terminals and creates a high harmonic content. It is the use of inductive loads like induction motors, power transformers that results in the current lagging behind the voltage (Kabir et al., 2017).

The inductive load needs real power to execute actual work, while the reactive power (KVA) maintains the magnetic fields. These magnetic fields are important to keep equipment operating, but they puts stress on the supply power parameters such as current and voltage and results in the current lagging the voltage.

$$\boldsymbol{Q} \quad = \sqrt{((\boldsymbol{P}^{\mathbf{2}}) + (\boldsymbol{S})^{\mathbf{2}})} \qquad \text{Eq. 5}$$

Where: Q – defined according to triangle as reactive power expressed in units of VAR

Furthermore, inactive motors work at less than a full load which contributes to low power factor (Jadhav, 2016). The solution to current lagging from voltage can be eliminated by the introduction of power factor correction.

In power supply circuit's, harmonic contents have a direct relationship with apparent power and as a result high harmonics indicate existence of distortion factor since the power factor is well below unity (Turchi et al., 2014). The distortion factor is primarily responsible for the non-unit power factor in the switch mode power supply (SMPS). The equation below (Eq.2) governs the relationship between real and apparent power defined as:

$$(Pin) = \sqrt{Vin(rms).Iin(rms)}\ .\text{Cos}\theta.\text{Cos}\theta \qquad \text{Eq. 6}$$

Where: Pin - present the real power,
Vin (rms) - is a input rms voltage of the transformer
Iin (rms) - the rms current.
VA – presents the apparent power

However, the apparent power:

$$(VA) = Vin\ (rms) * Iin\ (rms) \qquad \text{Eq. 7}$$

It can be noted that the graphical presentation of relationship between current laggings behind voltage indicate high harmonic contents, which results in the poor power factor existence in the supply circuit. Figure 11 shows the current lagging behind the voltage as the harmonic content is presented as high.

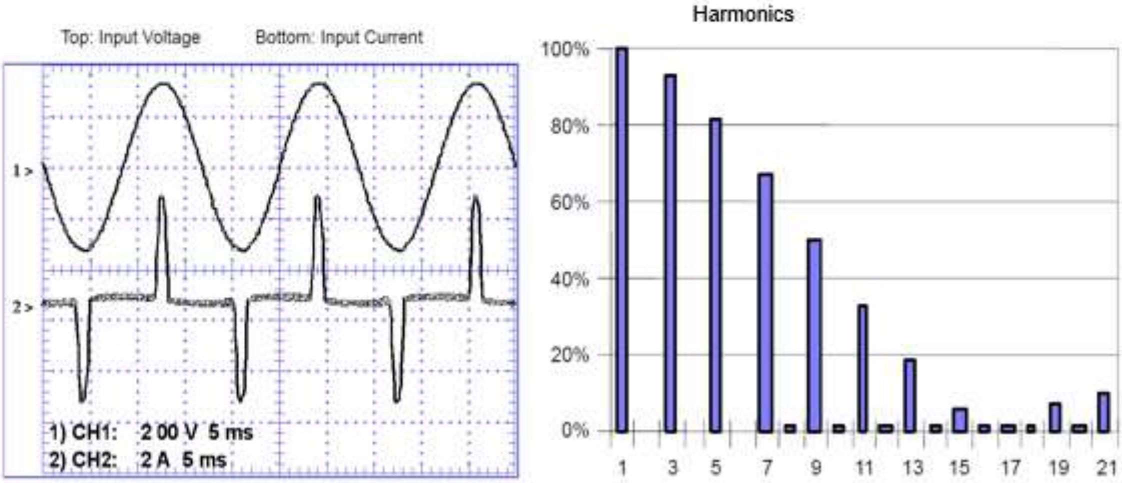


Figure 11: illustration of relationship of amps, volt and harmonics (Turchi et al., 2014).

However, the power supply with power factor correction can display different results which correctly represents the same phase, amplitude, and shape relating to current and voltage (Turchi et al., 2014). It is current that mimics the voltage in terms of waveform patterns which indicates power factor equate to unity (Jadhav, 2016). The power factor equal to 1, indicates current harmonics contents close to zero.

Power factor correction is the term given to a technology that is used to restore the power factor to as close to unity as possible. Based on the Figure 11 above, there is a clear opposite relation between power factor and harmonic, meaning high power factor then low harmonics.

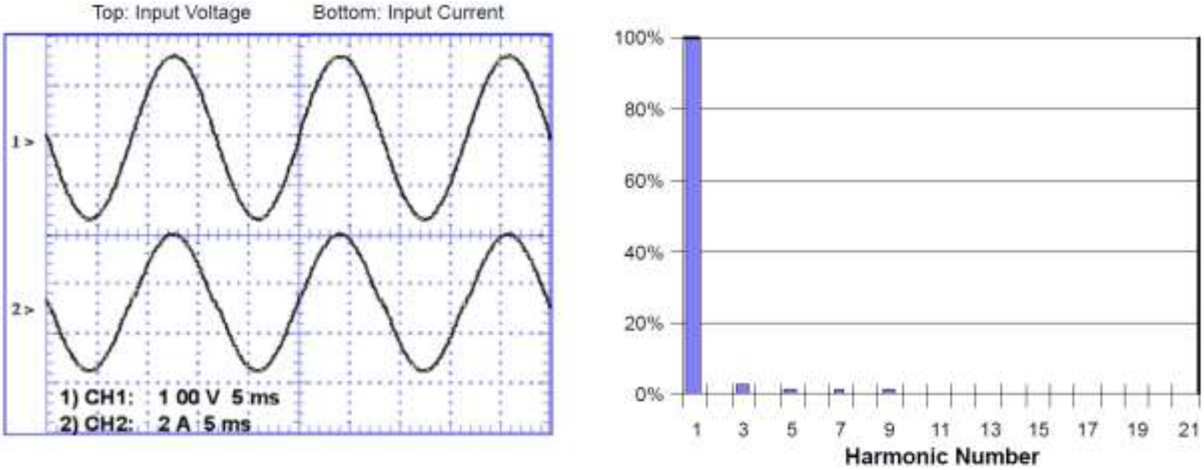


Figure 12: Power with power factor correction (Turchi et al., 2014*).*

This PFC mandate is normally achieved by the installation of capacitors to the electrical network and Figure 12 showcase the corrected voltage and current. As a result, the reactive power charges can be eradicated to provide instant savings.

2.6.4.4.2. Types of PFC

There are two types of PFC: active PFC and passive PFC (Turchi et al., 2014). Active PFC uses electronic circuits to efficiently distribute power to devices connected to the power supply. On the other hand, passive PFC is simple and uses capacitors and inductors in enhancing efficient power distribution. The complexity in the method used in Power Factor Correction by active PFC makes it more expensive than passive PFC. Yet, active PFC is also more efficient in the use of power compared to passive PFC (Turchi et al., 2014).

A PFC Power Supply is a device that ensures power for electronic equipment is efficiently used (Kabir et al., 2017). It also reduces the cost of electricity by minimizing the amount of reactive power produced by motors and other devices.

The PFC power supply should be connected to an uninterruptable power supply to ensure the devices have suitable power in case the main power source goes out. Different types of compensation should be adopted depending on the performance requirements and complexity of control such as the below mentioned.

- Fixed PFC – Perfect for the correction of steady state electrical loads and individual motors. Fixed power factor correction is used typically for wattles equipment, and is characterized by a constant reactive power requirement.
- Automatic PFC – Sometimes referred to as ‘bulk’ PFC as it tends to be installed at or close to the main electricity incomer. This corrects the power factor of the whole system (Kabir et al., 2017).
- Detuned PFC – Fixed, automatic or dynamic, for use on harmonic-laden systems or to avoid possible resonance conditions.
- Dynamic PFC – Often referred to as ‘real-time’ power factor correction, are thyristor-switched capacitor banks that typically respond within one cycle to provide the necessary power factor correction for rapidly changing dynamic

loads (Turchi et al., 2014). This reactive power compensation technology is also often used in voltage control applications.

2.6.4.4.3. Relationship of capacitor with power factor

The capacitor is a most important component that supplies capacitance reactance, which is negative reactive power (Dhameliya et al., 2017). As indicated in the previous sections, power systems have inductive load which caused lagging power factor and that can make capacitors produce a leading current to compensate for the lagging current within the system. An as a result, it makes smaller the three phase angle distance between real power and apparent power. Figure 13, describes the relationship between inductive load and capacitors.

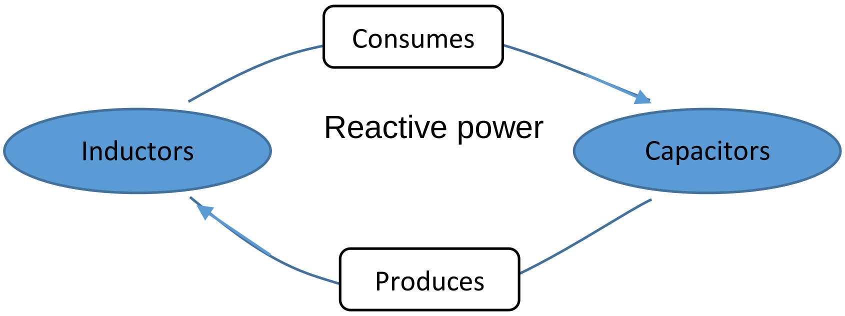


Figure 13: Derived relationship between inductors and capacitors (Dhameliya et al., 2017).

Electric motor loads are phase lagging which needs capacitor banks as power factor correction to counter their inductance. However, leading power factor due to capacitive load requires inductors to correct. The inductors consume reactive power and the capacitors appear to supply them.

It is a norm that capacitors are Y-connected in the three phase distribution feeder and neutral grounded for fuse protection or any fault that might occur due to a capacitor's faults. The operating frequencies are standardised to 50 or 60Hz. The equation (Eq.8) that is used to calculate the capacitor in farad is indicated below.

$$C= Var/2*\prod*f*V^2 \qquad \text{Eq. 8}$$

Where: ∏ - 3.14, a constant value

C - Capacitor,

VAR - the capacitor unity of Var rating,

F - Frequency a system use

V - Capacitor unit rated voltage.

Mandal et al (1994) in the study indicated that the use of a microcomputer PF controller model to compensate for reactive power loads can be controlled by binary ratio with zero voltage static switches. Others still prefer one single large shunt capacitor to deal with reactive power. However, it should be known that the power factor correction technique cannot reduce the total real power that the consumer consumes, but demand power in volt-amperes (Cousins, 2009).

Summary: Analysis of best incentive-based programs

Under the incentive-based programs, demand side management technique has abundance of opportunities for consumers and producers, in order to achieve demand energy reduction. However, it was demonstrated in this literature review that some of incentive –based techniques cannot provide much needed demand energy reduction, but they can reduce the actual power consumption. These incentive-based programs are summarized and evaluated based on capacity to reduce demand power and capacity to reduce the actual power (kW). In summing these programs, it come down to four categories such as energy efficiency systems (EES), Conservative voltage regulation (CVR), load shifting and load shaver as shown in Table 3 below.

Incentive-based programs	Capacity level to reduce demand power	Capacity level to reduce actual power consumption	Efficiency level
EEC(retrofit)	No	Yes	Quicker technique to reduce load consumption, easy to impalement
CVR	No	Yes	It works efficiently for short or long peak demand interval.
			Saves energy by reducing the level of voltage supplied to consumers.
			However, Utility losses on investment income during CVS.
Load Shifting	No	Yes	Work efficient by ToU tariff, But it is not a good DSM
Load shaver		Yes	Renewable energy is efficiency depend on weather conditions
			Diesel generator has high efficiency , but has expensive operating cost
	Yes		Power factor correction has high efficiency on demand power, good return on investment
			Short payback time.

Table 3: Matrix to select best fit technology

To address the objectives set in the research, the best fit technique should be directly able to reduce the demand power, easy to implement with high operation efficiency. Considering the Literature review and summarized table 3 above, it come clear that load shaver specific power factor correction will be appropriate demand side management to reduce demand power. However, the load shaver with renewable energy or generator source have ability to reduce actual power, but power factor can supplement the demand power required for the system to operate. It is cheap system compare to other options, and has ability to pay itself within short period of time. On the long run, the consumer will benefit from low demand, which will results in low demand cost and system installed capacity demand power will increase.

2.7. Chapter summary

Chapter 2 has explored the demand side management strategies which are in place to deal with high energy demand required from energy producers to the consumer’s side. This energy imposes strains on the generation, distribution, and transmission network, and at the same stage inflicts voltage drops and transmission losses which affects utilities in term of costs associated with those factors.

This literature review reflects the best DSM techniques that provides consumers with knowledge about options that are adequate for their load consumption pattern to reduce the peak demand load. These demand response programs each has advantages and barriers over each other, which is why it is important for consumers or end-users to choose a suitable program that could benefit them in terms of energy reduction and associated costs. The study emphasised and demonstrated the benefits of energy efficient systems, and together with DSM programs, lower greenhouse gases and improved efficiency of the energy system can be achieved. In addition, the use of these techniques could aid utilities in increasing its energy sale markets. The analysis and evaluation of the best fit incentive-based and time-based programs are selected for research design modelling.

3. Chapter Three: Power metering strategy

3.1. Introduction

This chapter begins with the background information about the research site facility and its power design structure. It deals broadly with the smart power metering system (SPMS), which is used in the study to obtain the facility load profile. The section explains methods used to measure power as well as locations where measurements are done in the facility. It is further demonstrates the design diagram of SPMS with detail explanation of technology used. The section also discusses the benefit value of SPMS to consumers to make informed decisions. The SCADA software that used to integrate all smart meters together is explain in detail in the section. The facility load profile are demonstrated such as real power, demand power and reactive power , which are used in the study as input data for Chapter 4.

3.2. Facility Electricity Background

This chapter discusses the operations and detail technical information about the SASOL Fuels Application Centre's energy composition. The facility's core work is based on fuels research application in which different vehicle engines are used as tools for fuels test application. The fuel application test covers the fuels performance and emissions test, which is done under the international and national fuel test methods, set out in the standards and according to ASTM methods. The fuels test process involves many instruments for measurement and control of all necessary points in the system, which require a huge amount of electricity to operate.

The source of energy for the complete facility comes from the city electricity grid, which feeds the facility 1MV transformer. The output supplies facility processes and office electrical systems that are connected to the main circuit board in the switchgear room. However, in the absence of main supply, the 600KVA generator kicks in. Internally, the electric circuits from the main circuit board supplies two boards called the dedicated board and City supply board.

- **Dedicated board supply**

This board supply all critical systems in the facility such safety circuit system, specialised emissions systems, and office machines and computers. It is called dedicated board because it serves equipment and systems with clear and protection against voltage sparks.

- **City supply board supply**
  This board supplies all machineries that need power for operation such as the lighting system, air-conditioning, HVAC, cooling tower, sump pumps, chillers, and blowers systems. Moreover, the board powers every electric board and electric instrument directly or indirectly connected through the electric supply-chain in the premises which all contributes to the total energy consumption of the building.

These two categories are supplied by the main supply circuit board which is interconnected to the city distribution lines via 1MVA transformer. However, in the absence of the main supply, during load shedding or scheduled maintenance, the supply comes from the facility’s 600KVA generator which is automated to start five seconds after the main collapses.

3.3. Design Model concept

In chapter 2, incentive based programs and power tariff rates are together utilised to reduce demand consumption. To achieve efficient energy-use and to be able to apply DSM techniques, the facility should install smart power metering, which gives consumers better monitoring and management of the load consumption. The Smart metering facility helps to measure and monitor the electricity consumption on the real time basis for all sections of the facility attached. In order to achieve efficiency and being able to applied any technique to reduction of electricity consumption.

a) Install smart power metering to measure and monitor electricity in the facility.

3.3.1. Smart Power Metering

The first part of the model is to design a power metering system to measure and monitor the load consumption of the facility as well as other sections of the building. This system makes it possible for consumer to monitor their total consumption which will aid in making informed decisions based on the consumption load pattern. This helps the consumer to plan their operation based on low tariff rate periods, which is beneficial to the end-user. A smart power metering has potential to monitors and stores electricity usage of each section of the facility via integrated network.

3.3.1.1. Smart Power Metering Architecture

This design structure is based on two potential sources of supply such as the main circuit and standby generator which fed four test stations. Each engine testing station is equipped with a dynamometer and a number of instruments. These test stations are categorised as high energy consumers in the facility due to dynamometers and electrical instruments fed from the facility load. However, the dynamometers are capable of producing energy and are equipped with power meters. The design diagram contains the modules that are vital for acquisition of data from the circuit breaker (CB) and consolidates them all into one which is displayed in the local StruxureWare power expert software. The system uses Modbus, Ethernet as a communication protocol. Figure 14 shows the power metering network structure and the makeup of components.

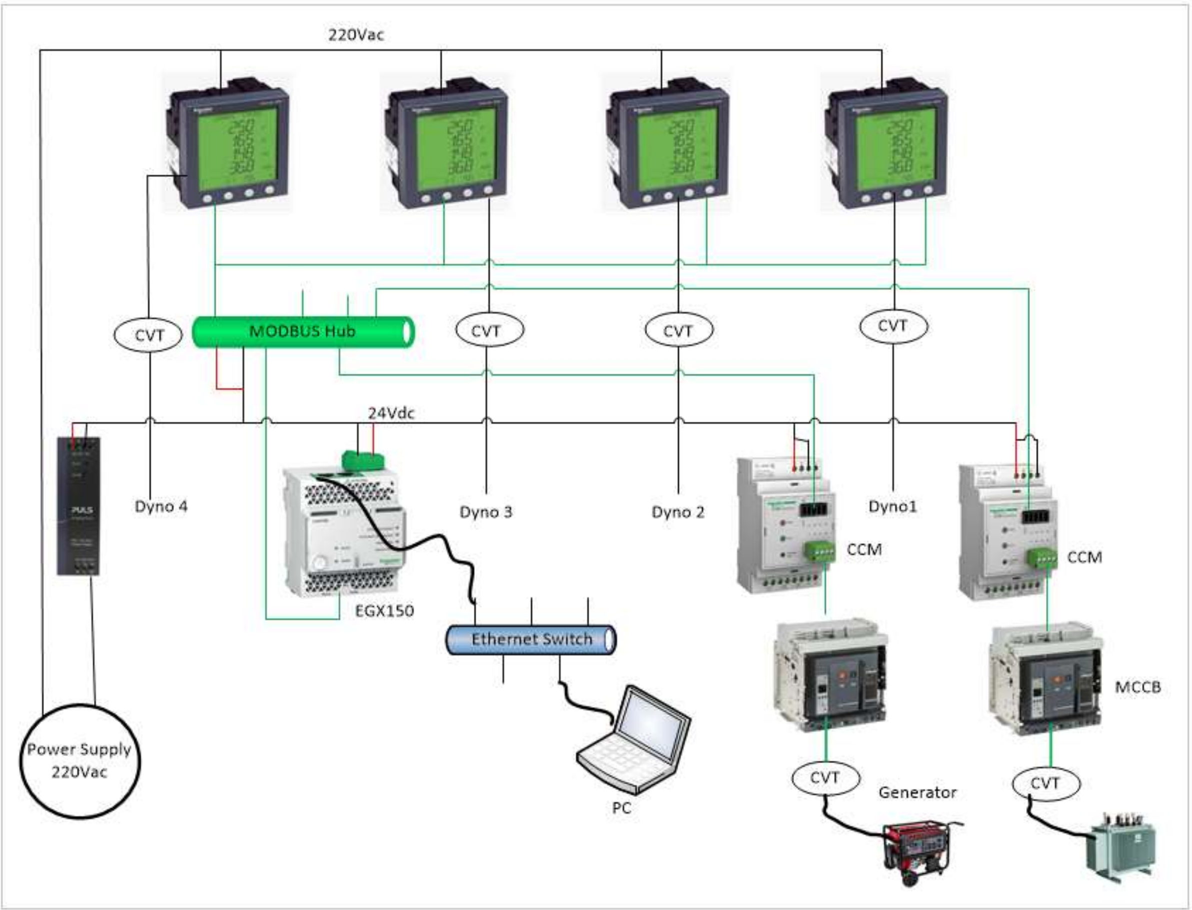


Figure 14: installed SFAC Power metering

3.4. Methods of Measurement and management

The smart metering system uses different power electronic devices connected together to form a system network to enable flexible exchange of information. These devices use different communication platforms such as Modbus and TCP/IP protocols. As indicated in Figure 14 above, system measures facility main power sources from 1MVA transformer and standby generator. It is further extends to measure from four identified high consumption areas in the facility such as Dynamometer 1-4. System uses mainly 24VDC supply power to communication modules and 230Vac for power meters.

3.4.1. How it works?

The current/ voltage transformer (CVT) sensors the current or voltage signals and transmit to power meters for processing and then output calculated power parameters such as actual power, power factor, apparent power, reactive power, load current and other critical power measurements. Then, transfer power parameters to a local computer for storage and display as shown in the Figure 15.

Figure 15: illustration of power measurements process

The system internal communication channel is Modbus protocol, however for data to reach local computer Modbus is converted into TCP/IP protocol. The system design is made up of smart devices and their functionality is explained below.

a) *Current transformer sensor unit:* The installed CT input of 1600A/5 at the output of 5A/1A. The CT sensors the current of the load and transmit to power meter.
b) *Voltage Transformer (VT):* The system uses the voltmeter as a device that measures high voltage across the system. It is connected on the secondary output. The output signal is transferred to the power meter.
c) *Power meter:* A power smart meter is a digital electronic device that collects data from the electrical circuit breaker and displays power parameters [7]. The installed PM210 meter received input data from CT. Then, perform power calculation and display. This power data is transferred through 2-wire Modbus daisy chained to be stored and displayed in Local Computer.
d) *Gateway (EGX150):* The gateway is installed to give local computer an access to smart devices for exchange of data. And also to be able to displayed data on the local computer. It is accessible via Modbus to Ethernet conversion switch.
e) *Cradle communication module (CCM):* The CCM communicates with breaker communication module (BCM) to read the status of main supply breaker via micro-logic. It serves as a gateway between the Modbus network and Modbus BCM. It monitors the communication parameters of the Modbus BCM and tripping unit.
f) *Modbus Converter:* Modbus converter allows to interface a Modbus device with one or more generic wiring configurations [20]. In this instance, the 4-wire configuration of the main breaker and generator signals are converted into 2-wire configuration.

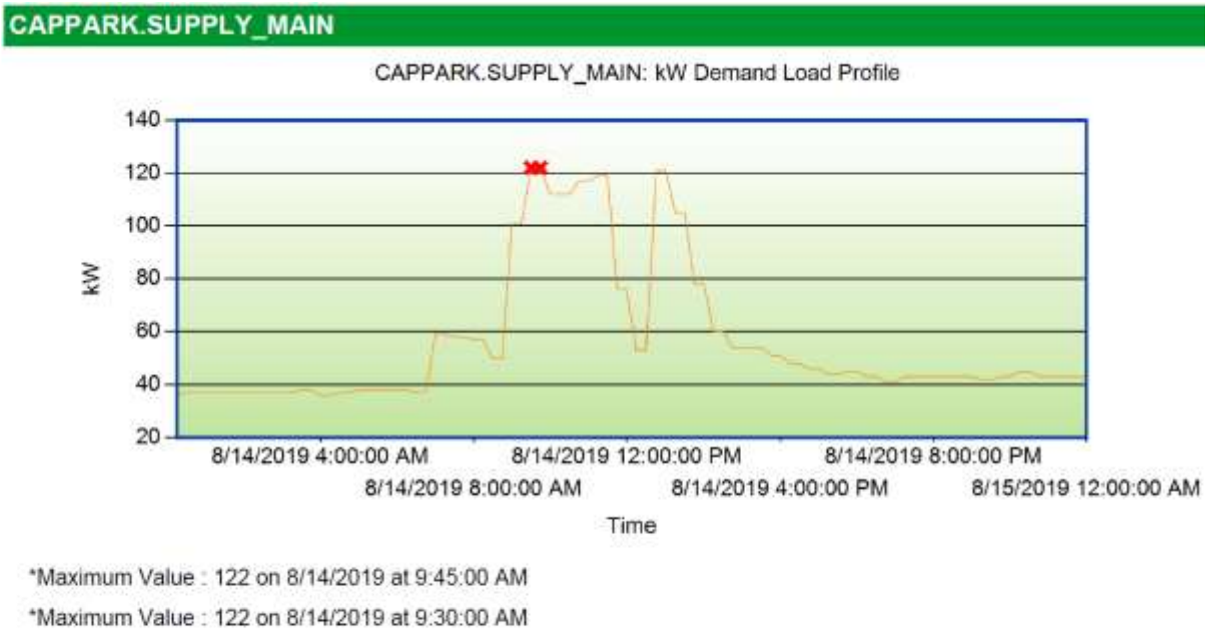
g) *Computer:* The power data are stored in local computer for SCADA information display for management and control. This information data is transferred through TCP/IP Ethernet protocol.

3.5. Software use by Power metering

The system uses a software that act as platform for presentation of all power parameters, is EcoStruxure power monitoring experts (PME) software. The software application serve as a SCADA for power metering. The modules interaction is controlled and manged by EcoStruxure power monitoring expert, which is windows-based software. The EcoStruxure power monitoring experts is window to digitalized power network. The modules are configured through EcoStruxure PME to allow transfer of information from Smart devices to local computer. It taking advantage of IoT connectivity and distribution intelligence. PME brings unique new capacity that makes it simpler to protect assets, keep operations running and save time and money.

3.6. SFAC Load Profile

The load profile of the facility averages from 40 to 65 kWh, which is an hourly consumption pattern that the facility experiences throughout the year without test cell and attached systems being in operation. However, Figure 16 below shown a main supply kW demand load profile of the facility. The normal load profile before trading hours remain below 40kWh and as occupancies arrive the demand load increases due to lighting, computers and air-conditioning systems switched on, this will gradual increase until approximately 60kWh. The system record the highest peak of the day, week and the month at 15 minutes the interval. In this case 122kW demand was recorded on 18/14/2019 at 9:30 and 9:45 am. These load demand profiles are demonstrated in a number of scenarios below.

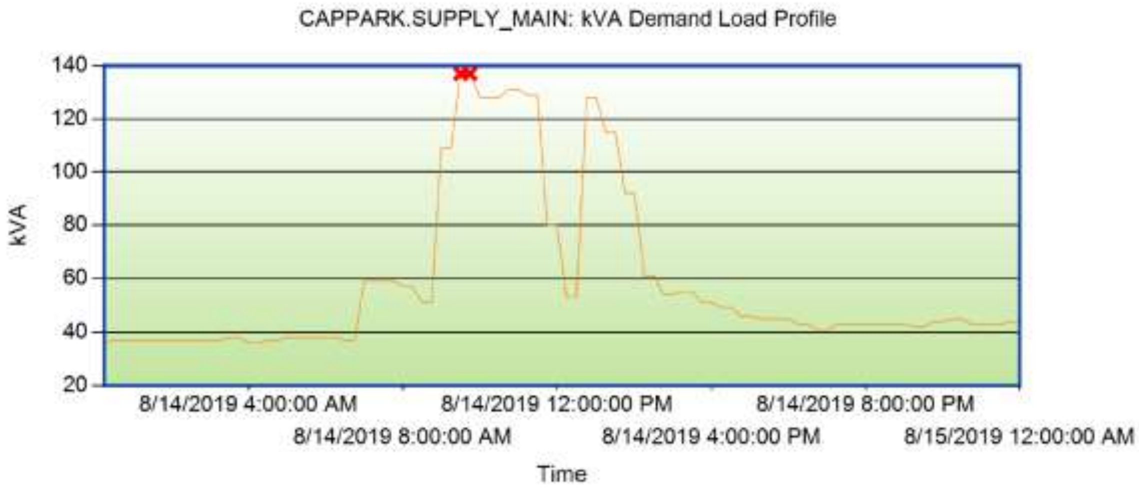


*Maximum Value : 122 on 8/14/2019 at 9:45:00 AM

*Maximum Value : 122 on 8/14/2019 at 9:30:00 AM

Figure 16: illustrate main supply kW demand load profile

While the system demanded kW indicated in Figure 16, the KVA for the same system in Figure 17 increased with recoded peak demand value of 137 KVA on the same day and time on the month. The systems with a demand power not at the same value as actual power present inefficiency with the electrical network of the facility. In an AC circuit, the product of the RMS voltage and the RMS current is called apparent power. When the impedance is a pure resistance, the apparent power is the same as the true power. This expression is clearly explained in the power triangle relationship in chapter 2.

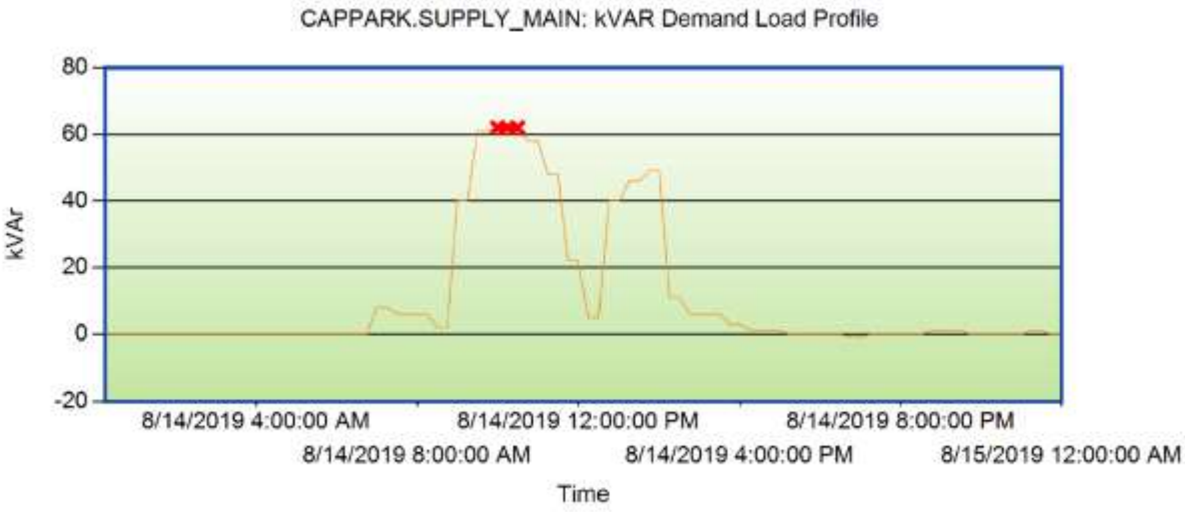


*Maximum Value : 137 on 8/14/2019 at 9:45:00 AM

*Maximum Value : 137 on 8/14/2019 at 9:30:00 AM

Figure 17: Demonstrates KVA of the demand load profile

Smart power metering provides technical real-time measurement of power parameters. Figure 17 demonstrates the graph with the main supply of reactive power demand load profile with peak demand values. And Chapter 2 teaches that high amount of kVAR demanded by system, more inefficiency exists in the system. As a results total demand KVA load profile could not be equally to total Demand kW load profile.



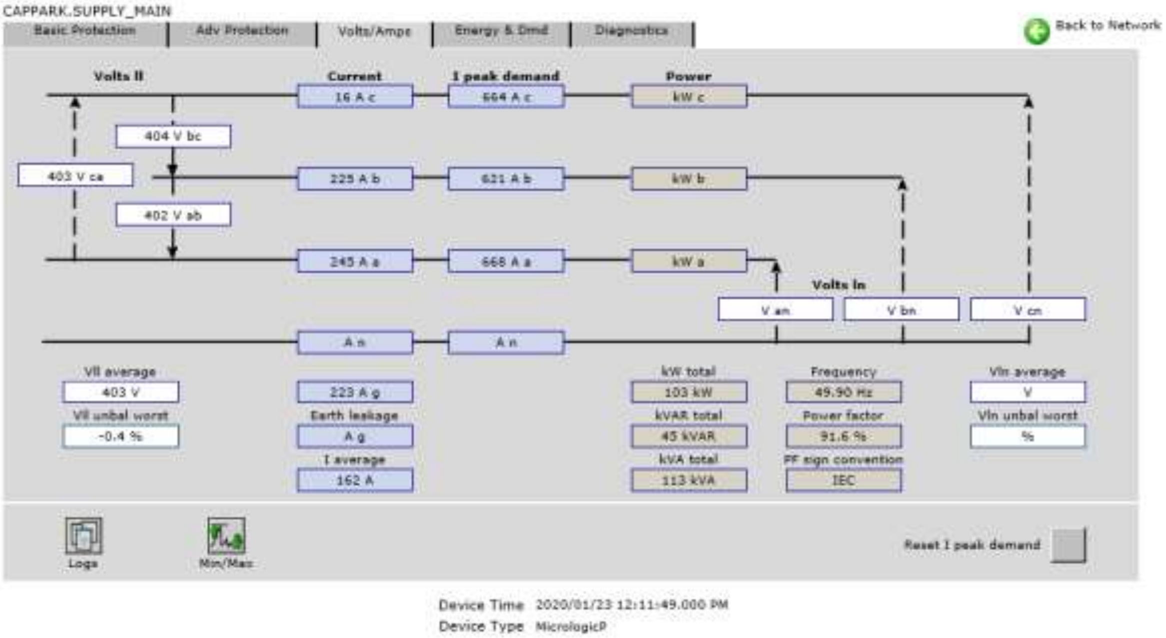
*Maximum Value : 62 on 8/14/2019 at 10:30:00 AM

*Maximum Value : 62 on 8/14/2019 at 10:15:00 AM

*Maximum Value : 62 on 8/14/2019 at 10:00:00 AM

Figure 18: shows KVAR of the demand load profile

The smart power metering further provide with technical details of input power parameter of facility. Looking in Figure 18 below the system provides with technical information such as board voltage of 403Vac, current of each phase load, phase kW. Now, with information it is clear that many can be investigated such as load balancing, power factor improvements.



Vll average: 403 V
Vll unbal worst: -0.4 %
223 A g
Earth leakage: A g
I average: 162 A
kW total: 103 kW
kVAR total: 45 kVAR
kVA total: 113 kVA
Frequency: 49.90 Hz
Power factor: 91.6 %
PF sign convention: IEC
Vln average: V
Vln unbal worst: %

Device Time 2020/01/23 12:11:49.000 PM
Device Type MicrologicP

Figure 19: Load parameter and behaviour measurements.

3.7. Advantages of SPMS for Commercial sector

Barai et al. (2015) study stated that the utility companies should aim for a high level of smart metering to ensure that regulation takes full advantage of technology before the investment became outdated. For the utilization of smart meters, utilities have regulation requirements to comply with.

For example, in Ontario, Canada, the main requirement for smart metering are automation meter reading, automation data communication and the capacity of TOU pricing (Barai et al., 2015). In Britain, BC clean energy act sets the regulation requirements for smart meters in both for Columbia and Canada.

The minimum requirements for Alberta is the potential to measure usage across multiple periods, customer and retailer access to the meter data, remote meter reading and also remote disconnection features (Barai et al., 2015).

3.7.1. Commercial benefits

The smart metering implementation provides a number of benefits to consumers, utilities, and the larger society. The direct benefits to commercials is that the end-user gets information continuously about the state of facility consumption. This information assists the consumer to make informed decisions about load reduction DSM strategies and plan alternative supply intervention during load shedding and high peak demand times (Javaid & Ahmed, 2018).

3.7.2. Utility benefits

The smart metering implementation provides benefits to the utility by giving access to control of transmission and distribution lines, to be able to control transmission lines losses and voltage drops produced by high strains on the power lines network (Longe et al., 2017). These benefits include the ability to control peak occurrences and to remotely control and better the management of billing and other consumer related issues (Barai et al., 2015). It gives the utility the ability to efficiently use the power resources and optimising income with existing resources.

3.8. Chapter summary

SPMS provides important power data for decision making of electrical network. This section dealt with the facility load profile, methods used to measure and monitor power consumption as well as technology used to measure power parameters. This power metering benefits the consumers with historical power data or locally real-time data on energy consumption and cost. The benefits of having SPMS indicated as advantage for commercial sector and utilities. The power data obtained by smart power metering system are integrated with the model design in chapter 4 to improve efficiency of electrical network. In order to reduce demand power and the total cost of energy in the facility consumption.

4. Chapter Five: Design Model

4.1. Power Factor Correction Model design (PFCMD)

The proposed power factor correction model is one of the DSM techniques that is an incentive-based program as discussed in detail in chapter 2. This focused on the mathematical analysis of the commercial electrical system, and aimed to improve efficiency while reducing the electricity bill. There are two important factors that a PFCMD has to perform to achieve this objective.

The first part of the model is power factor improvements to compare electrical response in terms of real power and reactive powers in order to bring PF close to unity (1). This intelligent process is controlled by a programmable logic controller accompanied with a capacity bank sized according to the required KVAR power as shown in Figure 20.

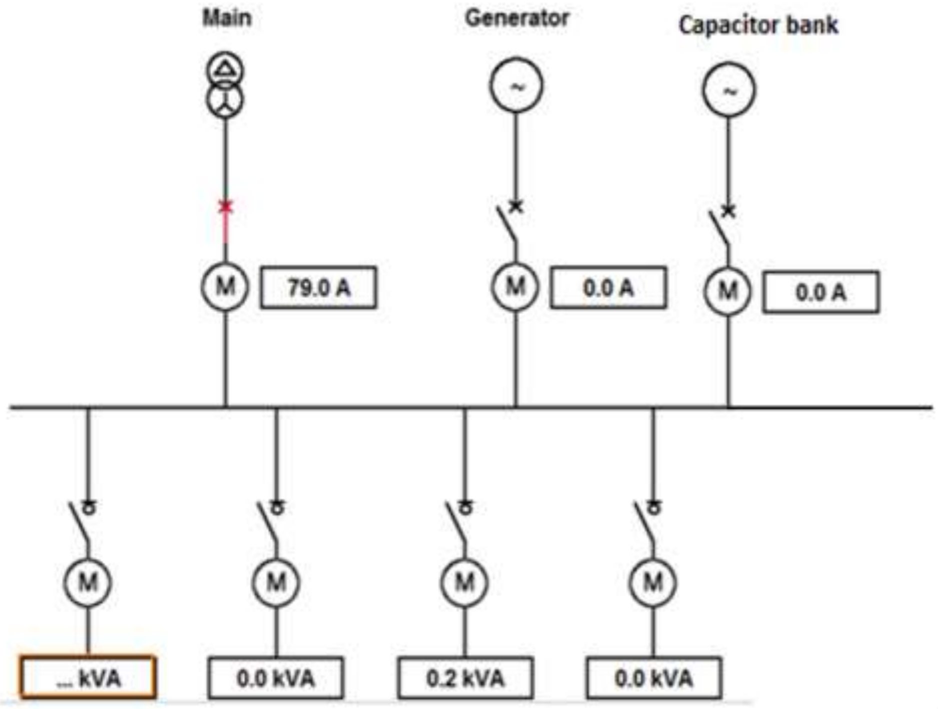


Figure 20: SCADA shows monitored load with capacitor bank

These capacitors are packaged according to the KVAR steps required, which could be up to the designer's desire to accurately match the demand load. Those steps will

be executed as per the instantaneous peak demand load in order to compensate for the required KVAR. This is a core function of the study as PFCMD reducing the peak demand load by forcing the power factor to be unity (1) will result in electricity costs as well as greenhouse gases being reduced.
The second part is to choose the best tariff structure that is in accordance with the facility's load consumption pattern. The model design tool uses Microsoft excel software to illustrate the energy reduction mechanisms, efficient use of energy, as well as reduction of the electricity bill.

Commercial and industrial businesses mostly utilise TOU tariff as a tariff of choice for demand side management. This tariff structure encourages the consumer to move part of their power load to an off-peak zone, which gives window for better utilisation of the generation and distribution network assets (Andruszkiewicz, J. et al., 2015).

However, a small user in the same space uses a flat rate tariff system, which technically benefits users at the expenses of generators. Figure 7 clearly demonstrates this risk. The City of Cape Town (CCT) tariff structure for small users is defined as a flat rate throughout the year with the expectation that users keep their demand energy below 500KVA and total consumption above 1000kW a month (City of Cape Town, 2017).

City of Cape Town Tariff structure 2017/18				
LPU-MV		Energy	Demand	Serv/day
		83.36	235.69	63.33
TOU-MV		Energy	Demand	Serv/day
Low-demand	1-L-OP	74.20	94.36	92.41
	2-L-S	101.89		
	3-L-P	136.17		
High demand	4-H-OP	81.66		
	5-H-S	128.32		
	6-H-P	363.39		
SPU(<500KVA)		Energy		Serv/day
		140.65		49.65

Table 4: Tariff structures of CCT (derived from City of Cape Town electricity tariff 2018/19).

It evident from the CCT tariff structure 2017/18 and Table 4 that the small power user only pays for the real power in kilowatts consumed as long as the demand is kept below 500KVA threshold, otherwise the city issues a penalty which could lead to disconnection if the demand load persists exceeding the threshold. This tariff structure could reduce electricity bills and also lower the pressure power producer’s encounter due to their generating systems. As a result, this may reduce carbon emissions which poses a danger to the health of society and the ecosystem.

4.1.1. PFCMD simulator

The PFCMD simulator is developed for the purpose of the study to demonstrate these DSM techniques in order to execute power efficient results for the defined operating load conditions for consumers and utilities who can benefit from the low cost of energy. The software uses Microsoft excel for the creation of the model. The technical data used in the model are from the facility used as a residence for the study.

The PFCMD simulator begins with the facility’s transformer technical details that can be adjusted to produce primary, secondary, and short circuit currents that the transformer can handle based on the load required. These details are acquired from a transformer installed on site and smart power meters installed and connected according to Figure 20 above, where the main, generator and other strategic areas of the facility are interconnected to the power network structure to show energy consumption patterns among areas within the facility.

In addition to the features of the PFCMD simulator, the energy consumed is being processed to produce the energy cost per tariff structure used. These values assist users to understand the total electricity bill components that city councils use for billing its customers. Moreover, adjustment applicable to the power factor produce real power at a small current to transmit the required load.

The facility’s load pattern changes every time an inductive load is introduced online. As a result, the power factor depreciates, which then results in a high demand load drawn from the grid. However, in this study KVAR is constantly being monitored and kept triggering the output of the DSM program to unleash PFC to compensate.

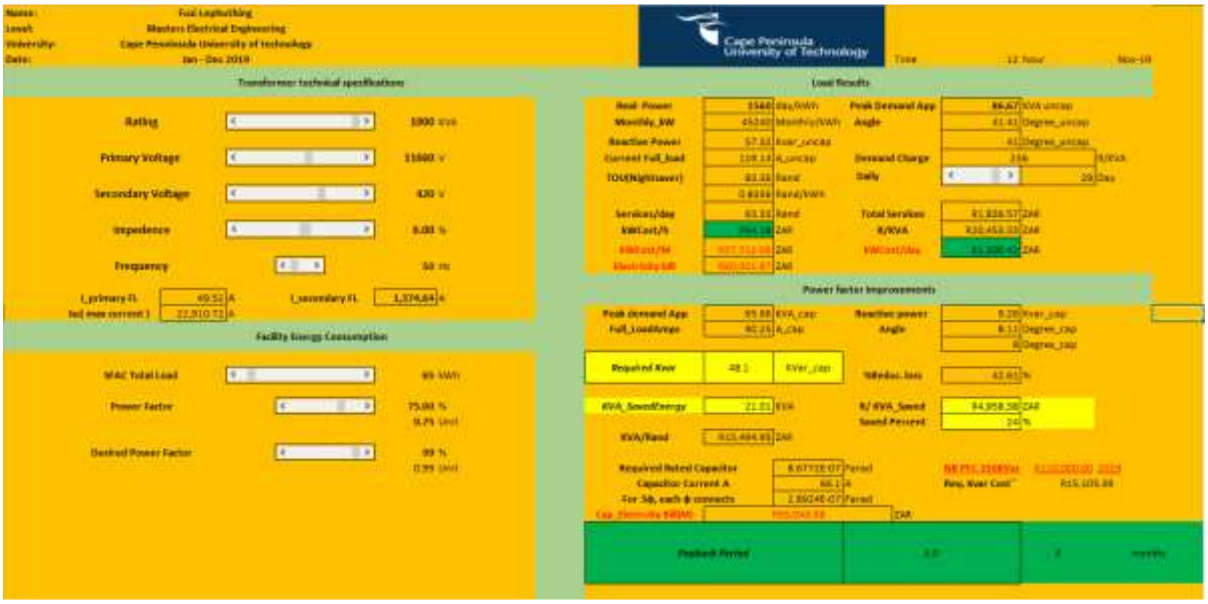


Figure 21: PFCMD simulator with LPU-Nightsaver

Referring to the PFCMD Simulator the model begins with the technical data input as information that the end-user provides to the simulator, which includes the facility load patterns, power factor, as well as transformer technical specifications.

The facility in the study uses LPU-Nightsaver tariff, which is operating on peak weekdays and off-peak during Sunday and Saturday. Figure 21 indicates the facility and its load consumption, LPU-Nightsaver contained charges as shown in table 4, which all influences the cost of energy charged to consumers.

For example, the model shows the cost of energy being R60, 001.97, which was spiked by the high demand load required by the facility as the result of the depreciation of power factor, increase current load, and phase angle. However, the model shows a reduced energy cost of R55, 043.58 by correcting the power factor, and trying to keep the KVA close or the same as kW. It is seen in the model that once the kW is close to the KVA, there is an increased reduction of KVA. Approximately 24% of KVA were saved according to the figure above, and as a result the current load decreases from 119.14A to 90.25A and the phase angle is reduced to approximately 8 degree with a reduction loss of 42.64%.

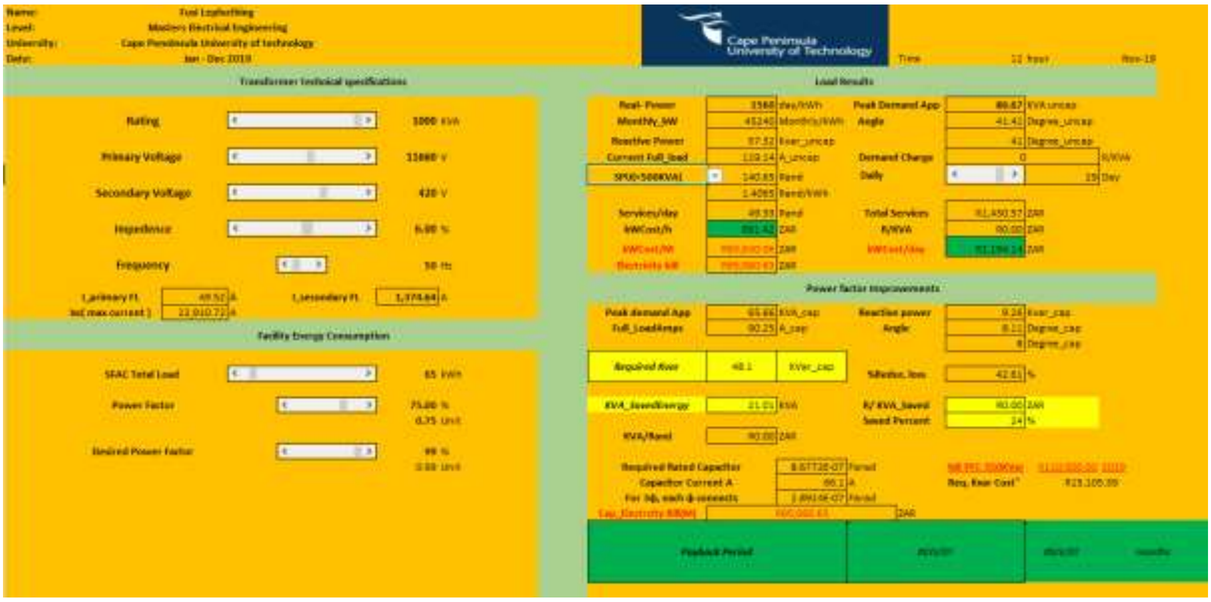


Figure 22: PFCMD Simulator with SPU (<500KVA)

For example, as indicated in Figure 22 above, the facility total load stands at 65 kWh at the power factor of 75% with the city tariff of (SPU<500KVA). The cost of energy is R65, 060.63 higher compared to Nightsaver. Although, in this tariff, the demand is set to be below 500KVA with zero charges, the phase angle 41 degrees. Under this tariff, the PFC system is inactive due to demand limit.

The study uses the TOU-Megaflex tariff in Figure 26 below, which is operating on three segments throughout the weekday, namely, peak, standard, and off-peak. On weekends it operates on two segments such as off-peak and standard on Saturday, and off-peak only on Sunday.

Figure 23 indicates the facility and its load consumption, TOU-Megaflex contained service charge a day, real power charge per hour, and demand charge per hour according to the tariff structures of the City of Cape Town 2018/19, which influences cost of energy charged to consumers.

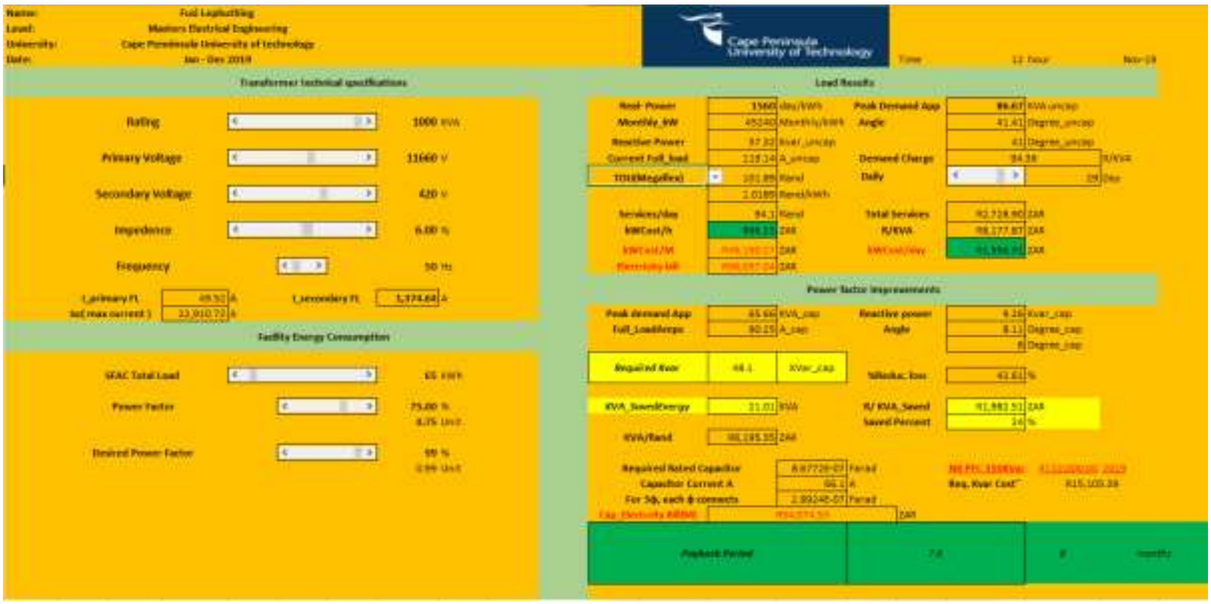


Figure 23: PFCMD Simulator with TOU-Megaflex

The model with TOU-Megaflex indicated the energy cost of R56,057.04 a month, under the same load pattern with R66.23/kWh of that month. However, after corrected power factor to 99%, the demand load reduced from 86.67 to 9.26KVA and as a result the energy cost lowered to R54, 047.53 and phase angle to 8 degrees. The required KVAR needed from PFC amounts to 48.1KVAR with three phase capacitor of 8.7pF to compansate the required load.

The power losses of an electric conductor depend on the resistance of the conductor itself and on the square of the current flowing through it. Since, with the same value of transmitted real power, the higher the power factor, the lower the current flowing through the conductor, it therefore follows that when the power factor rises, the losses in the conductor on the supply side of the point of application of the power factor correction equipment will decrease.

The power factor improves the electrical system by reducing the reactive power proportionately reducing the electricity bill to the consumer. The model illustrates the fact that the power factor has direct influence on demand energy power KVA, which means the lower power factor the higher demand power and vice versa.

4.1.2. PFCMD Calculations

This section focuses on the mathematical calculation of the model to obtain desired results with the use of DSM methods and strategies. The model calculation demonstrates the applied mathematical method to gain benefit from reduction in load and cost by using a peak shaver program in the form of PFC and tariff rate. Both strategies are applied in the PFCMD simulator to transform demand energy load pattern in order to produce efficient use of the load consumption and reduce the peak demand load of the facility.

The sites technical information about the transformer as follows: 1000KVA @ 11660V/420V and an impendence of 5%. Then, calculating the current of the primary and secondary coils will be as follows;

$$I_p = KVA*1000/(\sqrt{3} *V_p) \qquad \text{E.q.9}$$

And

$$I_s = KVA*1000/(\sqrt{3} *V_s) \qquad \text{E.q.10}$$

Where, I_p = Current though the primary coil

V_p = Voltage across the primary coil

I_s = Current though the secondary coil

V_s = Voltage across the secondary coil

KVA = Transformer rating KVA

The full load of I_p and I_s are important for understanding of the power parameters in the windings. More importantly I_s is critical for sizing and configuration of current transformer (CT). In this case 1600/5A CT, which gives a ratio of 320 for configuration.

The simulator tool is used to test the impact of power factor on the power electrical network. The table 5 below is developed with the results of from Simulator tool, in this case the real power is set constant at 65kWh throughout the test and power factor is changed from 25 to 100%. This test is able to show the changes in power factor has positive impact to power parameters.

Power Parameters					
% Power Factor	kW	KVA	KVAR	Load_A	θ
25	65	260	251.74	357.41	76
50	65	130	112.58	178.7	60
60	65	108.33	86.67	148.92	53
70	65	92.86	66.31	127.65	46
75	65	86.67	57.32	119.14	41
85	65	76.46	40.28	105.12	32
90	65	72.22	31.48	99.28	26
95	65	68.42	21.36	94.05	18
99	65	65.66	9.26	90.25	8
100	65	65	0	89.35	0

Table 5: Impact of change of PF to electrical network

The table 5 shows that at 25% power factor, while the real power remain unchanged the KVA demand and KVAR values are high at 260KVA and 251.74KVAR respectively. And the load current at the full lod and phase angle are extremely high. In general the table shows that low power factor is equivalent poor power factor which highlights inefficient in electrical system. A poor power factor leads to a poor electrical efficiency, which causes lagging current to the voltage of circuit at the load side. System will need leading current to improve power factor efficiency. As a results the consumer will suffer from high cost of electricity.

However, as power factor increases towards 100% the system efficiency improve, demand power and reactive power decreases. At PF of 100% system demand power is the same as the actual power, reactive power and phase angle are at Zero.

$$\text{At phase Angle } (\theta) = \cos^{-1}(\mathrm{PF}) \qquad \text{Eq. 11}$$

Where, Θ = a phase angle between kW and KVA measured in degree

4.1.3. Power Factor working strategy

Power factor correction is the process of compensating for the lagging current by creating a leading current by connecting capacitors to the supply. The reduction on the reactive power can lower the electricity bill, due to its directly proportional relation to apparent power, Table 3 above shows relationship. This can be achieved by increasing power factor values closer to 100%. The required KVAR_Q to correct the efficiency of electrical network is old KVAR substrate the Capacitor KVAR and..

Required KVAR_Q = KVAR –KVAR_cap Eq. 12

% Red. Loss = 100-100*(Original PF/New PF)^2 Eq. 13

Where, New PF = desired power factor measured as ratio

Required KVAR_Q= a required amount of VAR to improve PF

%Red. Loss = a percentage reduction loss the system prevented to occur by implementing the system.

Study indicated that 95-99% of power factor is a perfect for operational efficiency. Theoretically it is possible to have 100% power factor. However, in practice 100% power factor correction could lead to inefficiency in electrical system and has potential to cause harmonics distortion, which will cause more money for harmonic filters.

4.1.4. Electricity Bill (City of Cape Town)

Electricity bills are made up of different components that together formulate the total energy consumption for each month. These components are as follows: real energy in kW, charges, demand energy in KVA, demand charges, and service charges.

This section deals with electricity bill analysis and compares between systems with and without power factor correction. It uses city electricity tariff in table 4 together with simulator tool.

	LPUMV(OLD)	LPUMV(TOU)
% Power factor	Total electricity cost	
25	ZAR 62,723.75	25,785.22
50	ZAR 32,043.75	13,518.42
60	ZAR 26,930.41	11,473.95
70	ZAR 23,278.03	10,013.62
75	ZAR 21,817.08	9,429.49
85	ZAR 19,410.80	8,157.52
90	ZAR 18,408.19	8,066.51
95	ZAR 17,511.11	7,707.83
99	ZAR 16,858.70	7,446.97
100	ZAR 16,703.75	7,385.02

Table 6: Change of PF to the cost of electricity

The research used the current research site tariff structure called large power user medium voltage (LPUMV (Nightsaver)), together with same range of time of use tariff (LPUMV (TOU)), which are city of Cape Town tariff for 2017/18 for critical cost analysis and comparison. The Table 6 also shows that the poor power factor results to high cost of energy, the total electricity bill is expensive. For example, the total electricity bill at 25% power factor the cost is R62,723.75, but at 95% power factor, the cost are very cheap compare to 25%.

4.2. PFCMD Flowchart

The model design sequence is indicated in the flowchart below. It shows step by step systems and the flow of instruction that the model follows for a successful power factor correction (PFC). The chart shows the flow of instructions as indicated in figure 24 model schematic below.

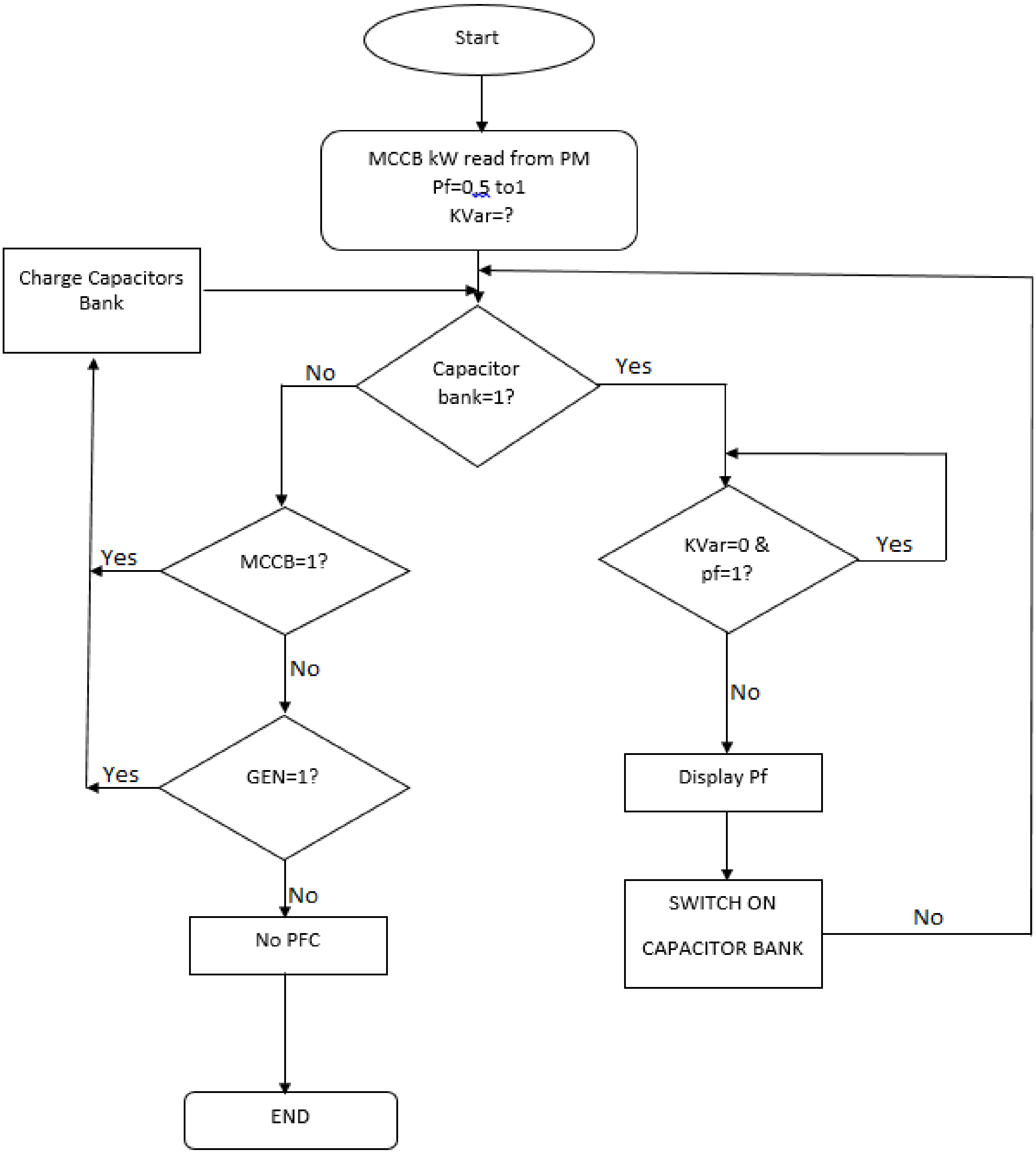


Figure 24: PFCMD flowchart

4.2.1. PFCMD Operation

The main power supply comes from two sources, such as the main power breaker which is directly connected to the 1MVA transformer, the generator will kick-in a few seconds after the main collapses. The sequence is as follows:

The PFC controller monitors the main power board of the facility to measure and monitor the PF value and whether the capacitor status is full or not. If the capacitor banks are not fully charged, the capacitors charging process have to start immediately.

First check if the main MCCB supply is there. If not, let the generator start and let charging start immediately until the capacitor bank is full. Otherwise, the model must not start.

However, if the capacitor bank is full, KVAR =0 and PF=1, then keep monitoring any changes on these two parameters. Then, If KVAR≠0 and PF≠1, release the required capacitor bank and recharge the capacitor bank to full. Repeat the sequence till the KVAR=0 and PF=1.

4.3. Energy efficiency systems

The facility has many options to reduce the baseload by means of conservation methods. The facility encompasses a number of air-conditioning systems and lights, as mentioned in the beginning of the study. These systems run through weekdays as well as weekends which then contributes to the increase of the baseload. The air-conditioning and lights energy audit was contacted as to understand the total consumption these specific systems have on the facility’s load pattern.

Lights	**Bulbs**	**Quantity**	**Operating Hours**	**Device kW**	**Total kW/day**
Office fluorescent lights	3	36	8	36	31.104
Air-conditioning		12	24	1800	518.4
Supply Fans		9	24	3467	748.872
Total kW/day					1298.376
Office LED lights retrofit (KK1934)	1	60	8	6	2.88
Air-conditioning		12	8	1800	172.8
Supply Fans		9	8	3467	249.624
Total kW/day					425.304

Table 7: Audit report with energy efficiency retrofit

The audit indicates the current load consumption caused by lights, air-conditioning, and fresh-air supply fans installed at the premises. The implementation of energy conservation on these systems will help to reduce the baseline load permanently and as a result consumption reduction could be realised as indicated in Table 7.

4.3.1. Lighting systems

The lighting system for the facility should include the energy efficient system to control the operating times. As indicated in the previous sections of this study, the facility trading hours are between 7:00am to 17:00pm on weekdays. On weekends the facility does not operate. There are two available ways to make the system have more efficient energy usage such as efficient lighting retrofit and control lighting system.

4.3.1.1. Efficient lighting retrofits

The downlight LED (KK1934) is as indicated in Appendix A. Lighting retrofits are normally a technology that aimed to transform the traditional electrical lighting space. This technology is commonly used commercially, industrially and residentially for in-door and out-door applications. The facility should embark on the conversion of its fluorescent lights into downlight LED lights as indicated in Appendix A. For example, the lights used in the offices, conferences, and corridors are fluorescent lights of 36W each, which according to Table 7 above totals to 31,1kW/day. However, with efficient retrofitting of LED lowered consumption to 2.88kW were realised.

4.3.2. Air-conditioning system

The fresh air supply into the offices are installed and operated by independent control fans circuit which is separate from the air-conditioners circuit. The fans have a direct on line (DOL) configuration that runs 24 hours on weekdays and cannot be operated or switched off. The audit figure above shows about 3.4kW of energy is being wasted by the system a day. Likewise with the installed air-conditioning units, each operate in isolation, meaning each office has independent operation and control of its air-conditioning. This is locally controlled and needs to be interfaced together with fans to enable consolidated control system that can be operated as per office needs.

A smart air-conditioning system has an intelligent control panel that users utilise for the control and management of the operation. These controls include start, stop, and other setting parameters such as temperature and operating times. These two systems need to be managed and controlled together at one point as indicated in Appendix B and C. For example, at the start of every facility's trading hours as the occupants switch on the air-conditioning system of the office simultaneously, the fresh air supply fan should start. Likewise, once air-conditioning is off, the fan must be off as well. It is also shown in the audit report that the intervention could reduce more energy by scheduling the control to happen simultaneously during the office trading hours, otherwise should remain off. This indicates the system will be running only for 8 hours on weekdays and off on weekends, thus the energy reduction of above 800kW a day can be realised.

4.4. Chapter summary

The PFCMD model has the ability to reduce demand load consumption for commercial businesses. Addressing the main question of the study, PFCMD has demonstrated that efficient use of energy can indeed reduce facility's demand load.

This DSM technique when implemented makes the load current reduce, while power factor correction tries to keep real power and apparent power the same in order to avoid peak demand load occurrence. This reduction has positive outcomes on the cost of energy as indicated in the PFCMD simulator software.

The addition of tariff rates into PFC adds improvements to the efficiency in the model for energy reduction and costs thereof. This is certainly shown in tariffs comparison exercises and was indicated in the model calculation and PFCMD simulator. The reduction of demand load consumption brings advantages to both utility and consumers such as a reduction in greenhouse gases, reduced amount of losses on the conductors, reduced distribution and transmission lines losses, and reduced phase angle. Further reduction by means of energy conservation as is indicated in the energy audit of lighting and air-conditioners. LED lights retrofitting could result in lower energy costs and eventually reduce the baseline, as well as changes in air-conditioners operating regarding duration and interconnecting control of Fresh air fans.

6. Chapter Six: Results and Analysis

6.1. Model design results

The model design and calculations as discussed in the previous chapter illustrated benefits the model made in SFAC facility for successful reduction of demand energy consumption. It encompasses site specific transformer technical input and output data, which assists the end-user to determine full load and short circuit currents.

The assumption made for the simulation of the model were as indicated in the calculations in the previous chapter. For example, the PF was assumed to be 75% at 65kWh consumption and the model delivered an 86.67KVA load, which turns to be high demand load that produced high load current of 119.4A and the load per day become 1560kWh as illustrated in Figure 21-23 as uncorrected load. The exercises results present inefficient use of the energy the SFAC facility consumed. This has a direct link with the cost of energy which eventually increased.

However, with the introduction of PFCMD at 99% power factor the energy characteristics changed. The analysis of results derived from PFCMD and calculations in chapter 5 shows the demand load reduced to a value of 65.67KVA at the same load of 65 kW, and the load current decreases to 90.25A. The phase angle decreases from 41.41 degree to 8 degrees. The PFCMD compensates the required KVAR by discharging the capacitor’s current to keep the KVAR zero and the kW and KVA consumption the same.

These results indicates that the increase in the power factor of the load consumption has a direct impact as shown in figure 26 below, This leads to the following improvements such as the reduction of the demand load, lowered current load, reduced load phase angle, and reduced conductor losses.

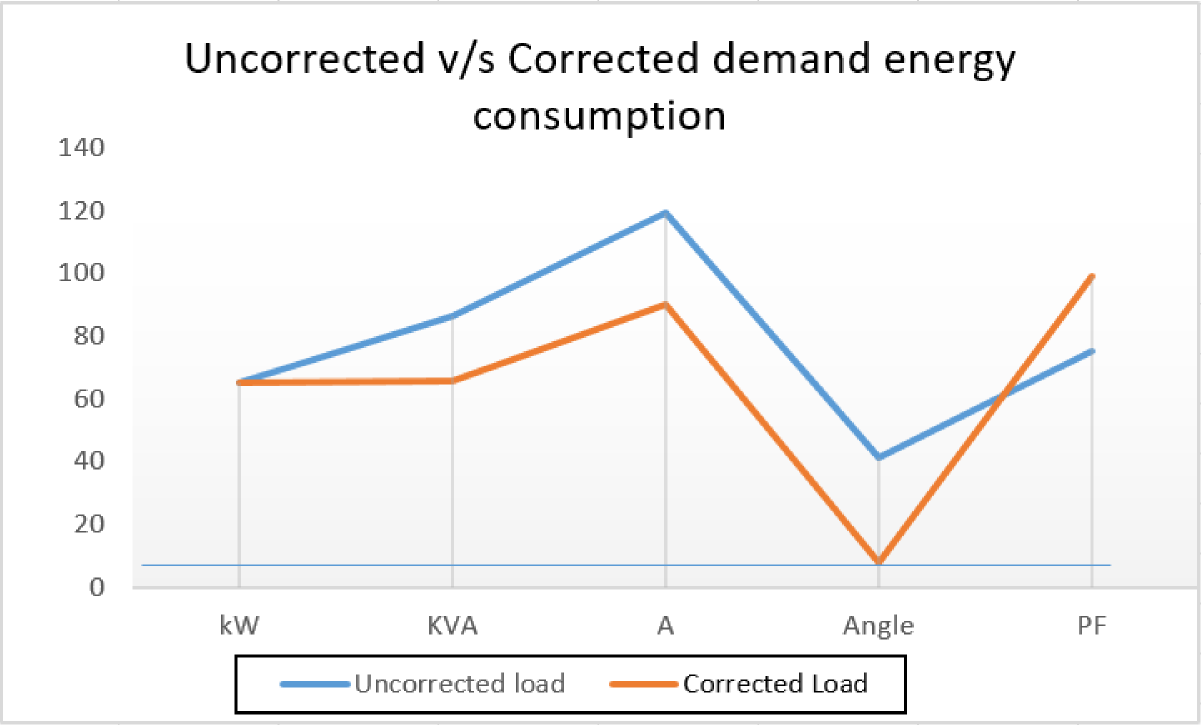


Figure 25: Illustration of uncorrected and corrected load consumption

Furthermore, the power factor improvement to unity (1), which results in the KVAR becoming zero, therefore, lessening the cost of energy. There are more benefit when the appropriate tariff structure is chosen together with power factor correction intervention.

According to the model design calculation and simulation results recorded, improvement of the power factor has a positive benefit to the total energy consumption the facility enjoys. Model simulations show that by increasing the power factor close to unity and choosing a correct tariff structure, the end-user experiences the benefit of a low cost of energy as well as reducing emission of greenhouse gases. The reactive power (KVAR) became close to or zero, and the load current become smaller to transmit the load, resulting in a reduced electricity bill.

6.2. PFCMD cost results analysis

The PFCMD contained the electricity bill. As indicated in the tariff structure in chapter 5, the model simulator had three types of tariffs on which a cost comparison was performed with each rate to produce results and the cost associated with the model.

Furthermore, the results derived from the model calculation also displayed the relationship between tariff type and energy cost. This model contained the tariff structure of the facility that the study was based on. These tariffs are as follows: LPU (Nightsaver), TOU (Megaflex) and SPU (<500KVA)

6.2.1. Flat tariff rate SPU (<500KVA) analysis

It was indicated in simulation exercises in chapter 5 that the PFCMD, due to SPU (<500KVA) requirements, that the load consumption must be above 1000kWh a month. Additionally, there are zero charges for demand load under the tariff. However, the end-user must keep the demand load below <500KVA.

Due to the fact that the tariff has zero demand charges, the model electrical characteristics perform power factor correction efficiently, but only demand load cost are not included in the electricity bill. At this period of time in the study the SPU (<500KVA) energy cost per 65kWh is R91,42, which appeared as the most expensive tariff structure which equates to a total energy of R65,060.63 including service fees.

This tariff can be beneficial to consumers, but is very bad for the utility because it is a flat rate tariff and the demand load does not account to consumers. However, the cost of energy is high due to high charges on kW and as a result the total energy cost increases. The model indicates zero demand load cost even after the power factor is increased to 99%, and indeed the KVA produced amounted to zero charges which greatly benefits the consumer.

However, the best DSM technique under the SPU tariff is to reduce the real power consumption by implementing energy efficiency retrofitting of facility lights and air-conditioning audit retrofit, improving the control of facility systems.

6.2.2. Tariff rate LPU (Nightsaver)

In this tariff structure, LPU (Nightsaver), the real energy charges per 65kWh consumption costs R54.18 which equates to R37, 712.06 a month with demand charges of R236 per KVA which equates to R20, 453.33. The load power factor remains uncorrected power factor of 75%.

The cost comparison between SPU (<500KVA) and LPU (Nightsaver) before power factor correction indicates that SPU has a higher cost of real energy compared to LPU. Although the cost of energy is high in SPU, the demand load is zero compared to LPU of R20, 453.33. The total electricity bill the producer charge the consumer in this situation add up to R60,001.97 a month, which is made-up of a monthly kWh plus demand load KVA and monthly service fees.

However, after power factor correction the demand load is reduced to 65.66KVA, which costs R15, 494.95. The model under this tariff managed to save 21,01KVA which is equivalent to R4, 948.38. As a result, the total electricity bill is R55, 043.58 for s corrected power factor of 99%.

The required 48.01KVARh cost R15, 105.39 and the payback period will be for three months. PFCMD can reduce the demand load as well as the demand load cost eventually as once the demand is reduced the total electricity cost decreases. In most instances, the demand load (KVA) raises up to approximately twice the real energy value once the instantaneous peak occurs.

6.2.2. Tariff rate TOU (Megaflex)

The PFCMD simulator operated under the same conditions as SPU (<500KVA) and LPU (Nightsaver) tariff. In this operating condition, the uncorrected power factor of 65kWh costed R66.23. In a monthly the cost becomes R56, 057.04, which includes the demand load of R8, 177.87 and service fees of R2, 728.90.

However, after implementing the correction, the total energy cost becomes R54, 074.53, which indicates a demand load reduction from R8, 177.87 to R6, 195.35. This reduction indicates R1, 982.51 savings. Based on the researched cost of PFC, the required size of 48.1KVAR could cost R15, 105.39 and its payback period could be approximately eight months.

Important factors to take note of are the cost of energy under SPU, LPU and TOU tariff structures. The TOU stands out as lower in cost compared to LPU. SPU tariff does not affect the demand load as is being excluded from cost of energy under the tariff. The model also indicated a reduction in the cost and energy, which as a result reduces the emissions, transmission and distribution losses, as well as improving the overall health of society. These benefits can be achieved by improved system efficiency.

6.3. Cost comparison with improved PF and tariffs

In this section the study compares different scenarios to establish the cost impact, return on investment (ROI) and payback time associated improved PF. The study assume the cost of power factor correction unit to be ZAR 150,000 throughout the test.

For example, the first case is to improve PF from 25% to 95% as shown in the Table 8 below, With LPUMV (Nightsaver). The results indicated the ROI as ZAR 45,212.64 and the payback time to be 4 months duration. However, with LPUMV (TOU) the ROI is ZAR 18,077.39 and payback time is 9 months.

PF	LPUMV(nightsaver) tariff			LPUMV(TOU)			PFC Unit Fixed Cost
	ROI	% Savings	Payback (month)	ROI	% Savings	Payback (Month)	
25 to 95	ZAR 45,212.64	72	3	ZAR 18,077.39	70	8	ZAR 150,000.00
70 to 95	ZAR 5,766.92	25	26	ZAR 2,305.79	23	65	
85 to 95	ZAR 1,899.69	10	79	ZAR 449.69	6	334	
90 to 95	ZAR 897.08	5	167	ZAR 358.68	4	418	
95 to25	-ZAR 45,212.64	-72	-3	-ZAR 18,077.39	-70	-8	
95 to70	-ZAR 5,766.92	-25	-26	-ZAR 2,305.79	-23	-65	
95 to 90	-ZAR 897.08	-5	-167	-ZAR 358.68	-4	-418	

Table 8: illustration of PF and the cost

The results also shown the fact that although LPUMV (Nightsaver) tariff charges are higher than TOU, the ROI amount is extremely good and payback period is shorter compare to LPUMV (TOU). However, the study reminds that the total cost of energy under LPUMV (TOU) is lower compare to LPUMV (nightsaver) tariffs.

Percentage= (Energy_Saved cost/ Uncap electricity cost)*100 Eq. 14

However, the savings percentages in terms of overview LPUMV (Nightsaver) saves more money. For example from Table 8 above shows that 85 to 95% power factor the LPUMV (nightsaver) saves 10% and LPUMV (TOU) saves 9%. But in principle, the amount consumer pays from LPUMV (Nightsaver) is ZAR 17,511.11, which is as double ZAR 7,707.83 for LPUMV (TOU). Now, the research suggested that research site should consider to change their current tariff structured to LPUMV (TOU), due to low power charges.

The negative energy cost in Table 8 indicates the losses the system could have by not implementing the power factor correction. And in other sense it can be translated or represented as the change occur once inductive load is applied to the system without correction. These losses are also occur in the form of energy cost.

6.4. Research objective and questions addressed

a) Does PFCMD address the objective of the research?

The research model dealt with reduction of demand energy consumption of the facility. The DSM techniques covered in chapter 2 dealt with different strategies that can be utilised to reduce demand load consumption. In response, the following outcome were produced:

i. The research found that the TOU (Megaflex) rate was the most cost efficient tariff structure, which could be used by the commercial sector to lower the electricity bill.

ii. Findings indicated that LED lighting retrofitting has a huge potential to reduce baseline load according to the energy audit report. Lastly, improving the operation control of fresh air supply and air conditioning by allowing them to operate together for trading hours of 8 hours a day, it was found effective.

b) Does PFCMD reduce the demand load consumption of the facility?

The model clearly demonstrated the reduction of power consumption characteristics by reducing demand load almost the same as real power, and as a result the load current, phase angle, and the electricity bill eventually decreased.

c) How efficient are energy demand response strategy?

The model efficiency response have achieved a demand power reduction percentage of 14% as a power factor improved from 85% to 99% efficiency. And also 24% as the PF efficiency improve from 75% to 99%. It demonstrated that improved PF reduce demand power and electricity bill.

7. Chapter Seven: Conclusion and Recommendation

This research was carried out in order to find the best available DSM techniques to reduce the high demand load consumption caused by insufficient use of energy within the SFAC facility. The strategy target was to apply the model on the total facility consumption load instead of specific areas only in order to achieve the full benefit. In addition to this, the total energy costs were analysed and determined among available tariff rates and the most cost-effective was considered. The systematic control and monitoring of the facility's demand load consumption interfaced between power factor correction and energy tariff rates were analysed.

In conclusion, the research work explored the modelling of a practical interface between the facility's load consumption, power factor correction, and as well as tariff rate structures. The PFCMD model simulator was developed and executed within the Microsoft Excel environment. The model simulator was tested and analysed on various load capacity operating conditions of the facility together with tariff rates. The work presented focused on the integration of DSM techniques such as power factor correction program and tariff rates to the facility's electrical infrastructure in order to sharply reduce the total facility demand load consumption.

The aim was to maintain the monitoring of facility power parameters as various consumptive systems are introduced to keep real power (kWh) and apparent power (KVAh) values close to each other in order to maintain a power factor of unity(1). To achieve this aim, equilibrium between kWh and KVAh was found to be essential for the functionality of efficient use of energy and very effective for the reduction of demand load consumption, by ensuring that required KVAR were continuously produced by the PFC system throughout the facility's consumption.

Additional conservative energy methods like retrofitting of lighting systems and air-conditioners seemed to be essential characteristics of baseline reduction and demand load.

- LED lights Retrofit for the offices and conference rooms has a permanent benefit to lower consumption rate to end-user.
- Collective control of air-conditioners and fresh air supply fans per office has an essential functionality to define the appropriate operating periods according to

site specific trading hours in order to save on energy usage as well as costs thereof.

The research work found that power factor correction together with correct tariff rates and retrofitting LED lights to the facility has the potential to save a significant amount of energy which translates to saving on costs. Another finding was that the implementation of the PFC system has a huge benefit to the consumer, and it has the ability to pay itself back.

Recommendations

There is an area of improvements in the SFAC facility's electrical infrastructure network and coordination among other generating systems.

- Radio control device

SFAC facility could improve the efficiency of stand-by generators and CCT supply interchange during load shedding period by eliminating deep occurrence. Site 600KVA generator starts 15 seconds after the main collapse and as a result deep occur and causes systems disturbance which eventually switch–off the processes. The radio control device installation between the generator and CCT electricity supply could improve the situation by sending direct energy information to the facility generator well ahead of time. For example, if load shedding is to occur at 9:00am today, then at 8:50am the facility generator will start and perform automatic changeover before load shedding occurs. This change will help the facility to lower consumption, supply disruption and prevent any load shedding to occur during changeover of generator-CCT supply.

8. References

[1]. Longe, M., Ouahada, K., Ferreira H., and Rimer, S. (2017). Consumer preference electricity usage plan for demand side management in the smart grid. 108(December), pp. 174–184.

[2]. Holdings, E., 2017. An overview of electricity consumption and pricing in South Africa An analysis of the historical trends and policies , key issues and outlook in 2017. , (February).

[3]. Longe, O., Oluwajobi, F.I. & Omowole, F., 2013. Electricity access in Sub-Saharan Africa - Case for renewable energy sources Microgrid. 2nd International Conference on Emerging and Sustainable Technologies for Power and ICT in a Developing Society, IEEE NIGERCON 2013 - Proceedings, pp.253–257.

[4]. Herbst, L. & Lalk, J., 2016. A review of the policy documents behind South Africa's Renewable Energy Independent Power Producer Procurement Programme: How its hits and misses impact society. International Symposium on Technology and Society, Proceedings, 2016–March, pp.1–6.

[5]. Majani C., 2011. Development of an active load shifting technique for demand side management applications. Master's degree in Technology in electrical engineering in the faculty of engineering at CPUT.

[6]. FoueJio-Tsobze, B. (2010). Energy management in the South African hotel industry. Master of technology electrical engineering (thesis), Cape Peninsula University of technology. CPUT copyright information.

[7]. Majumdar, S., Mandal, K., Chakrabort, N., 2013. Optimal Sizing of a Photovoltaic System for Peak Power Shaving Application. 2013 International Conference on Circuits, Power and Computing Technologies [ICCPCT-2013], pp350-355

[8]. Cousins, J.T., 2009. Using time of use (TOU) tariffs in industrial, commercial and residential applications effectively. TLC Engineering Solutions. Available at: http://www.tlc.co.za/white_papers/pdf/using_time_of_use_tariffs_in_industrial_commercial_and_residential_applications_effectively.pdf.

[9]. Keshtkar, A., Member, S. & Arzanpour, S., 2014. A Fuzzy Logic System for Demand-Side Load Management in Residential Buildings. , pp.1–5.

[10]. Satish Saini, 2004. Demand-side Management (module 15). Sustainable energy, regulation and policymaking for Africa. www.unido.org/fileadmin/media/documents/pdf/Module15.pdf

[11]. Wang, S., Xue, X. & Yan, C., 2014. Building power demand response methods toward smart grid. HVAC&R Research, 20(6), pp.665–687. Available at:http://www.tandfonline.com/doi/abs/10.1080/10789669.2014.929887.

[12]. Aksanli, B., Rosing, T. & Pettis, E., 2013, Distributed Battery Control for Peak Power Shaving in Datacenters.

[13]. Qi, R., Lu, L. & Yang, H., 2012. Investigation on air-conditioning load profile and energy consumption of desiccant cooling system for commercial buildings in Hong Kong. Energy & Buildings, 49(June 2012), pp.509–518. Available at: http://dx.doi.org/10.1016/j.enbuild.201

[14]. Zhou Y., Yi Y., Cui G., Jin P., Guo X., Yang C., 2016. Demand Response Control Strategy of Groups of Central Air-Conditionings for Power Grid Energy Saving. IEEE International Conference on Power and Renewable Energy (2016), pp.323–327.

[15]. Bhattacharyya D., Mukherjee, P., Ray, A. & Sengupta, S., 2004. Arsenic-polluted groundwater in West Bengal : A cost-effective remedy. , 86(9), pp.0–3.

[16]. Nghiem, X., Behl M., Mangharam, R. & Pappas, J., 2011. Green scheduling of control systems for peak demand reduction. IEEE Conference on Decision and Control and European Control Conference, pp.5131–5136. Available at: http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=6161164.

[17]. Riaz, H., Zeeshan, M., Hasan-ul-Banna, Kamal, T., Shah, S., 2017. Demand Side Management Using Different Energy Conservation Techniques, pp.17–20.

[18]. Andruszkiewicz, J., Lorenc, J., Borowiak, W & Michalski, A., 2015. Time of use tariff design for domestic customers integrating the management goals of efficient energy purchase and delivery, pp. 1–5.

[19]. Muhammad Saad, 2016. Research & Reviews: Journal of Engineering and Technology Methods of Demand Site Management and Demand Response. , 5(3), pp. 63–68.

[20]. Department of Energy, 2016. Post-2015 National Energy Efficiency Strategy. Department of energy, 428 No. 40515. Government Gazette, 23 Decemberv 2016.

[21]. Javaid, N. & Ahmed, A., 2018. Day Ahead Real Time Pricing and Critical Peak Pricing Based Power Scheduling for Smart Homes with Different Duty Cycles.

[22]. Dong, Y. & Zou, B., 2015. A Research of Real-Time Pricing Mechanism and Its Characteristics. , (April), pp. 240–249.

[23]. Doostizadeh, M. and Ghasemi, H. (2012). A Day-Ahead Electricity Pricing Model Based on Smart Metering and Demand-Side Management. Energy, **46**, 221-230. http://dx.doi.org/10.1016/j.energy.2012.08.029.

[24]. Rao, N.D., Agarwal, A. & Wood, D., 2015. SMALL-SCALE ELECTRICITY SYSTEMS. A Study of Rural Communities in India and Nepal. WWW.iiasa.ac.at.

[25]. Ethiopia Energy Situation, 2017. https://energypedia.info/wiki/Ethiopia_Energy_Situation.

[26]. Hunt Allcott, 2011. Rethinking real-time electricity pricing. Department of Economics, New York University, 19 W. 4th St., 6th Floor, New York, NY 10012, United States, Available online 23 June 2011. https://doi.org/10.1016/j.reseneeco.2011.06.003

[27]. Faruqui, A., Sergici, S. & Palmer, J., 2010. The Impact of Dynamic Pricing on Low Income Customers, s.l.: Edison Foundation Available at: http://www.edisonfoundation.net/IEE/Documents/IEE_LowIncomeDynamicPricing_0910.pdf.

[28]. Mohsenian-Rad, A. & Leon-Garica, A., 2010. Optimal Residential Load Control With Price Prediction in Real-Time Electricity Pricing Environments. IEEE Transactions on Smart Grid Available at: http://ieeexplore.ieee.org/document/5540263/, 1(2), pp. 120-133.

[29]. Kiani B. & Annaswamy, A., 2014. A dynamic mechanism for wholesale energy market: stability and robustness. IEEE Trans. Smart Grid, 2014, 5, (6), pp. 2877–2888

[30]. Mathieu, J.L., Kamgarpour, M., Lygeros, J., Andersson, G., & Callaway, D.S. (2015). Arbitraging intraday wholesale energy market prices with aggregations of thermostatic loads. *IEEE Transactions on Power Systems, 30*, 763-772.

[31]. Reddy K. , Panwar L., Panigrahi B, Kumar R., & Yu H., 2017. Demand side management with consumer clusters in cyber-physical smart distribution system considering price-based and reward- based scheduling programs. 2, pp. 75–83.

[32]. Stenner K., Frederiks R., Hobman V., Cook S., 2017. Willingness to participate in direct load control : The role of consumer distrust. Applied Energy, 189, pp. 76–88. Available at: http://dx.doi.org/10.1016/j.apenergy.2016.10.099.

[33]. Cappers, P., Goldman, C., Kathan, D., 2010. Demand response in U.S. electricity markets: Empirical evidence. Available online: April 2010 35: 1526-35

[34]. FERC. 2012. Assessment of Demand Response and Advanced Metering. Staff Report. Washington, DC: Federal Energy Regulatory Commission; 2012.Available online: <http://www.ferc.gov/legal/staff-reports/12-20-12-demand-response.pdf

[35]. MUTONDO PAUL MATENDA, 2014. Development of an energy model in system modelling language for future automated residential building applications. Master of Technology: Electrical Engineering in the Faculty of Engineering at the Cape Peninsula University of Technology.

[36]. Braga, M., Mota, J., Theodoro, T., Oliveira, Y., Junior, C., & Braga, H., 2014. 60W incandescent lamp alternatives found in Brazilian market. 2014 11th IEEE/IAS International Conference on Industry Applications, 1-8.

[37]. Dmitrijs B., 2017. Implementing Energy Efficiency and demand-side management in Glasswork Company. Institute of power engineering. Riga Technical Unversity. 978-1-5386-3846-0.

[38]. Mandal, R., Basu K., Kar A., & Chowdhury, P., 1994. A microcomputer-based power factor controller. IEEE Transactions on Industrial Electronics, 41(3):361–371, 1994.

[39]. Khalid, W., Shah A., Mehfooz, Q., Irshad, N., & Mahood, W., 2015. Reduction in Building Energy Requirements by Modern Energy

Conservation Techniques. 2015 Power Generation System and Renewable Energy Technologies (PGSRET), pp.1–5.

[40]. Sen, P. & Lee, K., 2016. Conservation Voltage Reduction Technique : An Application Guideline for Smarter Grid. IEEE Transactions on Industry Applications, 52(3), pp.2122–2128.

[41]. Kampezidou, S. & Wiegman, H., 2017. Energy and Power Savings Assessment in Buildings via Conservation Voltage Reduction. 978-1-5386-2890-41/17. 2017 IEEE.

[42]. ESKOM, 2019. SCHEDULE OF STANDARD PRICES FOR ESKOM TARIFFS 1 APRIL 2019 TO 31 MARCH 2020 FOR NON-LOCAL AUTHORITY SUPPLIES, AND 1 JULY 2019 TO 30 JUNE 2020 FOR LOCAL AUTHORITY SUPPLIES. , 207(April 2019), pp.1–52.

[43]. Malinowski, J. & Kaderly, K., 2004. Peak Shaving - A Method to Reduce Utility Costs. , pp.1–6.

[44]. Insight, R., Tracey, B. & Wallach, J., 2003. Peak-Shaving / Demand Response Analysis.

[45]. Shi, Y., Xu, B., Wang, D., & Zhang, B., 2017. Using Battery Storage for Peak Shaving and Frequency Regulation : Joint Optimization for Superlinear Gains. , pp.1–10.

[46]. Lupsa-Tataru, L., 2009. Comparative simulation study on synchronous generators sudden short circuits. Publication: Modelling and Simulation in Engineering January 2009 Article No.: 8 https://doi.org/10.1155/2009/867150.

[47]. Chua, K., Lim, S., Chew X., 2017. Economic Assessment of Standby Diesel Generator for Peak Reduction in Commercial and Industrial (Malaysia Case-study). Manuscript received May. 09, 2017; revised October. 18, 2017.

[48]. Motiang, M. & Nembahe, R., (2017). Energy price Report. Energy data collection, management and analysis. Published by Department of energy of South Africa. publications@energy.gov.za.

[49]. International Energy Agency, (2018). CO2 emissions from fuel combustion statistics. IEA Publications: International Energy Agency Website: www.iea.org. Contact information: www.iea.org/aboutus/contactus Typeset by the IEA, October 2017.

[50]. Hammons, T., Blyden, K., Calitz, C., Gulstone, B., Isekemanga, E., Johnstone, R., Paluku, K., Simang, N. & Taher, F., 2000. African electricity infrastructure interconnections and electricity exchanges. IEEE Transactions on Energy Conversion, 15(4), pp.470–480.

[51]. Heidary, A., Radmanesh, H. & Ghorbanyan, K., 2016. Bank current. 2016 21st Conference on Electrical Power Distribution Networks Conference (EPDC), (May), pp.98–101.

[52]. Ma, K. & Wang, X., 2015. HyStore : Hybrid Energy Storage for Cost-efficient Server Power Shaving in Data Centers.

[53]. Buchana, P. & Ustun, T.S., 2015. The Role of Microgrids & Renewable Energy in Addressing sub-Saharan Africa's Current and Future Energy Needs. IEEE Renewable Energy Congress, pp.1–6.

[54]. Temaneh-nyah, C. & Mukwekwe, L., 2015. An Investigation on the Effect of Operating Temperature on Power Output of the Photovoltaic System at University of Namibia Faculty of Engineering and I . T Campus. , pp.22–29.

[55]. Department of Energy, 2011. Integrated Resource Plan for Electricity 2010-2030., (March), p.78. Available at: http://www.energy.gov.za/IRP/irp files/IRP2010_2030_Final_Report_20110325.pdf.

[56]. Rosenqvist, A., Shimada, M., Igarashi, T., Watanabe, M., Tadono, T., Yamamoto, H., 2003 "Support to multi-national environmental conventions and terrestrial carbon cycle science by ALOS and ADEOS-II -the Kyoto & carbon initiative", Geoscience and Remote Sensing Symposium 2003. IGARSS '03. Proceedings. 2003 IEEE International, vol. 3, pp. 1471-1476, 2003.

[57]. Ilupeju, S., Inambao, F., Mutombo, N., Nalubega, T. & Ustun, T., 2015. Sustainable energy generation from pumped hydropower, International Conference on the Domestic Use of Energy (DUE), Cape Town, 2015, pp. 177-185.

[58]. Shuma, R., Madyira, D., Makonese, T. & Oosthuizen, G., 2015. Energy content and combustion behaviour of loose biomass available in Limpopo. 2015 International Conference on the Domestic Use of Energy (DUE), Cape Town, 2015, pp. 93-100.

[59]. Kabir, Y., Mohsin, Y., & Khan, M., 2017**.** Automated Power Factor Correction and Energy Monitoring System.

[60]. Turchi, J., Dalal, D., Wang, p. & Jenck, L., 2014. Power factor correction (PFC) handbook. Choosing the right power factor controller solution. HBD853/D Rev.5, Apr-2014. www.onsemi.com.

[61]. Jadhav, P., 2016. Reduce harmonics using PI controller in d-q reference frame for active power filter. 2016 International Conference on Global Trends in Signal Processing, Information Computing and Communication (ICGTSPICC), pp. 653–656.

[62]. Agwa-Ejon, J., Mulaba-Bafubiandi, A. & Pretorius, J., 2016. A comprehensive overview and promotion of bioenergy systems for social development in South Africa. Portland International Conference on Management of Engineering and Technology (PICMET)2016, Honolulu, HI, pp. 1838-1846.

[63]. Kheshti, M. & Kang, X., 2015. Geothermal Energy, a key point in Energy and Development in China, pp. 3–6.

[64]. Herbst, L. & Lalk, J., 2016. A review of the policy documents behind South Africa’s Renewable Energy Independent Power Producer Procurement Programme: How its hits and misses impact society. International Symposium on Technology and Society, Proceedings, 2016–March, pp.1–6.

[65]. Longe, O., Oluwajobi, F. & Omowole, F., 2013. Electricity access in Sub-Saharan Africa - Case for renewable energy sources microgrid. 2nd International Conference on Emerging and Sustainable Technologies for Power and ICT in a Developing Society, IEEE NIGERCON 2013 - Proceedings, pp. 253–257

[66]. Zoll, K., 2010. A wealth of possibilities. Textile Network, (9–10), pp.19–20.

[67]. Milad, M. & Darwish, M., 2014. UPS System. How can future technology and topology improve the energy efficiency in Data centres? Department of Electrical Engineering and Electronics. 2014 49th International Universities Power Engineering Conference (UPEC), pp.1–4. 978-1-4799-6557-1/14.

[68]. Dhameliya, R., Domadiya K., Miyani P., Savaliya H., Jariwala P., 2017. Automatic power factor control using Arduino. International Journal of Advance Engineering and Research. Volume 4, Issue 4, April-2017, pp.270–276.

[69]. Services, M. & Electric, S., 2013. Optimal Sizing of a Photovoltaic System for Peak Power Shaving Application. pp.350–355.

[70]. Oliveira, R., Ferreira, L. & Ribeiro, E., 2017. MODELING AND SIMULATION OF CONTROLLABLE AC SERIES RESISTIVE LOAD.

[71]. Jianguo Z., Qiuye S., Huaguang Z. & Yan Z., 2012. Load Balancing and Reactive Power Compensation based on Capacitor Banks Shunt Compensation in Low Voltage Distribution Networks. Proceedings of the 31st Chinese Control Conference, (20090461187), pp.6681–6686.

[72]. Barai, G., Krishnan, S. & Venkatesh, B., 2015. Smart Metering and Functionalities of Smart Meters in Smart Grid. 2015 IEEE Electrical Power and Energy Conference (EPEC), pp.138–145.

[73]. Khan, I., Huang, Z., Masud, M., & Jiang, Q., 2016. Segmentation of Factories on Electricity Consumption Behaviours Using Load Profile Data., 4.

[74]. Saidur, R., Rahim, N., Islam, M. & Solangi, K., 2011. Environmental impact of wind energy. Renewable and Sustainable Energy Reviews, 15(5), pp.2423–2430. Available at: http://dx.doi.org/10.1016/j.rser.2011.02.024.

[75]. Masden A., Reeve, R., Desholm, M., Fox, D., Furness, W. & Haydon, T., 2012. Assessing the impact of marine wind farms on birds through movement modelling. , (May), pp.2120–2130.

[76]. Stephens, R., Smith, B. & Mahanti, A., 2015. Game Theoretic Model Predictive Control for Distributed Energy Demand-Side Management. , 6(3), pp.1394–1402.

[77]. Chuan, L., Rao, K. & Ukil A., 2014. Load profiling of Singapore buildings for peak shaving. Asia-Pacific Power and Energy Engineering Conference, APPEEC, 2015–March.

[78]. Garcia, F., Marafao, F., Souza, W. & Silva, L., 2017. Power Metering: History and Future Trends. , pp.26–33.

[79]. Patel, N. & Somani B., 2017. A Review on Implementation of MODBUS Communication Protocol and its Applications. International Journal of Electronics Engineering Research. ISSN 0975-6450 Volume 9, Number 4 (2017) pp. 621-629

[80]. Karimeh, A., Karami N., El-Sheikh, H., 2016. A Modified Adaptive Power Factor Correction Technique. 2016 IEEE International Multidisciplinary Conference on Engineering Technology (IMCET).

[81]. Lloret, J., Tomas J., Canovas ,A. & Lorena Parra, L.,2016. An Integrated IoT Architecture for Smart Metering. (December). https://www.researchgate.net/publication/312435094

[82]. Anon, 2009. PowerLogic System.

[83]. Modbus.org, 2012. Anon, MODBUS over Serial Line Specification & Implementation guide. , pp.1–44. http://www.modbus.org/

[84]. Sa, T., 2014. Power factor correction : a guide for the plant engineer. , (August). Technical Data SA02607001E, EATON.

Appendices

This section indicates the available equipment and system technologies to be utilised for energy efficient operation. It also cover the design improvements that can be employed for existing technology for efficient operation. This appendices are as follows.

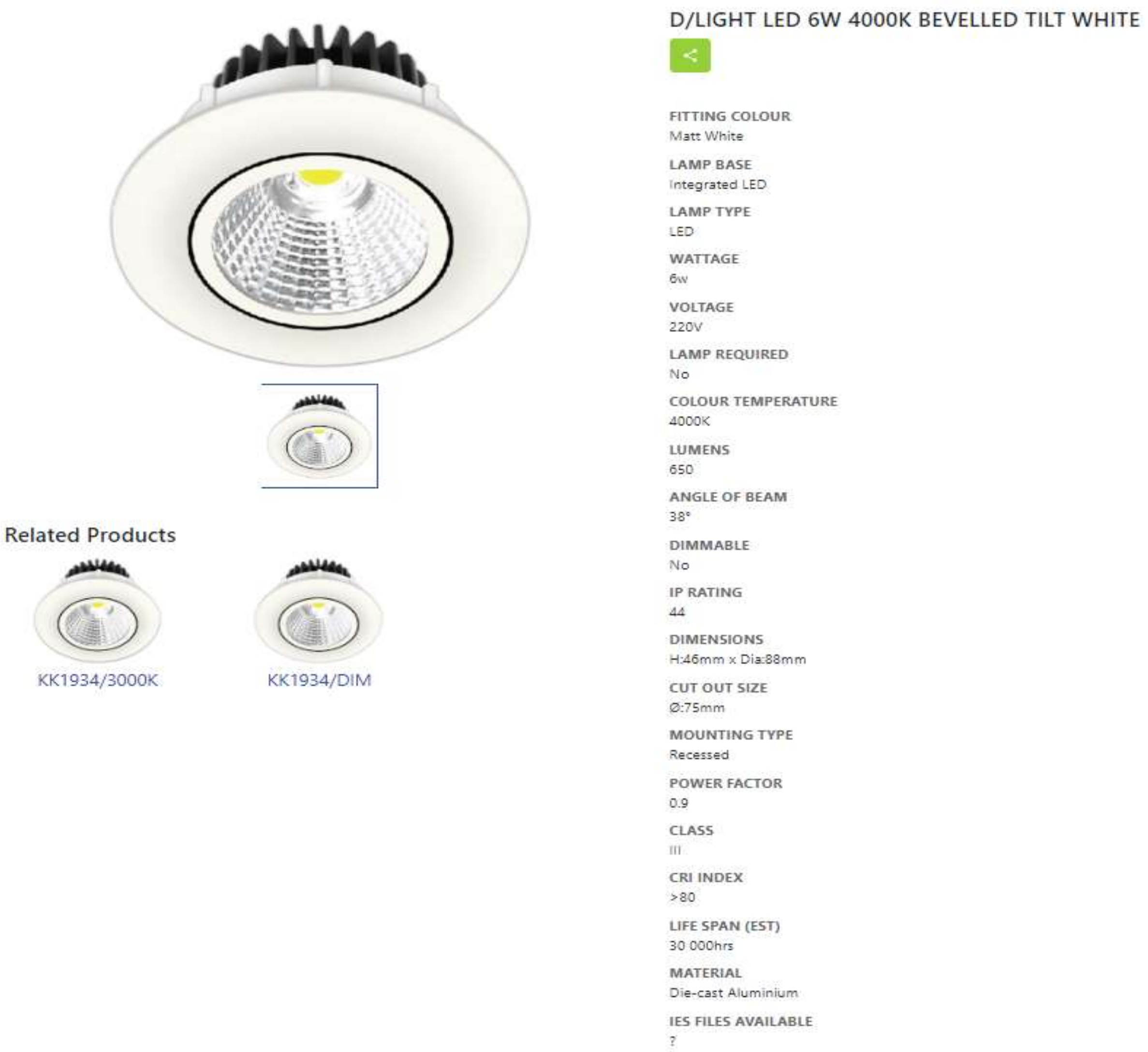
Appendix A

Lighting retrofit: LED downLighting

SFAC lighting have to employ LED downlight for most office and conferences in order to cut down on lighting consumption of electricity. This project can just be retrofit with low participation in changing electrical infrastructure.

LED DOWNLIGHT

KK1934
1x 6W LED
Warm White
Bevelled Edge
IP44
3000K
Height: 63mm
Diameter: 88mm
Cut-out: 75mm
Colour: White
Tilt: 30 degree



D/LIGHT LED 6W 4000K BEVELLED TILT WHITE

FITTING COLOUR
Matt White

LAMP BASE
Integrated LED

LAMP TYPE
LED

WATTAGE
6w

VOLTAGE
220V

LAMP REQUIRED
No

COLOUR TEMPERATURE
4000K

LUMENS
650

ANGLE OF BEAM
38°

DIMMABLE
No

IP RATING
44

DIMENSIONS
H:46mm x Dia:88mm

CUT OUT SIZE
Ø:75mm

MOUNTING TYPE
Recessed

POWER FACTOR
0.9

CLASS
III

CRI INDEX
>80

LIFE SPAN (EST)
30 000hrs

MATERIAL
Die-cast Aluminium

IES FILES AVAILABLE
?

Related Products

KK1934/3000K

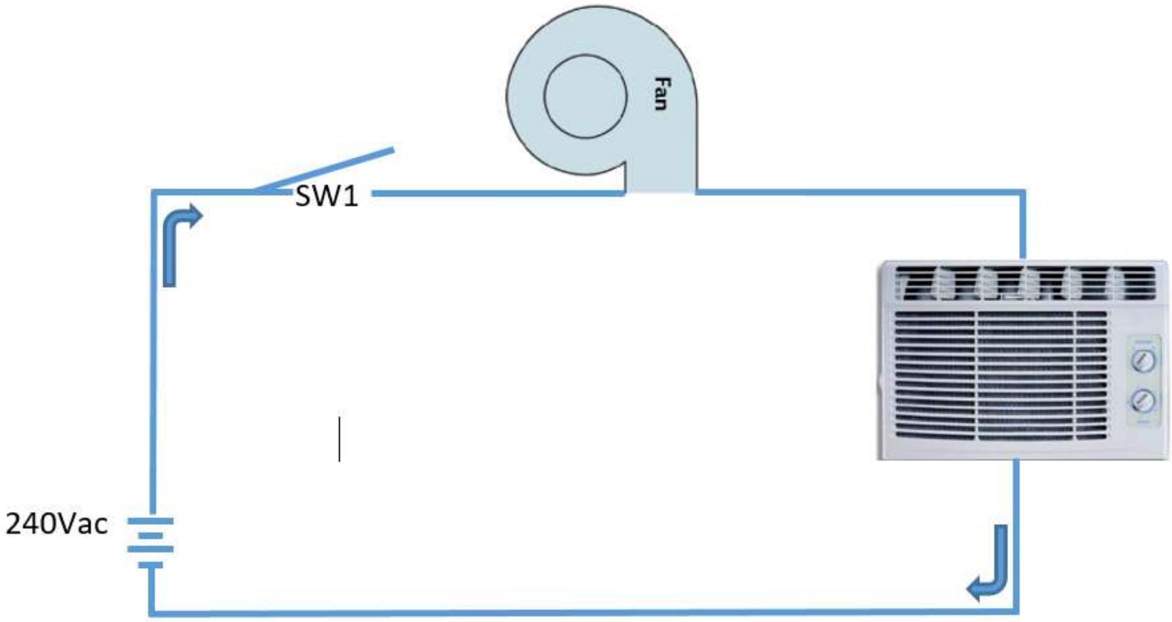
KK1934/DIM

Source: Eagle lighting, 2019. Domestic catalogue. Downlight LED. Page 21. https://www.eaglelighting.co.za/

Appendix B

Series Connection of fresh air supply fan and Air-conditioning

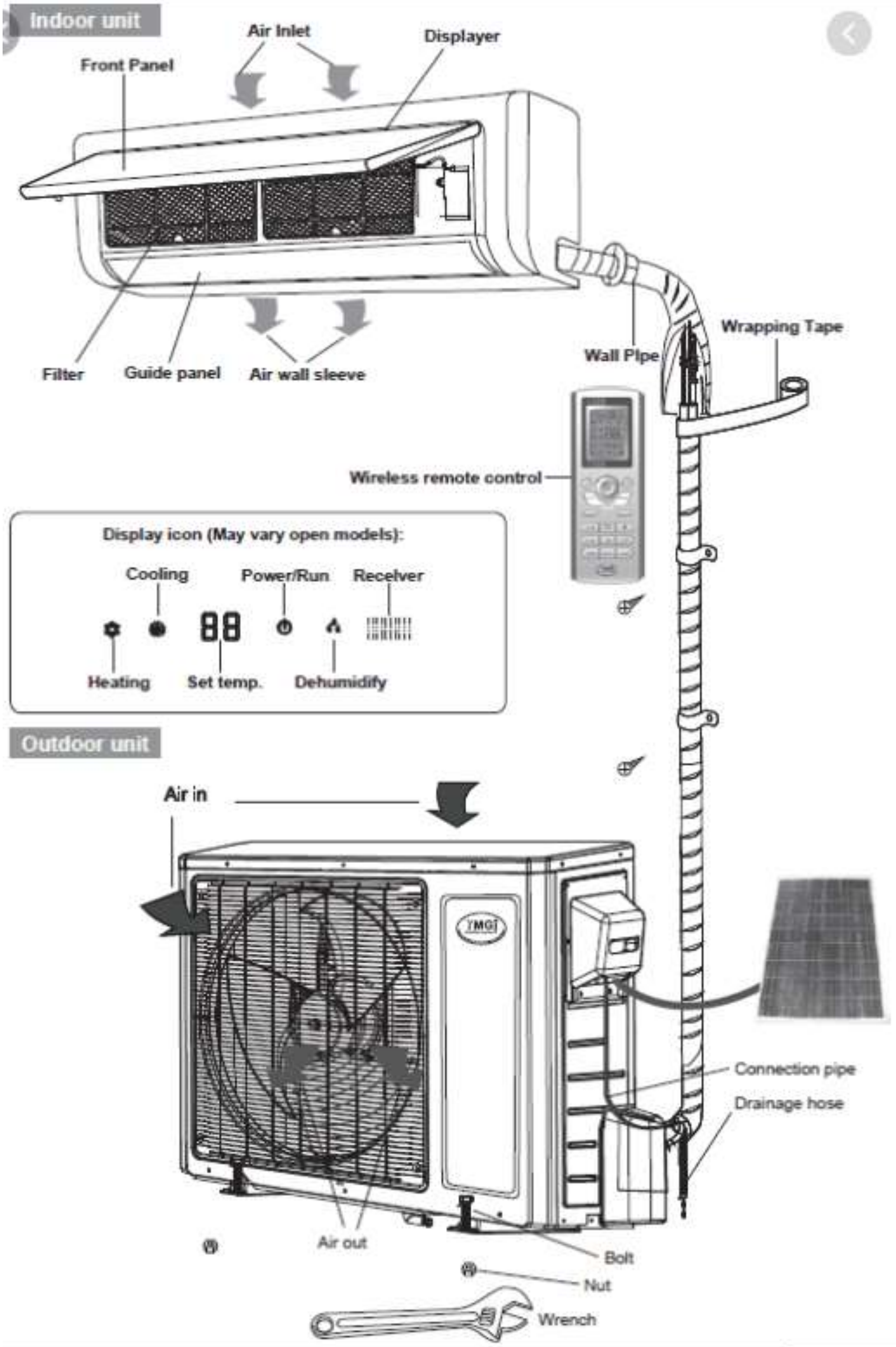
The current system Fresh air supply fan runs 24hours in regardless of office occupancy. However, Air-conditioning is controlled by occupancy and due to inconsistence air-conditioning could run 24 hours or oven throughout weekend and long holidays unattended. This can have negative impact to the total electricity consumption and increase the bill. The diagram indicates the proposed electrical configuration for the efficient use of energy for offices fresh air fans and air-conditioners per room.



The SW1 is presented as an electronic control panel switch for air-conditioners, which power supply is powered both units in series. When SW1 is on, both units will run at the same time and versa vice.

Note: Smart Air-conditioning can also be programmed to run during trading hours only. And as it start it send signal to supply fan to start. This will do the same as it switches off.

Appendix C



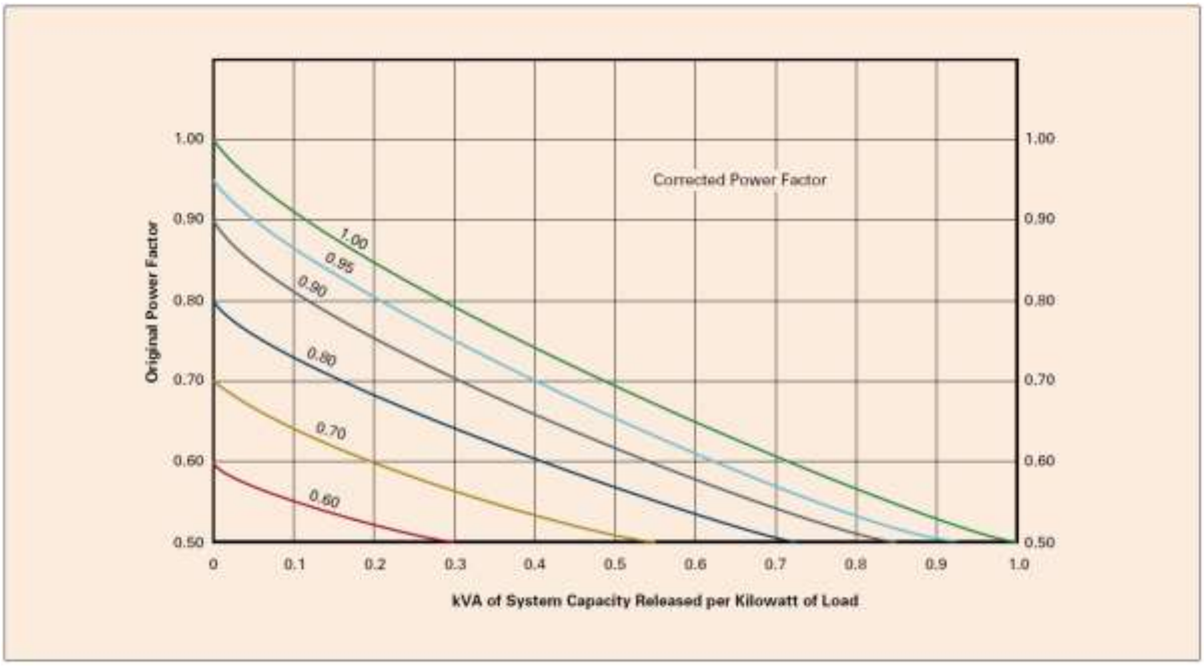
Source: DAIKIN ROOM AIR CONDITIONER OPERATION MANUAL

Appendix D

Advantage of having improved power factor to the system.

Including power capacitors in your new construction and expansion plans can reduce the size of transformers, bus, switches, and the like, and bring your project in at lower cost.

The figure below shows how much system kVA can be released by improving the power factor. Raising the power factor from 70% to 90% releases 0.32 kVA per kW. On a 400 kW load, 128 kVA is released.



Source: Sa, T.D., 2014. Power factor correction: a guide for the plant engineer. (August).