ADAPTIVE SCHEME FOR IMPROVEMENT OF LOAD FACTOR OF WATER HEATER LOADS IN RESIDENTIAL BUILDINGS

by

PHILLEMON NONYANE

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Supervisor: Prof. A. A. Yusuff

Co-Supervisor: Prof. M. Sumbwanyambe

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DECLARATION

Name: Phillemon Nonyane

Student number: 41471180

Degree: M-Tech Electrical Engineering

I, the undersigned, declare that this dissertation entitled:

"ADAPTIVE SCHEME FOR IMPROVEMENT OF LOAD FACTOR OF WATER HEATER LOADS IN RESIDENTIAL BUILDINGS"

is my own work and that all the sources that I have used or quoted have been indicated and acknowledged by means of complete references.

I further declare that I submitted the dissertation to originality checking software and that it falls within the accepted requirements for originality.

I further declare that I have not previously submitted this work, or part of it, for examination at Unisa for another qualification or at any other higher education institution.

____________________ __________________

P. Nonyane Date

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ABSTRACT

The South African power utility, Eskom, and, in turn, the metropolitan and local municipalities, have difficulty meeting the country's growing demand for electricity. In this study, electric water heaters have been identified as the appliances consuming the most energy in residential buildings.

There are periods when the demand for electricity is very high across the power system, specifically in the mornings and evenings during winter from May to August, when consumers' need for electricity, for lighting, cooking, and heating water, peaks. Methods are constantly being sought to assist Eskom and municipalities with network constraints and overloading during periods of high demand, as well as to assist consumers in reducing their electricity costs. Overloading the power system can result in power outages and blackouts and damage to equipment. These challenges can be prevented by introducing load management systems, also known as Demand Side Management, to balance the supply of electricity on the network. This is a method of controlling the load to meet the demand, thereby reducing peak loads, and maintaining and protecting power system stability. Constant upgrading of power plants and primary and secondary substations is needed to meet the growing peak demand, but, alongside this, measures to save electricity must constantly be explored.

This dissertation examines ripple control as a load management tool to shift the energy demand of electric water heaters in residential buildings from periods of high demand for electricity to off-peak periods. Ripple control enables the power utility to switch off the electric water heaters of a group of consumers simultaneously, to prevent high demand during peak hours overloading the power system. This could assist municipalities with network constraints and provide considerable savings to the consumer. This method has been successfully used throughout South Africa by Eskom and municipalities.

A dynamic of control load model of ripple controller was used in this research, to obtain real-time load measurements on the consumption pattern of electric water heaters. The Rietvlei substation is supplied with 400 kV from Eskom transmission lines and stepped down to 132 kV. Data to measure the load was collected from the City of Tshwane Municipality's Eskom meter connected inside the Rietvlei substation. The ripple control telegram was injected into the medium voltage busbars in the substation and propagated down to the low voltage networks throughout the distribution area, where receivers picked up the signal and switched loads or tariffs, as indicated in the study conducted. The results confirmed the effectiveness of the ripple controller for load shifting and load factor improvement during high peak demand.

A capacity test indicated that Centurion has 8 000 receivers to operate. Based on 8 000 receivers, the annual saving on the municipality's Eskom account is over R 11 592 000 per year at today's tariff. This provides evidence that the application of such a system is essential. The prime objective of a Load Control scheme is to do energy shifting and avoid demand peaks.

Key words: Electric Water Heater, Ripple Control, Substation, Time of Use, Power factor, Demand Side Management, Load Shifting, Residential building.

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LIST OF ACRONYMS AND ABBREVIATIONS

ABC	Arial Bundle Conductor
ANFIS	Adaptive Neuro Fuzzy Inference System
AS	Adaptive System
CC	Conventional Controllers
CB	Circuit Breaker
CLPU	Cold Load Pick-up
DB	Distribution Boar
DC	Direct Control
DSM	Demand Side Management
DN	Distribution Network
ES	Energy Shifting
ESKOM	Electricity Supply Commission
EWH	Electric Water Heater
HWLC	Hot Water Load Control
HV	High Voltage
Hz	Hertz
ILC	Indirect Load Control
kV	Kilovolts
kWh	Kilo Watt-hour
LC	Load control
LF	Load Factor
LM	Load Management
LMA	Local Municipality Authorities
LMSE	Load Management System Energy
LPU	Large Power User

LR	Load Reduction
LS	Load Shedding/Shifting
LV	Low Voltage
MD	Maximum Demand
MLC	Maximum Load Current
MPC	Micro Single Controller
MSC	Modulator System Control
MV	Medium Voltage
MW	Megawatt
MWh	Megawatt hours
NERC	Neutral Earthing Compensator Resistor
NERSA	National Energy Regulator of South Africa
NMD	Notified Maximum Demand
OF	Overload Fault
POD	Power on demand
PU	Power utilities
QoS	Quality of Supply
RC	Ripple Control
SCADA	Supervisory Control and Data Acquisition
SG	Smart Grid
SWH	Solar Water Heater
SPU	Small Power User
TOU	Time of Use
TRFN	Takagi-Sugeno-Kang (TSK)-type Recurrent Fuzzy Network
VSD	Variable Speed Drive

CHAPTER 1: INTRODUCTION

1.1 INTRODUCTION

South African consumers depend on electricity generated by the power utility, Eskom, and by municipalities. Utilities have an obligation to maintain a constant supply of electricity to all consumers, both small power users (SPUs), such as domestic consumers, and large power users (LPUs) such as the mining sector and municipalities. Shifting the load required by household electric water heaters (EWHs) is one of the possible methods of ensuring that load demand is not more than supply, so that consumers have a reliable and sustainable supply of electricity [1], and the network infrastructure not overloaded.

Residential consumers use electric water heaters which, when switched on, contribute significantly to the consumption of, and demand for, electricity and constraints on the power network generation capacity. Most domestic electricity usage occurs during two daily peak periods in the mornings and evenings [2].

This coincident usage affects the overhead transformers, the Aerial Bundle Conductors (ABCs) and the 16 mm^2 x 4 3-phase cables from the pole box to the distribution boxes on the overhead network. It also affects the mini substations, 70 mm^2 / 90 mm^2 cables and 16 mm^2 x 4 3-phase cables from the kiosk.

1.2 BACKGROUND

Electric water heaters (EWHs) generate hot water used for various household purposes such as bathing, cooking, and washing dishes. Alternative methods of generating hot water could be an electric kettle, electric or gas stove, wood fire, paraffin, or coal. However, some of these methods may have serious side-effects on health, causing asthma, cancer, heart and lung diseases, as well as contributing to global warming.

A significant portion (30% - 50%) of a household's electric bill can be attributed to the use of EWHs. The consumption pattern of EWHs especially poses a challenge when a substantial number of EWHs are being used at the same time, creating an overload on the distribution network.

To alleviate the impact of coincident usage of electric water heaters on the distribution network and on overload, the government and utility companies have attempted to introduce solar water heating (SWH) systems. However, it has been reported that solar water heaters may not necessarily reduce overload in a distribution network, because their usage pattern is complex, involving factors such as occupancy behaviour, time of use, and environmental (seasonal) and social influences [3].

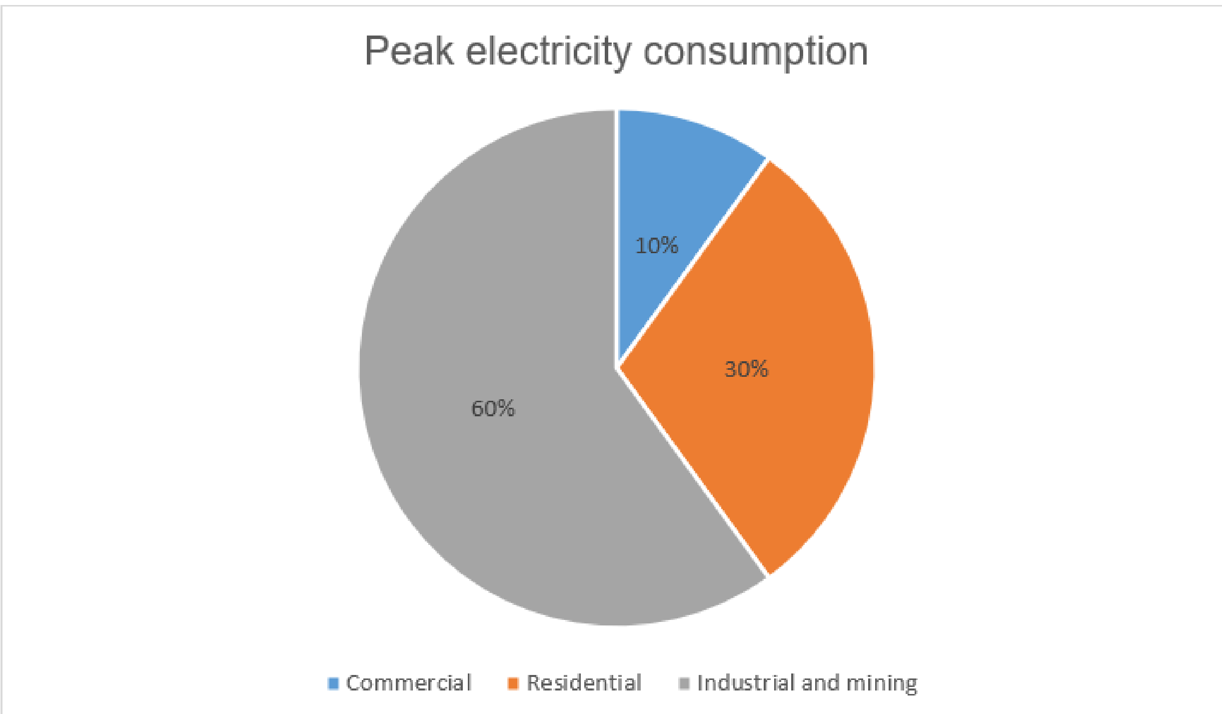

Figure 1.1: Peak electricity consumption per sector

Source: Researcher's own compilation

The energy usage in South Africa is divided into three sectors: the commercial sector, the residential sector, and the industrial and mining sector, with each of the sectors exhibiting different consumption patterns. As shown in Figure 1.1, residential consumers contribute about 30% to the total energy consumption during peak periods.

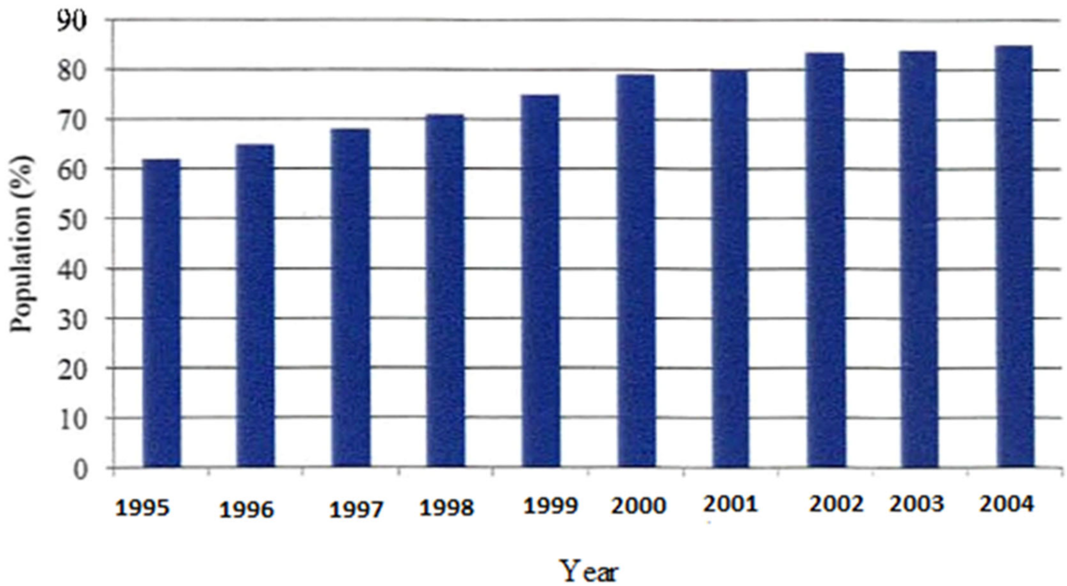

Figure 1.2: South Africa - Access to Electricity

Source: Eskom

Many factors have contributed to the drastic rise in the demand for electricity in South Africa over the years. There have been huge economic and technological developments, the population has grown and the number of people needing housing and access to electricity to improve their quality of life has increased dramatically.

In 1995, 61% of the population had access to electricity. By 2004 it had increased to 84% as indicated in Figure 1.2, an increase in the power demand of about 50%.

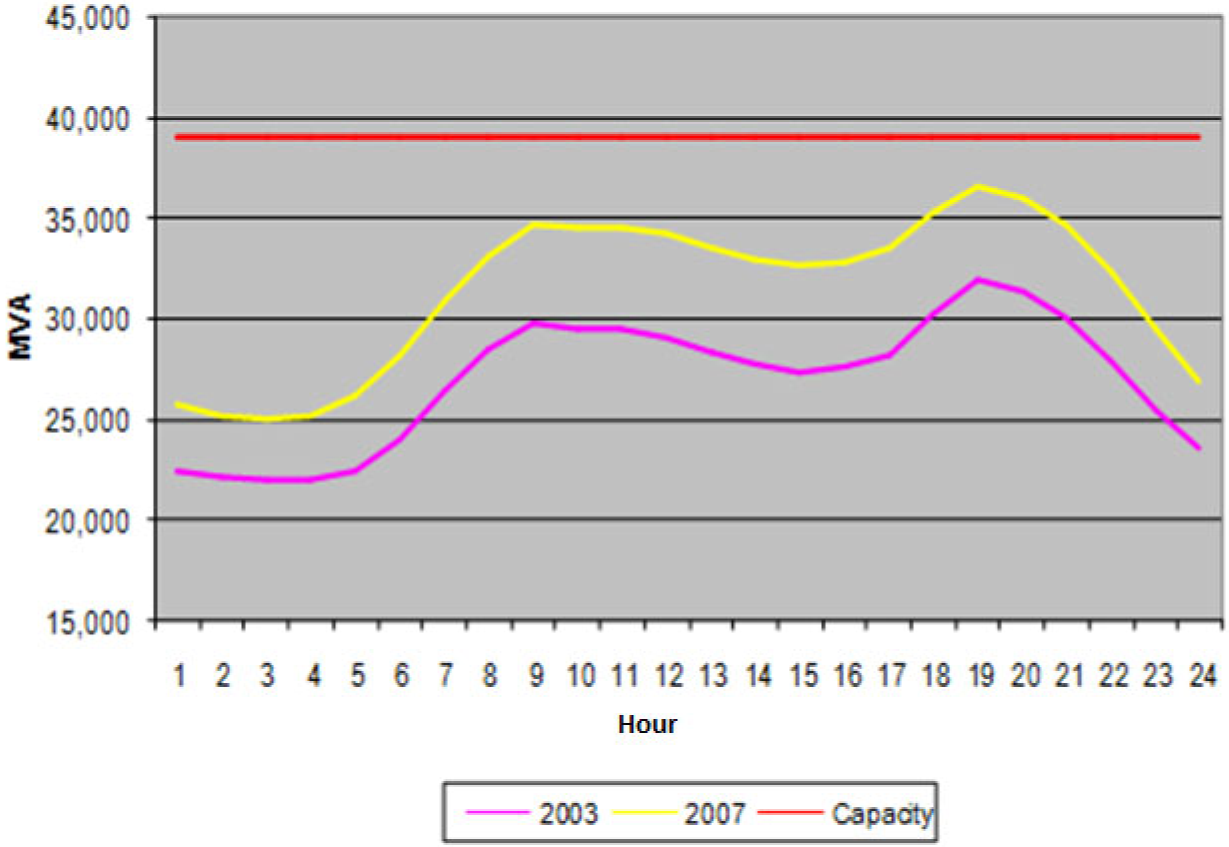

Figure 1.3: An example of a residential daily usage load curve

Source: [4]

Figure 1.3 [3] shows the energy load profile, measured in megawatt (MW), on Eskom during 2007, indicating peak usage times from 05:00 to 08:00 in the morning and from 17:00 to 20:00 in the evening.

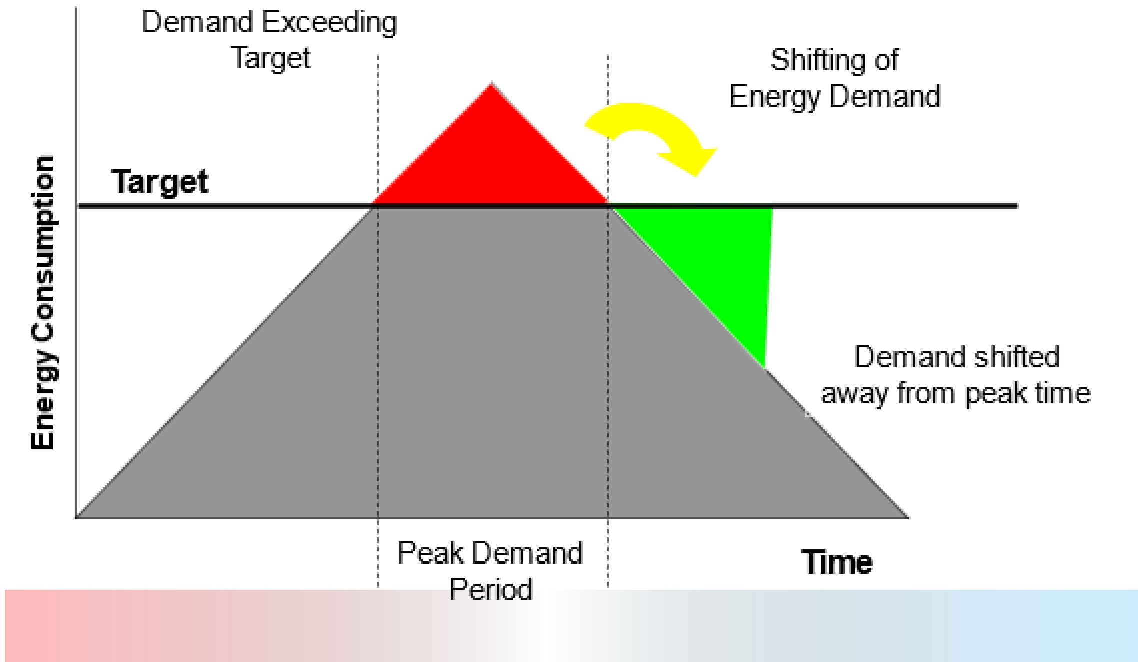

Figure 1.4: A systematics view of a load management system [4]

Figure 1.4 shows one of the methods used to reduce the peak demand period. During the peak demand period, shown in red, the e-load control system switches off the load and then restores it after the peak demand period, shown in green. Electric water heaters are appliances that are well-suited to peak demand shifting because they can be switched off during peak times and restored slowly after a peak period [5]. The target to which the load must be cut is also indicated and programmed into the load controller.

1.3 AIM AND OBJECTIVES

The aim of this research is to develop an adaptive scheme that will improve the load factor of electric water heaters in residential buildings. The specific objectives of the research are as follows:

a) To model an electric water heater that is typically used in residential buildings.
b) To collect information on the consumption pattern of EWHs.
c) To develop an adaptive scheme that will improve the load factor of EWHs.

1.4 PROBLEM STATEMENT

Electric water heaters may cause unnecessary power interruptions to the power system. If the demand on the power utility cannot be managed, more power generation plants will need to be erected to accommodate this increase in demand.

When the demand for electricity exceeds the capacity of power supply during peak periods, the network experiences power outages, resulting in profit losses to industries and small and medium business owners, as well as great inconvenience to all consumers. As the population increases, there are new housing developments which affect demand on the capacity of power supply, resulting in an increased need for systems that could improve energy efficiency and reduce high power demand.

1.5 RESEARCH CONTRIBUTIONS

This research examines the use of a Ripple Controller for EWHs, from which both the power utility and residential consumers would benefit. If the demand in residential buildings is reduced, the demand on the power utility will be reduced, and energy efficiency for both will be optimised. This method would enable society to assist the power utility with their Demand Side Management (DSM) objectives and goals and save money on their infrastructure.

1.6 RESEARCH QUESTIONS

Electric water heaters have a significant impact on residential energy consumption. The energy efficiency of electric water heaters needs to be enhanced to reduce the energy consumption of residential consumers. This research will therefore seek answers to the following questions:

a) Is the amount of energy consumed by electric water heaters reduced by improving the load factor?
b) Can the proposed load controller be installed at a low cost?
c) To what extent will residential consumers be affected or inconvenienced when the load shifting takes place?

1.7 DELIMITATIONS OF RESEARCH

This research focusses on the use of a controller to shift the load from peak to off-peak periods, thereby increasing the efficiency of residential electric water heaters and reducing peak demand.

1.8 BENEFIT OF THE DISSERTATION

Without load management, high demand can cause severe damage to a power system's apparatus when overloaded. If load management in a power system is compromised, the quality of supply (QoS) will not be good and the electrical loads connected to the power grid may fail, resulting in reduction of the life span of the electrical equipment connected. The application of ripple control could help protect electrical equipment by switching off the supply to the electric water heater during peak demand periods for a pre-determined period. Groups of EWHs will be controlled and monitored centrally from the local municipal energy centre by means of a radio-based communication system. The centre will also take care of all customer queries.

1.9 SUMMARY OF CHAPTER

This chapter provided the introduction, background and motivation for this dissertation and outlined the aim of evaluating a ripple control method of Demand Side Management to improve the load factor of electric water heaters, and how this would benefit utilities and consumers. The chapters that follow will elaborate on the introductory chapter and will focus on the application of RC to a power system, with the results indicating the effectiveness of this application in reducing peak demand for electricity.

1.9.1 Dissertation outline

Chapter 1: Presents an introduction to the dissertation

Chapter 2: Focuses on reviewing the literature referred to in the dissertation

Chapter 3: Presents the methodology of applying RC to a power system. It focuses on understanding the basis of RC and how it can be applied during peak periods.

Chapter 4: Presents results and shows the effectiveness of the RC method.

Chapter 5: Concludes the dissertation by summarizing its most important results, and suggestions for future work.

CHAPTER 2:
LITERATURE REVIEW

2.1 INTRODUCTION

An electrical power system comprises several generation units, transmission lines, distribution lines, and substations. These systems function together to form a complete electrical power system (EPS). The electrical power generated is rated at about 11 kV to 25 kV, then it is stepped-up to 220 kV or 400 kV using a generator transformer, depending on the rated transmission voltage parameters required for long distance transmission lines. Before the power is fed to the grid, it must be transmitted through the transmission line as depicted in Figure 2.1. If the secondary substation is overloaded, it will cause power interruptions on the transmission lines. High-power demand will be experienced by generation power plants, which might lead the power utility to plan for load shedding or load rotation. Load rotation could be considered by power utilities on specific areas of a household if the load readings are high on the power meter link to the secondary substation. Load readings are taken during morning and evening peak hours. Electrical networks may trip on overload during these peak times as people cook and boil water, while at the same time using electric water heaters to heat water for bathing. The substation will trip from the circuit breaker which is used to protect the whole substation from catching fire, causing a power outage, and leaving consumers with no electricity. Load control could prevent this by shifting the load during peak hours.

A typical transmission line is divided into three functional sections, as illustrated in Figure 2.1:

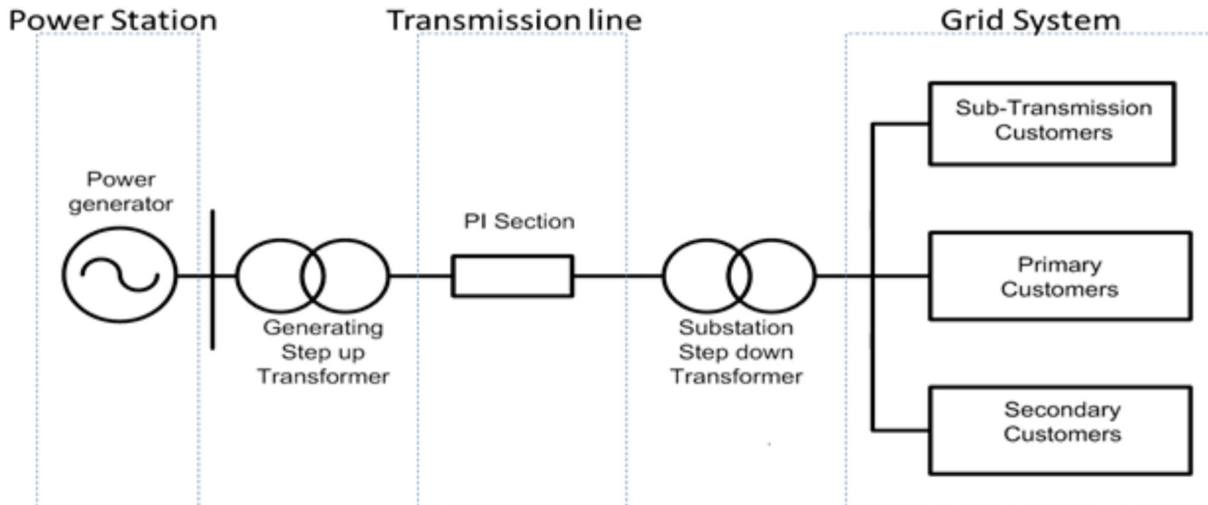

Figure 2.1: A model of a power system

Source: Researcher's own compilation

Power systems consist of the following:

a) The generation site,

b) The transmission line, and

c) The distribution site.

As shown in Figure 2.1, the grid system plays a vital role in the operation and control of the power system. This dissertation will be looking at protecting the power system by using a Load Control (LC) system to shift the load. Energy shifting plays an important part in meeting the stability requirements of electrical power systems, in terms of voltage stability and especially by controlling and protecting against high demand during peak hours [6]. Furthermore, reducing demand peaks safeguards critical electrical components from damage, protects systems against overload faults, and maintains operational integrity.

2.2 LOAD MANAGEMENT BY LOAD CONTROL

The prime objective of a Load Control scheme is to do energy shifting and avoid demand peaks. Load control of electric water heaters is a reaction on the LV network that delivers control of peak demand benefits to the MV and High Voltage (HV) networks (bottom-up approach not top-down) [7]. Ripple Controllers have a long life span, which makes them good Load Control system investments, solving a variety of distribution constraints and investment needs which emerge across various parts of the supply network.

Shifting energy means a reduction in energy purchases by avoiding using non-essential loads during peak periods. Cutting the demand peaks therefore means the demand charges, as well as the maximum demand (MD) related investments that must be made by the Municipality, are kept as low as possible. Load control basically means that certain devices are switched off during peak periods. It is important to differentiate between imposed load control and induced load control. Imposed load control is used by the utility to control appliances which exhibit storage characteristics, such as water heaters, air conditioning, and storage heating, that are particularly suitable for load control. In the past, only imposed load control has been used. Induced load control is applied where consumers pay different energy rates depending on the time of the day. By charging more during peak times, the consumer is encouraged to consume energy during standard and off-peak hours [8]. Electrical water heaters consume significant amounts of electricity in residential buildings and therefore present a problem on the power system.

2.3 CHALLENGES OF ELECTRIC WATER HEATERS

The rapid growth of electrical power systems in terms of size and complexity implies that challenges, especially in the transmission line, substation, and distribution network, are unavoidable. Power challenges are an undesired short circuit condition that is observed either between two phases or between a phase and ground. Electric Water Heaters contribute to these challenges because of their high energy consumption, especially if many consumers have their EWHs on simultaneously, during peak periods, contributing to power interruptions and blackouts.

High peak demand is often a challenge to the grid and could result in measures such as the need for procurement of additional plants to meet the peak demand, higher tariffs for consumers, undesirable load shedding or even blackouts [3].

Demand charge tariffs will be high if the load of EWHs isn't shifted from peak period to off-peak periods.

2.3.1 Demand Charge Tariff

Local and metropolitan municipalities of South Africa are billed by the power utility in terms of demand charge tariffs which consist of the following:

Demand charge: Charged per kilovolt ampere (kVA) or kilowatt (kW) of the maximum demand monthly.

Active energy charge: A fixed charge for each kilowatt hour (kWh) of active energy consumed by the consumers.

The tariff structure is regarded as a DSM control strategy to be used for pricing and indicates the national peak demand times [9]. Local and metropolitan municipalities have been forced to control the load during high demand times to save on the power utility bill. Consumers who can monitor their electricity consumption and maximum demand in terms of the utility standard period are suited to be included in the time of use (TOU) tariff. Therefore, consumers, local municipalities and metropolitan municipalities are eager to utilise TOU tariffs to reduce energy demand consumption during national peak periods.

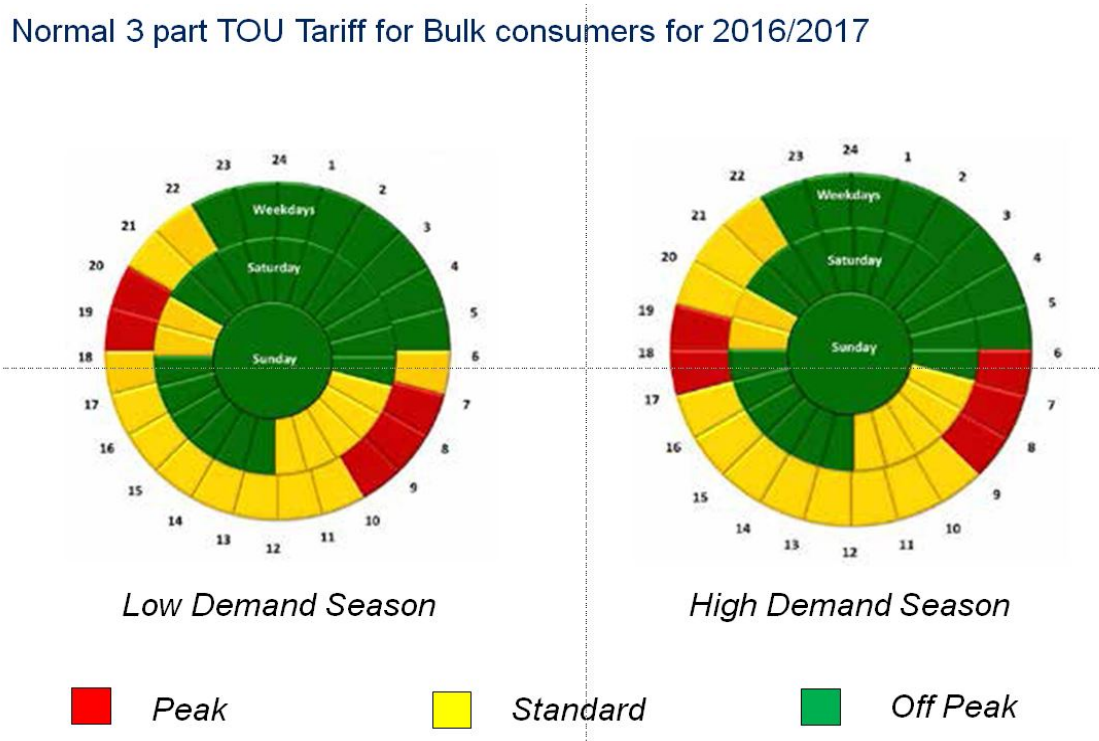

Figure 2.2: Normal 3-part TOU tariff for bulk consumers for 2016/2017

Source: Researcher's own compilation

Figure 2.2 illustrates the different time periods for the Peak, Standard, and Off-Peak periods. Notice there is a difference between weekdays and weekends during the low demand season from September to May (9 months) and the high demand season from June to August (3 months).

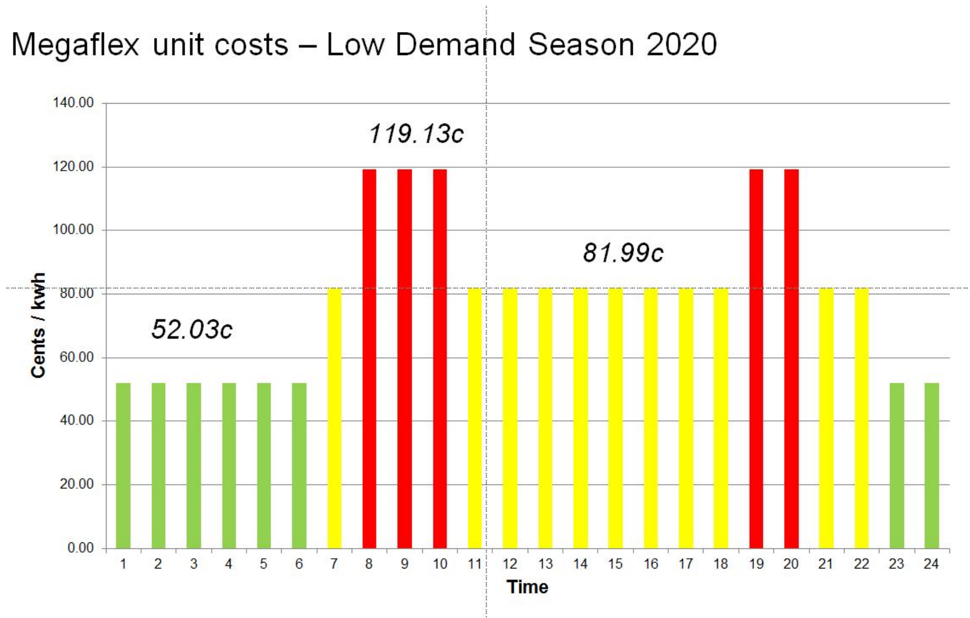

Figure 2.3: Megaflex unit costs – Low demand season 2020

Source: Researcher's own compilation

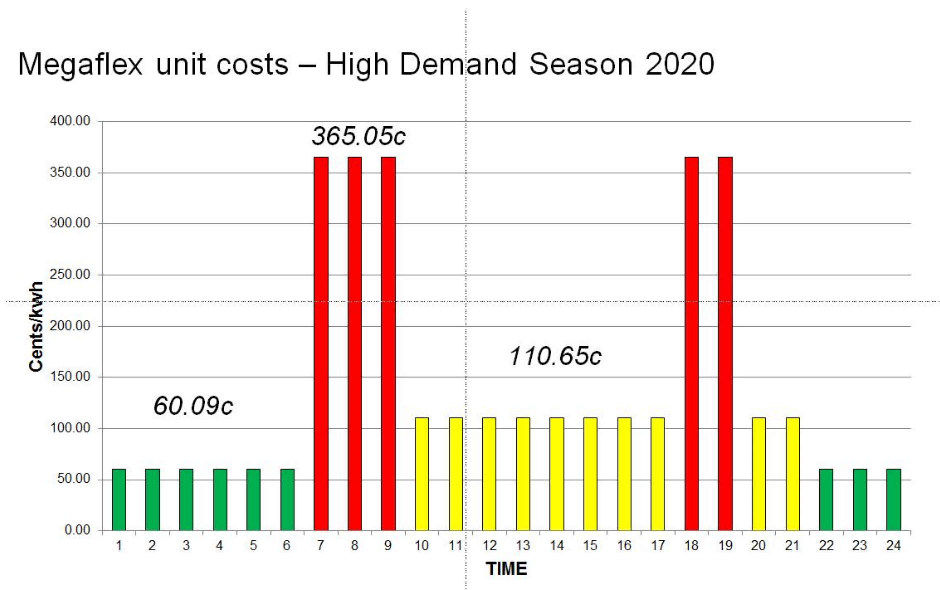

Figure 2.4: Megaflex unit costs – high demand season 2020

Source: Researcher's own compilation

Figures 2.3 and 2.4 illustrate the costs for Energy (cents/kWh). It can clearly be seen that there is a big incentive to move energy usage from an expensive period to a cheaper period. Using a Load Management System, energy loads such as those of electric water heaters, air conditioners and pumps can be shifted.

Figure 2.3 graphically shows the benefit of shifting energy usage from peak to off-peak, especially in the low demand season where the peak rate is 119.13c as compared to the standard rate at 81.99c, a difference of 37.14c. Figure 2.4 graphically shows the need to shift energy, especially in the high demand season where the peak rate is 365.05 c to the standard at 110.65c, a difference of 254.40c.

Table 2.1: Savings with Mega flex Tariff [10]

		Active energy charge [c/kWh]												Transmission network charges [R/kVA/m]	
Transmission zone	Voltage	**High demand season** [Jun - Aug]						**Low demand season** [Sep - May]							
		Peak		Standard		Off Peak		Peak		Standard		Off Peak			
			VAT incl		*VAT incl*		*VAT incl*		*VAT incl*		*VAT incl*		*VAT incl*		*VAT incl*
≤ 300km	< 500V	**347,10**	*399,17*	**105,62**	*121,46*	**57,63**	*66,27*	**113,64**	*130,69*	**78,43**	*90,19*	**49,99**	*57,49*	**R 9,67**	*R 11,12*
	≥ 500V & < 66kV	**341,63**	*392,87*	**103,51**	*119,04*	**56,21**	*64,64*	**111,44**	*128,16*	**76,70**	*88,21*	**48,67**	*55,97*	**R 8,82**	*R 10,14*
	≥ 66kV & ≤ 132kV	**330,85**	*380,48*	**100,22**	*115,25*	**54,43**	*62,59*	**107,93**	*124,12*	**74,29**	*85,43*	**47,12**	*54,19*	**R 8,59**	*R 9,88*
	> 132kV*	**311,81**	*358,58*	**94,46**	*108,63*	**51,29**	*58,98*	**101,71**	*116,97*	**70,00**	*80,50*	**44,41**	*51,07*	**R 10,87**	*R 12,50*
> 300km and ≤ 600km	< 500V	**349,93**	*402,42*	**106,01**	*121,91*	**57,56**	*66,19*	**114,15**	*131,27*	**78,59**	*90,38*	**49,85**	*57,33*	**R 9,71**	*R 11,17*
	≥ 500V & < 66kV	**345,04**	*396,80*	**104,53**	*120,21*	**56,76**	*65,27*	**112,57**	*129,46*	**77,47**	*89,09*	**49,14**	*56,51*	**R 8,92**	*R 10,26*
	≥ 66kV & ≤ 132kV	**334,09**	*384,20*	**101,20**	*116,38*	**54,95**	*63,19*	**108,98**	*125,33*	**75,00**	*86,25*	**47,57**	*54,71*	**R 8,65**	*R 9,95*
	> 132kV*	**314,92**	*362,16*	**95,42**	*109,73*	**51,80**	*59,57*	**102,71**	*118,12*	**70,71**	*81,32*	**44,85**	*51,58*	**R 10,97**	*R 12,62*
> 600km and ≤ 900km	< 500V	**353,42**	*406,43*	**107,07**	*123,13*	**58,13**	*66,85*	**115,28**	*132,57*	**79,36**	*91,26*	**50,35**	*57,90*	**R 9,84**	*R 11,32*
	≥ 500V & < 66kV	**348,52**	*400,80*	**105,57**	*121,41*	**57,33**	*65,93*	**113,71**	*130,77*	**78,21**	*89,94*	**49,64**	*57,09*	**R 8,98**	*R 10,33*
	≥ 66kV & ≤ 132kV	**337,49**	*388,11*	**102,22**	*117,55*	**55,50**	*63,83*	**110,06**	*126,57*	**75,75**	*87,11*	**48,04**	*55,25*	**R 8,72**	*R 10,03*
	> 132kV*	**318,07**	*365,78*	**96,37**	*110,83*	**52,32**	*60,17*	**103,77**	*119,34*	**71,41**	*82,12*	**45,30**	*52,10*	**R 11,12**	*R 12,79*
> 900km	< 500V	**356,97**	*410,52*	**108,15**	*124,37*	**58,73**	*67,54*	**116,45**	*133,92*	**80,14**	*92,16*	**50,85**	*58,48*	**R 9,89**	*R 11,37*
	≥ 500V & < 66kV	**352,00**	*404,80*	**106,62**	*122,61*	**57,91**	*66,60*	**114,81**	*132,03*	**79,02**	*90,87*	**50,11**	*57,63*	**R 9,08**	*R 10,44*
	≥ 66kV & ≤ 132kV	**340,89**	*392,02*	**103,27**	*118,76*	**56,08**	*64,49*	**111,19**	*127,87*	**76,51**	*87,99*	**48,54**	*55,82*	**R 8,79**	*R 10,11*
	> 132kV*	**321,21**	*369,39*	**97,35**	*111,95*	**52,90**	*60,84*	**104,83**	*120,55*	**72,16**	*82,98*	**45,80**	*52,67*	**R 11,20**	*R 12,88*

Source: Eskom

Table 2.1 shows that customers with a Notified Maximum Demand (NMD) higher than 1 MVA can shift the load. Eskom defines the costs for purchasing electricity for the Megaflex tariff, which includes losses, based on the voltage supply and transmission zone. A 300 km transmission zone is applicable to Johannesburg and other areas such as the Eldoraigne substation used in this study, which is within the radius of 300 km from Johannesburg. Customers using ≥ 66 kV and ≤ 132 kV will be charged R330,85 during peak periods of high demand season. Customers using ≥ 66 kV and ≤ 132 kV will be charged R100,22 during standard periods of high peak demand. Those using ≥ 66 kV and ≤ 132 kV will be charged R54,43 during off-peak periods of high demand season. Customers using ≥ 66 kV and ≤ 132 kV will be charged R113,64 during peak periods of low demand season. Those using ≥ 66 kV and ≤ 132 kV will be charged R74,29 during standard periods of low demand season. Those using ≥ 66 kV and ≤ 132 kV will be charged R47,12 during off-peak periods in low demand season. It is ideal for customers to use electricity during off-peak periods because they will pay less for electricity than those who use electricity during peak period.

The Rand/kVA/m transmission network charge is based on the supply voltage as highlighted in yellow in Table 2.1. Yearly utilised power and transmission lines and distribution networks measured in Power on Demand (POD) is always applicable. A cent/kVAr reactive energy charge supplied more than 30% (0,96 power factor or less) of the kWh recorded during the peak and standard periods as highlighted in yellow in Table 2.1. Excess network capacity charges are payable in the event of an NMD exceedance as specified in accordance with the NMD rules. It can be clearly seen from Table 2.1 that by reducing maximum demand, shifting use of energy from peak to standard, or standard to off-peak, utilities and customers save money.

Table 2.2: Calculation of ripple control savings

based on a per 1000 basis

February 2020

Eskom Megaflex Tariff used for calculations, ≥ 66kV and ≤ 132kV for Centurion

Assumptions

Price Rands, Excl VAT	Season			
	Low	**High**		
Network Demand Charge	11,69	11,69	R per kVA	≥ 66kV and ≤ 132kV
Network Capacity Charge	6,32	6,32	R per kVA	≥ 66kV and ≤ 132kV
Transmission Network charge	8,59	8,59	R per kVA	≥ 66kV and ≤ 132kV
Urban LV subsidy	15,48	15,48	R per kVA	Only applicable ≥ 66kV
Total MD charge	**42,08**	**42,08**		
Peak units	107,93	330,85	C per kwh	<300 km from JHB and ≥ 66kV and ≤ 132kV
Standard units	74,29	100,22	C per kwh	<300 km from JHB and ≥ 66kV and ≤ 132kV
Off-peak	47,12	54,43	C per kwh	<300 km from JHB and ≥ 66kV and ≤ 132kV
Number of Weekdays/ season	187	64	days	
Number of Saturdays/ season	40	15	days	
Number of Sundays	39	15	days	
No. of Geysers	1000	Units		
Geyser size	2,60	kW		
Diversity	0,35	%		
Annual price escalation according to Nersa	3%			
Possible Max Demand Reduction	0,91	MVA		

Energy Shift calculation for Low Season: Sept to May

Energy Shift (MWh)	Peak to Standard (MWh)	Standard to Off-Peak (MWh)		
Weekday mornings, 3 hours	2,7	0	Low demand times	07h00 to 10h00
Weekday Evenings, 2 hours	1,8	0	Low demand times	18h00 to 20h00
Saturdays Morning and evening	0	1,8	Low demand times	07h00 to 12h00 (2 hours only shifting)

Energy Shift calculation for High Season: June to August

Energy Shift (MWh)	Peak to Standard (MWh)	Standard to Off-Peak (MWh)		
Weekday mornings, 3 hours	2,7	0	High demand times	06h00 to 9h00
Weekday Evenings, 2 hours	1,8	0	High demand times	17h00 to 19h00
Saturdays Morning and evening	0	1,8	High demand times	07h00 to 12h00 (2 hours only shifting)

Energy shift and Demand Savings.

Low Season: Sept to May				
Network Demand & Access & Transmission		R 344 635		9*R 42.08* MD saving*1000
Shifting from Peak to Standard		R 286 226		187 weekdays*diff in tariff*MWh*1000/100
Saturdays Standard to Off Peak		R 19 780		40 saturdays*diff in tariff*MWh*1000/100
	Total for 9 months		R 650 641	
High Season: June to August				
Network Demand & Access & Transmission		R 114 878		3* R 42.08* MD saving*1000
Shifting from Peak to Standard		R 671 595		64 weekdays*diff in tariff*MWh*1000/100
Saturdays Standard to Off Peak		R 12 501		15 saturdays*diff in tariff*MWh*1000/100
	Total for 3 months		R 798 974	
Total Savings for	1000	receivers	R 1 449 615	
	Savings per receiver		**R 1 450**	each per year

Year	Escalation	Savings	Accumulated Savings
From 01.04.2019	9,4%	R 1 600 016	R 1 600 016
2	8,1%	R 1 741 040	R 3 341 056
3	5,2%	R 1 836 540	R 5 177 597
4	5,2%	R 1 937 279	R 7 114 876

Source: Eskom

Table 2.2 is a worksheet which shows the possible energy and maximum demand savings by analysing how much energy can be shifted in winter and summer from Peak to Standard periods. Table 2.2 is the actual Eskom tariff sheet for Local Municipality Authorities. From the Eskom pricing structure, it can clearly be seen that Eskom requires utilities such as municipalities and mines to shift energy. Table 2.2 contains calculations showing the potential savings per receiver operated under the Time of Use Tariff. A load control receiver is installed at the customer's premises and operates under the following parameters:

a) In winter the EWHs are switched off between 06:00 and 09:00, 17:00 and 19:00 weekdays (peak to standard) and between 10:00 and 12:00 Saturdays (standard to off-peak). Total of 7 hours
b) In summer the EWHs are switched off between 07:00 and 10:00, 18:00 and 20:00 weekdays (peak to standard) and between 10:00 and 12:00 Saturdays (standard to off-peak). Total of 7 hours
c) Average size of an EWH is 2.6 kW
d) Diversity of 35%. Some of the EWHs could be hot therefore do not require energy (thermostats open). So for calculations we assume 3.5 out of 10 electric water heaters would require energy during peak times [11].

2.3.2 High energy consumption

High energy consumption by electric water heaters during high peak demand periods is the main problem examined in this research. High demand has a large impact on electrical supply points. The improvement of the load factor of electric water heaters will play an important role in preventing power system outages [12]. In this study, an adaptive scheme will be used to improve the load factor of electric water heaters in residential buildings [13].

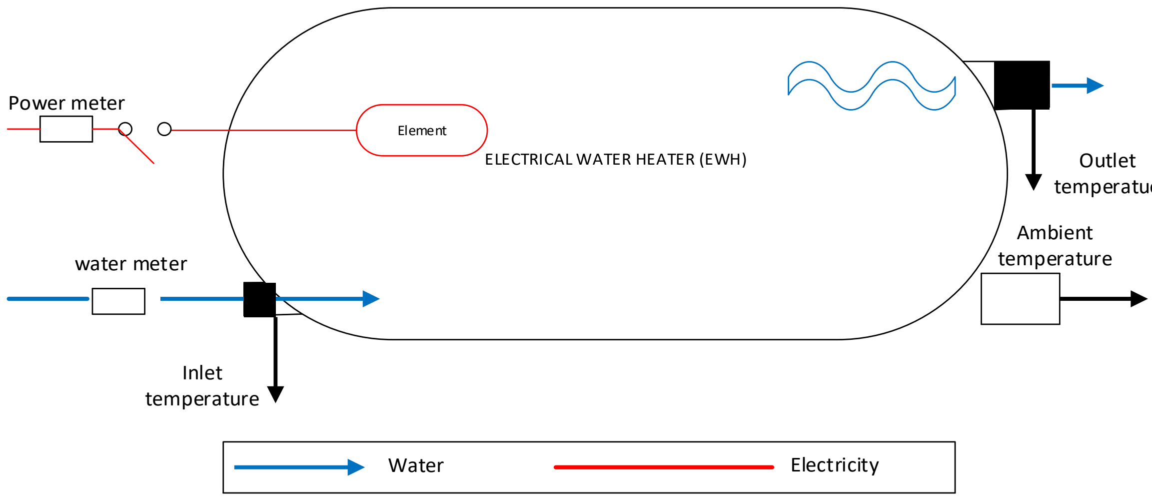

Figure 2.5: The arrangement of the Electric Water Heater

Source: Researcher's own compilation

A schematic diagram of an electric water heater (EWH) is shown in Figure 2.5. In the figure, water flow is estimated by an in-line stream meter associated with the water channel pipe. The meter uses a turbine method whereby a turbine hinges when there is a positive stream into the EWH.

Stream plates avert negative flow from turning the turbine the other way. The alignment of this turbine is estimated as heartbeats by means of a hall sensor. EWHs have a power meter, a water meter, an outlet temperature sensor, and an ambient temperature sensor. All four areas are measured to get accurate information on the EWH.

Challenges to the current capacity of the power supply system are increasing, with services being interrupted more and more regularly. Power outages and blackouts negatively affect businesses and the economy, as well as disrupting people's lives [14]. The traditional black-start process to restore electricity after a shut-down also often leads to damage to equipment [16]. Electric water heaters contribute significantly to power outages and total blackouts. The implementation of ripple control reduces the risk of power blackouts and power failures due to power system overloads.

2.4 DEMAND SIDE MANAGEMENT

A consistent, reliable, stable power system is required to ensure that supply meets demand. Power companies and municipalities are experiencing higher and higher demand for electricity since the South African population is growing rapidly. The upgrading of electrical infrastructure in generation, transmission and distribution is being done, but cannot keep up with the demand. DSM changes the demand load position by applying peak load shifting and peak load shaving [15]. This can be achieved by changing consumer demand profiles. Ripple control (RC) is a good energy management control which contributes to DSM in South Africa and many other countries. Ripple control is used in residential buildings to switch off power that is distributed to electric water heaters during peak demand.

2.5 RESIDENTIAL DEMAND SIDE MANAGEMENT

Residential buildings consume 17% to 30% of the energy supplied by Eskom. Electric water heaters are accountable for 30% to 50% of this demand [16]. The electric water heater is the main contributing factor to residential electricity consumption.

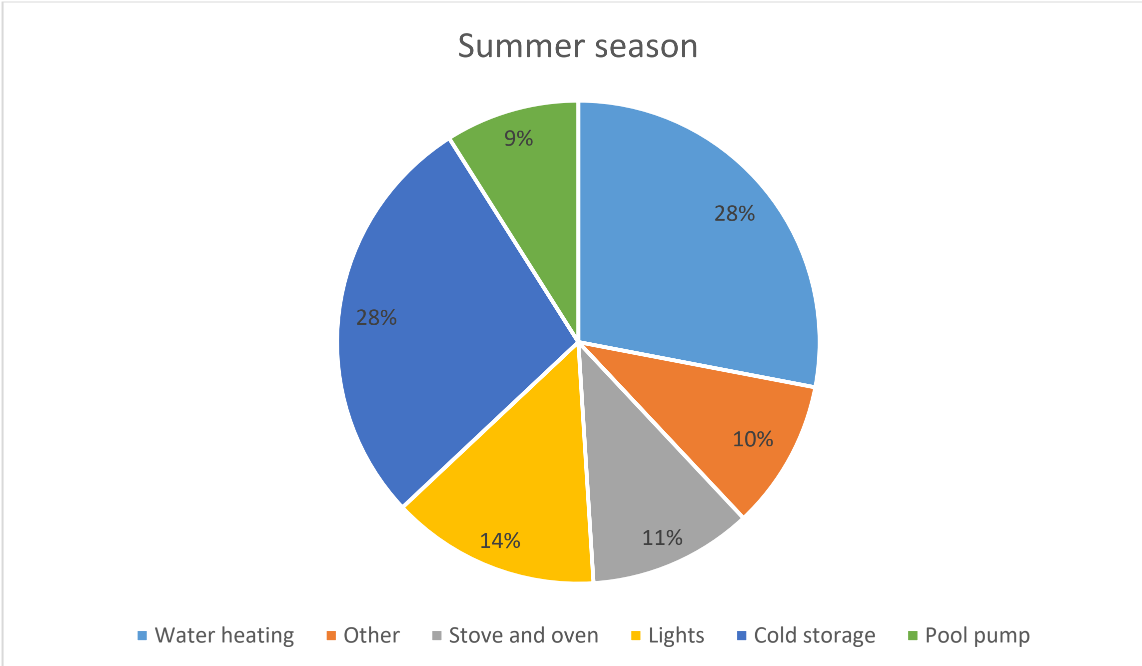

Figure 2.6: Summer residential load distribution in SA

Source: Researcher's own compilation

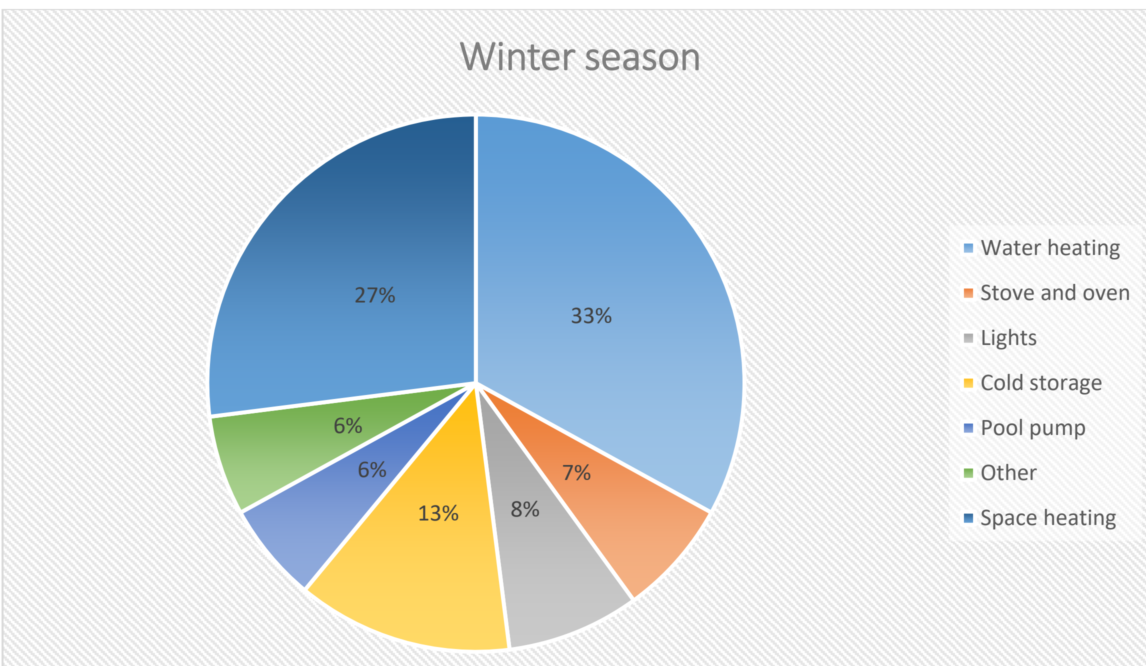

Figure 2.7: Winter residential load distribution in SA

Source: Researcher's own compilation

Figures 2.6 and 2.7 indicate that appliances are responsible for more than 80% of residential consumption of electricity. Some residential Demand Side Management (RDSM) strategies that have been introduced to minimize this high electricity consumption at peak times are:

a) Ripple control (RC)
b) Cold efficient standard
c) Tariff system, metering, and payment
d) Limit of breaker ratings
e) Electricity efficiency sources
f) Electricity usage awareness; and
g) Electricity efficiency on streetlights.

2.6 DEMAND RESPONSE

Demand Response (DR) can be described as a response from the consumer's electrical appliances in residential, industrial, and commercial buildings. There are two types of Demand Response: direct load control (DLC) and indirect load control (IDC). Direct load control is effective and successfully utilised by power utilities and municipalities to peak load shaving during high demand times [17]. Ripple control is a type of DR which requires more demanding communication and management of electrical networks. Ripple control is a one-way communication system using the existing distribution network as a communication channel. All electricity consumers, residential, commercial, and industrial, can benefit from DR. Consumers who participate in the events of DR may get bill savings and motivation payments. If consumer participation is successful, the infrastructure will be more reliable and there will be fewer power outages, less load shedding and load shaving (LS) as well as demand reduction (DR). Upgrading the infrastructure, including substations, transmission lines and distribution networks will also help avoid power interruptions and high maintenance costs on the power system.

2.7 EFFECTS OF HUMAN BEHAVIOR

Demand side management strategies could assist in changing the behaviour of consumers [18]. But before that can be done, it is important to know the consumers' behaviour. The following three stages will be considered:

a) Before implementation: Identifying and using the behaviour of consumers
b) During implementation: Monitoring the electricity consumption of appliances and the market rate.
c) After implementation: Determining the amount of DSM intervention required long-term.

2.8 WATER HEATING

Approximately 25% to 35% of a domestic consumer's electricity bill can be attributed to water heating. Residential consumers utilize a lot of electricity during peak hours (from 06:00 to 09:00 in the morning and 17:00 to 20:00 at night), when their water heaters are on load. Most people get up at around six in the morning and go to work at seven and they prepare to go to bed in the evening. Load control will be used to shift electricity during high peak demand. Load control will manage power consumed by electric water heaters effectively, benefitting municipalities, power utilities and consumers. The consumer's lifestyle will not be affected, because hot water cylinders will stock energy and hot water will always be available.

2.9 STUDY TECHNIQUES

The load control approach was selected because it was appropriate for both the research scope and available data.

DSM programs have the potential of reducing peak electricity demand, thereby cushioning, or delaying the need for further capacity development. Optimal Load Management and Demand Side management (DSM) appear to be an economically feasible solution.

Some of the methods that have been examined in the literature research are fuzzy logic control, demand side management, optimal load management, passive water heating, intelligent centralised control, proportional integral derivative control, direct inverse control and artificial neural network [19].

Existing DSM strategies for electric water heaters focus on on/off control, where a group of heaters are disabled during certain periods of time, using a direct load control strategy. Based on the status of the above variables, the Ripple Controller will determine the percentage of maximum power that the water heater should be allowed to consume. The control of domestic water heaters makes a considerable contribution to achieve Demand Side Management goals, especially in countries where the peak demand is experienced during the winter months [20]. The optimization approach is flexible enough to accommodate various lengths of control periods, different levels of resolution of the approximate water heater model, and adjustable minimum comfort water temperatures or comfort probability indices. The design, development and analysis of a low cost hybrid water heating system that uses a passive method to pre-heat the water before sending it to conventional hot water heater is also reviewed [21]. Smart grid (SG) technology is on the rise and emerging Internet of things technology augments the adoption of SG technology to address the problem of DSM. Computer simulation models are widely being used in problem solving and decision making. A simulation model was used for temperature control. The temperature control of an air conditioning system is very complex, because of the nonlinearities and uncertainties of such a system, but that of a ripple controller offers a simpler, quicker, and more reliable solution that has clear advantages over the conventional technique.

An advantage of a Ripple Controller (RC) is that no mathematical modelling is required since the controller rules are especially based on the knowledge of system behaviour. RC is proposed in this work to shift the average power demand of residential load and to improve the load factor [22].

A TSK-type Recurrent Fuzzy Network (TRFN) control has certain advantages when applied to temperature control problems: It is relatively easy to learn, considerably reducing training time for the controller and requiring no prior knowledge of the power plant. This eases the design process. TRFN also shows good and robust control performance. Proportional-Integral (PI) also performs the same experiments as Ripple, Fuzzy and Neural Network Controllers [23].

A programmable timer is an electronic timer which is installed next to the circuit breaker in the distribution board. It has a built-in memory with a battery back-up. Programmable timers ensure that the consumer has hot water according to the home's usage profile. Two devices available that provide a higher level one of control are the electro smart and electric water heater systems. One disadvantage of a programmable timer is that it allows the consumer to control it by switching it on/ off at any time. It cannot be controlled or managed by the municipality or utility.

Artificial neural network (ANN) based input and output is used to tune the membership functions in a fuzzy system [24]. When compared with other controllers, such as Ripple, PID and Fuzzy Control, Neural Network shows a better performance achieved with its tuning [25].

Easy computing is required to solve difficulties, make decisions, and model and control problems. Ripple Control (RC), Artificial Neural Network (ANN), Fuzzy Logic Control (FLC), and Adaptive Neuro-fuzzy Inference systems (ANFIS) all provide easy computing [26] [27]. However, Ripple control offers a simpler, quicker, more reliable solution that has clear advantages over conventional techniques. Based on the status of the variables, RC will determine the percentage of maximum allowable power that the water heater should consume. Ripple control is a simple control strategy which works well for control of certain classes of non-linear systems that contain variables with uncertainty.

The use of ripple control to shift the average power demand of residential load and to improve the load factor is examined in this study [28]. With a RC strategy, it will be possible to reduce the peaks of average residential water heater power demand [29]. Ripple control determines output based on the variables of the input. Ripple control tests consumption - when the demand is low it switches on and when the demand is high it switches off. Therefore, the load factor of the average residential power demand will be improved by ripple control [30].

2.10 CONVENTIONAL RIPPLE CONTROL MECHANISMS

There is a high probability of experiencing high power demand in a power system, hence ripple control has been employed to switch off a group of consumers at the same time to reduce high demand during peak hours. The prime objective of a load control scheme is to do energy shifting and avoid demand peaks.

2.11 CHALLENGES AND LIMITATIONS

Based on the literature review, it is evident that improvement of the load factor via control of electric water heaters forms an important element of system modelling and control. From a power systems perspective, the improvement of water heaters forms an important performance enhancement technology. In this research study, Ripple control is presented as a feasible and efficient solution for the improvement of the load factor of water heaters [31].

Conventional load control techniques depend on the input and output current and input and output voltage. Existing electric water heater demand-side management (DSM) strategies focus on on/off control of the water heater, where a group of heaters are disabled during certain periods of time using a direct load control strategy. High electricity demand is a daily problem to the power system, and could lead to power failures, blackouts, and high tariffs for consumers. However, these issues can be alleviated by introducing ripple control techniques for effective energy management of peak demand. In this chapter, an improvement of load factor using ripple control is examined.

Table 2.3: Comparison between Ripple Control and conventional Load Control

Characteristic	Ripple control	Convectional load control
Speed response	High speed operation	High speed operation
Vulnerability to tampering	Signal cannot easily be shielded or replicated	Easy to tamper with
Speed and reliability	Fast and reliable	Fast and reliable
Tariff	Tariff control	No tariff control
Switching ease	Switch 27 000 consumers in 6.6 sec	Switch single consumer

Source: Researcher's own compilation

Table 2.3 shows that the response speed of both ripple control and conventional load control is high. Ripple control cannot easily be tampered with, while conventional load control is vulnerable to tampering. Ripple control is used to control traffic lights and conventional load does not control traffic lights. Ripple control can switch many consumers concurrently and conventional load control can only be used to switch a single consumer.

2.12 OTHER NEW LOAD CONTROL METHODS

2.12.1 Fuzzy logic control

Fuzzy logic control can be used as an effective tool for high speed digital relaying and for switching a single electric water heater on/off [32]. Correct detection is achieved within a cycle of the fault incident.

Figure 2.8 represents a fuzzy logic controller. A fuzzy logic control consists of the Inference engine, where the decision-making of the controller takes place, with fuzzification and defuzzification for interacting with the process plant for control. Fuzzy sets and neural networks deal efficiently with the two very distinct areas of information processing [33]. When FLC and RC were evaluated, it was found that FLC was good on knowledge representation and RC had effective structures, was reliable, accurate and capable of controlling power systems [34]. Both techniques have their advantages and disadvantages.

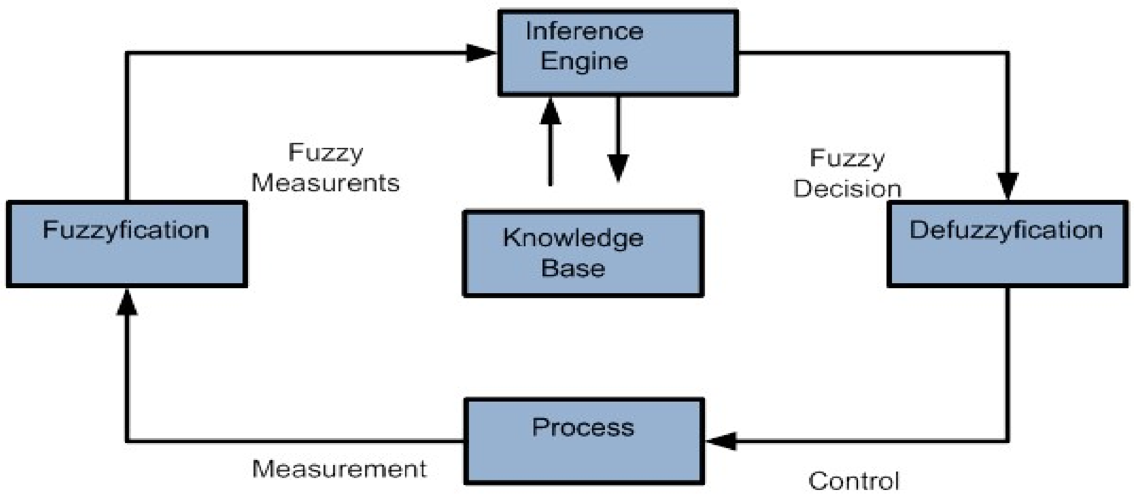

Figure 2.8: Fuzzy logic control block diagram

Source: Researcher's own compilation

2.13 RIPPLE CONTROL

Utilities all over the world face increasing consumption of electricity, together with unbalanced daily load curves. Ripple control improves the load factor of distribution networks by mobilizing hidden reserves. Ripple controls are used by municipalities or sub-vending customers of municipal DSM to control the loading effect of electric water heaters in residential areas. The main purpose of the ripple relay is to shift the heating load of EWHs out of peak demand times. This is done by switching off the electric water heaters in a group of homes for short periods during these peak demand times. Command signals are sent to the ripple relays via the distribution network (mains) or by radio frequency, switching the EWHs either on or off. The command signals for the relays are sent from the control centre, via the substation, to the consumer's home. Ripple controls need to be managed correctly because the control may cause additional load peaks.

Ripple control systems can be integrated into existing distribution networks at moderate cost. Ripple Control is one of the most established and proven technologies for achieving effective, reliable, and cost-efficient load management. As a result, investment into costly generation capacity or expansion of the network can be avoided or deferred. Better matching of the demand curve with the online generation capacity can be achieved, through direct or indirect load control.

Load management using ripple control always increases the load factor, therefore making better use of the existing distribution network. The risk of blackouts due to system overload is reduced. In addition to peak demand reduction, various services to communities and customers can be offered.

Other possible applications of ripple control are:

Direct load control: Domestic water heaters, storage and space heaters, air conditioners, heat pumps, water pumps, washing machines and dishwashers.

Indirect load control**:** Switching of tariff registers of multi-tariff meters, resetting of maximum demand (MD) meters.

The receiver mounted at any point in the low voltage network, switches one or several of its built-in relays on reception of the according Ripple Control telegram. A highly selective filter ensures that switching is only performed on proper ripple control code detection. Loads, tariff registers or any appliances can be directly connected to the relays, therefore allowing load control at any time.

Ripple control is a one-way communication system using the existing distribution network as a communication channel. The ripple control telegram is injected into the medium voltage busbars in the substation and propagates down to the low voltage networks throughout the distribution area, where receivers pick up the signal and switch loads or tariffs accordingly.

A ripple control system typically consists of a controller that generates ripple control telegrams; a transmitter that converts the controller signal into power signals; a coupling circuit consisting of an isolation transformer, coupling capacitors, and tuning coils; the distribution network itself; and the receivers.

Table 2.4: Advantages and disadvantages of ripple control and fuzzy logic control

Ripple Control	Fuzzy logic control
Advantages	***Advantages***
Its learning ability doesn't require intelligence	Fast adaptation to changes
Intelligently protects the power system	Smooth operation over control regimes
Faster computational times	Reduces the effects of non-linearity
Adaptive features are to learn to new problems	Learning ability limited doesn't require Intelligence
Efficient network quality monitoring	Classifies the network
Disadvantages	***Disadvantages***
Requires careful analysis	Difficult to model mathematically
Components are expensive	High cost installation points

Source: Researcher's own compilation

Table 2.4 compares ripple control and fuzzy logic control, indicating the advantages and disadvantages of each. The advantages of ripple control are intelligent protection of the power system, faster computational times, efficient network monitoring and learning ability doesn't requres intelligence. The advantages of fuzzy logic control are fast adaption to changes, smooth operation over control regimes and classifies of the network [35]. Disadvantages of ripple control are that it requires careful analysis and its components are expensive. Disadvantages of fuzzy logic control are that it is difficult to model mathematically and has high-cost installation points.

Table 2.5: Suite of energy efficiency options [36]

Options	Consumption Neutral	Assists Procurement	Damand Savings	Cost Savings	Cost to Eskom	Eskom Control	Billing Dependancies	External Dependencies	Risk	Focus
Solar Water Heating with Timers	Red	Red	Red	Red	Red	Red	Green	Yellow	Yellow	Energy efficency through behavioural change initiatives
Solar Water Heating with Ripple Control	Red	Green	Green	Green	Red	Green	Green	Yellow	Yellow	
Communications (Incl. Power Alert)	Green	Yellow	Yellow	Yellow	Green	Red	Green	Yellow	Green	
TOU Metering with Ripple Control	Green	Green	Green	Green	Green	Yellow	Green	Red	Red	
HWLC with Ripple Control	Green	Green	Green	Green	Green	Yellow	Green	Green	Green	Energy Efficency through predominatly demand response initiatives
Demand Market Participation	Red	Yellow	Green	Green	Green	Green	Green	Green	Yellow	
Smart Metering Infrastructure (AMI)	Yellow	Yellow	Green	Green	Red	Green	Red	Red	Yellow	
Utility Load Manager (ULM)	Yellow	Yellow	Green	Green	Red	Green	Green	Red	Yellow	

Favourable (Green) *Intermediate* (Yellow) *Negative Impact* (Red)

Source: Researcher's own compilation

Table 2.6: Position of ripple control in demand management options

Options	Energy Neutral	Demand Savings	Tariff Savings	Lifetime Cost	Usefulness beyond 2015	Comply with GG 773	Comply with Elect Act
Solar Water geyser with ripple control	Problematic/Negative Impact	Favourable	Favourable	Problematic/Negative Impact	Favourable	Favourable	Favourable
TOU metering with ripple control	Favourable	Favourable	Favourable	Favourable	Favourable	Favourable	Favourable
Geyser control with Ripple control	Favourable	Favourable	Favourable	Favourable	Favourable	Favourable	Favourable
Smart Metering Infrastructure	Favourable	Problematic/Negative Impact	Intermediate	Problematic/Negative Impact	Favourable	Favourable	Favourable
Utility Load Manager	Intermediate	Problematic/Negative Impact	Problematic/Negative Impact	Problematic/Negative Impact	Problematic/Negative Impact	Problematic/Negative Impact	Problematic/Negative Impact

Favourable   Problematic/Negative Impact   Intermediate

Source: Researcher's own compilation

Tables 2.5 and 2.6 compare the performance of different control mechanisms. Table 2.5 shows that hot water load controls (HWLCs) with ripple control perform well when compared to other controls, in terms of energy consumption (neutral), procurement, demand savings, cost savings, billing dependencies, external dependencies and risk. HWLCs have eight favourable advantages and one intermediate. Other control mechanisms are more problematic/negative control. Table 2.6 shows that TOU metering with ripple control and EWH control with ripple control are good control mechanisms. TOU metering with ripple control and EWH (geyser) control with ripple control are both favourable in terms of energy neutral, demand savings, tariff savings, lifetime cost, usefulness beyond 2015, and compliance with GG 773 and the Electricity Act. Other control mechanisms show intermediate to problematic/negative.

2.14 SUMMARY OF CHAPTER

This chapter presented an overview of the literature. It focused on power system control techniques such as ripple control to shift the average power demand of residential load and to improve the load factor [37]. Several researchers have proposed different techniques for load shifting and load control. This research proposes ripple control to control and shift the load in a power system, resulting in fewer power outages, less load shaving and reduction in demand. However, the ripple control method does require further testing to confirm its performance [38].

CHAPTER 3:
LOAD CONTROL OF ELECTRIC WATER HEATERS

3.1 INTRODUCTION

In this chapter, ripple control will be presented and validated as a model for shifting load from periods of high demand to low demand. Ripple control will be compared to other load control models. Verification of electrical demand in households will also be considered. The methodology employed for data collection and data analysis most appropriate for this research is outlined.

Alternative means of Demand Side Management that can be used by individual consumers will be considered, such as lower charges for electricity used at off-peak times.

The device, which many municipalities have installed for load control, could be used by the consumer to control that part of his/ her electrical load which can be used at off-peak times. The device would switch-on or switch-off as it does at present: that is, it would be on when the power consumption is low (electricity tariff also low), and it would be off when the power consumption is high (tariff also high).

In chapter 3 statistical modelling of the energy consumption of an electrical water heater model, and the average electric water heater temperature model, will be discussed in full.

The impact of using ripple control as a load management tool will also be presented in this chapter.

Table 3.1: Comparison of Power ratings of Appliances

Appliance	Power Rating	Daily usage
Electric Water Heater	2 600 W	3 hours
Heater	1 200 W	4 hours
Kettle	2 000 W	0.3 hours
Fridge	160 W	5 hours
Other	1 200 W	1 hours
Electronics	100 W	24 hours
Electric stove	3 000 W	1.5 hours

Source: Researcher's own compilation

Table 3.1 indicates the power ratings of various appliances used in residential buildings. An electric water heater consumes 2 600 W when used for 1.5 hours in the morning peak period and 1.5 hours in the evening peak period. The model of the load is a merged model of customer appliances [21].

3.2 LOAD FACTOR AND DISTRIBUTION NETWORK CAPACITY

South African power utilities and municipalities are faced with increasing consumption of electricity, together with an unbalanced daily load. Ripple control can improve the load factor of distribution networks by mobilizing hidden reserves. Better matching of the demand curve with the online generation capacity can be achieved through direct or indirect load control. As a result, investment into costly generation capacity or expansion of the network can be avoided or deferred. Ripple control systems can be integrated into existing distribution networks.

Load management using RC improves the load factor and makes monitoring the existing distribution network easier. The risk of blackouts due to system overload during peak demand periods is reduced, improving service delivery to customers.

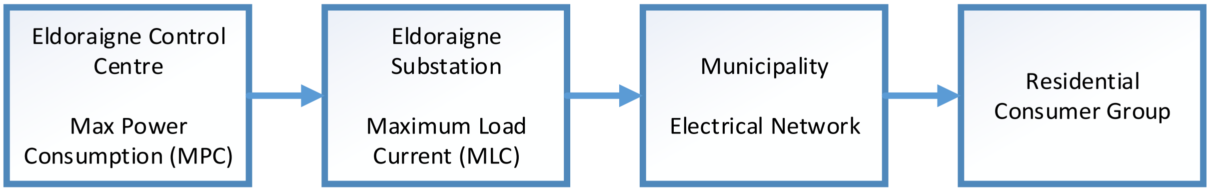

Figure 3.1: Power alteration model

Source: Researcher's own compilation

Figure 3.1 illustrates the four components of a power alteration model for load shifting, where energy is controlled from the supply side before it is supplied to consumers.

The Control Centre controls the Maximum Power Consumption (MPC) to the substations. It consists of an industrial grade process control unit for operation in harsh environments, together with any standard PC for programming and data retrieval. Thirty-two substations can be remotely controlled by one Micro Single Controller (MSC). The substation controls the maximum load current (MLC) to the Municipal Electrical Network, and to the residential consumer group.

The experiment was conducted on only one substation. The Micro Single Controller offers a cost-effective solution to maximum power consumption in the residential consumer group.

The municipality's electrical network receives power from the power utility and must ensure that it controls it. One of the ways this can be done is by switching water heaters on and off according to peak demand. This will reduce the cost to the municipality and to the consumer. However, before such measures can be successfully implemented, the municipality must ensure that consumers are informed as to how this load shifting will be done and how it will affect them. This method enables the municipality, not the consumer, to control when the electricity is used, although the cost benefits will be passed on to the consumer. The power utility or municipality should ensure that residential consumers understand the method used and be informed of the switching schedule of the power, so that they do not lose confidence in the supplier [39].

The rating of the HV transformers, MV switchgear, MV cables and MV busbars connected to the substation in the network should be specified in the design. A cold pick-up test will be done to ensure that no damage is done to electrical apparatus connected to the power system when energy is restored.

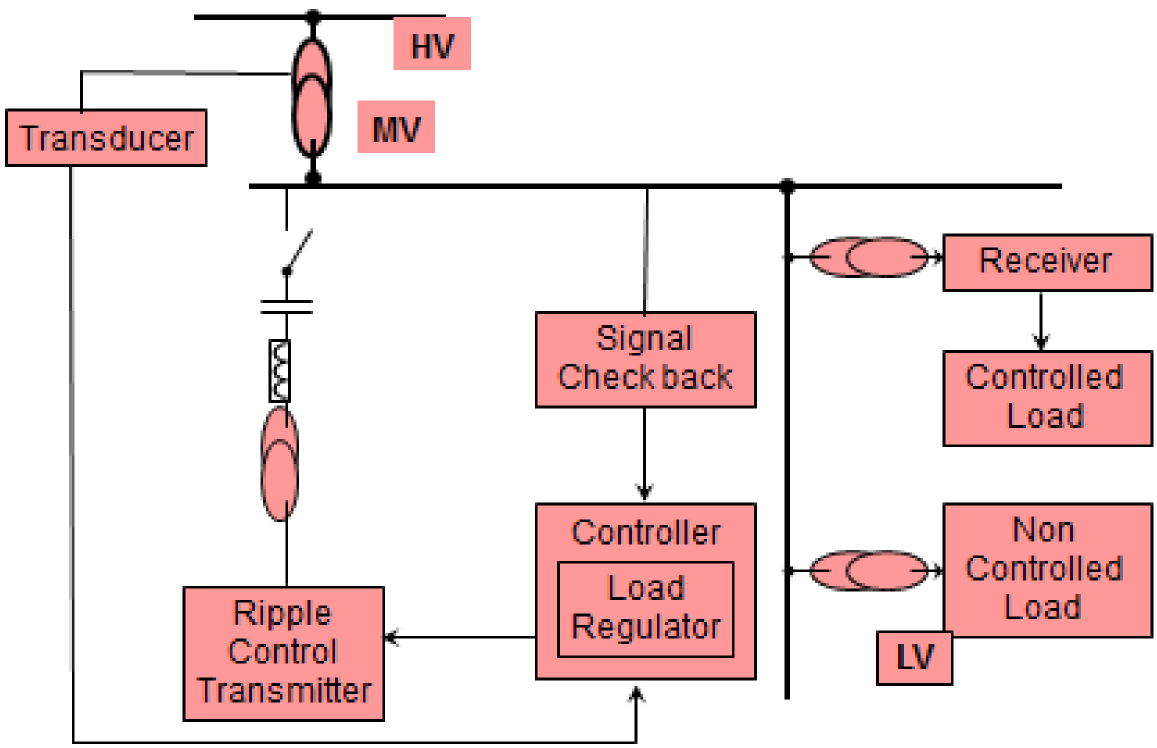

Figure 3.2: Close loop control with ripple control

Source: Researcher's own compilation

As shown in Figure 3.2, the ripple control transmitter is connected to the medium voltage (MV) busbar network in the substation through a coupling system. High voltage (132 kV) is converted to medium voltage (11 kV) by means of a step-down transformer. Ripple control always increases the load factor, therefore making better use of the existing distribution network. Besides peak demand reduction, RC also offers other benefits to consumers.

Demand Side Management (DSM) has the aim of changing the demand load position over peak load shifting and peak load shaving [3]. This can be achieved by changing consumer demand profiles. Ripple control (RP) is a good energy management control which forms DSM in many countries besides South Africa.

3.2.1 Overview of a Ripple Control system

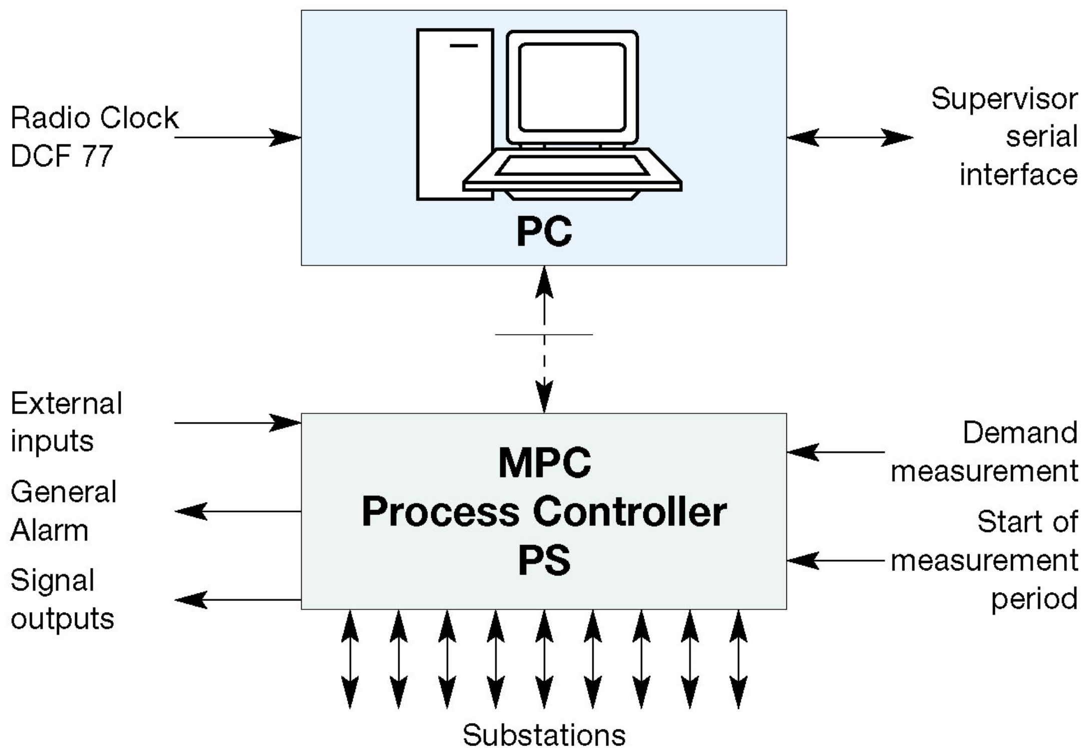

Figure 3.3: Simplified diagram of ripple system

Source: Researcher's own compilation

Figure 3.3 represents a simplified diagram of ripple system. After successful completion of the ripple control, a trip command is given to the circuit breaker to trip the power network, and a signal confirms the location of the area disconnected. This process is iteratively performed within the ripple control system. The substation is modelled using distribution line parameters. This model is commonly found within the literature studied for this research, and forms the basis of this study.

3.3 MODELLING ENERGY CONSUMPTION OF ELECTRIC WATER HEATERS

3.3.1 Residential Consumer Group Configuration

The model represented in Figure 3.4 indicates groups of consumers outlined in the municipality load management. The residential consumer mode input consists of the inputs and outputs which contribute to the performance of the local municipality in terms of service delivery. Residential consumers should be categorized into separate groups that have similar needs and behaviours with regards to the use of hot water. Residential customer group tests can be conducted in different groups using RC. This research aims to indicate that by using RC at a particular time of day a consumer group can have good results. The consumption of hot water energy may change for different groups of consumers depending on their work/home schedules and there will be measurable differences on the following days:

a) Monday and the day after public holidays
b) Regular holidays, Wednesdays, and Thursdays
c) Fridays and the day before a public holiday
d) Saturdays
e) Sundays and public holidays

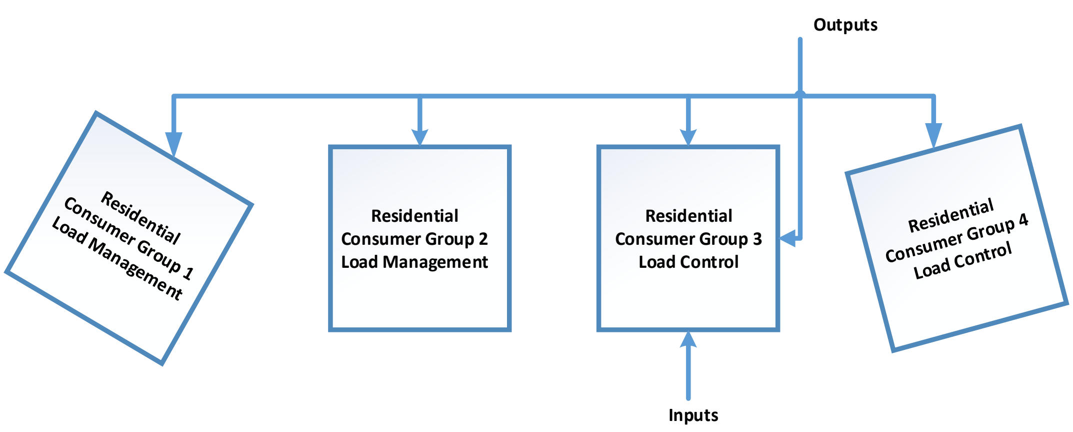

Figure 3.4: Residential consumer group model for load control

Source: Researcher's own compilation

Different Load Management profiles can be chosen for energy storage for different groups and controlled by the ripple controller, as shown in Figure 3.4. With this storage capacity, the cold load pick-up outcome of one group can be reduced by switching off the other groups when the load is restored.

The following are five types of hot water consumers:

a) Morning madness: Is the type of person that will aim to get hot water early in the morning between 05:00 and 08:00. The main aim is to reduce cold load pickup when the load is switched on and the load is restricted during the night. The residential consumers may be switched off in the morning peak periods if the RC is convinced that the average electric water heater temperature remains beyond the middle or minimum level temperature between 05:00 and 08:00.

b) Sundowners**:** This group uses more hot water in the evenings from 17:00 to 20:00.

c) Day timer**:** The number of consumers in this group is small. These are mostly pensioners, who don't demand access to hot water at all times.

d) Full Throttle**:** The are the ones that will be switched off first and switched on last. This category of members is unfortunate, and most are students that are controlled by lifestyle unlike Day timer. The resultant saving per residential consumer is still dependent on the Load Management of this category.

e) Crisis Controller**:** This group of residential consumers are not interested in a Load Controller, because they earn good salaries. They are only concerned when they are affected by planned national load shedding or load rotation. Their customer-comfort level settings must ensure that they always have hot water available from their EHWs. This group will be utilized to determine the maximum demand required and the quantity of EWHs connected on the grid.

Different switching strategies, (frequent switching, regular switching, or lenient switching), can be used for each of these consumer groups. A high number of residential consumers will require a lenient switching strategy, and it will depend on the ratio of the number of residential consumers to the hot water of EWHs.

3.3.2 The Price of Power

The price of electricity in South Africa is decided on by the National Energy Regulator of South Africa (NERSA) and determines the price Eskom and municipalities will charge. This is communicated to every customer. The higher the price charged by Eskom charges, the higher the cost to the Municipality and this in turn will affect consumers.

The Load Controller makes use of the time of use (TOU) price, which provides a schedule per week and per month to assist residential consumers save money. The TOU price method will assist the municipality to implement the model, because it will assist them to reduce the cost of electricity, which will be attractive to consumers. The electricity price should be in line with the maximum demand charges, so it should not be shifted to another period of the next day. Cold load pickup should be managed by the municipality during peak periods [10].

Residential consumers have different lifestyles and requirements, which affect the performance of the municipality. The load management controller must easily be able to control groups of residential consumers without challenging different cultures or lifestyles. Groups will have their own load management pattern and switching style that will restrict their electric water heaters. If a residential consumer is experiencing a problem with a certain group restriction, he may apply for a regular or lenient switching strategy to meet his or her lifestyle. The load controller can ensure that the MD charge setting amount change is lower than the savings because of the energy shifting at that time. Let us look at the Megaflex price for example:

MD Cost = Energy Savings Cost

(MD Cost/kW) x (Increased kW) = (Effective Cost of Savings) x (Amount of Energy Shifted)

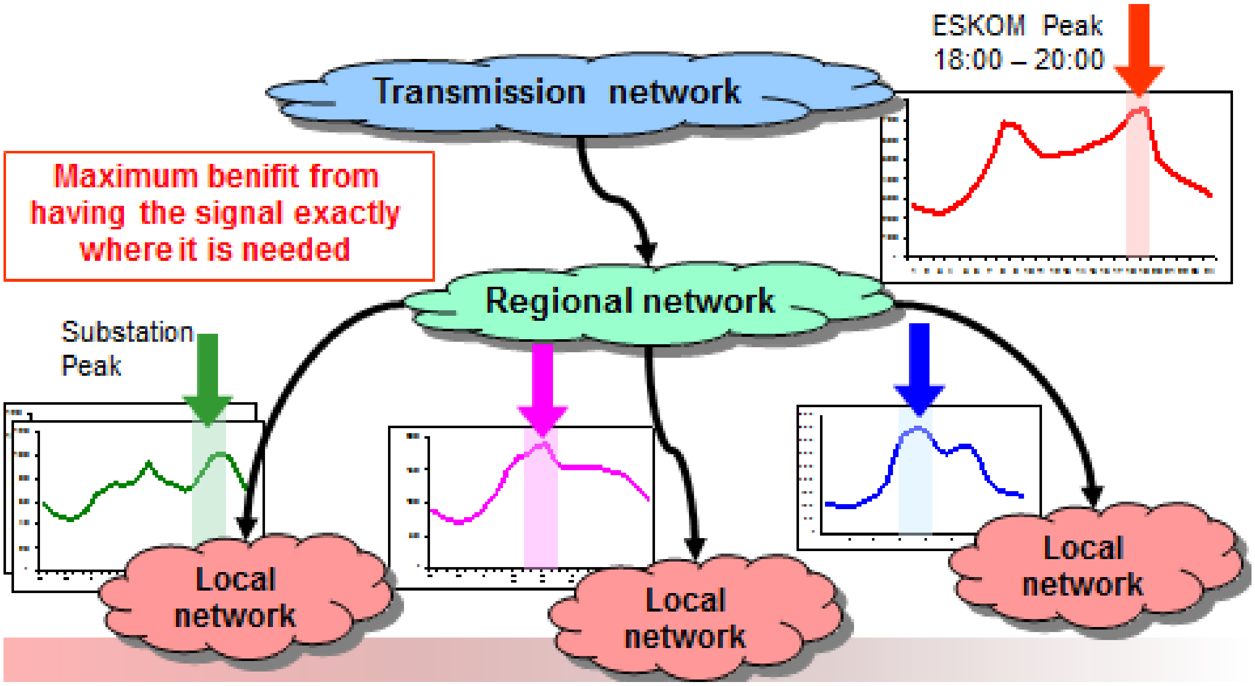

Figure 3.5: Medium voltage versus high voltage injection

Source: Researcher's own compilation

Power is generated from the generation power plant, transmitted via transmission lines to supply energy to substations [40]. Thereafter, power will be transmitted to the distribution substations before it is transferred to local networks (domestic, commercial, and industrial consumers), as shown in Figure 3.5. When residential consumers utilise a lot of electricity during peak hours (from 18:00 to 20:00), the substation is operating at high demand.

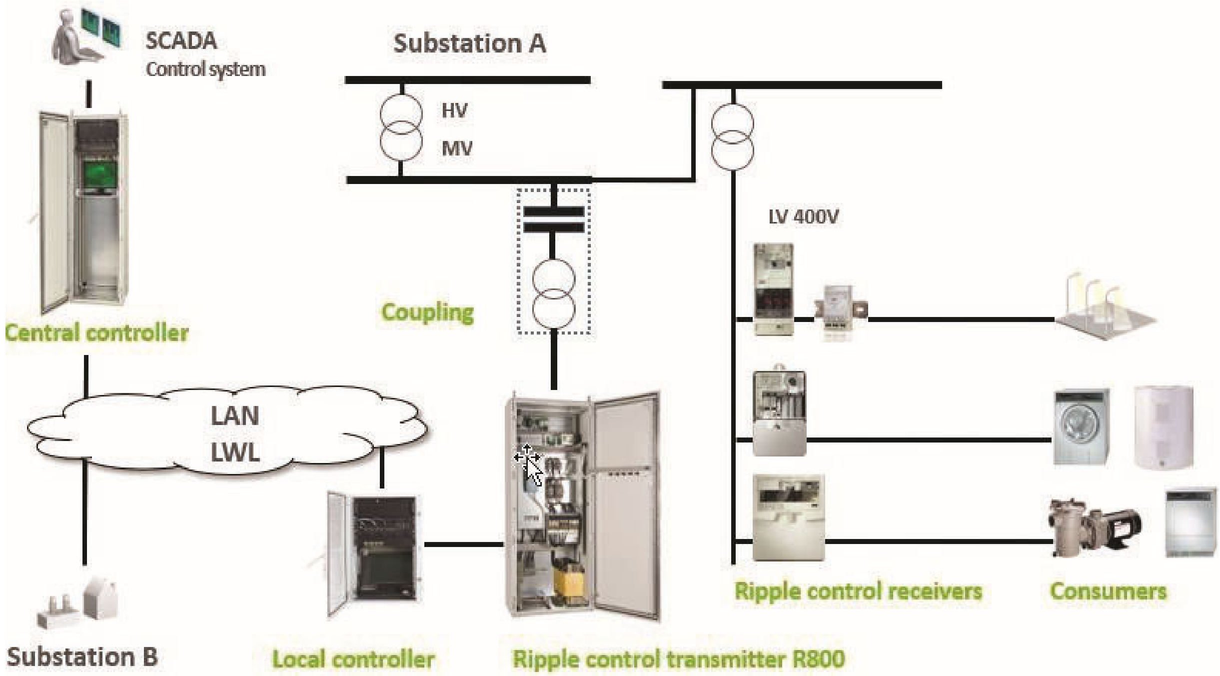

Figure 3.6: System architecture of a ripple control system

Source: [39]

To reduce the impact of peak hours on the substation, a ripple control system can be used for load shifting. Figure 3.6 illustrates such a system. A controller generates the required ripple control message according to a time schedule or list of events as shown in Figure 3.6. The command message can be generated either by a local controller unit or by a remote central controller unit communicating with the substations [41]. To increase the reliability and lifespan of the power system, central and local controllers can be used concurrently. The local controller unit is only brought into service if the central equipment is not available, for example due to fault or a failure of the communication link.

The controller unit only provides the message as a digital signal. The audio frequency signal is produced in the transmitter. The coupling provides a low impedance path for the ripple control signals but inhibits the network voltages and harmonics from being returned to the transmitter. The coupling normally forms a band-pass filter. In addition, the coupling provides potential separation between the medium or high voltage and the transmitter [42].

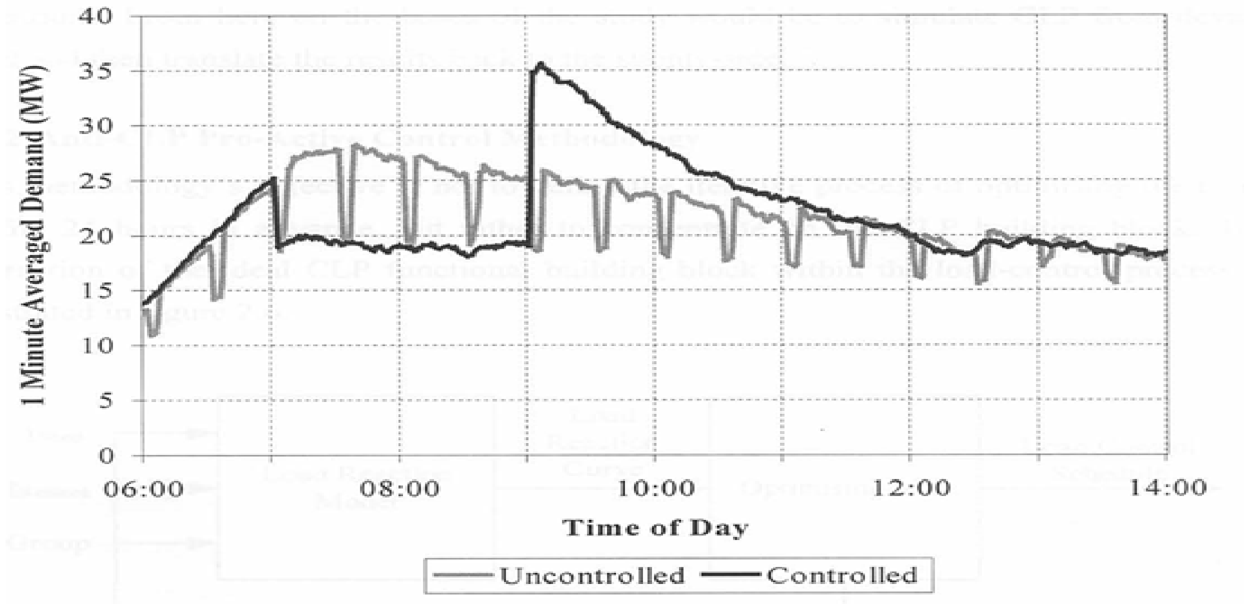

Figure 3.7: Controlled and uncontrolled load profile

Source: Researcher's own compilation

A comparison between controlled and uncontrolled load profile is presented in Figure 3.7. The maximum demand is increased by 8 MW after it was reduced from 16 MW. The total maximum demand at 09:00 was 36 MW when it was uncontrolled and after the load was controlled it was reduced to 28 MW as shown in Figure 3.7. The load profile comprises of the load-base, ripple power consumption and CLP power demand.

Total Load = Load-base + Power Consumption + CLP power demand

It is evident in the figure that the maximum of 1 minute average demand for uncontrolled and controlled load profiles during the peak period from 6:00 to 9:00 are 28 MW and 20 MW respectively. In Figure 3.7, the peak for the controlled load profile has been shifted to between 9:00 and 10:00, which is usually off-peak for most substations.

3.3.3 Modelling of Energy Consumption and Load Factor

Specific management policies are in place to ensure that the required comfort level for all groups of residents is met in accordance with the permitted minimum temperature for electric water heaters. It is important to measure the temperature of each customer's electric water heater before the ripple is connected.

The study was conducted using data from the municipality to validate a combination of two models on the current load management system - the power alteration model and the residential consumer model.

One ripple control system can control many electric water heaters, depending on how many are connected to it from the substation. The number of EWHs connected to the Eldoraigne substation is about 8 000. The micro-level system was used to do the research and provide information to the system, with public participation and engagement.

The improvement of the load factor of electric water heaters will play an important role to prevent power system outages and blackouts [4]. In this work, an adaptive scheme was used to improve the load factor of water heaters in residential buildings [43]. As the maximum demand improved or reduced, the load factor improved.

L_F: load factor

$$L_F = \frac{Average\ demand}{Peak\ demand}$$

Table 3.2: Maximum demand of electric water heaters

No. of electric water heaters	Maximum demand
1 000	0.9 MW
1 500	1.35 MW
2 000	1.8 MW
3 000	2.7 MW

Source: Researcher’s own compilation

P_{ave} = average power

$P_{ave} = \frac{Pmax\ demand}{Peak\ demand}$

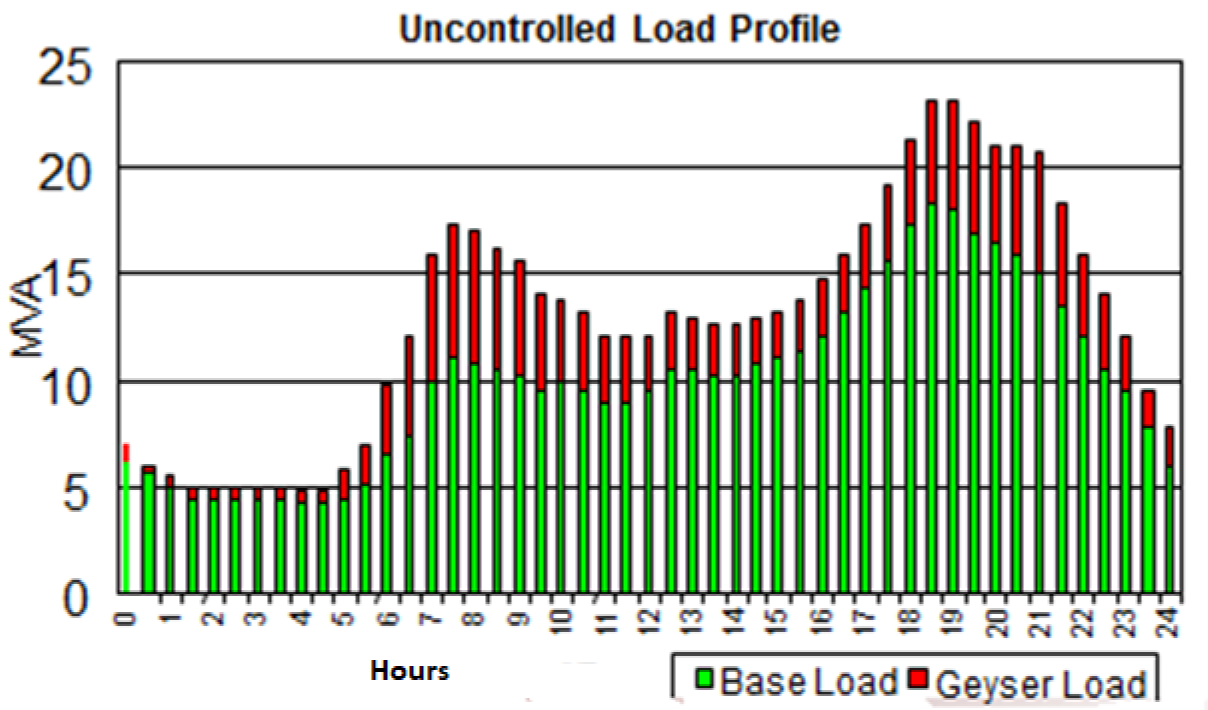

Figure 3.8: Uncontrolled load profile

Source: Researcher's own compilation

Figure 3.8 illustrates a 24-hour load cycle of an uncontrolled load profile, where the red indicates the base load while EWHs (geysers) are switched on and green indicates the load without the EWHs connected to the grid. The test was done when the power was on, in order to check how much power is consumed by electric water heaters for a period of 24 hours. After the test was conducted, the modelling and validation was done. The results will be used to determine how much power the municipality needs to request from the power utility and how much can be cut when load shedding takes place. The results were used to see how much power can be shifted from high peak demand to off-peak by using RC.

3.3.4 Capacity or Cold Load Pick-Up (CLPU) Test

The purpose of the capacity or cold load pick-up test, is to check how many electric water heaters are connected to the power network. A CLPU test involves switching off all the electric water heaters on a network for a minimum of 6 hours. After 6 hours they are switched back on again, and the load in the substation on the protection relay measured. The power measured in MW / 2.5 kW = no. of EWHs connected on the network. All electric water heaters would have been cold when this takes place. The time interval used to conduct a notch test is as follows:

- CLPU tests conducted from 22h00 until 04h00
- All EWHs switched off at 23h00 then on at 05h00
- Duration of off period is 6 hours

$$No\ of\ EWHs = \frac{Pmeasured\ (MW)}{2.5MW}$$

3.3.5 Notch Test

The purpose of a notch test is to determine the load on the power system. The power is switched on and off every 5 minutes during peak period to check power consumption. Notch testing was done to determine the electric water heater load profile for 2 800 electric water heaters for both winter and summer months. Notch testing involves switching off all EWHs for a short period, then restoring power to switch them back on. The resulting dip in the load profile is what is called a ‘notch’ and characterises the total capacity of the EWHs for the testing period. The following is the time interval used to conduct the notch tests:

a) Notch tests from 06:00 until 22:00
b) All EWHs switched off then on every half hour
c) Duration of off period is 5 minutes
d) No load control during tests

3.4 RIPPLE CONTROL SCHEMES

Ripple control is a one-way communication system using the existing distribution network as a communication channel. The ripple control telegram is injected into the medium voltage busbars in the substation and propagates down to the low voltage networks throughout the distribution area, where receivers pick up the signal and switch loads or tariffs accordingly.

A ripple control system typically consists of a controller that generates ripple control telegrams; a transmitter that converts the controller signal into power signals; a coupling circuit consisting of an isolation transformer, coupling capacitors, and tuning coils; the distribution network itself; and the receivers.

A ripple control transmitter generates the required frequency. The coupling cell is tuned for the ripple control signal on the medium voltage network. A coupling cell consists of a capacitor and inductor, these two are tuned for a ripple frequency.

$$X_L = X_C$$

$$2\pi f l = \frac{1}{2\pi f c}$$

Where f is a ripple frequency.

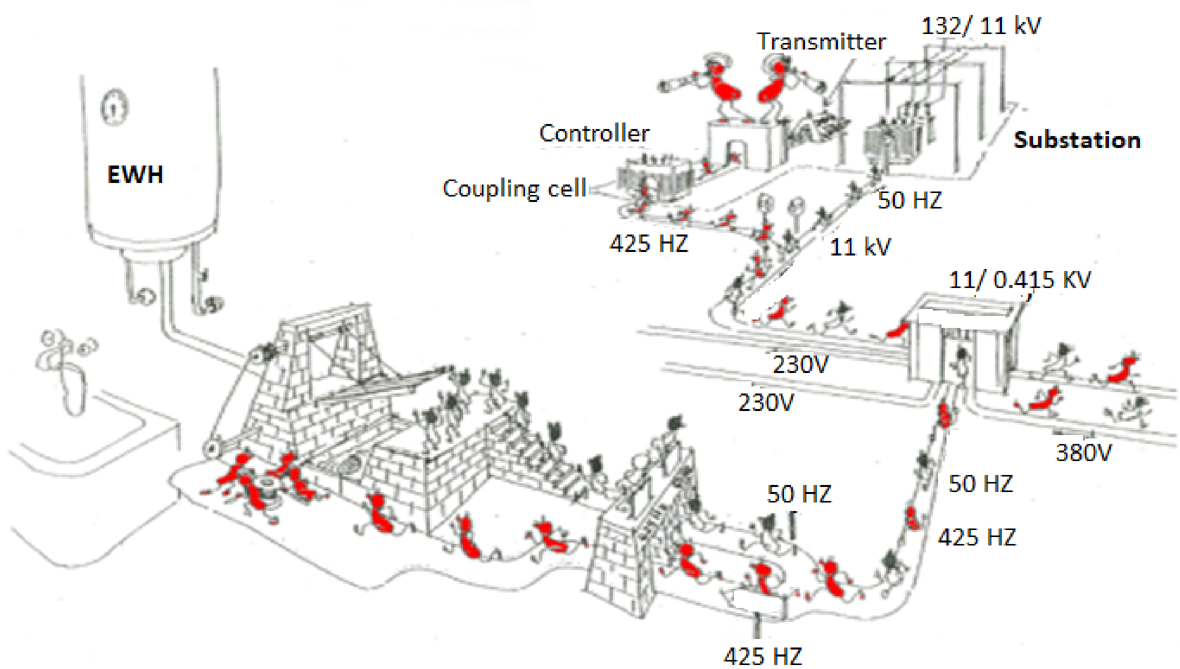

Figure 3.9: Representation of a network with ripple control

Source: Researcher's own compilation

Primary substations are remotely controlled by one Maximum Power Consumption (MPC). For applications with only one substation the Micro Single Controller (MSC) offers MPC functionality as a more cost-effective solution. An MPC Ripple Controller generates the required ripple control message according to a time schedule or list of events as shown in Figure 3.9. Maximum Load Current (MLC) is a local controller for ripple control installations with a central controller and one or more substations where the injection of 425 Hz is applied. It provides for emergency operation of the ripple control system after failure of the central station or the communication line between central and substation. A frequency of 317 Hz is used to inject Rustenburg and Witbank area and 425 Hz is used in the Kwazulu Natal electrical network. A 425 Hz is used in Gauteng, due to new electrical network designs. Different frequencies are applied in different areas due to specific electric parameters of the electrical network, such as impedance.

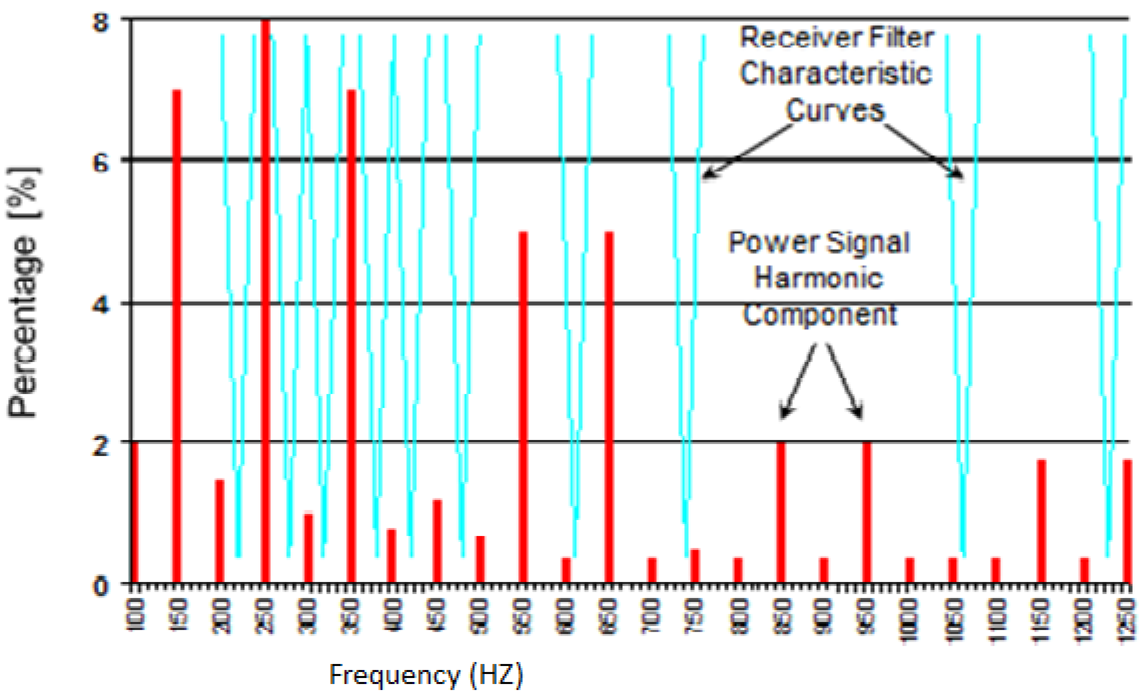

Figure 3.10: Ripple frequency 425 Hz selection vs harmonic in a distribution network

Source: [42]

Figure 3.10 shows that the ripple frequency signal is produced in the transmitter. The coupling provides a low impedance path for the ripple control signals, but inhibits the distribution network voltages and harmonics from being returned to the transmitter [44].

3.4.1 Emergency Shedding and National Crisis

During load shedding or during a crisis, a RC system can be used effectively to reduce the demand quickly. The RC system can also be used by the power utility and municipality to conduct load rotation or load reduction.

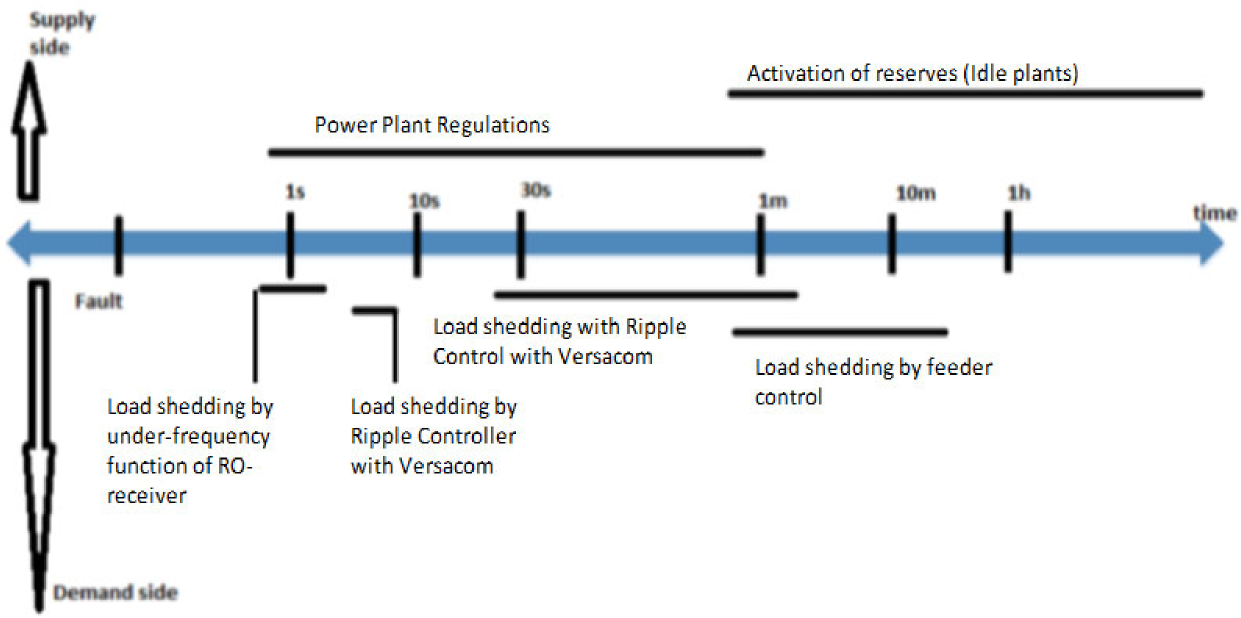

Figure 3.11: Ripple control reaction speed of shedding load

Source: Researcher's own compilation

Figure 3.11 shows the reaction times to control the load by switching an electrical network on or off during load shedding declared by the power utility or municipality. The power utility will publish the load shedding schedule nationally and the municipality will publish it for their specific area, so that customers will know when power will be off and when it will be restored. Load shedding is conducted at the control centre remotely. The reaction time can be within 7 seconds. In other words, all deferrable loads can be switched off, preventing the need to switch off areas in the network within 7 seconds.

3.4.2 Coupling Cell

A Coupling cell is the equipment (tuned LC coupling) connecting the 380 V transmitter to the 11 kV network to inject the ripple audio signal. Coupling cells may only be reconnected when the coupling capacitors are discharged, as shown in Figure 3.12. It must therefore be ensured that the coupling capacitors are fully discharged through the 4-pole isolator, before the coupling cell is switched on again. The coupling capacitors must never be discharged directly across their terminals. The discharging current must be limited by the impedance of the tuning coils.

Figure 3.12: Coupling cell

Source: Researcher's own compilation

3.4.3 Coupling types and their operation

Ripple control couplings can be divided into two main types: Parallel (KT, KI) couplings and serial couplings, as shown in Figure 3.12. A coupling will normally be provided with various supervision circuits. Provision depends on the type of coupling. In parallel ripple control coupling, the high voltage circuit breaker opens when a parallel coupling supervision circuit detects a fault, as shown in Figure 3.13. The normal 50 network operation can continue unaffected.

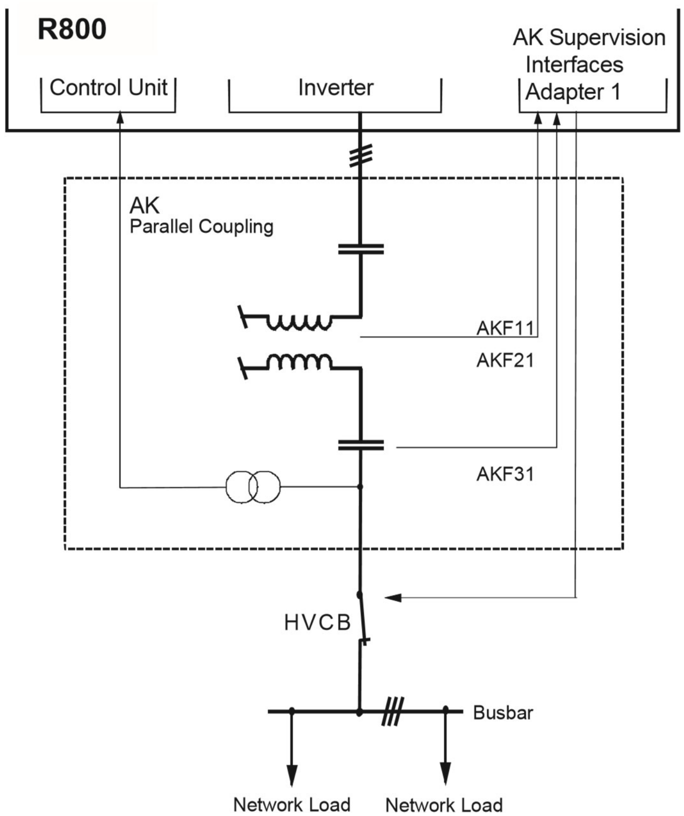

Figure 3.13: Parallel coupling

Source: Researcher's own compilation

3.4.3.1 Serial Coupling

When the prerequisite is fulfilled, isolator TR 3 is closed. This bypasses the series coupling as shown in Figure 3.14. Subsequently isolators TR 1 and TR 2 are opened. The coupling is disconnected from the network.

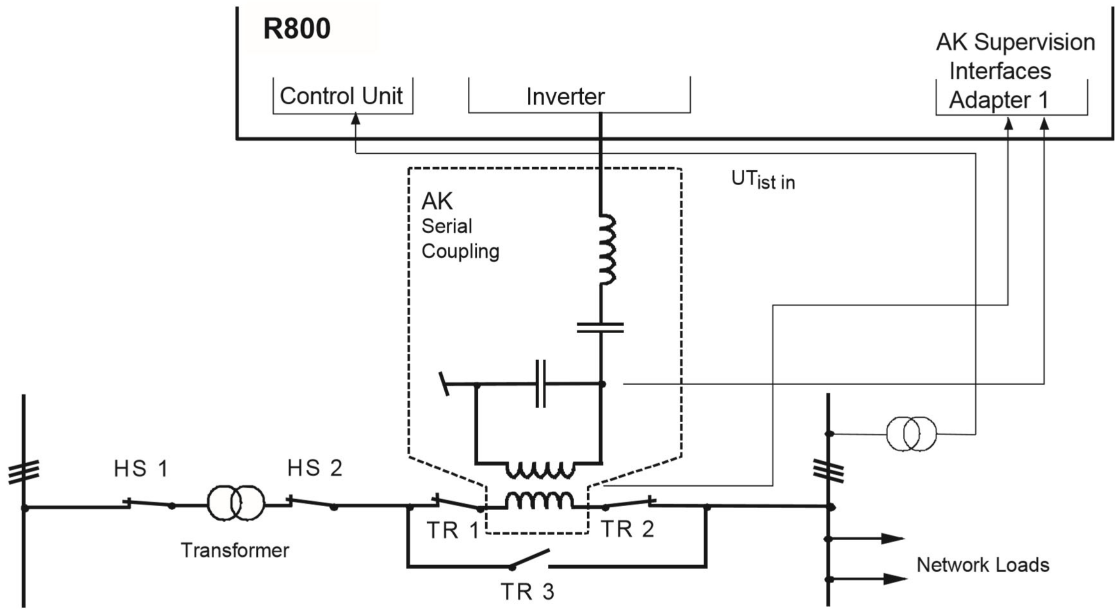

Figure 3.14: Serial coupling

Source: Researcher's own compilation

Some examples of deferrable loads are:

a. Electric water heaters
b. Air conditioners
c. Pumps for swimming pools
d. Heat Pumps
e. Space heaters
f. Non-essential lighting

A 16 A relay was used to control the electric water heater. The relay of choice had a coil voltage of 24 V DC. The reason for choosing 24V DC was due to the lower coil resistance, resulting in less current being drawn by the relay. The control circuit had to switch a 3 kW element. The power rating of the relay was calculated using the following equation:

P: Power V: Voltage I: Current

$$I = \frac{P}{V}$$

By replacing the variable's power with 3 000 AW and voltage with 220 V AC, the current drawn by the 3 000 W element was calculated at 13.63 A. The relay coil required 27 mA to be energized.

3.4.3.2 Ripple Control Transmitter

Throughout the distribution systems, receivers pick up the signal and switch loads or tariffs accordingly. Ripple control is a one-way communication system using the existing distribution network as a communication channel [6]. Ripple control can reduce system overload on the power network when a substantial number of electric water heaters are in use. Ripple control is introduced to shift the load from peak period to off-peak period to improve the load factor. It should be noted that during transmission of the ripple control signal for load factor improvement, the coupling cell connection state should not change [45].

Figure 3.15: Ripple control transmitter R800

The R800 transmitter comprises the following components:

1. Monitoring, control, and communication components
2. Power components with frequency inverter
3. Output transformer
4. Inputs and outputs

The R800 transmitter is part of a ripple control system. It generates the required ripple signal with adequate power for the network injection as shown in Figure 3.15. The R800 is suitable for all common types of ripple control couplings: loose/rigid parallel coupling, serial coupling, and neutral conductor coupling. Up to three couplings per transmitter, four on request. It covers the entire functionality of all the Landis+Gyr transmitter types.

3.5 SUMMARY OF CHAPTER

This chapter presented ripple control as a method of improving the load factor of electric water heaters in residential buildings by shifting the load from peak demand to off-peak. A power alteration model and residential consumer group model was chosen to model and validate the power consumption of EWHs for load control. Consequently, the success of the RC process was satisfied, which indeed determines the methodology development process.

CHAPTER 4:
IMPLEMENTATION OF ADAPTIVE LOAD SHIFTING

4.1 INTRODUCTION

In this chapter, a power alteration model to reduce power consumption by shifting high demand for power from peak to off-peak times will be presented. The RC system was designed based on the power alteration model which includes MPC, MLC, electrical network, and a consumer group. The data was collected from Eskom meters at the Eldoraigne substation to validate how much power was consumed by customers who are connected to the grid. As stated in the previous chapter, the research involves modelling and validation of models. There will be fewer power interruptions on the electrical network by using RC to shift the load from peak to off-peak demand.

This chapter gives an overview of the application of RC to shift the load from peak period to off-peak period to prevent overload causing damage to equipment, or power outages and blackouts of power system networks [46]. If this shift does not take place, the overload may result in major breakdown in the entire network of the power system.

4.2 RIPPLE CONTROL

For this study, ripple control will be utilized to reduce energy consumption during national peak period, and to save consumers money. The R800 transmitter is part of a RC system [47]. It generates the required ripple signal with adequate power for the network injection. Many of the values are critical parameters that should not be amended by the user.

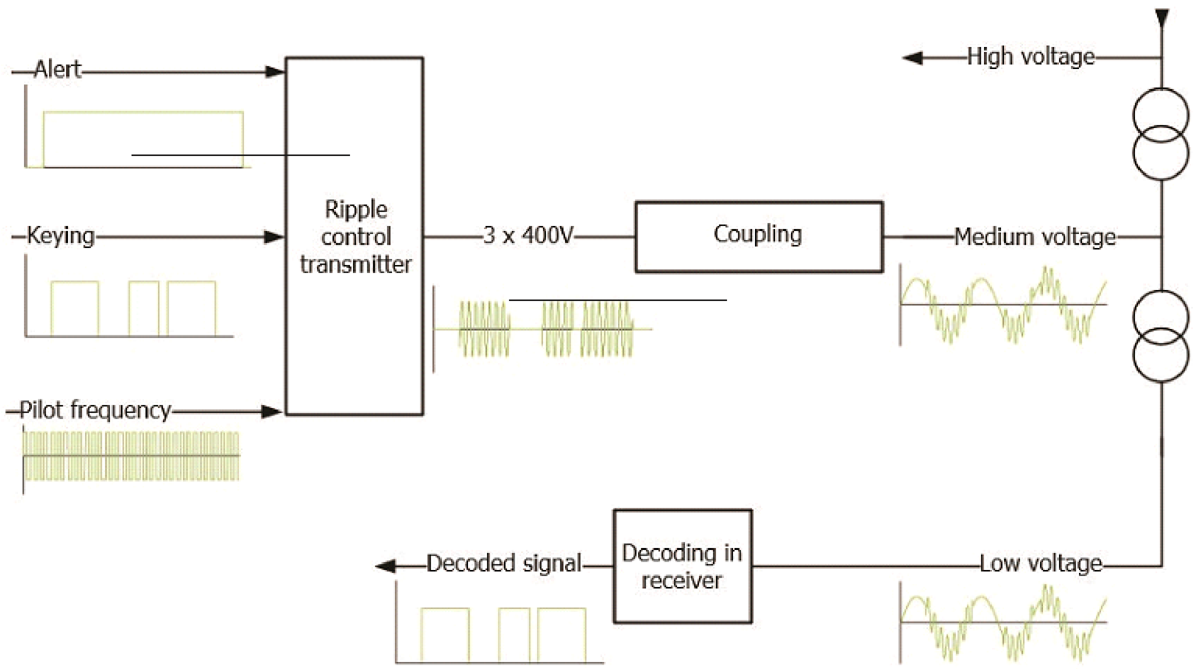

Figure 4.1: Principle of the ripple control message

Source: Researchers own compilation

If a ripple control system comprises more than one transmitter and coupling, synchronization may be necessary, depending on the network situation. If the injection level of the network or the back network (via the next higher voltage level) is tightly coupled, it is necessary to synchronize the installation as shown in Figure 4.1. Synchronization means providing a common pilot frequency to all transmitters so that the message is always injected at the same common frequency and phase relationship. Without this additional equipment, the ripple control signals would interfere with each other in the network and pulses could be amplified or attenuated.

4.3 DESCRIPTION OF TSHWANE DISTRIBUTION SYSTEM

4.3.1 Eldoraigne Substation with Load Control

The Eldoraigne 132/11 kV substation is located in Centurion and falls under the City of Tshwane Municipality. The Eldoraigne substation can supply 40 MVA firm load capacity to Eldoraigne customers. The substation has three 20 MVA Transformers with the three Neutral Earthing Compressor Resistors (NECRs) transformers and the 11 kV switchgears for the two stages (A and B). The third transformer is a reserve transformer (T x R) used for back-up in case one transformer is faulty, and it will keep on idling when the other two transformers are on-load. The integration of the 11 kV switchgear protection, control and Supervisory Control and Data Acquisition (SCADA) are used for protection. The substation is connected with an RC transmitter with a frequency of 425 HZ, which is used to control the load by sending a signal to the EWH receivers when power demand is high during peak periods.

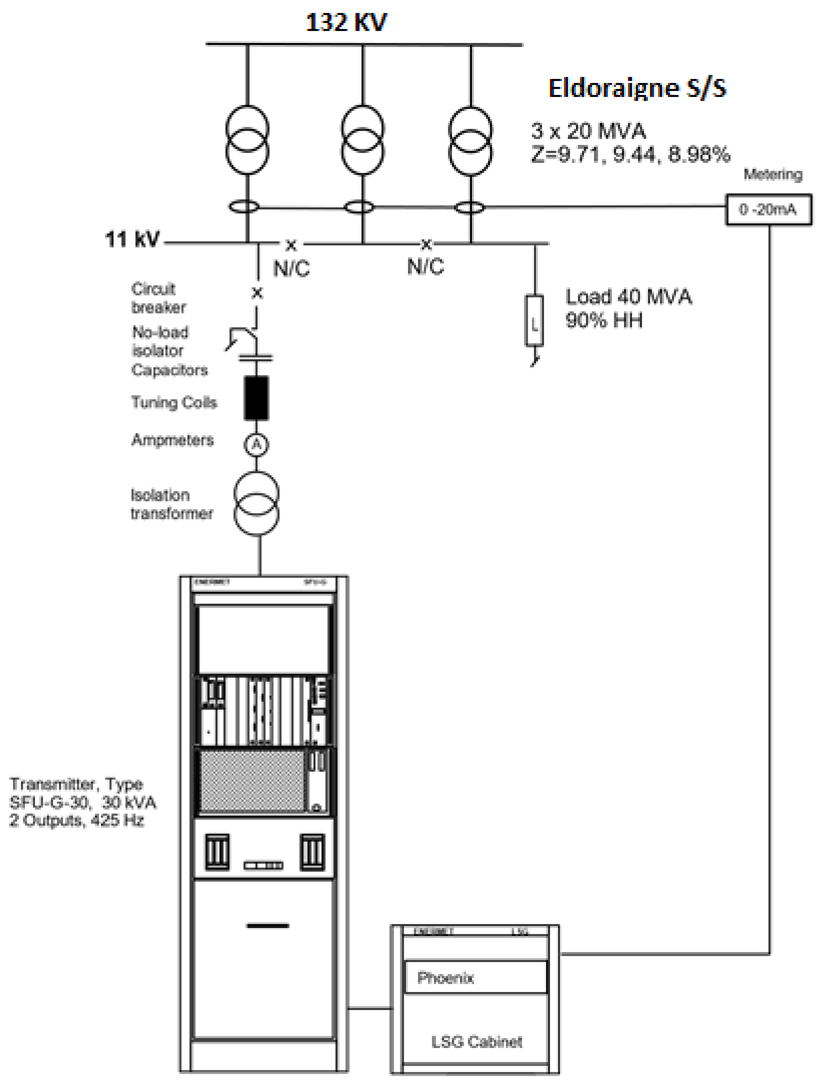

Figure 4.2: Eldoraigne substation with Ripple Control

Source: Researcher's own compilation

Data was collected from municipal meters connected to the Eldoraigne substation and compared with the substation load capacity of 40 MVA as shown in Figure 4.2. If the maximum demand is higher than the load capacity of the substation, an RC algorithm is applied to mitigate the overload of the substation. To switch off electric water heaters the 11 kV busbars need to be injected and a signal will be sent to the receivers. Once the receivers receive the message then it will automatically switch on or switch off a group of electric water heaters.

The City of Tshwane municipality distribution network performs differently during summer and winter seasons. This was observed when the transformers and miniature substations connected to the grid were sometimes overloaded when a notch test was conducted on them, particularly during winter months. During the rainy season, underground cables of the electrical network experience sensitive earth faults and trip the breaker in the secondary substation. During the winter season, the overhead transformers and underground cables experience overload faults caused by the high consumption of electricity of electric water heaters during peak periods. If the power consumption exceeds the rated capacity of the overhead transformer or miniature substation, then the relay will send a message to trip the breaker in the substation. Therefore, the consumers connected to the electrical grid will be affected. So, it is important to control the load to avoid power interruptions on the electrical network.

Table 4.1 Network performance analysis

Panel name	Cable size	No. of miniature substation	CT Ratio	Summer load data (05:00 to 08:00)	Winter load data (15:00 to 08:00)	Summer load data (17:00 to 20:00)	Winter load data (17:00 to 20:00)
P1	95 mm	7 x 500 kVA 6 x 315 kVA	400/1A	315 A	451 A	310 A	462 A
P2	95 mm	5 x 500 kVA 3 x 315 kVA	400/1A	311 A	403 A	316 A	448 A
P4	95 mm	6 x 500 kVA 3 x 315 kVA	400/1A	306 A	462 A	286 A	409 A
P6	95 mm	3 x 500 kVA 7 x 315 kVA	400/1A	289 A	463 A	331 A	364 A
P7	95 mm	5 x 500 kVA 6 x 315 kVA	400/1A	303 A	470 A	300 A	526 A
P8	95 mm	4 x 500 kVA 6 x 315 kVA	400/1A	317 A	501 A	271 A	483 A
P15	95 mm	4 x 500 kVA 9 x 315 kVA	400/1A	305 A	570 A	299 A	590 A
P21	95 mm	5 x 500 kVA 10 x 315 kVA	400/1A	299 A	457 A	300 A	461 A

Source: Researcher's own compilation

Table 4.1 shows the number of panels, cable size, number of miniature substations, current transformer ratio, winter loads and summer loads on the Eldoraigne substation network. The test was conducted during summer and winter season to analyse the performance of the substation. The data was collected on the relays of different panels. The results will assist the Planning section to decide whether Eldoraigne needs to be upgraded or not. It was found that the substation is overloaded due to housing development in the Centurion area. It was also found that all panels in the Eldoraigne substation are overloaded, and the circuit breakers were melting. The substation was overloading due to parallel connection of 132/11 kV transformer. The switchgears in the substation were also blown up due to overload. For the substation to continue supplying power to consumers, the settings were changed to 120% of the fault current level. Panel 15 consumed high current in the morning peak and evening peak, as shown in Table 4.1. The value of the current during the summer season is 305 A in the morning and 299 A in the evening. The value of the current during the winter season is 570 A in the morning and 590 A in the evening. This indicated that there is an overload on Panel 15 of the Eldoraigne substation exacerbated by the use of electric water heaters during peak periods. Based on this evidence, ripple control was applied to control the load in the morning peak and evening peak period.

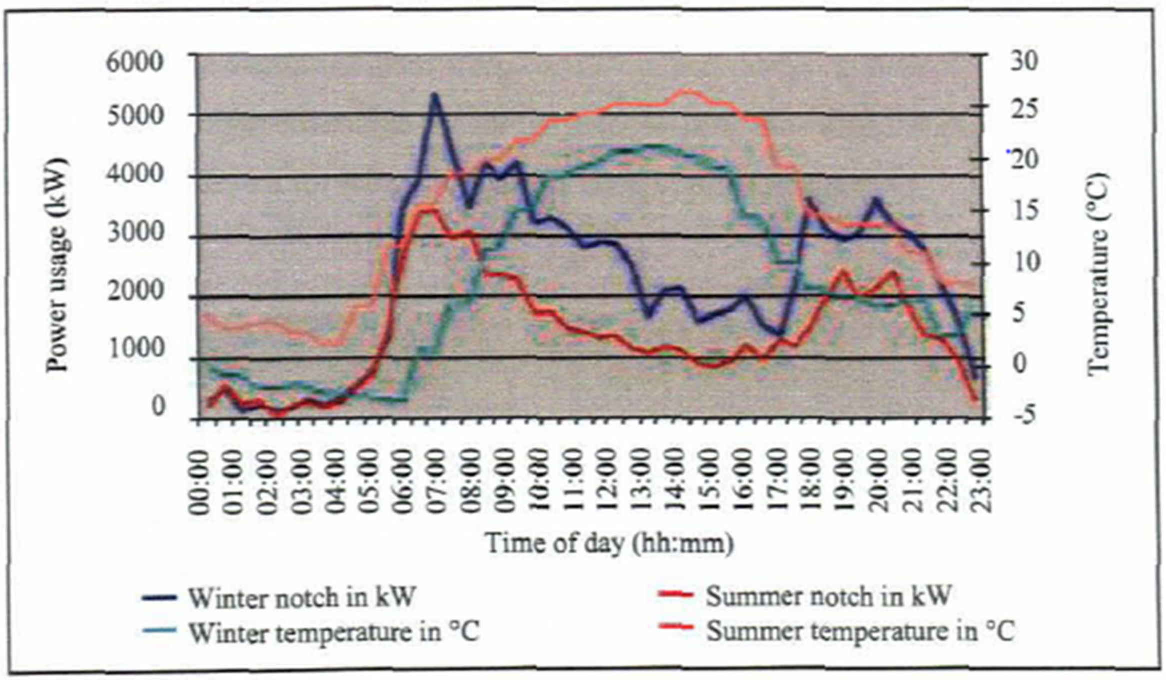

Figure 4.3: Notch test for 2 800 EWHs [10]

Source: Researcher's own compilation

The summer and winter load profiles are shown in Figure 4.3. During winter months the weather is colder, and the average ambient temperature is lower than that of the summer months. The higher power consumption during winter plays an important role. During winter months when it is cold, the water is also cold, and electric water heaters will consume high electric energy from the Tshwane distribution network to heat it during peak periods. During the summer months, when the weather is hot, the water is already warm and to heat it with an electric water heater will consume less electric energy from the Tshwane grid.

4.4 NOTCH TEST AND COLD LOAD PICK-UP TEST

4.4.1 Performance of a ripple control

With the implementation of ripple control, electric water heaters are switched on and off during peak periods or when there is high demand for energy from Eskom. This would help the municipalities mitigate network constraints and overloading and would result in considerable savings to the Eskom account. The load is controlled from the MPC model and MLC model which was discussed in Chapter 3. The signal is sent from the control centre to the receivers so that they can be switched off or on.

MPC control is an integrated approach for effective load management. An MPC controller is installed in the control room, checking the network load, and switching the power on and off. It indicates how much average demand, instant demand, and ideal demand power is used. It also calculates power consumed and required on the electrical network. It supports all standard Ripple Control Codes.

A load profile is used to on day to day operations to measure how much power electric water heaters consume. A load profile can be represented as a graph of variation of electrical load with respect to time. A load profile will vary according to the type of customer (residential, commercial or industrial), the temperature, and the season [48]. A load profile, morning notch and evening notch test were conducted on four consecutive days.

The data obtained for the load profiles is presented in Figures 4.4 to 4.7.

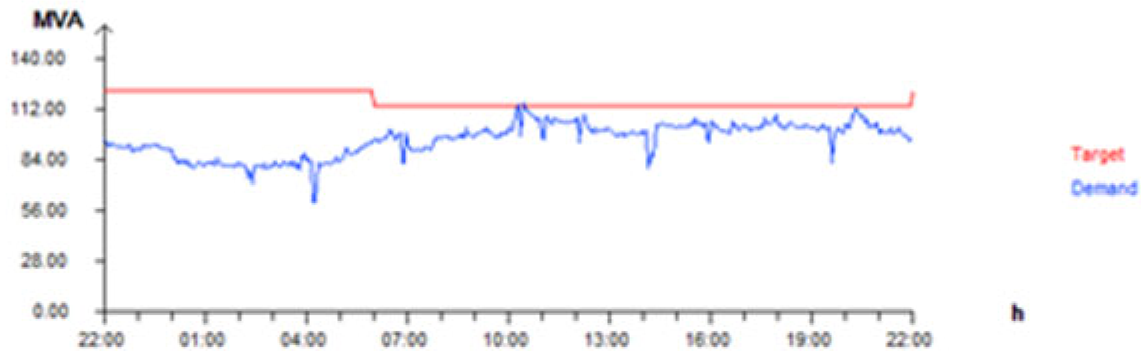

Figure 4.4: Load profile 1, Megaflex control, Monday 18 November 2019Figure 4.4 shows the heating cycles of an electric water heater over a 24-hour period. The maximum power consumed is 112 MVA and is represented by two heating cycles, one from 10:00 to 12:00 and one from 20:00 to 21:00. During the morning peak hours (05:00 to 08:00) the demand is below the target. During the evening peak hours (18:00 to 20:00) the demand reached 112 MVA. During the off-peak day hours (10:00 to 11.00) the demand reached the target of 112 MVA.

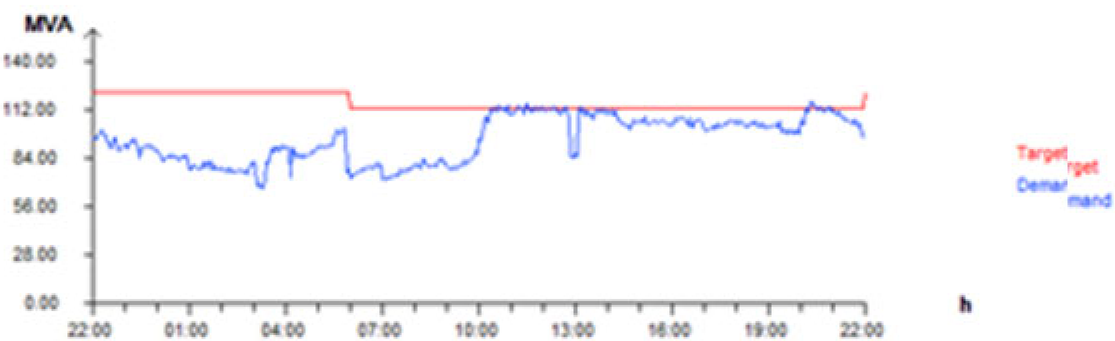

Figure 4.5: Load profile 2, Megaflex control, Tuesday 19 November 2019

Figure 4.5 shows the heating cycles of the electric water heaters over a 24-hour period. The maximum power consumed is 98 MVA and is represented by heating cycles present between time intervals 06:00 to 07:00. The maximum power consumed is 98 MVA and is represented by the heating cycle present from 20:00 to 21:00. During the morning peak hours (05:00 to 08:00) the demand is below the target and during the night peak hours (18:00 to 20:00) the demand is also below the target demand. On the off-peak the demand is beyond the target of 112 MVA during the morning hours (10:00 to 13:00) and evening hours (18:00 to 20:00).

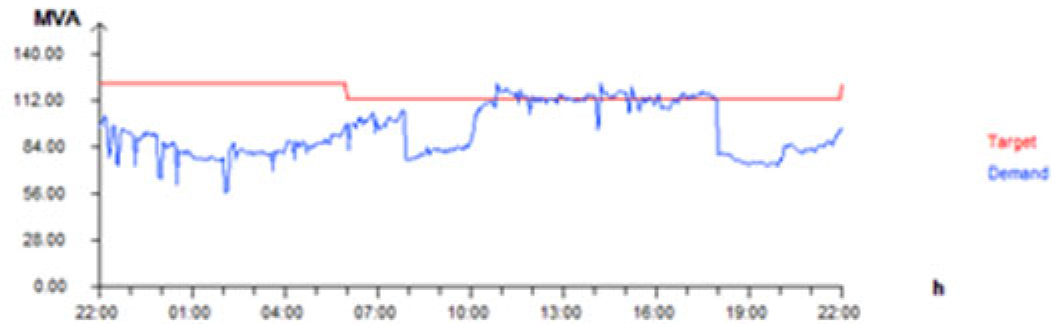

Figure 4.6: Load profile 3, Megaflex control, Wednesday 20 November 2019

Figure 4.6 shows the heating cycles of the electric water heaters over a 24-hour period. The maximum power consumed is 112 MVA and is represented by heating cycles present between time intervals of 06:00 to 08:00. The maximum power consumed is 112 MVA and is represented by heating cycle present between time intervals of 14:00 to 15:00. During the morning peak hours (05:00 to 08:00) the demand is below the target and during the night peak hours (18:00 to 20:00) the demand is also below the target demand. On the off-peak the demand is beyond the target of 112 MVA during the morning hours (10:00 to 13:00) and afternoon hours (14:00 to 16:00).

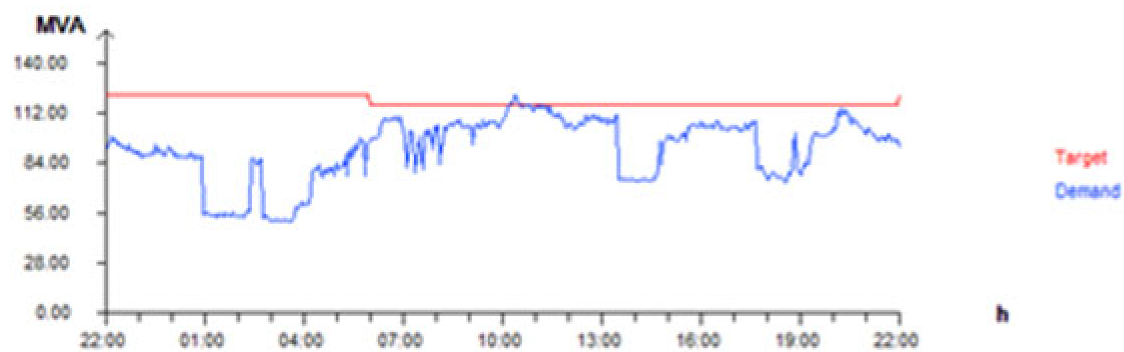

Figure 4.7: Load profile 4, Megaflex control, Thursday 21 November 2019

Figure 4.7 shows the heating cycles of the electric water heaters over a 24-hour period. The maximum power consumed is 120 MVA and is represented by heating cycles present between the time interval from 10:00 to 11:00. The maximum power consumed is 120 MVA and is represented by the heating cycle present between the time interval from 20:00 to 21:00. During the morning peak hours (05:00 to 08:00) the demand is below the target and during the night peak hours (18:00 to 20:00) the demand is also below the target demand. During the off-peak the demand is beyond the target of 112 MVA during the Morning hours (10:00 to 13:00) and evening hours (18:00 to 20:00).

4.4.2 Notch test

The following test equipment was used to conduct the notch test:

a) ENERMET MPC/MSC Controller
b) Existing transmitting equipment
c) Existing metering equipment

The purpose of a notch test is to check how much load is available to help determine how much power is used and how much can be cut. The test is done for a period of 24 hours. The test involves switching all the load control devices off every 30 minutes for five minutes, and then restoring power to EWH elements afterwards. The EWHs that withdrew current before the five-minute notch interval would continue drawing power after the power is restored. If the electric water heaters are hot, the peak becomes high, and if the electric water heaters are colder, the peak becomes smaller. The notch value of power can be used to determine how much power is consumed by EWHs, and how much power can be shifted to off-peak period. The power was switched on and off every 5 minutes to check the power consumption on the power system. Notch testing was done to determine the electric water heater load profile for 2 800 electric water heaters for both winter and summer months. Notch testing means to switch off all EWHs for a short period, whereafter power is restored and they are switched back on. The resulting dip in the load profile is what is called ‘notch’ and characterizes the total capacity of the EWHs for the testing period.

Notch tests were done on weekdays as shown in Table 4.2.

Table 4.2: Notch test schedule

Notch test done on		
18 November 2019	Monday	Weekday
19 November 2019	Tuesday	Weekday
20 November 2019	Wednesday	Weekday
21 November 2019	Thursday	Weekday

Source: Researcher's own compilation

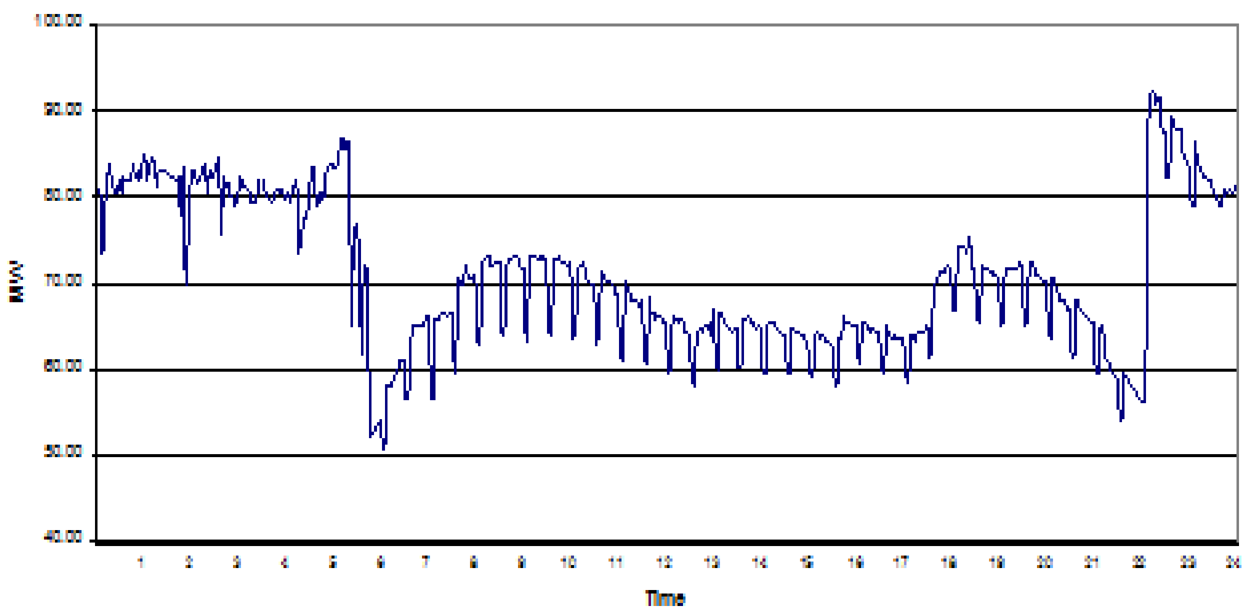

Figure 4.8: Load profile, Monday 18 November 2019

Figure 4.8 shows the heating cycles of the electric water heater over a 24-hour period. The maximum power consumed is 86 MW and is represented by the heating cycle present between the time interval from 03:00 to 05:00 during off-peak hours. The power consumed for the period amounted to 92 MW and is represented by the heating cycle present between 22:00 to 23:00. During the morning peak hours (06:00 to 08:00) the demand was 73 MW and during the night peak hours (18:00 to 20:00) the demand was 75 MW.

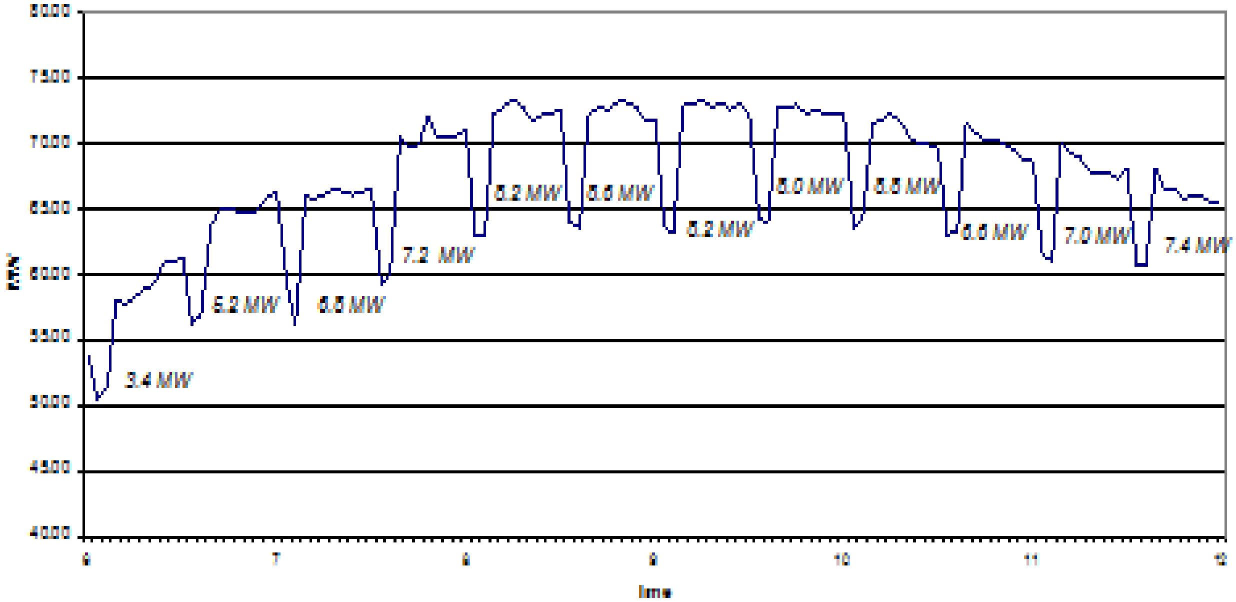

Figure 4.9: Morning notch test, 18 November 2019 Monday

Figure 4.9 shows the heating cycles of the electric water heaters over a 6-hour period. During the morning peak hours (06:00 to 06:30) the notch value was 3.4 MW. When the peak reached 3.4 MW (54 MW – 50.60 MW) indicated when EWHs started to get hot. During the off-peak hours (09:00 to 09:30) the value reached 5.2 MW (61.4 MW – 56.2 MW) which shows that EHWs were hotter, and the maximum demand was high, as shown in Appendix 1.

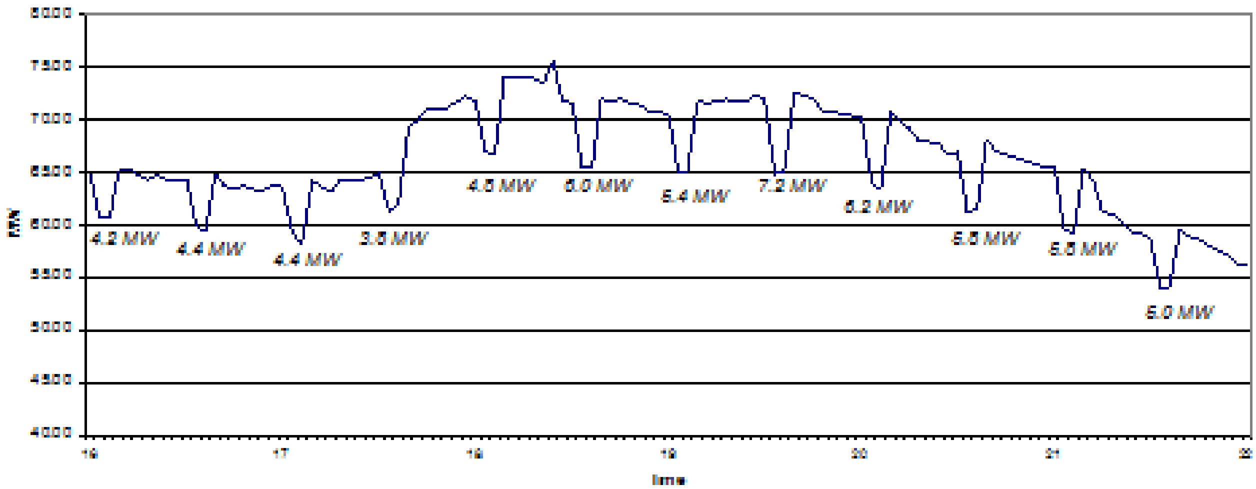

Figure 4.10: Evening notch test, Monday 18 November 2019

Figure 4.10 shows the heating cycles of the electric water heaters over a 6-hour period. During the morning peak hours (16:00 to 16:30) the notch value was 4.2 MW. When the peak reached 4.2 MW (65 MW – 60.8 MW) was when EWHs started to get hot. During the peak hours (16:30 to 17:00) the notch value reached 4.4 MW (64.4 MW – 60 MW) which showed that EHWs are hotter, and the maximum demand was high as shown in Appendix 1.

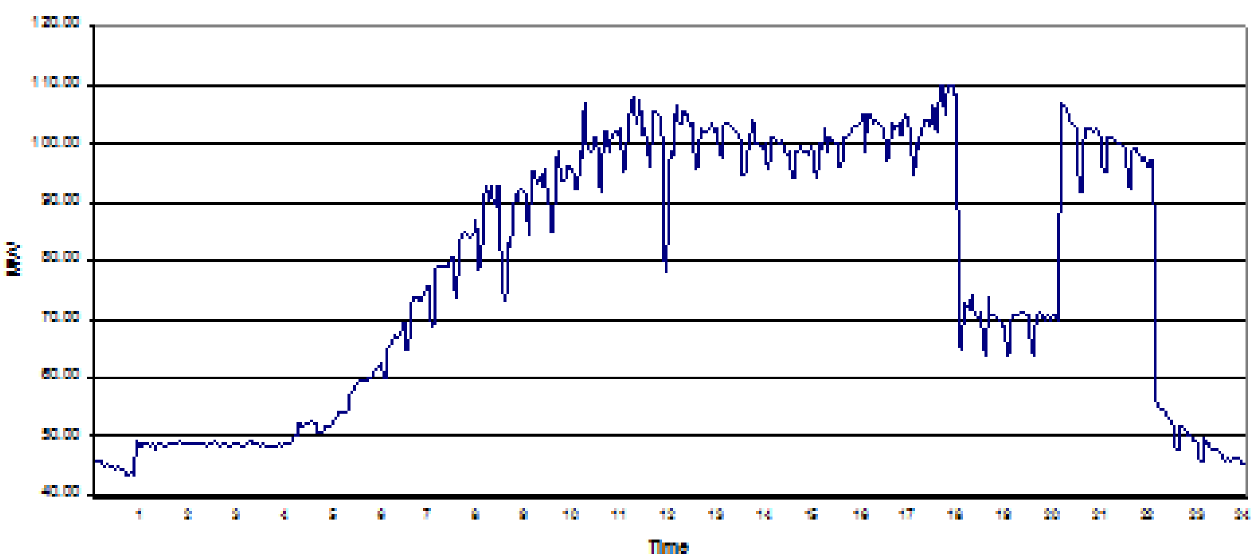

Figure 4.11: Load profile

Figure 4.11 shows the heating cycles of the electric water heaters over a 24-hour period. From Figure 4.11, it can be seen that between 03:00 and 05:00, the average power seems to be 50 MW, hence the consumption in that time period should be 50 MW x 2 hours. The maximum power consumed is 52 MVA and is represented by heating cycles present between 03:00 and 05:00 during off-peak period. The maximum power consumed for the period is 92 MW and is represented by the heating cycle present between 20:00 and 22:00 during off-peak period. During the morning peak hours (06:00 to 08:00) the demand was 75 MW and during the night off-peak hours (18:00 to 20:00) the demand was 74 MW.

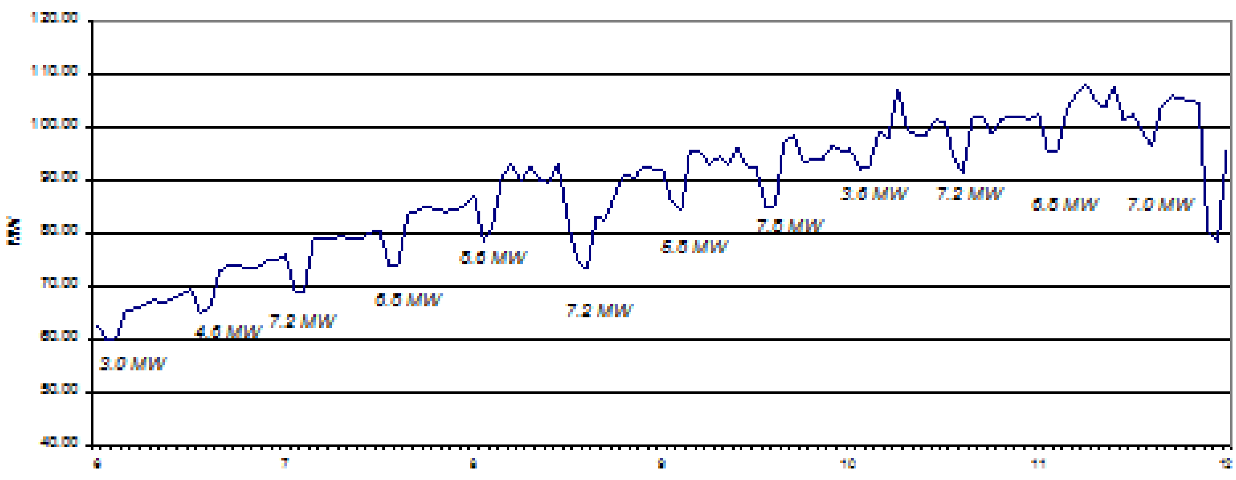

Figure 4.12: Morning notch test, 19 November 2019

Figure 4.12 shows the heating cycles of the electric water heaters over a 6-hour period. During the morning peak hours (06:00 to 06:30) the notch value was 3 MW. When the peak reached 3 MW (62.8 MW – 59.8 MW) was when EWHs started to get hot. During the peak hours (06:30 to 07:00) the notch value reached 4.6 MW (69.4 MW – 64.8 MW) which shows that the EHWs were hotter, and the maximum demand was high as shown in Appendix 1.

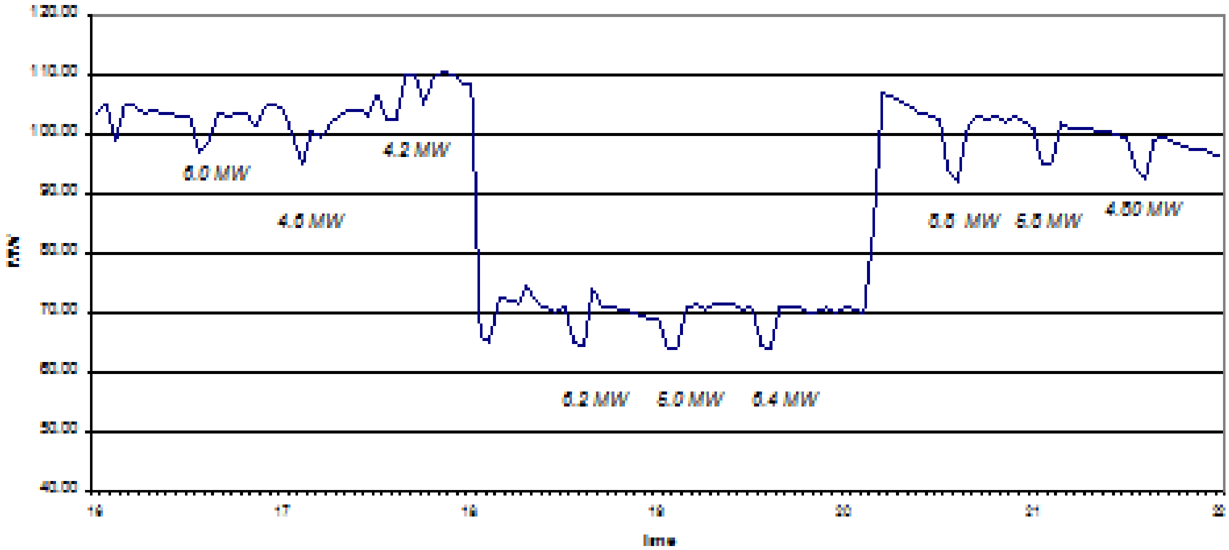

Figure 4.13: Evening notch test, 19 November 2019

Figure 4.13 shows the heating cycles of the electric water heater over a 6-hour period. During the evening peak hours (17:30 to 18:00) the notch value was 5 MW. When the EWHs started to get hot the peak reached 5 MW (104 MW – 97 MW). The maximum demand was high during peak period as shown in Appendix 1.

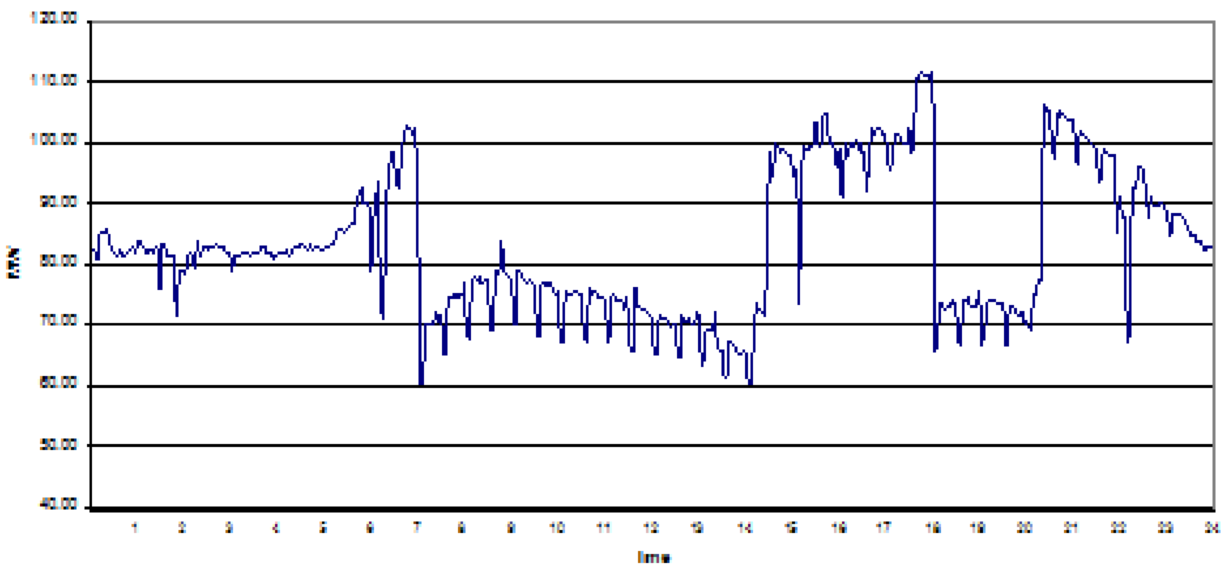

Figure 4.14: Load profile, 20 November 2019

Figure 4.14 shows the heating cycles of the electric water heater over a 24-hour period. The maximum power consumed was 83 MVA and is represented by the heating cycle present between the time interval from 03:00 to 05:00 during off-peak period. The maximum power consumed was 105 MVA and is represented by the heating cycle present in the time interval from 20:00 to 22:00 during off-peak period. During the morning peak hours (05:00 to 08:00) the demand went high to 103 MVA and during the night peak hours (18:00 to 20:00) the demand was 74 MVA.

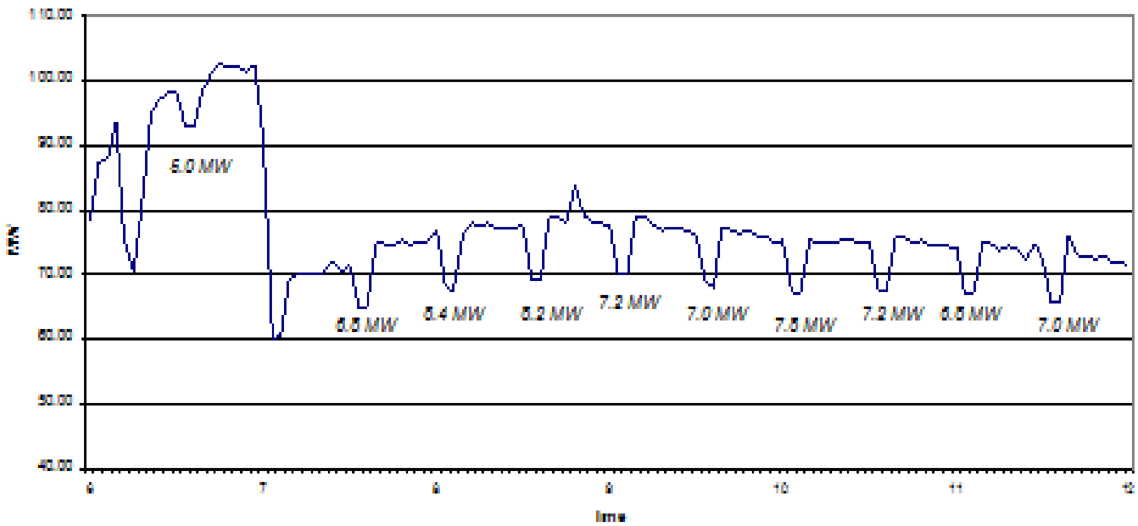

Figure 4.15: Morning notch test, 20 November 2019

Figure 4.15 shows the heating cycles of the electric water heaters over a 6-hour period. During the morning peak hours (06:30 to 07:00) the notch value was 5 MW. When the peak reaches 5 MW (98.2 MW – 93.2 MW) was when EWHs start to get hot as shown in Appendix 1.

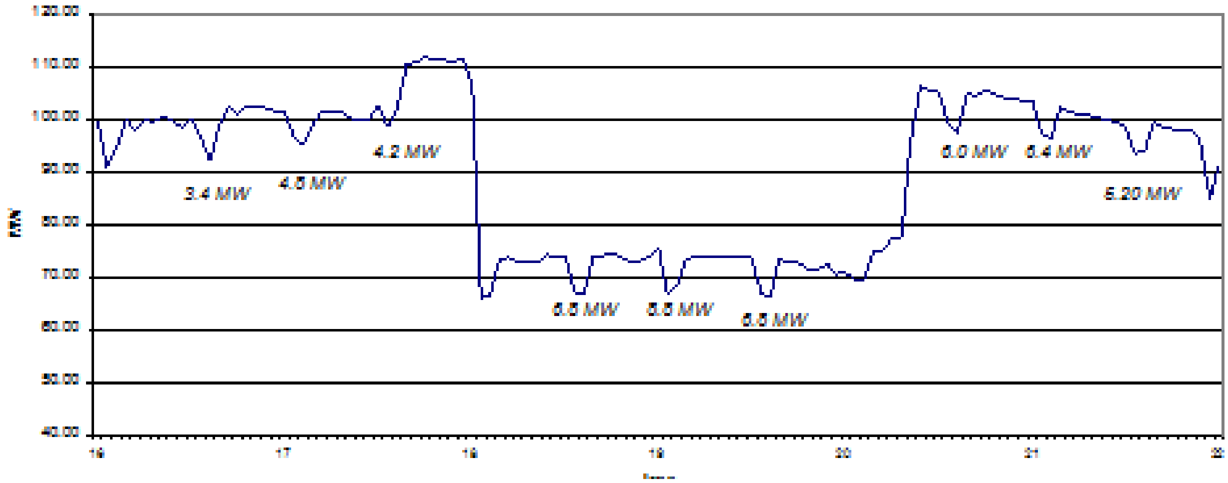

Figure 4.16: Evening notch test, 20 November 2019

Figure 4.16 shows the heating cycles of the electric water heater over a 6-hour period. During the morning peak hours (16:30 to 17:00) the notch value was 3.4 MW. When the peak reach 3.4 MW (100 MW – 96.6 MW) when EWHs starts to get hot during the peak hours as shown in Appendix 1.

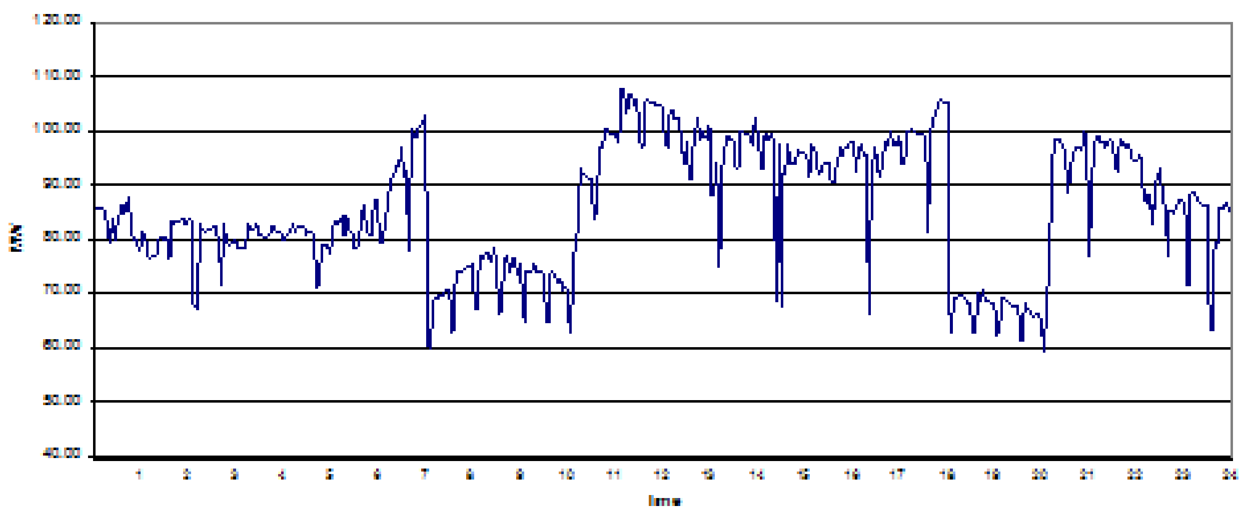

Figure 4.17: Load profile, 21 November 2019

Figure 4.17 shows the heating cycles of the electric water heater over a 24-hour period. The maximum power consumed was 107 MVA and is represented by heating cycle present between time intervals of 11:00 to 13:00 during off-peak period. The maximum power consumed was 100 MVA and is represented by heating cycle present between off-peak time intervals of 20:00 to 22:00 during off-peak period. During the morning peak hours (06:00 to 08:00) the demand was 102 MVA and during the night off-peak hours (18:00 to 20:00) the demand dropped to 70 MVA.

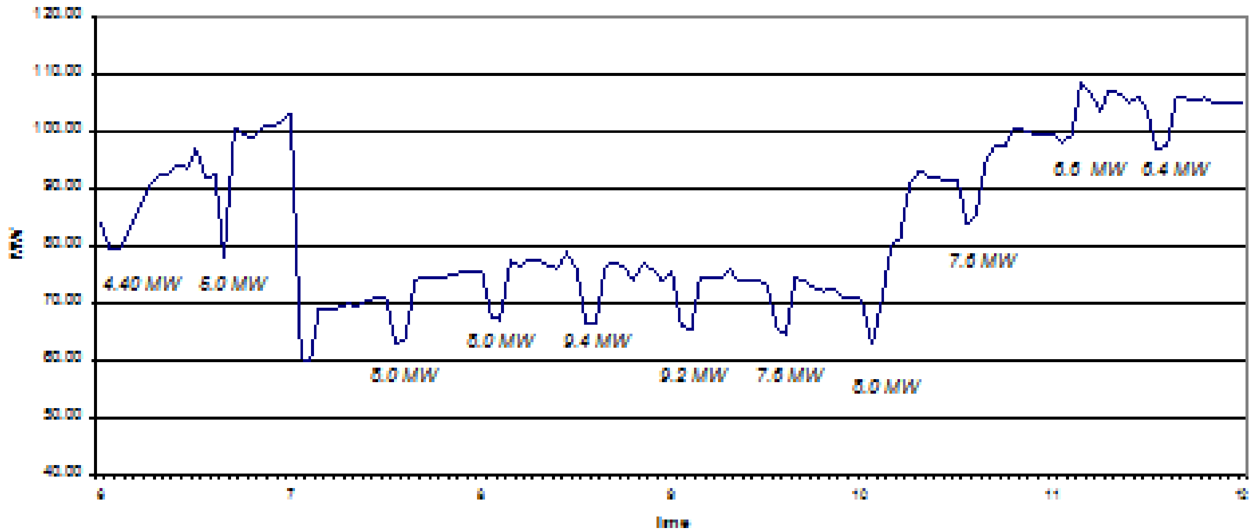

Figure 4.18: Morning notch test, 21 November 2019

Figure 4.18 shows the heating cycles of the electric water heater over a 6-hour period. During the morning peak hours (06:00 to 06:30) the notch value was 4.4 MW. When the peak reaches 4.4 MW (83.6 – 79.2 MW) was when EWHs start to get hot. During the off-peak hours (10:00 to 10:30) the notch value reached 5 MW (96.8 MW – 91.8 MW) which shows that EHWs were hotter, and the maximum demand was high as shown in Appendix 1.

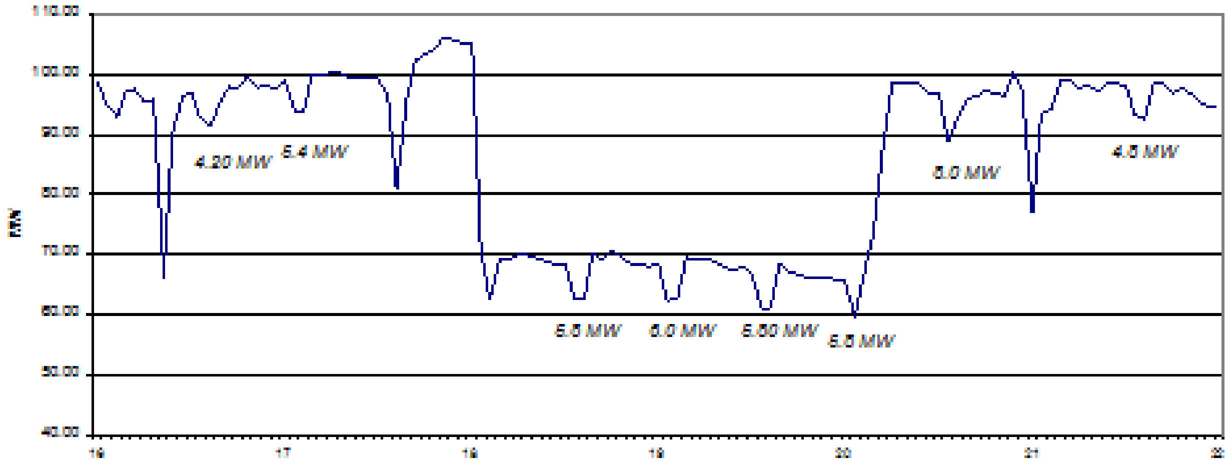

Figure 4.19: Evening notch test, 21 November 2019

Figure 4.19 shows the heating cycles of the electric water heaters over a 6-hour period. During the morning peak hours (16:30 to 17:00) the notch value was 4.2 MW. When the peak reached 4.2 MW (96.8 MW – 92.6 MW) when EWHs starts to get hot during the peak hours as shown in Appendix 1.

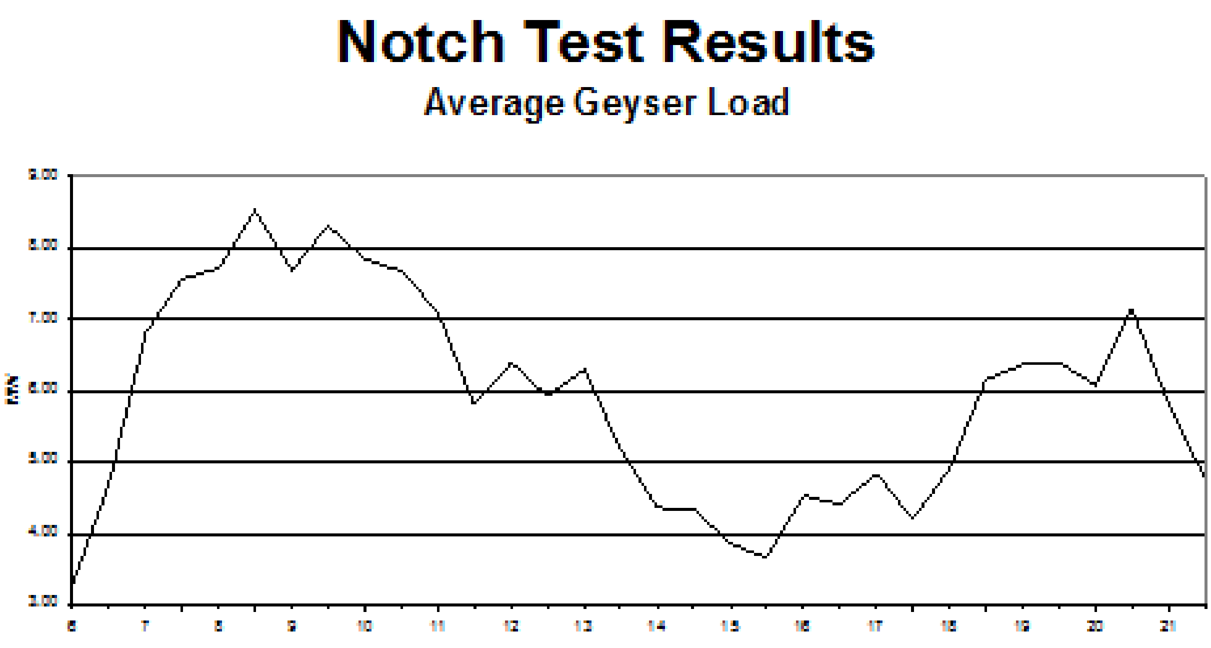

Figure 4.20: Notch test results

Figure 4.20 shows the average half-hourly notch for the 4 days, that was averaged out to give the average EWH load during peak periods. Averages of 3.3 MW, 4.68 MW, 4.53 MW, 4.4 MW and 5.8 MW are outlined in Appendix 1.

4.5 CAPACITY OR COLD LOAD PICK-UP TEST

The purpose of the capacity or cold pick-up test is to check how many electric water heaters are connected to the power system. Capacity or cold pick-up test is when all the electric water heaters on that network are switched off for a minimum of 6 hours. After 6 hours, they are all switched back on and the load in the substation on the protection relay is measured (power measured in kW/ 2.5 kW = no of EWHs connected). All the electric water heaters would have been cold when this takes place. To do a capacity or cold pick-up test, all channels are switched off at 22:00 during the night and switched on at 04:00 in the morning. When the power is switched on, the load will increase, and the load is measured. CLPUs were conducted as indicated in Table 4.3.

Table 4.3: Capacity or cold load pick-up test schedule

Capacity or Load Pick-up tests done		
24 November 2019	Sunday	Weekend
25 November 2019	Monday	Weekday
26 November 2019	Tuesday	Weekday
27 November 2019	Wednesday	Weekday
28 November 2019	Thursday	Weekday
29 November 2019	Friday	Weekday

Source: Researcher's own compilation

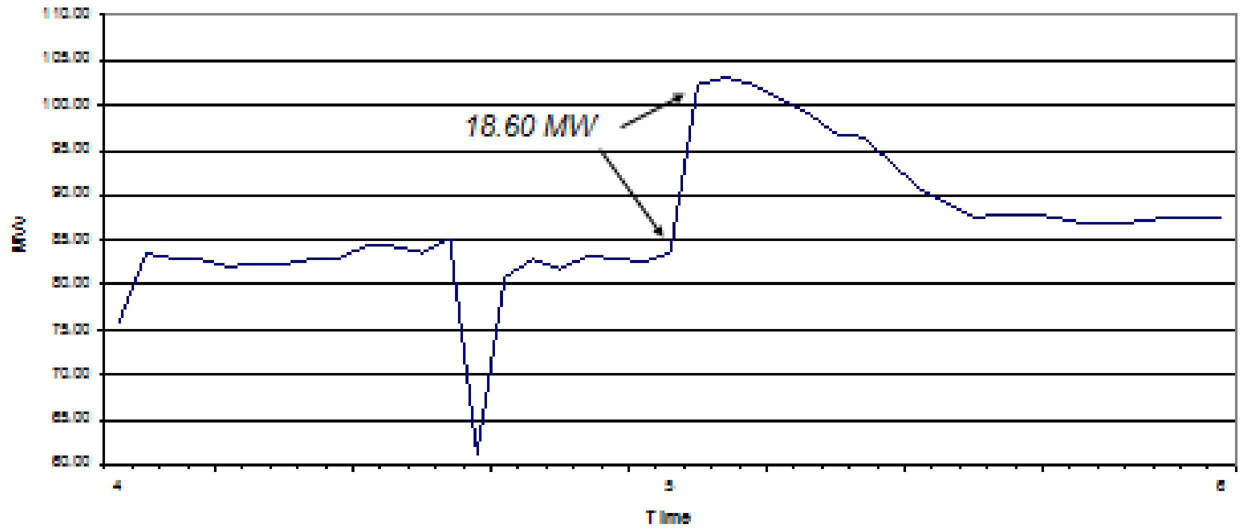

Figure 4.21: Cold load pick-up, 24 November 2019

Figure 4.21 shows the heating cycles of the electric water heater over a 2-hour period. The power consumed for the period measured from 85 MWh during peak period (04:00 to 05:00) to 103.60 MWh during peak period (05:00 to 06:00). After the electric water heaters were switched on, the demand was increased by 18.6 MWh, as shown in Figure 4.21. Electric water heaters were off from 04:00 to 05:00 and they were energized from 05:00 to 06:00 as shown in Appendix 2.

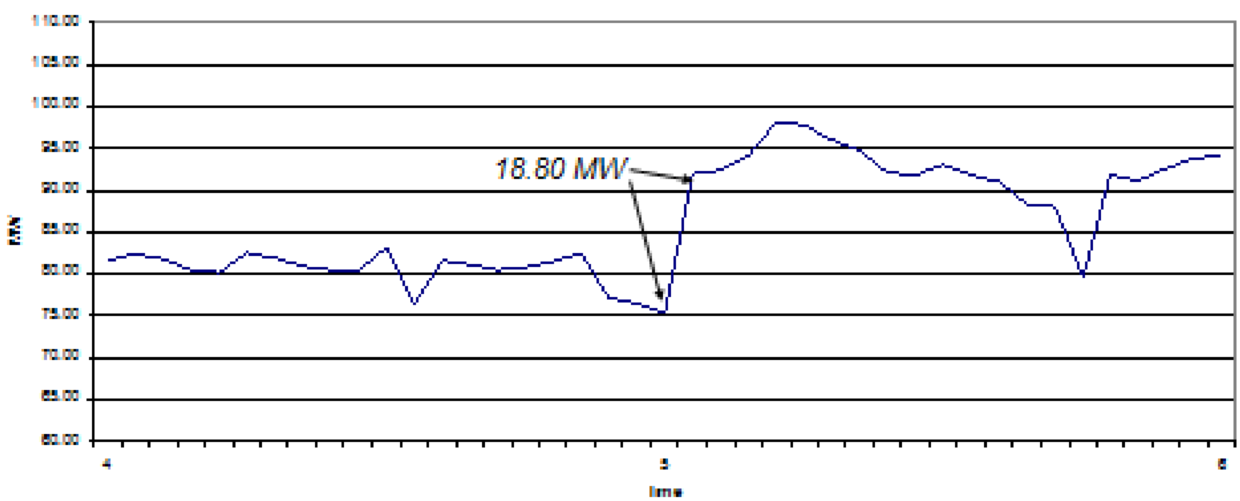

Figure 4.22: Cold load pick-up, 25 November 2019

Figure 4.22 shows the heating cycles of the electric water heaters over a 2-hour period. The power consumed for the period increased from 75 MWh during peak period (04:00 to 05:00) to 93.80 MWh during peak period (05:00 to 06:00). After the electric water heaters were switched on the demand was increased by 18.80 MWh. Electric water heaters were off from 04:00 to 05:00 and they were energized from 05:00 to 06:00 as shown in Appendix 2.

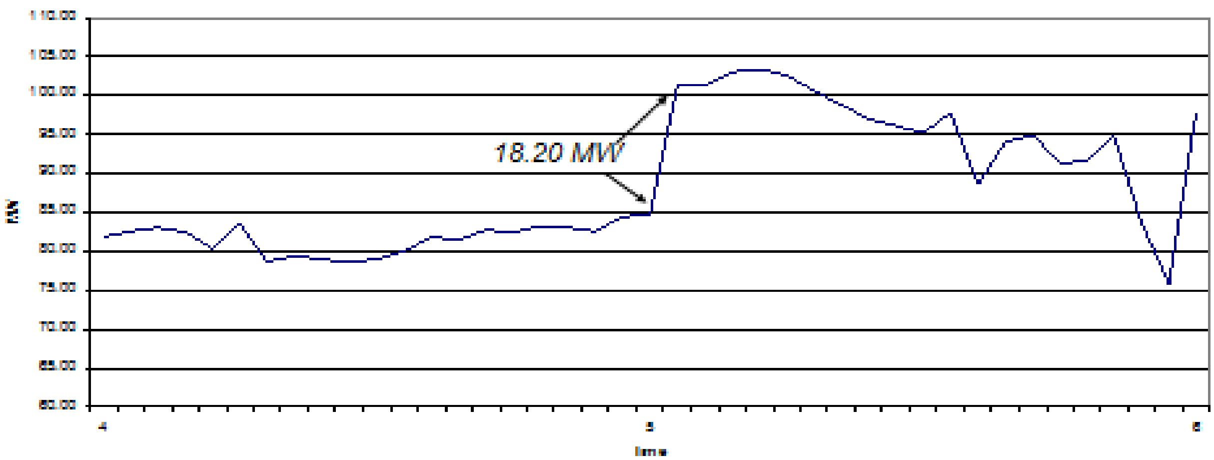

Figure 4.23: Cold load pick-up, 26 November 2019

Figure 4.23 shows the heating cycles of the electric water heaters over a 2-hour period. The power consumed for the period measured from 85 MWh during peak period (04:00 to 05:00) to 103.20 MWh during peak period (05:00 to 06:00). After the electric water heaters were switched on the demand was increased by 18.20 MWh. Electric water heaters were off from 04:00 to 05:00 and they were energized from 05:00 to 06:00 as shown in Appendix 2.

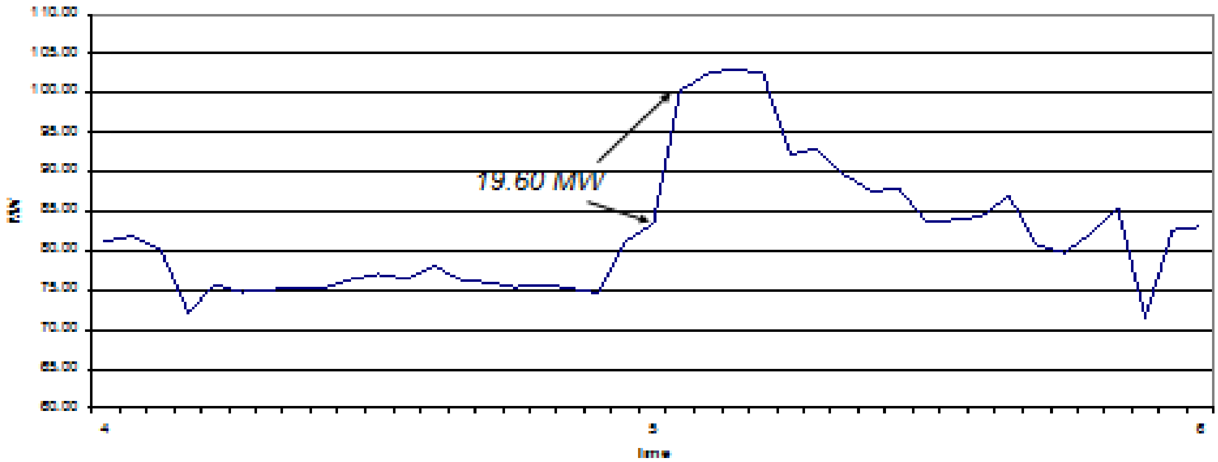

Figure 4.24: Cold load pick-up, 27 November 2019

Figure 4.24 shows the heating cycles of the electric water heaters over a 2-hours period. The maximum power consumed for the period measured from 84 MWh during peak period (04:00 to 05:00) to 103.60 MWh during peak period (05:00 to 06:00). After the electric water heaters were switched on the demand was increased by 19.60 MWh. Electric water heaters were off from 04:00 to 05:00 and they were energized from 05:00 to 06:00 as shown in Appendix 2.

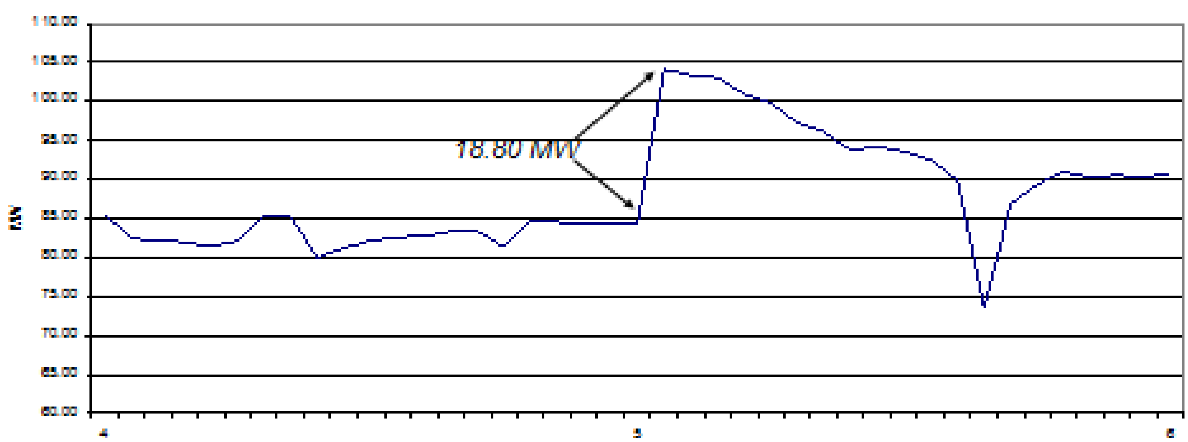

Figure 4.25: Cold load pick-up, 28 November 2019

Figure 4.25 shows the heating cycles of the electric water heaters over a 2-hour period. The maximum power consumed for the period measured from 86 MWh during peak period (04:00 to 05:00) to 104.80 MWh during peak period (05:00 to 06:00). After the electric water heater were switched on, the demand was increased by 18.80 MWh.

Electric water heaters were off from 04:00 to 05:00 and they were energized from 05:00 to 06:00.

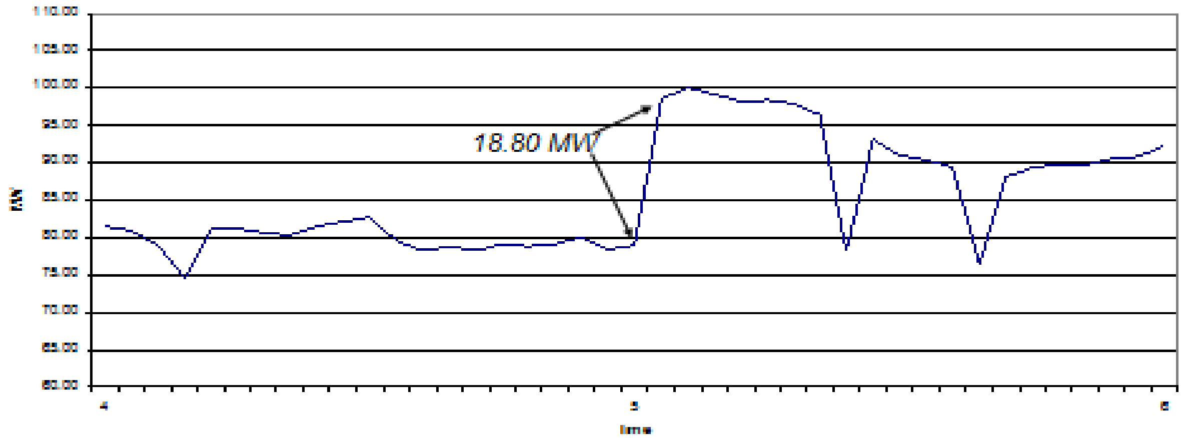

Figure 4.26: Cold load pick-up, 29 November 2019

Figure 4.26 shows the heating cycles of the electric water heater over a 2-hour period. The maximum power consumed for the period measured from 82 MWh during peak period (04:00 to 05:00) to 100.80 MWh during peak period (05:00 to 06:00). After the electric water heaters were switched on, the demand was increased by 18.80. Electric water heaters were off from 04:00 to 05:00 and they were energized from 05:00 to 06:00 as shown in Appendix 2.

The average of all the cold load pick-up tests is depicted in the form of the graph in Figure 4.27:

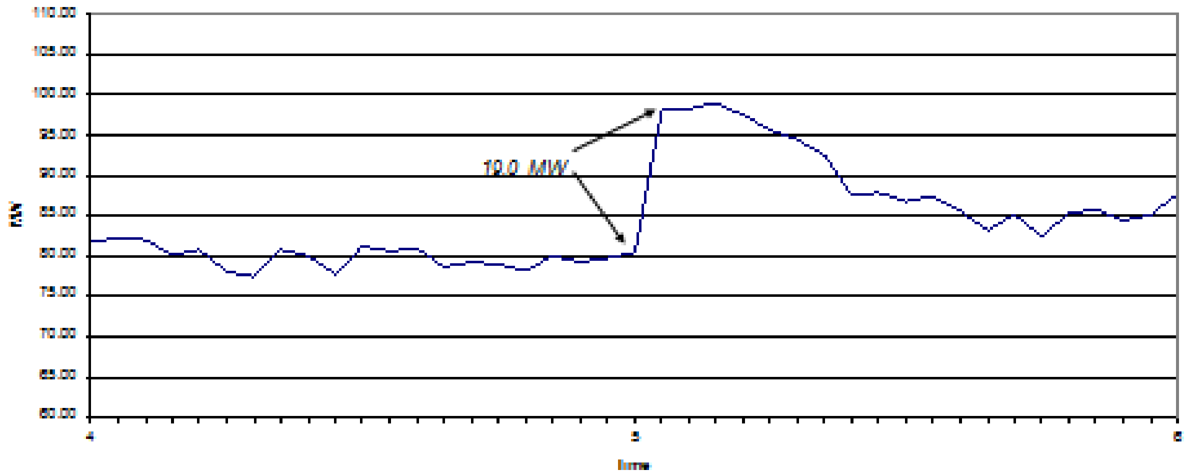

Figure 4.27: Average cold load pick-up

Figure 4.27 shows the heating cycles of the electric water heater over a 2-hour period. The average cold load pick-up for the period amounted to 80 MWh during peak period (04:00 to 05:00) to 99 MWh during peak period (05:00 to 06:00). After the electric water heaters were switched on, the demand was increased by 19 MWh. Electric water heaters were off from 04:00 to 05:00 and they were energized from 05:00 to 06:00.

Table 4.4: Cold load pick-up tests

Day	Date	Power (MW)
Sunday	24 November 2019	18.60
Monday	25 November 2019	18.80
Tuesday	26 November 2019	18.20
Wednesday	27 November 2019	19.60
Thursday	28 November 2019	18.60
Friday	29 November 2019	20.20
		19.00 Average power

Source: Researcher's own compilation

Table 4.4 indicates the schedule that was followed to conduct the cold load pick-up tests. Electric water heaters were tested over a period of 24 hours and results were recorded. The average power for six days is also recorded on the table.

Table 4.5: Number of electric water heaters operating

Determination of number of operating Geysers			
Assumption	Average Geyser size (kW)	Average Notch Value (MW)	Estimated no. of controlled
1	1.50	19	12667
2	2.00	19	9500
3	2.50	19	7600
4	3.00	19	6333

Source: Researcher's own compilation

Table 4.5 shows the number and size of electric water heaters connected in residential buildings. The average notch value is 19 MW for 1.5 kW, 2 kW, 2.5 kW and 3 kW water heaters. The estimated number of 1.5 kW EWHs controlled is 12 667, 2 kW is 9 500, 2.6 kW is 8 000 and 4 kW is 6 333. It was noted that in the townships most consumers make use of 1.5 kW EWHs and in the suburbs most consumers make use of 3 kW EWHs. Semi suburbs of the municipality make use of 2 kW and 2.5 kW EWHs.

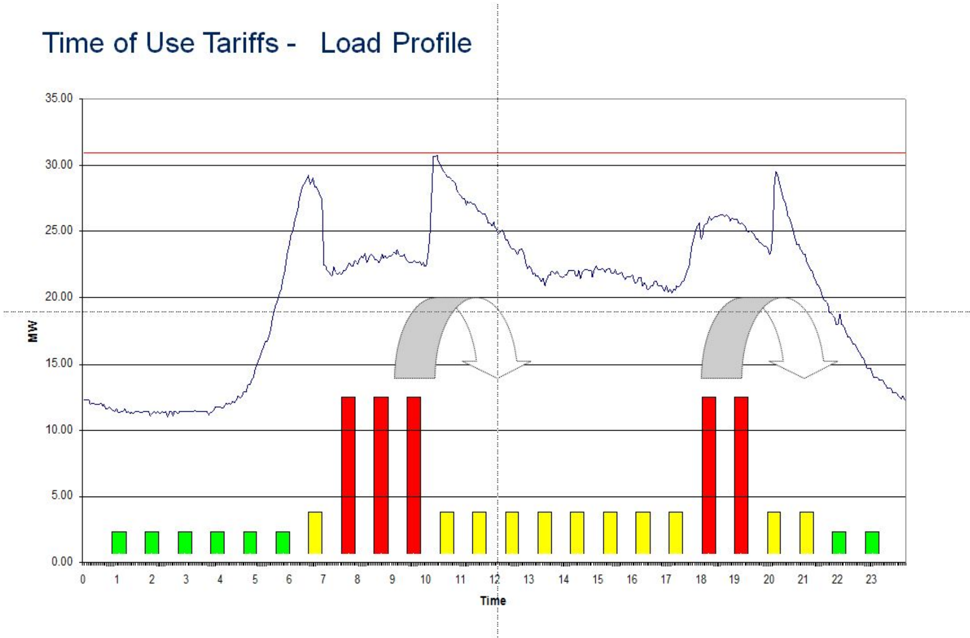

Figure 4.28: TOU Tariffs

Source: Researcher's own compilation

In Figure 4.28 the load was shifted from peak periods to off-peak periods. The maximum demand is 31 MW as indicated in red. From 06:00 to 09:00 the power decreased from 29 MW to 23 MW during peak periods. From 09:00 to 14:00 power decreased from 31 MW to 21 MW and increased from 23 MW to 30 MW during off-peak periods. This result indicated that ripple control was successful in shifting the load from peak demand periods to off-peak periods to avoid overload and ensure that the municipality saves money.

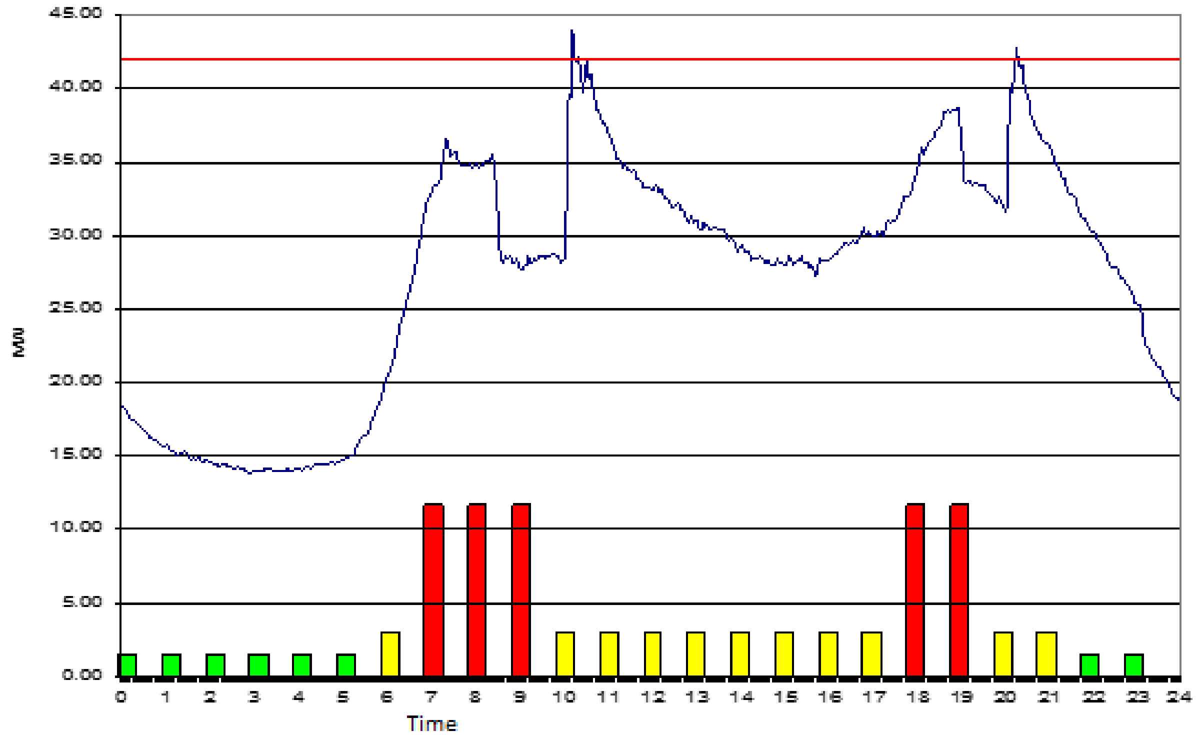

Figure 4.29: Controlled EWH with ripple control

Source: Researcher's own compilation

As shown in Figure 4.29, the load was shifted from peak periods to off-peak periods. The maximum demand is 42 MW indicated in red. From 06:00 - 08:00 the power decreased from 32 MW to 30 MW during peak periods. From 10:00 - 10:30 the power increased from 27 MW to 44 MW and increased from 33 MW to 43 MW during off-peak periods. This once again illustrates that the use of ripple control can shift the load from peak demand periods to off-peak periods to avoid overload and ensure that the municipality saves money.

Table 4.6: Controlled load

Load control		
Lower peak	**Higher peak**	**Power controlled**
27 MW	44 MW	17 MW
40 MW	42 MW	2 MW
Total load controlled: 19 MW		

Source: Researcher's own compilation

4.6 THE IMPLEMENTATION OF RIPPLE CONTROL

It has been shown from various studies done in S.A. [21] that the system peak occurs during the peak tariff period. The after diversity of EWHs during peak period is approximately 70% since the Time of Use (TOU) peak window is longer than the system peak.

Assuming that the average diversity during the time of control is half of the known peak value of 35%. From existing load control experience, it is known that EWHs can be switched off for 2 to 3 hours without any inconvenience to consumers. The cost impacts assume that the energy that is shifted out of the morning period is restored from 09:00 onwards in winter and 10:00 onwards in summer, and the energy that is shifted out of the evening period is restored after 19:00 in winter and 20:00 in summer.

In other words, the procurement of energy from Eskom is optimised.

Total Annual Savings = High season + Low season

Total Annual Savings = R 798 974 + R 650 641

= R 1 449 615 excl. VAT per 1 000 EWHs

equating to R 1 449 per consumer per year as shown in Table 2.2 of Chapter 2.

If we accumulate these savings with the NERSA approved increases announced in March 2019 plus the existing 3% under-recovery increase, we achieve a saving of R 7.1 M per 1 000 EWHs over 4 years, as shown in Table 4.7:

Table 4.7: Yearly escalation and accumulated savings

Year	Escalation	Savings	Accumulated Savings
2020	9.4%	R 1 600 016	R 1 600 016
2021	8.1%	R 1 741 000	R 3 341 000
2022	5.2%	R 1 836 000	R 5 177 000
2023	5.2%	R 5 177 000	R 7 114 000

Source: Researcher’s own compilation

Table 4.7 illustrates the possible energy and maximum demand savings. Many years of experience with load control have proven that the feasibility is excellent. These calculations show that by using a modern ripple control, the City of Tshwane could reduce their purchases from Eskom and save themselves and their customers money. A capacity test has revealed that Centurion has 8 000 receivers to operate. Based on 8 000 receivers, the annual saving on the municipality's Eskom account is over R 11 592 000 per year at today's tariff. This provides evidence that the application of such a system is essential. For the purposes of this study, RC was applied to the Eldoraigne substation during peak periods when the consumption is high and the network overloaded.

The advantages of RC can be summarized as follows:

a) Fast, reliable signals

b) Cost effective: low cost per installed point, savings on electricity costs

c) Municipalities make use of their own existing communications infrastructure and have no reliance on external service providers

d) High degree of 'tamper-proofness' – signal cannot be easily shielded or replicated.

Ripple control improves the load factor of distribution networks by mobilizing hidden reserves. Ripple controls are used by municipalities or sub-vending customers of municipal DSM to control the loading effect of electric water heaters in the residential areas. The main purpose of the ripple relay is to shift the heating load of electric water heaters out of peak demand times. This is done by switching off the electric water heaters to multiple homes for short periods during these peak demand times. Command signals are sent to the ripple relays via the distribution network (mains) or by radio frequency, switching the electric water heaters either on or off. The command signals for the relays are sent from the control centre, via the substation, to the consumer's home. Ripple controls need to be managed correctly because they may cause additional load peaks.

Ripple control can reduce electricity bills. A ripple control system consists of a transmitter to generate a frequency; a coupling cell to allow the frequency to superimpose on the 11 kV network, and a load control regulator to monitor maximum demand and energy usage from the transducer or power utility meter. Check-back signals ensure that signals are operating on the electrical network. Ripple control receivers are installed indoors, connected to controllable loads such as electric water heaters and air conditioners, and are installed outdoors, connected to loads such as streetlights and swimming pool pumps.

4.7 IMPLEMENTATION OF RIPPLE CONTROL FOR THE TSHWANE DISTRIBUTION NETWORK

The research focuses on the Eldoraigne substation, which is comprised of Hennopspark and Wierda Park in Centurion. The supply area is fed by the Eldoraigne substation from the Rietvlei substation 132/11 kV through radial of two circuit 132 kV power lines. The substation consists of 3 x 20 MVA transformers connected from the GIS (Gas Insulated Switchgear) 132 system. The substation has a firm capacity of 40 MVA and fully installed capacity of 60 MVA. The total power consumption by Eldoraigne substation in November 2019 was 52 MVA which is 30% above the firm capacity. This is an identified risk for overload placed on both 20 MVA transformers. The overload could rather be prevented before breakers and cables begin to melt, by using ripple control, injecting 11 kV busbars, and switching off the receivers on the LV customer side. Load control of EWHs is a reaction on the LV network that delivers control of peak demand benefits to the MV and HV networks (bottom-up approach, not top-down). Ripple control investments have a long life expectancy, over which time a variety of distribution constraints and investment needs will emerge across various parts of the supply network.

Electric water heaters are switched on and off during peak times or when there is high demand for energy from Eskom. This would help City of Tshwane with network constraints or network overloading with considerable savings to the Eskom account (see Table 1.2 savings under feasibility report on savings).

Tshwane can operate the ripple control system for several reasons, especially economic reasons. As shown on the attached Eskom tariff Table 2.2 of Chapter 2, Tshwane is charged an energy charge varying from 330.85 c/kWh in winter peak period to 47.12 c/kWh in summer off-peak. The ratio of highest to lowest is 7 to 1. This gives The City of Tshwane considerable scope for reducing payments to Eskom, providing purchases during the expensive periods can be minimized, and purchases during the cheaper periods maximized. The maximum demand component of the account is made up of the Network Demand Charge, Network Capacity Charge and Transmission Network Charge and totals R 42.08 /kW irrespective of summer or winter.

Since the peak consumption of the City of Tshwane is in the mornings and evenings when Eskom charges peak tariffs, the City of Tshwane can respond to these pricing signals sent by Eskom to reduce consumption. This in turn reduces the maximum demand costs. By using a ripple control system, it is possible to choose when to use energy from Eskom and therefore at what cost.

4.8 CHAPTER SUMMARY

This chapter illustrated the modelling and validation of a ripple control model. The results indicated that ripple control can successfully be used to shift the load from peak demand to off-peak demand, resulting in fewer electrical interruptions to residential buildings. By using a modern ripple control, local municipalities and metropolitan municipalities could minimize their purchases from Eskom.

CHAPTER 5:
CONCLUSION AND FUTURE WORK

5.1 INTRODUCTION

Electric water heaters form part of power systems. However, system operators experience a high volume of overload during peak periods. In response to this, there have been several attempts to mitigate overload. The aim of this dissertation was to study the use of a Ripple Controller as a mechanism for shifting the load from peak demand to off-peak demand. Load shifting (LS), load control (LC), EWH load control or load reduction (LR) could improve the load factor (LF). The prime objective of a load control scheme is to do energy shifting and avoid demand peaks.

This study has concluded that RC is an effective method of shifting the load from peak demand to off-peak demand. This study has confirmed that good performance results can be obtained by using RC, appropriately tested, using validated data.

The objectives have been achieved, the performance of RCs have been examined, and detailed within the dissertation. One of the influences not fully examined is that of load shedding determination via RC, primarily due to time constraints of this research project.

Ripple control has many applications, but diligent care is needed in data preparation and formulation. Ripple control is a one-way communication system using the existing distribution network as a communication channel. All electricity consumers, residential, commercial, and industrial, benefit from demand reduction. The infrastructure would be more reliable and there would be fewer power outages, less load shaving (LS) and demand reduction (DR), if consumer participation is successful.

One of the challenges experienced was that not all the objectives could be achieved, particularly influenced by load shedding. However, the basic principle of applying RC to shift the load from peak demand to off-peak demand has been illustrated. Extending these results to the determination of load shedding would consist of preparing appropriate data, based upon the power blackouts and this information could then be used to test the RC accordingly.

Performance results show that the application of ripple control as an adaptive scheme for improvement of load factor of water heater loads in residential buildings is feasible**.**

5.2 FUTURE WORK

Future work will focus on better understanding the influence of data, and of minimizing the amount of data necessary to perform good RC design. In addition, we would also like to investigate the performance of RC on real hardware such as embedded systems, to analyse the processing speed performance of RC. The determination of load shedding via RC is reserved as a future study with its manifold applications.

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APPENDIX 1: NOTCH TEST RESULTS

Notch tests				
Mon	**Tue**	**Wed**	**Thu**	**Fri**
18-Nov-19	**19-Nov-19**	**20-Nov-19**	**21-Nov-19**	**22-Nov-19**
81,00	45,80	82,40	85,40	82,00
80,20	45,80	82,20	85,80	82,00
73,60	46,00	80,60	85,60	81,80
79,60	45,20	85,00	85,40	80,80
81,40	45,00	85,40	85,40	80,80
83,80	45,40	85,20	81,40	77,20
81,80	45,00	85,80	79,40	80,60
80,60	44,60	84,40	84,00	81,40
80,60	44,40	82,40	80,00	81,00
82,00	44,60	82,00	83,80	80,40
80,40	44,60	81,40	85,00	80,20
82,40	44,20	81,80	86,60	81,40
82,00	44,40	82,40	84,60	81,40
82,00	43,60	81,20	86,40	81,20
82,00	43,60	81,40	87,80	81,20
83,80	43,80	82,00	81,80	80,40
82,60	43,60	82,20	80,00	80,60

	83,20	49,20	82,80	80,00	80,20
	81,80	49,00	82,00	77,80	82,40
1	83,80	48,00	82,20	78,00	80,00
	85,20	48,80	84,00	81,40	79,20
	82,00	48,80	83,40	80,20	78,60
	84,00	48,60	82,80	77,20	79,60
	84,80	48,20	81,60	76,60	79,20
	83,00	48,60	82,60	77,00	79,00
	81,20	48,00	82,40	77,00	79,20
	83,00	48,80	82,00	77,60	79,40
	83,40	48,40	83,00	80,40	78,60
	83,00	48,60	82,40	80,80	79,20
	82,80	48,20	75,80	80,00	78,80
	82,60	48,60	83,60	80,60	80,40
	82,60	48,60	82,60	76,20	83,60
	82,40	48,80	81,20	83,60	82,80
	81,80	48,60	81,80	82,80	82,00
	82,40	49,00	81,20	83,60	83,40
	78,00	49,40	81,80	83,20	81,20
	83,80	48,80	71,60	83,80	81,40
	69,80	48,80	78,20	83,80	81,00
	75,00	48,60	79,20	82,40	81,40
2	81,80	49,00	78,40	83,80	81,20
	83,20	49,20	79,20	83,40	82,60
	83,00	48,60	81,60	68,20	81,40

	81,40	49,00	81,80	67,20	82,40
	82,20	48,80	80,20	67,00	81,60
	82,80	48,80	79,40	83,00	81,20
	84,20	48,60	83,80	82,00	79,80
	80,60	48,20	81,60	81,60	80,80
	83,00	48,80	82,60	82,00	80,40
	82,20	48,60	82,60	82,00	80,40
	82,40	48,80	82,80	82,20	80,20
	83,80	49,20	82,40	82,60	82,60
	84,80	48,60	83,00	81,80	82,20
	75,60	48,40	82,80	78,80	81,20
	82,40	48,80	83,40	71,60	75,80
	81,20	48,60	83,00	82,60	72,00
	81,80	48,40	83,00	80,00	56,40
	79,80	48,40	82,60	79,00	54,80
	80,00	48,40	82,00	79,20	59,80
	78,80	49,00	82,00	79,20	80,00
3	80,20	48,80	81,80	79,80	79,80
	82,60	49,00	79,00	78,60	81,40
	81,20	48,20	81,20	78,60	69,20
	81,20	48,40	81,20	78,40	72,20
	81,20	48,60	81,60	78,80	77,20
	80,80	49,00	81,80	82,80	76,40
	79,40	49,40	81,80	82,20	77,80
	79,40	48,40	82,20	81,40	80,80

	80,40	48,80	81,80	82,00	77,00
	82,00	48,60	81,60	82,80	77,20
	82,40	48,40	82,00	80,80	77,60
	81,60	48,80	82,00	80,60	73,80
	80,00	48,20	81,80	80,60	75,00
	80,00	48,40	83,20	80,60	75,00
	79,40	48,00	83,00	81,00	73,60
	79,80	48,40	83,00	81,40	74,00
	80,80	48,20	81,40	82,60	73,00
	81,20	48,60	82,00	81,60	77,00
	80,40	48,60	80,80	81,20	73,00
	81,20	48,40	81,40	81,00	80,40
4	79,80	48,60	81,40	79,80	81,00
	80,60	48,80	81,80	80,60	79,60
	79,60	48,80	82,00	81,00	80,80
	80,80	49,20	82,00	81,20	80,40
	82,00	50,20	82,20	82,60	80,40
	80,80	50,20	81,40	81,60	80,60
	73,60	52,40	81,80	82,20	81,00
	76,00	51,80	82,80	82,00	66,80
	77,60	51,80	83,20	82,40	66,80
	77,40	52,20	83,00	82,00	67,40
	80,60	52,40	83,40	80,80	80,20
	83,40	52,60	83,40	81,40	79,60
	83,40	52,40	83,00	81,40	80,00

	80,20	52,40	82,20	81,00	80,40
	79,00	50,60	83,20	71,00	80,00
	80,80	50,60	82,40	71,40	82,00
	79,60	51,00	82,60	79,00	81,60
	82,80	51,60	83,00	79,00	82,20
	83,40	51,60	82,60	79,20	82,00
	84,20	51,40	82,40	78,60	81,00
5	83,60	52,40	82,40	77,40	83,00
	83,40	53,20	83,00	82,20	81,20
	84,00	53,40	82,80	83,60	80,40
	85,80	54,40	83,60	83,00	80,60
	87,00	54,00	83,20	83,60	80,40
	85,60	54,00	85,20	84,60	82,40
	86,80	54,40	85,80	80,60	83,00
	75,80	57,00	85,60	84,20	82,60
	64,80	57,80	85,80	81,60	82,80
	76,20	58,00	85,20	81,40	81,80
	77,00	59,00	85,80	78,60	83,00
	74,20	59,20	86,40	78,60	83,00
	61,60	59,60	86,80	79,40	79,80
	72,20	59,80	86,60	83,60	77,20
	71,80	59,20	90,20	86,20	75,80
	64,20	59,80	91,80	83,20	83,40
	52,20	60,20	92,80	80,80	84,00

							18-Nov-19	19-Nov-19	20-Nov-19	21-Nov-19	22-Nov-19	
	52,40	60,80	90,00	80,80	81,40							
	53,20	61,20	90,20	86,00	81,40	am	8,80	8,60	8,40	9,40	11,20	
	53,60	62,00	89,60	87,40	82,60	pm	7,20	8,80	8,80	8,00	6,60	
6	54,00	62,80	78,40	83,60	82,00		3,40	3,00		4,40	2,40	3,30
	50,60	59,80	87,40	79,20	79,60							
	51,60	60,20	88,00	79,40	80,00							
	58,00	65,00	93,80	82,80	83,40							
	57,80	65,80	75,60	85,80	86,80							
	58,40	66,20	70,80	90,00	88,00							
	59,00	67,40	80,40	92,00	87,80							
	59,40	66,80	95,20	92,40	87,60							
	61,00	67,80	97,00	94,20	66,40							
	61,00	68,60	98,20	93,40	85,20							
	61,40	69,40	98,20	96,80	88,80		5,20	4,60	5,00	5,00	3,60	4,68
	56,20	64,80	93,20	91,80	85,20							
	57,00	66,00	92,80	92,40	86,20							
	63,80	72,80	98,60	78,00	90,40							
	65,00	73,80	101,40	100,40	91,00							
	65,20	74,00	102,80	99,40	90,00							
	64,80	73,20	102,00	98,60	92,00							
	64,80	73,40	102,40	100,60	92,80							
	65,00	74,80	101,40	100,60	92,20							
	66,00	74,80	102,40	101,60	97,20							
7	66,40	75,80	91,40	103,00	94,20		6,80	7,20			6,40	6,80

	59,60	68,60	60,20	60,20	87,80						
	56,20	69,20	60,40	59,80	86,00						
	66,00	78,80	69,20	69,00	78,80						
	65,80	79,20	70,40	69,00	92,60						
	66,20	79,00	70,20	69,20	92,60						
	66,60	79,40	70,00	69,80	94,60						
	66,40	78,80	70,60	69,40	95,60						
	66,20	78,80	72,20	70,40	97,80						
	66,40	80,20	70,60	70,80	98,40						
	66,60	80,60	71,80	70,80	98,80	7,20	6,80	6,80	8,00	9,00	7,56
	59,40	73,80	65,00	62,80	89,80						
	60,00	74,20	65,00	63,60	89,80						
	70,60	83,60	74,80	74,00	96,60						
	69,80	84,20	74,80	74,40	99,00						
	70,00	85,00	74,40	74,20	98,40						
	72,20	84,40	75,40	74,40	100,40						
	70,60	84,00	74,60	74,80	100,80						
	70,60	84,40	75,20	75,40	100,00						
	70,60	85,00	75,20	75,00	101,20						
8	71,20	87,00	76,80	75,60	99,40	8,20	8,60	8,40	8,00	5,40	7,72
	63,00	78,40	68,40	67,60	94,00						
	63,00	80,80	67,60	67,00	95,00						
	72,40	90,80	76,40	77,20	103,80						
	72,80	92,80	78,00	76,40	103,20						
	73,40	90,00	77,60	77,40	103,60						

	72,80	92,60	78,00	77,60	102,60						
	71,80	90,00	77,20	76,40	104,80						
	72,20	89,40	77,20	76,00	104,40						
	72,40	93,00	77,40	78,60	103,60						
	72,60	81,80	77,60	75,80	104,60	8,60	7,20	8,20	9,40	9,20	8,52
	64,00	74,60	69,40	66,40	95,40						
	63,60	73,20	69,40	66,60	96,80						
	72,20	83,00	78,80	76,20	106,00						
	72,80	82,60	79,00	77,00	110,00						
	72,60	87,20	78,20	76,20	111,80						
	73,20	91,20	83,80	74,00	113,80						
	73,20	90,40	79,20	76,80	107,40						
	72,80	92,40	78,20	75,80	107,00						
	71,80	92,00	78,00	73,60	109,80						
9	71,80	91,80	77,60	75,40	109,20	8,20	5,80	7,20	9,20	8,00	7,68
	63,60	86,00	70,40	66,20	101,20						
	63,20	84,20	70,20	65,00	102,80						
	73,00	95,40	79,00	74,40	112,20						
	73,00	95,20	79,00	74,40	108,60						
	73,40	93,00	77,80	74,20	108,60						
	72,80	94,20	77,00	75,80	108,40						
	73,20	92,80	77,20	74,00	110,20						
	72,60	95,80	77,40	74,20	106,40						
	73,20	92,60	76,80	74,00	106,60						
	72,40	92,40	76,20	73,20	110,60	8,00	7,80	7,00	7,60	11,20	8,32

	64,40	84,60	69,20	65,60	99,40						
	64,00	85,20	68,00	64,40	98,60						
	73,00	96,80	77,40	74,40	109,60						
	72,80	98,60	77,00	73,60	109,00						
	73,00	93,60	76,40	72,80	111,00						
	72,40	93,80	77,00	72,00	108,20						
	72,60	93,80	76,20	72,60	109,20						
	72,40	96,40	76,00	70,80	110,20						
	72,20	95,40	75,20	71,00	110,80						
10	72,40	95,60	75,40	70,60	109,40	8,80	3,60	7,80	8,00	11,00	7,84
	63,60	92,00	67,60	62,60	98,40						
	64,20	92,20	67,00	69,60	96,60						
	71,60	99,00	75,60	80,00	108,40						
	71,80	97,60	75,20	81,20	108,80						
	72,40	107,00	74,80	91,20	109,00						
	71,80	99,40	75,20	93,00	109,00						
	70,60	98,60	75,60	92,00	109,20						
	70,00	98,60	75,40	91,80	108,60						
	70,00	101,20	75,20	91,00	107,40						
	69,60	101,00	75,00	91,20	107,40	6,60	7,00	7,20	7,60	10,00	7,68
	63,00	94,00	67,80	83,60	97,40						
	63,40	91,40	67,40	85,20	97,40						
	71,60	101,80	76,00	94,60	106,80						
	70,80	102,20	76,00	97,20	104,20						
	70,20	98,40	75,00	97,20	106,80						

	70,40	101,40	75,40	100,60	107,80							
	70,00	101,80	74,40	100,00	107,20							
	69,60	102,20	74,80	99,40	102,80							
	68,80	101,40	74,40	99,20	104,40							
11	68,60	102,40	74,20	99,40	104,20	7,00	7,20	6,80		7,40		7,10
	61,60	95,20	67,40	98,00	96,80							
	61,00	95,60	67,40	99,20	87,40							
	70,20	103,20	75,00	108,20	101,40							
	69,20	106,40	75,00	106,40	98,60							
	69,00	108,00	73,80	103,20	98,20							
	67,80	105,00	74,40	107,00	101,80							
	67,80	103,60	74,20	106,40	101,00							
	67,80	107,60	72,40	104,60	98,20							
	67,40	101,20	74,80	106,00	104,00							
	68,20	102,40	72,60	103,20	101,80	7,40	3,20	7,00	6,60	4,80		5,80
	60,80	99,20	65,60	96,60	97,00							
	60,60	96,20	65,60	97,40	93,20							
	68,20	103,60	76,40	105,60	101,00							
	66,60	105,60	73,00	105,60	100,00							
	66,60	105,40	72,80	105,20	98,40							
	65,80	104,80	72,60	105,60	102,20							
	66,20	104,40	73,00	104,60	100,80							
	66,00	80,40	72,20	104,80	101,20							
	65,40	78,20	72,00	104,60	102,20							
12	65,60	95,80	71,60	104,60	102,80	6,00		6,40	6,40	6,80		6,40

	59,60	99,00	65,20	98,20	96,00						
	59,80	98,00	65,00	96,60	96,40						
	66,00	106,40	71,80	103,80	105,80						
	66,20	103,40	71,60	103,80	101,00						
	65,40	103,20	71,00	102,20	104,40						
	66,20	105,40	71,00	102,40	100,40						
	65,80	104,60	70,40	102,60	101,80						
	64,40	105,00	69,60	98,60	100,20						
	64,20	103,20	70,40	94,20	99,60						
	64,20	103,60	70,00	97,80	100,40	4,80	8,20	5,20	6,20	5,20	5,92
	59,40	95,40	64,80	91,60	95,20						
	58,00	95,80	64,80	90,80	94,40						
	64,40	102,40	71,80	96,40	100,40						
	64,60	102,00	70,60	100,00	100,80						
	64,80	102,40	70,60	102,20	99,60						
	64,40	102,20	71,00	98,40	95,00						
	65,20	102,80	70,00	99,80	101,40						
	64,80	103,40	70,20	98,80	101,40						
	63,80	102,00	71,20	98,20	98,80						
13	66,80	102,80	72,40	101,40	103,00	6,20	4,80	6,60		7,60	6,30
	60,60	98,00	65,80	88,00	95,40						
	60,00	97,60	63,40	89,40	94,40						
	66,60	103,20	69,00	94,00	101,00						
	66,20	103,60	69,20	74,80	100,60						
	65,20	103,20	69,40	93,20	99,80						

	64,80	103,00	69,20	96,40	100,80						
	64,60	102,80	72,40	99,20	102,80						
	64,20	101,80	66,20	99,00	99,00						
	64,80	101,60	66,00	98,20	100,60						
	64,60	100,20	66,00	98,20	98,20	4,40	5,80	4,60	5,00	6,20	5,20
	60,20	94,40	61,40	93,20	92,00						
	60,40	95,00	61,60	93,20	94,00						
	66,00	98,40	67,20	100,00	98,40						
	66,00	101,60	66,80	99,80	97,40						
	66,20	104,00	66,80	99,00	96,20						
	65,20	100,00	65,80	99,40	95,60						
	65,20	99,80	65,40	98,80	95,60						
	64,60	99,60	65,40	97,20	96,40						
	64,80	99,20	65,60	102,20	95,40						
14	64,80	100,00	65,40	99,40	94,60	5,40	4,40	5,00	3,40	3,60	4,36
	59,40	95,60	60,40	96,00	91,00						
	59,40	96,80	60,40	92,80	90,60						
	65,60	101,60	66,20	99,60	95,80						
	65,20	100,80	70,00	98,40	95,40						
	65,40	100,40	73,40	98,20	95,80						
	65,40	99,80	72,40	99,40	94,00						
	64,60	100,80	72,00	97,80	94,20						
	64,40	99,40	71,80	68,40	94,20						
	64,00	98,20	77,60	97,40	91,80						
	64,00	98,60	98,80	67,80	94,80	4,20	4,20	4,60			4,33

	59,80	94,40	94,20	92,20	95,60							
	59,20	94,00	95,20	92,20	91,60							
	64,80	99,00	100,00	97,60	96,00							
	64,60	98,80	99,20	94,00	95,60							
	64,20	99,40	98,60	93,80	96,20							
	64,40	98,40	98,80	94,00	95,60							
	63,80	98,60	98,40	96,40	95,40							
	64,00	98,20	97,80	96,20	96,20							
	63,20	99,40	98,40	96,00	95,40							
15	62,80	99,60	96,60	96,00	95,20	3,60	4,60	2,60		4,60		3,85
	59,20	95,00	94,00	95,00	90,60							
	58,80	94,20	95,40	91,40	90,00							
	64,20	100,00	73,60	97,40	96,40							
	64,60	99,20	96,60	97,20	95,20							
	63,60	102,80	99,40	93,20	94,20							
	64,20	98,60	99,00	92,00	93,60							
	63,40	100,80	98,80	92,40	93,00							
	63,20	100,80	99,40	93,60	92,40							
	63,00	100,20	99,80	94,20	94,20							
	62,60	100,20	103,60	94,20	93,00	3,80	4,00	3,60	3,20			3,65
	58,80	96,20	100,00	91,00	92,40							
	58,00	96,40	99,20	90,40	88,60							
	63,80	101,00	104,60	93,00	95,20							
	63,60	101,20	104,60	94,40	93,80							
	66,20	101,20	105,00	97,20	94,00							

	65,40	102,00	99,80	95,60	94,80							
	65,40	103,00	100,20	97,00	92,80							
	65,20	103,00	99,00	96,60	93,00							
	65,00	103,20	95,80	98,00	93,80							
16	65,00	103,60	99,20	98,20	94,20	4,20			3,40	6,00		4,53
	60,80	105,20	90,80	94,80	88,20							
	60,60	98,80	94,80	92,80	89,80							
	65,20	104,80	100,00	97,00	94,80							
	65,40	105,00	97,80	97,40	94,40							
	64,80	103,40	99,80	95,20	93,20							
	64,40	104,00	99,40	95,80	94,40							
	64,80	103,40	100,40	66,20	92,40							
	64,20	103,20	99,80	90,20	94,00							
	64,40	102,60	98,20	96,20	94,00							
	64,40	102,80	100,00	96,80	93,60	4,40	6,00	3,40	4,20	4,00		4,40
	60,00	96,80	96,60	92,60	89,60							
	59,40	98,80	92,00	91,20	89,40							
	65,00	103,60	98,40	94,80	94,80							
	63,80	102,80	102,40	97,80	94,60							
	63,40	103,20	101,00	97,40	74,60							
	63,80	103,60	102,60	99,60	64,00							
	63,40	101,20	102,40	97,60	73,00							
	63,40	104,40	102,20	98,40	64,60							
	63,80	105,00	101,40	97,20	80,00							
17	63,60	103,80	101,20	99,20	93,60	4,40	4,60	4,80	5,40	5,00		4,84

	59,20	99,20	96,40	93,80	88,60							
	58,20	94,60	95,20	93,80	91,00							
	64,20	100,40	98,80	100,00	96,60							
	63,80	99,20	101,60	99,60	97,20							
	63,20	101,60	101,40	100,40	96,40							
	64,40	103,00	101,40	100,00	96,40							
	64,20	104,00	100,20	99,40	96,80							
	64,40	104,00	99,60	99,20	99,40							
	64,60	103,00	99,60	99,20	98,40							
	65,00	106,60	102,60	99,40	99,80	3,80	4,20	4,20	3,20	5,60		4,20
	61,20	102,40	98,40	96,20	94,20							
	62,20	102,00	101,60	81,00	95,40							
	69,40	110,00	110,40	95,80	103,20							
	70,00	110,00	110,60	102,20	104,60							
	71,20	105,00	111,60	103,00	105,40							
	71,20	109,40	111,40	104,20	104,80							
	71,20	110,20	111,20	106,00	105,60							
	71,80	110,00	110,60	105,60	107,20							
	72,20	108,60	111,60	105,00	104,20							
18	71,80	108,60	106,60	105,20	104,80	4,80				5,00		4,90
	67,00	65,80	66,00	70,40	99,80							
	66,80	65,00	66,40	62,60	99,40							
	74,20	72,40	73,40	69,20	77,80							
	74,20	72,00	73,60	69,00	97,00							
	74,20	71,60	72,60	69,80	104,40							

	74,00	74,40	72,80	69,80	104,00						
	73,40	71,60	72,80	69,20	106,60						
	75,60	70,80	74,40	68,80	104,20						
	71,80	70,20	73,60	68,20	104,40						
	71,60	71,00	73,80	68,40	107,00	6,00	6,20	6,60	5,80		6,15
	65,60	64,80	67,20	62,60	92,20						
	65,40	64,20	66,80	62,60	99,60						
	72,00	73,80	74,00	70,40	107,20						
	71,80	71,00	74,00	69,00	108,00						
	72,00	70,80	74,60	70,60	106,00						
	71,60	70,60	73,60	69,60	107,40						
	71,40	70,00	73,00	68,40	105,40						
	70,80	69,60	73,00	68,40	106,40						
	70,80	68,80	73,80	68,00	105,20						
19	70,40	68,80	75,60	68,40	106,00	5,40	5,00	8,80	6,00	6,60	6,36
	65,00	63,80	66,80	62,40	99,40						
	65,20	64,00	68,40	62,80	100,20						
	71,80	70,80	73,40	69,40	107,40						
	71,60	71,20	74,00	69,20	108,80						
	71,80	70,60	73,80	69,20	107,00						
	72,00	71,20	73,80	68,80	95,60						
	71,80	71,40	74,00	68,00	95,60						
	71,80	71,20	73,60	67,40	106,20						
	72,40	70,60	73,60	68,00	105,80						
	72,00	70,80	73,60	67,00	106,60	7,20	6,40	6,80	5,80	5,80	6,40

	64,80	64,40	66,80	61,20	100,80						
	65,20	63,80	66,60	61,20	100,80						
	72,60	70,80	73,40	68,40	107,60						
	72,40	71,00	72,80	67,20	108,00						
	72,00	70,80	72,80	66,80	108,20						
	70,80	70,20	71,60	66,00	107,40						
	70,80	70,00	71,20	66,20	101,40						
	70,60	70,80	72,40	66,40	105,80						
	70,40	69,80	70,60	65,60	106,20						
20	70,20	70,80	70,80	65,40	106,20	6,20			5,80	6,20	6,07
	64,00	70,60	69,60	59,60	100,00						
	63,40	69,80	69,20	66,60	100,40						
	70,80	85,20	75,00	73,80	105,40						
	70,00	106,80	75,00	87,40	105,20						
	69,20	106,20	77,60	98,80	106,40						
	68,00	105,20	77,40	98,20	105,60						
	68,00	104,40	95,20	98,20	105,00						
	67,80	103,40	106,20	98,20	104,40						
	66,80	103,00	105,40	96,80	102,80						
	67,00	102,40	105,00	96,60	100,00	5,80	8,80	6,00	8,00		7,15
	61,20	93,60	99,00	88,60	65,40						
	61,60	91,80	97,40	92,20	63,00						
	68,20	100,80	104,60	95,80	63,60						
	67,00	103,00	104,40	96,20	63,20						
	66,80	102,40	105,40	97,20	63,00						

	66,40	102,80	104,60	96,60	62,40						
	66,20	101,80	104,00	96,40	61,80						
	65,80	102,80	103,80	100,20	62,20						
	65,60	102,20	103,60	97,40	61,80						
21	65,40	100,80	103,60	76,80	61,60	5,80	5,80	6,40		5,20	5,80
	59,60	95,00	97,20	93,20	56,40						
	59,20	95,00	96,20	94,20	56,80						
	65,40	101,60	102,00	98,80	61,60						
	64,20	101,00	101,40	99,00	61,60						
	61,20	100,80	101,00	97,60	62,20						
	61,00	100,80	100,60	98,00	60,60						
	60,40	100,20	100,20	97,00	60,20						
	59,40	100,40	100,00	98,20	60,00						
	59,20	99,60	99,20	98,20	59,80						
	58,80	99,20	98,60	98,00	59,80	5,00	4,80	5,20	4,80	4,00	4,76
	53,80	94,40	93,40	93,20	55,80						
	54,20	92,20	93,80	92,40	55,20						
	59,60	99,00	99,20	98,40	60,20						
	59,00	99,40	98,40	98,40	67,80						
	58,60	98,60	98,00	96,80	69,40						
	58,20	98,00	98,00	97,60	69,00						
	57,60	97,40	98,00	96,60	91,00						
	57,20	97,60	96,00	95,20	92,00						
	56,40	96,60	85,00	94,60	91,40						
22	56,40	96,00	91,40	94,60	91,00						

	56,20	97,20	87,60	95,20	90,80
	56,20	97,20	87,60	95,20	90,80
	88,40	56,00	67,00	87,20	95,60
	91,80	55,00	68,00	88,60	95,20
	92,60	54,40	92,60	85,80	95,00
	90,80	54,40	92,80	88,60	87,60
	91,20	53,80	92,60	82,80	91,20
	91,80	53,40	96,00	89,60	92,80
	87,60	52,80	96,20	92,00	92,40
	87,60	52,20	95,60	93,00	90,60
	82,40	48,00	91,40	87,20	87,00
	83,60	47,60	87,60	85,80	88,20
	89,40	51,80	91,20	77,00	92,60
	88,20	51,60	89,80	85,20	92,20
	88,00	51,40	89,60	85,00	91,20
	88,00	50,60	89,40	85,00	92,00
	88,00	50,00	90,20	86,20	91,00
	84,40	50,00	89,80	87,40	90,00
	84,40	49,20	89,40	87,40	88,80
23	83,80	48,80	88,60	86,20	88,00
	79,40	45,80	85,40	82,00	86,40
	79,00	45,60	84,80	71,40	86,20
	86,40	49,80	88,20	88,60	90,20
	83,80	48,80	88,20	88,80	89,60
	83,60	48,60	88,40	88,20	88,60

	82,60	48,00	87,80	86,80	88,40
	82,40	48,00	87,60	86,80	88,20
	82,00	47,80	86,60	86,00	87,40
	82,00	47,40	86,40	86,40	87,00
	81,40	47,20	85,00	86,40	86,20
	80,60	46,60	85,00	63,60	85,80
	80,00	45,80	84,80	63,20	86,40
	79,00	46,20	83,60	79,40	86,00
	79,00	45,80	83,80	79,20	85,00
	80,80	46,40	83,00	86,20	84,60
	80,40	46,00	82,20	85,40	86,00
	80,60	46,60	83,00	86,00	86,60
	81,00	46,00	82,80	86,80	85,60
	80,40	45,20	83,00	85,20	85,40
24	81,60	45,20	83,00	85,40	85,60

APPENDIX 2:
COLD LOAD PICK-UP TESTS

Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Average
24-Nov-19	**25-Nov-19**	**26-Nov-19**	**27-Nov-19**	**28-Nov-19**	**29-Nov-19**	**30-Nov-19**	**1-Dec-19**	**2-Dec-19**	**3-Dec-19**	**4-Dec-19**	**5-Dec-19**	
84,20	81,00	82,00	86,80	83,00	82,00	77,60	86,60	83,40	85,00	86,00		
84,40	80,40	83,60	86,40	78,60	82,60	77,20	85,80	82,60	83,80	86,00		
84,20	80,20	82,60	86,20	82,80	79,40	78,00	85,00	83,40	84,80	86,20		
84,40	80,20	85,20	85,20	82,60	80,60	81,60	84,80	81,60	86,60	84,80		
83,80	81,20	85,40	74,40	81,80	80,60	86,80	81,80	80,60	85,00	85,00		
85,00	80,60	85,00	78,00	80,60	81,20	85,00	84,40	76,40	86,20	85,60		
84,40	80,40	84,80	81,40	82,20	83,20	85,40	84,60	81,20	69,60	85,40		
84,20	80,80	84,80	81,20	78,80	82,40	84,60	84,00	82,00	85,60	86,40		
82,60	81,00	82,80	84,20	81,40	81,20	85,00	86,00	83,40	82,80	85,60		
84,80	81,20	82,80	83,80	78,60	80,40	86,00	84,60	79,20	82,40	86,20		
84,60	81,40	83,20	83,60	78,60	82,40	83,20	86,00	79,40	86,20	84,40		
84,00	80,40	83,60	84,60	79,80	83,60	84,20	84,60	82,20	84,20	84,00		
83,20	70,60	85,60	68,20	79,20	83,00	84,20	86,20	82,40	84,20	84,60		

Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Average
24-Nov-19	**25-Nov-19**	**26-Nov-19**	**27-Nov-19**	**28-Nov-19**	**29-Nov-19**	**30-Nov-19**	**1-Dec-19**	**2-Dec-19**	**3-Dec-19**	**4-Dec-19**	**5-Dec-19**	
83,60	81,20	83,40	68,40	79,00	81,40	81,20	84,60	81,40	82,60	84,00		
84,00	80,80	84,20	69,20	78,60	84,00	83,20	83,60	81,60	83,60	83,60		
83,60	82,00	83,60	68,60	79,20	82,40	83,00	86,20	82,00	83,60	84,20		
81,40	79,60	83,60	66,60	80,20	83,40	84,60	85,40	82,20	86,00	83,60		
82,00	81,20	83,40	66,80	78,60	83,60	83,40	85,20	82,20	85,00	83,40		
81,60	80,20	83,00	66,20	77,00	82,80	84,40	85,60	82,00	84,20	83,40		
82,00	79,40	85,00	67,60	79,80	81,20	83,80	84,60	82,40	84,40	82,80		
82,00	78,40	84,20	82,60	79,60	81,00	83,80	84,20	83,20	84,60	83,40		
82,40	79,00	84,00	82,60	78,80	82,40	84,80	83,00	83,80	80,00	82,80		
83,00	80,40	83,80	82,20	79,60	83,20	83,60	82,80	82,20	81,40	83,00		
84,20	80,20	83,40	82,60	78,60	81,20	84,00	83,40	82,80	82,80	82,00		
84,60	80,80	86,20	83,00	81,00	81,60	82,40	85,20	82,20	84,00	83,40		
81,80	80,60	88,00	80,60	78,80	81,00	82,80	85,80	82,00	84,20	82,20		
81,20	81,80	83,80	79,20	82,80	79,80	83,80	86,00	81,80	84,60	80,80		
81,40	80,80	83,60	80,80	82,20	80,40	83,60	85,80	81,80	85,00	84,00		

Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Average
24-Nov-19	**25-Nov-19**	**26-Nov-19**	**27-Nov-19**	**28-Nov-19**	**29-Nov-19**	**30-Nov-19**	**1-Dec-19**	**2-Dec-19**	**3-Dec-19**	**4-Dec-19**	**5-Dec-19**	
79,80	82,00	83,60	82,00	82,40	81,20	83,20	86,40	81,40	84,00	81,40		
80,80	82,00	83,60	80,80	82,80	81,40	81,40	86,20	81,00	82,00	81,00		
81,20	81,00	83,60	81,20	83,60	80,80	83,00	86,80	81,80	82,20	81,00		
81,20	80,60	83,00	81,40	66,80	80,80	81,40	86,20	82,60	74,80	81,40		
81,60	81,40	84,60	80,80	77,80	81,40	81,40	85,60	82,00	78,00	80,80		
82,80	80,60	84,20	81,20	77,80	84,40	81,80	86,20	80,80	82,80	82,20		
82,80	81,20	83,60	81,40	79,60	84,20	83,00	85,00	81,00	78,80	83,20		
83,40	80,60	83,00	80,60	79,20	83,80	83,80	86,40	81,20	82,00	81,80		
83,60	77,80	83,40	81,20	65,60	84,20	82,40	86,20	82,80	81,80	82,00		
83,60	78,00	83,40	81,20	80,00	85,20	80,80	85,40	80,60	81,80	81,60		
74,00	78,60	83,20	80,60	78,40	84,60	83,00	85,00	80,80	81,20	82,00		
65,40	79,00	83,00	80,20	78,00	83,40	82,20	84,40	80,60	81,80	81,80		
77,40	79,00	82,00	84,00	77,20	85,60	83,60	84,80	80,60	80,80	82,20		
77,20	76,20	83,00	84,40	77,80	84,40	83,00	84,60	81,60	83,60	82,20		
78,20	78,80	83,60	84,00	66,00	84,60	83,60	86,40	81,40	83,40	82,60		

Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Average
24-Nov-19	**25-Nov-19**	**26-Nov-19**	**27-Nov-19**	**28-Nov-19**	**29-Nov-19**	**30-Nov-19**	**1-Dec-19**	**2-Dec-19**	**3-Dec-19**	**4-Dec-19**	**5-Dec-19**	
79,00	79,80	83,00	83,60	67,40	83,60	83,40	85,00	81,00	83,40	80,80		
81,20	79,20	82,80	83,00	78,20	81,80	82,00	84,80	81,20	84,40	80,60		
81,20	80,00	83,40	82,80	61,40	83,00	84,00	84,40	81,00	83,20	80,60		
83,00	78,60	83,40	83,80	67,40	83,20	85,00	84,40	80,60	83,60	80,20		
83,60	78,60	83,00	82,20	81,20	85,00	83,40	84,00	81,20	83,80	81,00		
82,00	78,00	83,00	81,40	81,00	83,00	84,60	84,60	81,20	83,80	78,80		
81,40	78,40	84,20	81,40	64,20	82,80	84,40	85,20	81,20	84,00	79,80		
81,40	76,60	84,20	82,00	63,60	83,40	83,20	84,40	82,60	83,60	80,60		
81,20	78,20	83,60	81,60	65,40	83,40	79,80	85,20	82,60	83,20	76,80		
81,20	79,20	84,00	80,20	65,00	82,80	82,40	84,60	76,60	85,60	81,00		
80,40	77,60	82,80	82,60	65,80	83,20	83,40	86,00	80,20	84,00	79,80		
80,20	79,40	82,20	81,20	64,80	83,80	83,20	85,20	81,60	84,60	79,20		
81,60	79,80	81,60	82,40	65,00	82,20	83,20	84,60	81,40	74,00	80,20		
81,80	79,40	82,80	83,00	64,80	85,00	82,40	85,20	81,40	76,80	79,00		
82,00	80,00	83,20	83,00	65,20	84,80	81,40	84,80	82,00	79,20	79,40		

Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Average
24-Nov-19	**25-Nov-19**	**26-Nov-19**	**27-Nov-19**	**28-Nov-19**	**29-Nov-19**	**30-Nov-19**	**1-Dec-19**	**2-Dec-19**	**3-Dec-19**	**4-Dec-19**	**5-Dec-19**	
82,60	78,20	82,80	82,40	80,00	83,60	82,80	84,80	81,80	83,40	79,20		
82,00	79,60	83,60	83,80	77,60	84,60	82,00	85,00	82,80	83,40	79,60		
81,40	78,40	82,80	83,60	81,40	83,80	83,00	85,00	82,20	83,60	78,80		
83,20	78,20	83,60	81,60	81,20	79,20	84,20	86,60	82,40	84,40	81,40		
80,20	79,40	82,40	82,00	81,60	82,80	84,20	85,60	81,20	83,00	79,60		
79,20	78,40	82,80	82,20	65,00	82,60	83,60	84,00	81,60	83,60	78,80		
79,80	78,20	83,20	81,20	66,00	82,00	84,80	82,80	81,00	83,20	79,40		
81,00	79,20	82,80	82,60	65,20	84,00	84,40	83,20	81,20	82,60	79,00		
82,00	79,00	83,60	82,80	65,80	84,00	84,40	84,00	81,40	82,80	76,40		
83,00	79,20	83,40	82,40	82,20	85,00	83,60	85,20	81,80	83,00	75,80		
81,20	78,20	83,00	75,60	82,20	80,60	83,20	85,40	81,20	84,20	75,60		
81,40	79,80	82,60	82,80	81,60	80,40	82,80	85,80	82,20	83,80	76,20		
81,20	81,00	82,80	83,20	80,80	80,20	82,20	86,00	82,80	86,00	76,20		
82,00	80,20	83,60	83,00	80,80	80,40	82,40	86,00	81,80	84,80	75,40		
84,80	81,00	84,20	82,60	81,20	80,80	82,40	87,00	81,60	77,80	76,40		

Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Average
24-Nov-19	**25-Nov-19**	**26-Nov-19**	**27-Nov-19**	**28-Nov-19**	**29-Nov-19**	**30-Nov-19**	**1-Dec-19**	**2-Dec-19**	**3-Dec-19**	**4-Dec-19**	**5-Dec-19**	
81,20	63,60	83,60	82,80	81,60	81,00	81,40	85,60	81,40	70,80	80,80		
81,00	72,20	83,60	86,40	81,20	80,80	82,80	86,40	81,60	73,20	79,40		
81,80	78,20	82,40	84,40	80,00	79,20	82,60	83,60	81,60	78,00	81,00		
82,00	78,00	81,20	82,00	79,80	79,40	82,20	85,00	82,00	75,60	81,20		
81,40	76,80	82,00	68,80	81,20	79,40	81,80	86,00	82,00	73,40	80,60		
81,80	79,40	83,00	69,00	81,20	77,80	81,60	86,00	80,60	82,80	80,40		
81,20	80,00	84,40	75,80	81,60	81,80	81,20	85,60	81,60	80,60	81,60		81,64
82,00	74,80	84,60	83,40	82,40	82,60	81,80	82,40	81,00	79,20	79,80		82,22
83,00	80,20	84,20	83,00	81,80	83,00	80,20	82,20	79,00	79,80	81,20		81,96
82,80	80,00	84,20	82,80	80,60	82,40	72,20	82,00	74,60	82,40	79,40		80,11
82,80	72,60	83,60	82,00	80,20	80,40	75,60	81,40	81,20	81,40	79,80		80,78
80,80	75,80	56,00	82,40	82,60	83,60	74,80	82,20	81,20	82,00	79,40		78,11
82,00	73,80	52,40	82,20	82,00	78,60	75,00	85,40	80,60	79,60	79,00		77,47
81,80	73,20	80,20	82,80	81,00	79,40	75,20	85,20	80,40	78,40	80,60		80,73
81,60	72,40	80,00	83,00	80,60	79,00	75,20	80,00	81,60	79,60	79,40		80,04

Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Average
24-Nov-19	**25-Nov-19**	**26-Nov-19**	**27-Nov-19**	**28-Nov-19**	**29-Nov-19**	**30-Nov-19**	**1-Dec-19**	**2-Dec-19**	**3-Dec-19**	**4-Dec-19**	**5-Dec-19**	
53,40	75,60	81,40	84,40	80,40	78,60	76,40	81,20	82,20	80,80	81,40		77,71
80,80	76,40	81,20	84,20	83,20	79,00	77,00	82,20	82,80	80,60	81,00		81,27
82,20	77,00	83,60	83,60	76,40	80,00	76,40	82,60	79,60	80,80	81,00		80,60
82,40	81,40	77,40	85,20	81,60	81,80	78,00	82,80	78,20	84,20	81,60		81,00
81,20	82,80	83,60	61,20	81,20	81,60	76,20	83,40	78,80	84,20	81,00		78,69
84,00	80,20	66,80	80,80	80,60	82,80	76,00	83,40	78,20	83,60	80,60		79,24
83,40	78,80	65,80	82,80	80,80	82,40	75,40	81,40	79,20	84,20	79,40		78,96
71,80	81,20	66,40	81,80	81,40	83,20	75,60	84,80	78,80	83,80	80,20		78,22
84,60	80,00	66,80	83,20	82,60	83,00	75,20	84,60	79,20	84,20	81,60		80,09
84,40	80,20	66,40	83,00	77,20	82,60	74,60	84,40	80,00	83,80	80,80		79,27
83,00	80,00	66,80	82,60	76,40	84,40	81,20	84,40	78,40	83,60	80,80		79,78
84,60	80,00	67,20	83,60	75,40	84,80	83,40	84,40	79,00	83,40	81,40		80,42
100,20	61,20	84,80	102,20	92,00	101,20	100,40	104,20	98,60	78,00	99,20		98,09
99,40	61,00	85,80	103,00	92,40	101,40	102,40	103,40	100,00	90,60	96,80		98,29
102,60	60,80	85,60	102,20	94,20	103,00	103,00	103,00	99,20	89,20	98,40		99,02

Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Average
24-Nov-19	**25-Nov-19**	**26-Nov-19**	**27-Nov-19**	**28-Nov-19**	**29-Nov-19**	**30-Nov-19**	**1-Dec-19**	**2-Dec-19**	**3-Dec-19**	**4-Dec-19**	**5-Dec-19**	
91,80	60,60	84,20	100,60	98,20	103,40	102,40	101,00	98,20	76,20	97,40		97,47
91,00	58,40	84,00	99,00	97,80	102,60	92,20	99,80	98,40	98,80	96,80		95,73
92,40	56,20	81,20	96,80	96,00	100,60	93,00	97,40	98,00	98,20	95,60		94,56
87,80	55,00	79,80	96,40	94,80	98,80	89,60	96,20	96,40	95,80	93,00		92,53
77,20	54,40	78,20	93,60	92,20	97,00	87,60	93,80	78,20	93,20	90,00		87,53
72,20	53,60	76,00	90,80	91,80	96,20	87,80	94,20	93,20	92,00	88,20		87,82
72,60	53,60	75,80	89,20	93,00	95,20	83,60	93,60	91,00	90,80	86,60		86,73
81,80	53,00	74,80	87,40	91,80	97,80	84,00	92,60	90,40	89,80	86,00		87,40
80,20	53,80	74,40	87,80	91,00	88,60	84,40	90,00	89,40	89,20	84,20		85,56
84,60	54,20	73,80	87,80	88,40	94,00	87,00	73,60	76,40	89,20	83,80		83,27
84,20	55,00	72,80	87,40	88,00	95,00	80,80	87,00	88,20	90,00	82,40		85,09
71,00	55,00	72,80	86,80	79,60	91,40	79,80	89,40	89,40	88,80	82,00		82,47
70,20	55,60	82,20	86,80	91,80	91,60	82,20	91,00	89,80	88,60	81,80		85,27
68,20	56,40	82,00	87,00	91,20	94,80	85,40	90,20	89,60	88,60	82,80		85,69
78,40	56,60	82,20	87,40	92,60	83,80	71,60	90,60	90,60	89,00	82,80		84,44

Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Average
24-Nov-19	**25-Nov-19**	**26-Nov-19**	**27-Nov-19**	**28-Nov-19**	**29-Nov-19**	**30-Nov-19**	**1-Dec-19**	**2-Dec-19**	**3-Dec-19**	**4-Dec-19**	**5-Dec-19**	
80,60	56,80	81,80	87,60	93,80	75,80	82,60	90,20	90,80	88,60	83,20		85,16
73,80	58,00	86,20	87,60	94,20	98,00	83,00	90,80	92,20	89,40	83,00		87,64
74,80	58,60	90,00	87,80	92,60	97,20	84,40	87,80	92,20	89,80	82,40		
73,60	67,20	90,60	88,00	96,80	91,20	74,00	85,40	91,80	90,00	83,40		
74,40	67,80	90,80	87,80	94,20	91,60	77,80	85,20	92,60	90,40	84,60		
76,20	68,40	90,60	87,40	95,40	92,40	78,20	84,80	93,60	90,80	83,60		
75,00	69,80	90,00	86,80	98,00	96,00	85,40	88,60	93,40	91,40	83,20		
75,60	78,60	89,80	87,00	99,60	96,80	76,40	88,40	93,60	91,80	83,80		
77,20	93,60	90,20	86,60	102,60	97,60	81,20	85,60	94,00	92,40	84,00		
75,80	98,60	90,60	87,80	101,80	98,60	85,80	88,20	95,60	92,60	83,20		
76,40	98,20	90,40	87,20	102,80	103,00	77,00	86,40	95,00	91,60	84,60		
66,00	99,20	92,40	87,20	102,40	100,20	90,00	86,20	96,40	91,20	84,60		
65,80	100,00	93,20	86,80	102,40	103,20	79,80	87,00	96,60	93,00	85,60		
67,20	104,00	94,00	87,20	102,40	104,60	80,60	88,00	96,00	92,00	84,60		
66,00	103,60	94,00	83,40	103,20	103,20	91,80	88,40	97,40	93,20	85,40		

Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Average
24-Nov-19	**25-Nov-19**	**26-Nov-19**	**27-Nov-19**	**28-Nov-19**	**29-Nov-19**	**30-Nov-19**	**1-Dec-19**	**2-Dec-19**	**3-Dec-19**	**4-Dec-19**	**5-Dec-19**	
67,80	103,20	93,00	79,40	102,60	94,60	91,20	87,60	97,00	92,00	86,00		
67,80	103,40	92,80	80,00	100,20	93,60	83,40	86,80	97,20	94,00	86,00		
68,40	104,00	94,40	79,60	100,80	98,80	78,40	87,20	96,80	91,60	83,80		
68,40	104,60	96,00	82,40	103,20	101,80	90,80	87,40	97,80	93,60	83,80		
71,00	104,60	96,60	88,20	102,20	105,40	81,40	84,40	99,40	94,40	84,40		
68,60	102,00	92,20	86,40	94,00	113,80	80,60	86,80	100,20	94,20	84,60		
69,00	68,20	96,00	81,40	68,20	77,40	80,20	88,00	99,80	93,80	86,20		
69,80	61,00	90,80	86,80	68,60	71,80	80,00	88,00	63,20	94,40	84,20		
69,40	60,80	93,40	88,40	69,00	73,00	73,40	88,00	63,40	95,80	83,80		
69,40	60,80	94,20	89,40	69,80	73,00	74,40	88,40	65,00	95,40	85,80		
69,00	60,40	95,40	88,20	69,00	73,00	74,20	89,00	64,80	96,00	86,20		
69,00	62,20	99,60	85,80	68,40	72,60	74,60	88,60	64,40	98,00	86,20		
69,60	61,40	95,60	87,80	69,80	72,80	75,20	88,60	65,40	96,40	85,80		
69,20	61,40	96,40	79,40	69,20	73,80	74,80	89,80	66,80	97,40	85,20		
69,60	62,00	97,00	83,20	69,40	73,80	75,00	91,20	66,20	97,60	87,60		

Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Average
24-Nov-19	**25-Nov-19**	**26-Nov-19**	**27-Nov-19**	**28-Nov-19**	**29-Nov-19**	**30-Nov-19**	**1-Dec-19**	**2-Dec-19**	**3-Dec-19**	**4-Dec-19**	**5-Dec-19**	
69,60	65,40	99,80	83,60	69,80	73,20	74,80	91,00	66,80	98,20	89,00		
73,20	74,00	101,40	83,80	69,40	73,40	74,80	90,00	67,60	99,60	89,60		
74,80	75,40	96,00	84,60	68,80	74,00	74,60	90,80	68,00	99,20	90,00		
70,60	75,80	74,20	85,40	69,00	73,60	75,40	92,40	68,00	99,60	89,40		
70,60	75,40	97,60	88,00	69,00	74,20	75,00	91,40	69,00	100,00	89,80		
71,00	75,20	98,20	88,80	69,00	74,20	75,60	91,00	69,00	100,20	91,80		
70,20	75,60	98,20	88,60	69,00	74,40	75,60	91,60	70,00	101,80	92,40		
70,60	74,20	102,00	85,60	69,20	75,00	76,00	92,00	69,80	101,00	91,80		
71,20	74,20	95,20	90,80	69,80	75,20	75,20	92,40	69,20	102,00	92,40		
71,00	74,80	100,00	89,00	69,80	75,00	75,00	92,80	69,40	103,40	92,20		
70,20	73,60	103,40	92,60	69,20	75,00	75,00	94,60	70,00	104,00	94,40		
70,80	74,00	100,80	96,40	69,40	74,80	75,80	92,80	70,20	104,80	94,80		
71,40	74,80	104,20	96,40	69,00	74,80	75,00	92,40	71,20	107,80	94,60		
71,60	74,60	105,00	97,60	70,20	74,80	74,80	94,00	72,20	107,20	96,40		
71,80	73,80	106,00	98,00	70,60	75,40	76,00	94,60	72,60	107,80	98,80		

Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Average
24-Nov-19	**25-Nov-19**	**26-Nov-19**	**27-Nov-19**	**28-Nov-19**	**29-Nov-19**	**30-Nov-19**	**1-Dec-19**	**2-Dec-19**	**3-Dec-19**	**4-Dec-19**	**5-Dec-19**	
71,40	74,00	106,00	98,60	70,20	75,00	76,00	96,60	72,60	108,00	98,40		
70,60	73,00	106,40	98,80	70,60	74,60	76,60	95,60	73,00	108,20	97,40		
71,40	73,20	107,80	98,80	70,20	74,60	76,00	96,20	74,00	109,00	73,80		
71,80	74,00	107,00	98,80	70,20	75,00	76,80	97,20	74,00	108,20	92,80		
71,40	73,40	108,00	100,20	70,00	74,00	76,80	82,60	74,00	106,20	97,20		
71,20	73,60	108,00	99,20	70,20	75,00	76,40	81,20	74,40	106,80	98,20		
71,00	74,00	107,80	99,60	70,40	74,60	75,80	96,40	65,00	105,40	98,00		
64,00	69,00	108,60	100,80	66,60	67,00	69,40	96,40	63,00	95,00	98,40		
64,00	74,60	107,00	101,80	68,20	67,80	70,60	96,00	60,20	102,40	97,40		
64,60	72,40	109,00	100,00	66,60	70,00	68,60	98,00	60,40	105,20	100,20		
63,80	72,40	108,20	101,20	66,20	66,40	68,60	97,40	59,20	106,60	98,80		
64,40	74,00	108,00	100,40	66,80	67,80	68,20	97,60	69,40	106,60	98,40		
63,40	72,60	107,40	100,60	66,60	68,80	72,80	98,20	70,20	107,60	98,40		
63,80	73,00	107,60	100,80	66,20	66,20	68,40	99,40	70,20	107,60	99,40		
63,40	72,20	90,80	101,20	66,80	66,00	68,40	101,20	69,40	108,20	100,40		

Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Average
24-Nov-19	**25-Nov-19**	**26-Nov-19**	**27-Nov-19**	**28-Nov-19**	**29-Nov-19**	**30-Nov-19**	**1-Dec-19**	**2-Dec-19**	**3-Dec-19**	**4-Dec-19**	**5-Dec-19**	
63,60	71,80	107,20	61,40	66,60	66,40	68,60	99,80	65,20	108,20	99,60		
64,20	73,80	108,20	61,80	66,60	66,00	69,40	102,40	67,00	107,40	79,40		
64,20	71,40	108,80	62,00	66,20	66,80	68,40	101,80	65,80	108,20	78,40		
64,00	72,00	107,80	62,40	66,20	68,20	67,60	100,80	65,80	108,80	99,20		
63,80	72,00	108,00	62,40	66,00	68,40	67,60	101,80	65,40	109,80	100,00		
63,80	72,00	109,20	63,00	70,60	66,80	66,80	101,20	65,60	109,20	99,20		
65,20	72,40	102,80	63,00	67,20	65,80	68,80	102,20	66,00	108,60	98,80		
63,60	71,60	104,40	62,40	68,40	65,60	69,20	101,80	65,80	109,20	99,40		
64,40	72,20	106,20	63,00	68,40	66,20	69,00	100,80	65,80	109,60	97,40		
63,80	72,00	106,00	62,60	68,00	66,80	68,80	100,40	66,80	109,60	97,40		
64,80	71,20	101,60	62,60	65,40	66,20	68,20	100,00	68,40	105,60	98,20		
65,20	71,20	102,80	62,60	65,80	66,40	68,40	100,40	65,40	107,80	98,80		
63,80	71,40	102,40	62,40	66,20	66,20	68,00	101,00	65,40	107,80	100,00		
64,00	71,60	98,60	62,00	69,40	66,20	66,80	104,00	66,00	106,80	99,80		
64,60	71,40	98,40	62,20	67,20	66,00	67,00	101,00	65,20	106,00	99,00		

Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Average
24-Nov-19	**25-Nov-19**	**26-Nov-19**	**27-Nov-19**	**28-Nov-19**	**29-Nov-19**	**30-Nov-19**	**1-Dec-19**	**2-Dec-19**	**3-Dec-19**	**4-Dec-19**	**5-Dec-19**	
63,00	71,00	97,40	62,00	65,40	65,80	66,40	96,60	68,00	107,40	101,20		
63,20	71,40	101,00	63,20	64,80	65,60	66,80	95,60	65,00	107,40	101,20		
63,20	70,80	100,20	61,80	66,60	65,20	66,40	100,20	65,40	107,60	101,80		
64,00	70,60	97,40	61,40	65,40	65,20	66,60	100,60	65,00	107,20	100,20		
62,40	71,40	97,00	61,40	65,40	65,60	67,00	99,40	65,40	107,80	100,40		
61,80	71,00	96,20	62,20	65,80	65,00	66,40	99,60	65,20	105,60	101,20		
62,60	70,60	96,80	61,40	65,40	65,20	66,40	99,20	64,20	106,00	99,40		
67,60	83,40	87,60	63,20	72,00	65,80	65,40	98,20	71,80	107,00	100,80		
78,00	90,00	89,00	61,00	79,00	77,60	74,00	93,40	81,00	98,80	101,00		
77,00	90,00	92,60	61,20	81,20	81,20	80,00	93,00	86,40	98,60	100,60		
75,80	99,60	92,20	61,40	80,40	80,20	79,20	92,60	86,20	98,20	100,60		
75,00	101,80	92,80	61,20	92,80	79,80	79,60	93,80	91,20	98,20	101,20		
74,00	100,60	96,40	61,00	92,80	82,20	77,60	92,40	109,80	98,20	100,40		
72,80	100,60	93,00	61,60	96,00	87,00	76,60	92,80	113,40	98,40	102,00		
72,20	101,80	97,20	63,80	97,00	84,20	77,20	93,40	111,80	98,60	101,00		

Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Average
24-Nov-19	**25-Nov-19**	**26-Nov-19**	**27-Nov-19**	**28-Nov-19**	**29-Nov-19**	**30-Nov-19**	**1-Dec-19**	**2-Dec-19**	**3-Dec-19**	**4-Dec-19**	**5-Dec-19**	
71,20	101,20	96,60	66,20	97,40	95,40	77,00	93,00	111,80	98,60	100,00		
70,60	100,60	97,20	66,60	105,20	95,00	77,40	92,80	110,80	99,20	99,40		
70,20	101,40	96,60	69,20	104,80	97,60	78,40	93,00	110,40	101,00	99,00		
70,40	100,00	99,80	84,20	104,40	100,00	78,20	93,00	108,60	99,20	98,20		
69,40	109,00	101,20	96,80	103,20	99,40	78,60	94,40	109,20	100,40	99,60		
69,00	109,60	101,00	94,40	107,40	99,40	76,40	90,60	109,00	98,20	99,60		
69,80	109,40	100,40	94,80	104,80	98,60	76,00	93,60	109,20	98,60	100,60		
72,20	112,80	99,20	94,40	106,00	98,00	75,60	92,80	108,80	105,00	99,80		
71,20	112,00	98,40	94,80	106,00	98,00	75,60	93,00	107,60	99,20	100,00		
71,00	112,00	98,80	94,20	106,80	98,20	75,40	92,00	109,40	101,40	100,00		
71,40	112,20	99,60	93,80	104,80	97,80	75,00	92,80	107,60	98,00	99,20		
72,20	112,20	95,20	92,40	104,80	100,80	75,20	93,40	108,40	97,40	99,60		
71,80	108,60	94,80	91,80	105,20	100,40	74,20	94,00	112,80	98,00	99,20		
71,40	108,20	84,80	92,00	108,20	104,00	74,60	92,40	109,20	77,80	98,80		
71,40	108,60	91,60	91,60	107,40	106,00	76,80	94,20	109,60	67,00	98,20		

Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Average
24-Nov-19	**25-Nov-19**	**26-Nov-19**	**27-Nov-19**	**28-Nov-19**	**29-Nov-19**	**30-Nov-19**	**1-Dec-19**	**2-Dec-19**	**3-Dec-19**	**4-Dec-19**	**5-Dec-19**	
72,00	107,80	91,20	97,60	105,20	103,20	77,00	91,80	108,20	66,00	98,80		
72,20	107,80	94,80	97,00	102,40	103,40	77,20	92,00	107,80	66,80	100,60		
71,40	107,00	97,80	97,20	101,60	103,20	76,80	91,60	92,00	66,20	100,40		
72,20	107,40	97,40	97,20	103,20	105,00	78,00	91,60	111,00	65,40	99,80		
71,80	107,60	98,00	97,60	102,60	107,80	76,80	93,20	111,00	94,00	99,40		
71,00	107,60	95,80	94,00	102,40	107,60	77,00	92,40	110,40	97,20	98,80		
71,00	107,60	91,20	91,80	103,00	107,60	76,80	92,00	94,80	96,20	99,20		
70,40	109,20	91,40	90,60	102,60	106,60	76,20	90,80	103,60	96,80	98,40		
70,80	108,00	94,40	93,60	102,40	107,40	77,40	91,00	110,40	97,40	97,80		
74,60	107,20	94,40	96,60	102,20	106,80	94,20	91,20	82,80	97,00	98,00		
74,00	96,40	97,80	96,60	103,00	105,60	93,00	89,60	106,60	97,00	98,20		
76,00	95,00	97,80	97,00	104,20	105,00	92,80	90,20	106,20	96,00	97,80		
75,60	107,40	97,60	97,20	103,60	104,40	94,80	88,40	106,20	96,00	98,60		
79,00	107,60	97,80	98,40	101,60	105,00	93,80	89,20	105,20	97,40	98,80		
78,80	107,60	97,80	98,60	103,00	106,40	94,00	89,80	105,20	97,40	97,60		

Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Average
24-Nov-19	**25-Nov-19**	**26-Nov-19**	**27-Nov-19**	**28-Nov-19**	**29-Nov-19**	**30-Nov-19**	**1-Dec-19**	**2-Dec-19**	**3-Dec-19**	**4-Dec-19**	**5-Dec-19**	
79,40	103,40	97,40	96,20	100,40	105,00	98,00	89,40	104,80	95,80	98,20		
80,80	103,80	97,80	97,00	100,60	105,00	94,00	91,20	107,60	95,40	97,40		
81,00	101,40	100,60	97,00	101,00	104,80	94,80	90,80	106,80	94,00	86,60		
81,40	103,00	111,60	98,80	100,40	106,00	94,20	101,60	106,80	103,00	96,20		
80,80	99,00	107,60	98,40	100,60	105,80	93,60	108,00	107,00	111,60	95,60		
80,40	100,20	113,60	97,80	102,40	105,20	93,00	107,20	107,00	110,80	95,00		
79,60	100,00	111,40	97,00	103,00	104,60	94,20	106,20	107,00	109,60	95,60		
78,60	100,00	110,00	95,60	101,60	103,00	93,60	105,20	107,00	108,80	95,80		
79,80	99,60	108,60	97,00	102,00	101,40	94,00	103,20	107,00	106,40	96,60		
78,60	99,60	108,00	96,80	102,80	105,40	94,20	104,00	106,60	105,20	95,60		
78,20	99,20	108,00	96,20	103,80	102,60	94,80	102,40	96,60	107,40	94,80		
83,20	98,00	107,60	96,80	101,60	95,80	93,40	101,00	101,80	105,00	95,40		
86,40	98,80	107,60	96,60	102,20	94,80	93,20	101,80	102,40	104,40	95,40		
87,00	99,80	107,00	97,80	101,20	99,60	93,20	101,20	105,00	103,40	95,40		
89,20	99,40	105,80	96,80	101,00	95,80	93,00	103,20	105,60	101,60	82,60		

Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Average
24-Nov-19	**25-Nov-19**	**26-Nov-19**	**27-Nov-19**	**28-Nov-19**	**29-Nov-19**	**30-Nov-19**	**1-Dec-19**	**2-Dec-19**	**3-Dec-19**	**4-Dec-19**	**5-Dec-19**	
88,40	99,60	106,40	96,60	100,60	99,00	91,80	102,00	104,80	95,40	73,60		
88,40	100,60	106,00	96,60	100,60	95,00	91,80	101,60	104,60	86,40	65,40		
89,40	99,60	104,00	96,20	100,80	94,20	92,00	101,60	104,60	84,80	65,00		
91,40	99,00	104,00	96,40	102,00	94,00	94,40	101,20	105,20	88,00	65,40		
69,80	98,40	104,40	97,40	101,20	94,80	93,20	81,40	104,40	86,20	65,20		
72,40	97,80	103,60	96,00	101,00	98,00	92,40	98,20	103,60	84,20	64,80		
88,80	97,80	80,00	96,60	102,60	104,20	91,80	98,40	103,80	84,40	64,80		
88,40	98,00	102,00	96,40	104,40	104,00	91,80	98,40	103,00	84,40	95,00		
69,00	97,40	102,20	96,00	100,80	104,80	92,60	97,60	103,60	84,20	88,40		
81,40	101,40	100,60	95,20	102,40	106,00	91,80	97,40	103,60	84,20	93,80		
86,80	101,20	100,00	95,40	100,60	103,80	90,40	97,60	103,60	84,00	95,60		
93,00	101,80	99,60	94,40	96,40	103,00	100,00	97,20	103,40	84,20	95,40		
93,20	101,60	98,00	93,80	100,40	102,60	102,00	97,20	103,00	83,40	94,80		
94,80	101,00	68,40	94,20	100,20	102,80	100,60	97,80	102,60	82,80	94,40		
93,60	99,20	61,20	78,80	86,60	100,80	102,20	97,20	104,80	61,80	93,80		

Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Average
24-Nov-19	**25-Nov-19**	**26-Nov-19**	**27-Nov-19**	**28-Nov-19**	**29-Nov-19**	**30-Nov-19**	**1-Dec-19**	**2-Dec-19**	**3-Dec-19**	**4-Dec-19**	**5-Dec-19**	
92,40	101,40	60,80	94,00	96,20	102,80	101,40	97,40	103,20	61,40	92,40		
94,00	100,40	61,00	94,20	96,80	101,20	101,00	96,60	103,40	61,20	90,60		
97,20	100,60	60,20	94,80	99,00	101,80	101,20	100,20	103,80	61,20	93,00		
96,80	104,20	60,20	94,20	99,40	101,20	102,00	98,60	103,00	60,40	94,20		
96,20	102,20	59,60	93,80	100,00	100,80	101,20	99,20	100,20	60,40	95,20		
95,40	101,40	60,00	77,40	99,20	100,80	103,20	99,80	71,60	60,00	95,60		
91,60	99,40	60,00	94,60	99,60	103,00	103,00	98,60	70,20	59,60	86,00		
90,40	100,20	59,40	94,40	99,00	102,60	106,00	95,80	70,00	59,80	94,80		
92,00	102,20	58,60	93,80	90,60	104,00	105,80	95,20	70,00	59,40	61,20		
92,80	102,00	58,20	93,60	100,00	99,40	88,40	61,60	91,80	58,80	61,20		
93,20	102,20	58,80	93,20	101,20	99,80	100,60	56,00	100,80	59,00	60,80		
93,80	101,40	57,80	94,00	100,60	100,00	103,60	56,00	100,20	59,40	90,60		
97,20	100,00	57,40	93,60	101,00	99,80	103,20	55,60	101,40	60,40	90,60		
97,60	100,60	57,60	94,20	102,00	98,40	102,00	55,40	100,20	58,40	89,60		
97,60	98,80	56,40	93,80	101,80	98,60	102,00	55,20	100,40	57,80	91,80		

Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Average
24-Nov-19	**25-Nov-19**	**26-Nov-19**	**27-Nov-19**	**28-Nov-19**	**29-Nov-19**	**30-Nov-19**	**1-Dec-19**	**2-Dec-19**	**3-Dec-19**	**4-Dec-19**	**5-Dec-19**	
98,00	99,80	56,00	94,60	100,40	98,80	101,80	55,20	100,00	57,80	90,20		
99,00	99,20	57,60	94,20	100,20	98,40	102,80	56,00	96,20	62,20	90,00		
97,00	98,80	62,60	94,00	99,40	96,80	101,80	54,80	97,80	62,00	90,60		
99,20	99,80	62,60	93,80	99,60	86,20	102,20	54,20	96,80	62,00	91,00		
99,40	99,80	63,20	92,80	100,60	85,80	102,80	54,80	96,00	62,40	90,20		
99,80	99,80	64,00	92,20	98,80	102,00	103,00	54,60	96,60	62,20	90,60		
96,80	101,00	65,00	92,40	99,20	101,40	103,20	56,80	97,20	61,80	90,60		
99,00	99,40	63,00	91,80	100,20	101,60	103,60	56,80	97,20	65,00	91,00		
99,60	99,60	75,60	91,00	99,80	101,00	103,80	64,20	97,60	84,00	91,20		
98,40	99,40	85,00	91,40	100,20	101,40	102,40	63,80	98,00	84,60	90,00		
98,60	100,60	64,20	91,60	100,40	101,00	102,00	64,00	98,80	77,40	91,00		
97,60	100,40	71,00	90,60	100,40	101,40	101,60	83,60	98,20	85,80	91,60		
98,00	99,20	85,60	91,00	102,40	100,60	76,40	94,20	98,20	91,60	81,00		
99,60	99,80	86,20	91,40	102,40	102,80	98,00	94,20	98,00	91,20	90,00		
99,00	100,40	86,20	90,80	102,00	102,60	100,00	93,80	98,80	91,20	80,40		

Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Average
24-Nov-19	**25-Nov-19**	**26-Nov-19**	**27-Nov-19**	**28-Nov-19**	**29-Nov-19**	**30-Nov-19**	**1-Dec-19**	**2-Dec-19**	**3-Dec-19**	**4-Dec-19**	**5-Dec-19**	
98,80	98,40	86,20	90,60	91,00	103,40	99,80	93,20	97,20	91,40	82,40		
100,40	99,60	84,20	92,20	75,60	101,40	101,80	94,40	97,80	91,60	89,80		
100,60	100,00	93,60	90,80	98,80	103,00	101,40	94,20	96,60	84,20	89,80		
100,00	99,60	95,40	92,00	102,40	103,40	101,60	95,60	96,40	92,80	88,60		
99,00	99,40	93,80	90,80	103,20	102,80	100,80	95,40	96,60	92,00	89,40		
100,00	100,00	91,80	90,40	103,40	102,00	101,80	95,60	95,80	91,40	89,00		
99,40	98,80	92,20	91,20	103,80	103,20	101,40	93,40	94,20	91,40	89,20		
95,80	98,60	93,00	90,60	104,00	103,00	101,20	93,40	95,80	91,20	88,60		
96,20	97,80	93,60	90,60	103,60	104,20	100,80	93,40	94,80	92,40	90,40		
95,40	98,80	92,20	91,00	101,60	100,60	101,60	92,80	81,60	91,60	90,20		
95,20	99,60	96,80	90,80	98,20	101,20	102,20	92,60	96,40	91,80	88,80		
95,00	97,40	92,60	90,80	98,80	102,00	101,40	93,60	97,60	91,80	90,20		
95,20	97,40	91,40	90,40	99,20	101,60	100,00	92,20	97,20	93,40	90,00		
96,00	97,80	91,80	90,60	101,20	103,60	103,00	92,40	95,80	92,60	89,40		
95,80	98,60	93,80	90,20	100,60	103,40	104,00	92,40	96,00	94,20	90,60		

Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Average
24-Nov-19	**25-Nov-19**	**26-Nov-19**	**27-Nov-19**	**28-Nov-19**	**29-Nov-19**	**30-Nov-19**	**1-Dec-19**	**2-Dec-19**	**3-Dec-19**	**4-Dec-19**	**5-Dec-19**	
95,80	97,40	92,00	90,00	100,80	104,20	102,20	92,80	96,80	95,60	90,00		
97,00	98,60	91,40	90,20	101,00	103,60	102,40	93,20	97,40	91,80	90,40		
99,20	97,80	91,80	88,60	101,20	104,60	103,60	93,40	96,80	91,60	90,80		
99,00	98,40	92,40	88,80	101,40	105,40	103,00	94,20	96,80	92,20	90,40		
96,20	98,20	93,40	88,60	101,00	104,40	103,40	93,00	97,40	92,80	91,40		
97,40	98,80	92,60	89,00	100,20	103,80	101,40	93,00	96,40	93,80	91,40		
97,20	97,60	93,60	89,40	100,40	104,40	100,80	92,80	96,40	93,00	92,00		
97,40	97,80	94,00	89,20	98,00	104,40	102,00	97,00	97,20	92,20	92,20		
97,60	97,80	94,40	89,40	99,20	104,40	101,60	97,20	96,00	92,00	92,00		
98,20	97,80	94,80	89,40	100,20	104,20	102,80	91,60	96,80	91,80	91,60		
98,80	96,80	95,80	89,20	100,80	104,40	102,60	96,00	97,60	92,80	91,60		
98,60	96,60	96,20	89,00	100,00	105,40	102,80	93,00	95,60	92,00	91,20		
100,00	97,40	96,60	90,60	99,20	103,60	103,40	85,20	96,40	93,40	91,40		
99,80	97,40	96,20	90,00	100,20	104,20	103,60	94,80	96,40	90,60	91,60		
98,40	97,20	96,40	89,80	100,00	104,40	103,40	95,80	97,00	91,00	89,40		

Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Average
24-Nov-19	**25-Nov-19**	**26-Nov-19**	**27-Nov-19**	**28-Nov-19**	**29-Nov-19**	**30-Nov-19**	**1-Dec-19**	**2-Dec-19**	**3-Dec-19**	**4-Dec-19**	**5-Dec-19**	
99,40	97,60	96,60	91,00	99,00	104,20	101,80	96,20	97,20	91,20	92,60		
98,80	97,00	96,40	88,80	99,40	104,40	103,20	95,40	98,40	91,80	92,20		
99,60	97,20	96,20	89,80	100,60	103,80	102,60	96,20	98,60	92,40	88,80		
99,80	97,80	96,00	88,40	99,00	102,80	99,40	90,80	97,80	93,40	92,00		
99,60	97,20	94,20	88,80	99,40	102,80	98,00	95,20	98,40	92,60	92,40		
99,20	98,60	95,20	88,00	98,60	103,20	100,80	95,00	99,60	93,80	91,80		
98,80	98,60	95,60	88,80	99,60	105,20	103,20	94,80	98,80	93,80	93,20		
98,60	98,60	96,60	88,40	100,20	103,60	101,00	78,60	96,00	94,20	93,80		
99,40	98,80	96,40	89,20	100,20	104,40	102,40	87,80	99,60	94,80	93,20		
98,20	98,40	97,20	88,20	99,80	106,40	102,60	94,80	100,20	96,40	86,80		
99,00	98,60	97,80	89,40	99,20	104,40	102,00	94,40	99,80	95,80	93,20		
99,40	97,20	96,60	90,40	100,60	78,40	101,80	96,60	97,80	97,20	93,60		
98,60	98,00	95,80	91,20	101,40	87,20	101,40	96,60	99,40	98,00	93,40		
97,80	97,00	94,40	92,20	101,20	102,40	101,80	97,00	84,60	97,80	93,40		
97,40	96,40	95,20	91,40	97,80	101,60	102,80	96,60	101,20	99,20	94,20		

Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Average
24-Nov-19	**25-Nov-19**	**26-Nov-19**	**27-Nov-19**	**28-Nov-19**	**29-Nov-19**	**30-Nov-19**	**1-Dec-19**	**2-Dec-19**	**3-Dec-19**	**4-Dec-19**	**5-Dec-19**	
97,00	97,00	94,80	91,60	97,80	89,20	99,00	96,40	100,00	97,80	94,00		
99,80	97,80	94,60	91,80	97,80	101,40	102,60	96,40	101,20	97,20	94,20		
99,80	98,20	98,40	94,00	97,40	106,20	95,60	96,80	97,20	97,40	94,40		
96,40	99,40	99,40	94,60	97,80	104,20	95,80	97,20	100,00	93,60	94,60		
97,00	99,40	100,00	92,00	101,60	104,00	78,40	99,80	101,20	93,00	95,80		
97,40	101,20	100,00	95,40	74,80	105,00	77,40	100,60	103,00	93,20	95,00		
100,20	103,00	101,20	96,40	90,40	105,00	93,80	101,00	101,60	98,80	96,40		
101,40	103,60	102,60	96,60	102,80	108,40	104,80	102,40	103,80	99,80	97,20		
103,80	104,40	104,00	97,60	104,40	108,60	82,00	103,00	104,80	99,40	99,00		
103,40	105,20	104,00	98,60	104,40	109,40	103,00	103,20	106,20	101,60	99,40		
103,60	106,20	104,80	97,60	104,00	111,00	106,40	103,60	106,80	101,80	99,80		
103,00	105,60	105,60	98,40	105,40	108,40	108,80	103,80	110,20	102,40	98,80		
102,80	106,80	104,60	98,20	105,60	106,80	109,40	103,20	107,20	103,60	101,60		
103,00	108,40	106,00	98,60	105,80	110,60	109,60	94,00	109,80	103,20	101,00		
103,60	107,00	103,20	102,00	107,40	112,60	109,60	101,00	106,80	102,60	100,60		

Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Average
24-Nov-19	**25-Nov-19**	**26-Nov-19**	**27-Nov-19**	**28-Nov-19**	**29-Nov-19**	**30-Nov-19**	**1-Dec-19**	**2-Dec-19**	**3-Dec-19**	**4-Dec-19**	**5-Dec-19**	
103,20	107,60	100,80	102,00	106,20	108,40	107,20	102,60	103,60	104,20	100,40		
72,80	100,80	100,20	104,00	107,00	106,20	107,80	104,80	108,00	105,40	100,00		
68,20	69,40	102,20	100,60	70,40	81,40	72,00	102,00	69,60	101,80	103,40		
68,60	70,40	101,40	100,80	69,20	74,20	72,40	102,00	69,80	102,20	103,60		
70,80	70,00	101,80	102,00	69,00	74,20	72,00	103,00	70,20	102,80	105,20		
70,60	68,60	101,20	100,40	70,00	73,60	71,60	104,00	69,20	103,40	103,40		
68,00	68,60	101,20	100,20	70,40	73,60	71,20	104,40	69,40	102,60	103,60		
67,80	68,00	101,40	100,60	70,00	73,00	70,60	104,40	69,20	103,20	104,40		
67,80	67,80	102,40	100,00	69,80	73,20	70,80	107,20	68,40	103,20	105,40		
67,60	68,40	103,60	100,80	69,60	73,20	70,00	107,20	68,40	102,60	104,80		
67,20	68,40	104,60	100,40	69,00	72,80	70,00	106,80	67,80	101,40	104,60		
66,40	69,20	101,80	101,00	70,00	72,60	69,40	106,80	68,60	105,60	104,60		
67,00	68,20	101,40	97,40	69,60	71,80	69,80	106,00	68,60	105,80	104,20		
66,80	68,40	105,00	99,00	70,40	72,00	70,00	101,60	67,80	101,00	105,20		
66,80	68,00	102,40	99,20	69,00	72,80	70,20	105,00	68,40	102,60	105,80		

Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Average
24-Nov-19	**25-Nov-19**	**26-Nov-19**	**27-Nov-19**	**28-Nov-19**	**29-Nov-19**	**30-Nov-19**	**1-Dec-19**	**2-Dec-19**	**3-Dec-19**	**4-Dec-19**	**5-Dec-19**	
66,60	67,60	103,80	99,20	68,00	76,20	71,60	104,00	67,60	102,00	105,00		
66,60	67,80	103,60	99,20	68,80	73,80	70,40	104,20	68,00	102,20	105,00		
66,20	67,60	103,80	100,00	69,00	71,20	71,40	104,80	67,40	103,60	102,80		
65,80	67,60	104,00	99,80	69,60	73,60	69,60	104,60	70,00	102,40	101,60		
65,80	66,40	103,60	98,60	66,80	73,20	71,40	105,40	67,60	102,80	101,00		
65,40	66,80	103,40	98,60	68,20	71,80	68,40	105,40	67,80	99,60	100,60		
65,40	66,40	103,80	98,80	66,00	73,40	69,00	106,60	67,40	99,80	99,60		
66,20	67,00	104,20	100,00	66,40	70,20	68,60	106,60	67,00	98,20	100,60		
66,40	67,20	104,00	100,20	67,20	71,20	69,00	105,40	68,00	102,80	103,40		
66,40	67,80	104,80	96,00	68,20	71,00	69,20	106,80	69,00	89,80	104,00		
67,00	67,60	104,20	98,80	67,40	70,60	69,80	105,00	69,00	87,80	104,40		
66,80	67,60	104,80	100,40	68,20	70,60	70,00	106,40	69,20	88,40	99,60		
66,60	67,40	101,00	99,80	69,00	71,40	70,00	106,00	69,00	92,00	101,00		
66,60	68,00	101,80	100,00	68,00	71,00	70,00	103,80	68,40	101,00	101,40		
66,80	66,80	101,40	100,00	68,40	70,60	69,40	103,40	68,80	100,80	101,00		

Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Average
24-Nov-19	**25-Nov-19**	**26-Nov-19**	**27-Nov-19**	**28-Nov-19**	**29-Nov-19**	**30-Nov-19**	**1-Dec-19**	**2-Dec-19**	**3-Dec-19**	**4-Dec-19**	**5-Dec-19**	
67,00	67,20	100,40	99,40	68,00	70,80	68,00	104,40	68,40	103,80	101,20		
66,80	67,00	100,00	99,80	67,20	70,40	68,40	100,60	68,80	104,20	101,00		
66,60	67,20	101,40	99,80	67,20	70,00	68,40	102,80	68,00	104,20	101,00		
66,80	67,40	101,80	100,00	67,60	71,20	68,20	102,80	68,00	103,00	100,40		
66,40	68,60	100,80	100,40	67,80	71,00	67,80	102,80	68,20	103,00	100,60		
66,20	67,40	100,20	97,00	67,20	70,40	68,00	101,20	68,20	102,80	101,20		
66,20	67,40	99,20	96,40	67,00	70,80	68,00	102,00	68,20	90,00	99,00		
65,80	67,00	102,80	98,80	67,20	70,40	68,60	101,00	68,00	96,60	100,00		
65,80	66,20	102,00	98,80	67,00	70,20	67,60	101,00	67,00	95,80	96,60		
65,80	66,00	103,60	101,20	66,80	70,20	67,40	102,20	67,00	99,00	98,00		
65,00	65,20	100,40	95,80	65,80	69,80	67,60	101,60	66,80	99,00	99,20		
64,60	65,00	100,00	96,20	65,00	69,40	67,00	101,20	65,80	87,00	99,40		
72,00	73,00	101,20	96,40	72,00	69,00	70,60	100,20	66,00	87,00	100,80		
72,00	72,00	100,60	95,80	71,00	76,80	73,40	98,60	73,40	86,60	100,60		
70,80	71,80	100,20	97,20	72,60	75,60	74,00	97,40	72,60	86,40	101,80		

Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Average
24-Nov-19	**25-Nov-19**	**26-Nov-19**	**27-Nov-19**	**28-Nov-19**	**29-Nov-19**	**30-Nov-19**	**1-Dec-19**	**2-Dec-19**	**3-Dec-19**	**4-Dec-19**	**5-Dec-19**	
71,00	71,20	99,60	94,40	72,60	89,20	91,00	98,80	93,80	86,00	101,80		
91,40	71,00	99,80	95,60	94,80	103,80	94,60	98,80	103,00	91,60	101,40		
94,80	71,00	100,60	95,20	99,40	103,20	97,00	97,60	102,40	92,00	100,40		
96,00	91,40	100,60	99,20	99,20	102,80	97,40	97,40	101,20	98,80	98,40		
94,40	98,00	100,20	96,00	99,60	95,80	97,40	98,40	101,60	95,00	97,40		
93,00	97,80	100,60	97,60	98,60	96,00	95,80	96,80	102,00	98,80	95,60		
93,40	97,00	101,00	95,60	99,00	94,40	95,40	96,20	102,20	99,60	97,20		
88,40	89,20	98,00	95,60	94,00	89,00	91,60	97,20	99,40	100,20	96,00		
87,80	88,00	97,40	94,40	93,20	86,80	91,20	96,40	96,40	100,20	95,20		
88,60	88,00	97,40	93,20	93,40	99,00	90,80	96,80	96,40	101,60	98,80		
93,00	92,20	96,80	95,60	93,20	84,80	97,00	95,40	97,00	101,60	98,80		
92,60	94,40	96,60	92,40	92,40	91,40	96,20	96,20	98,20	98,20	98,60		
91,80	95,20	96,60	92,40	83,60	98,40	95,80	95,40	97,60	97,00	97,80		
91,20	95,60	98,20	93,40	92,80	99,00	95,60	94,80	96,20	102,60	95,40		
92,80	95,00	95,40	93,40	92,20	97,80	96,20	94,60	96,20	100,40	95,80		

Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Average
24-Nov-19	**25-Nov-19**	**26-Nov-19**	**27-Nov-19**	**28-Nov-19**	**29-Nov-19**	**30-Nov-19**	**1-Dec-19**	**2-Dec-19**	**3-Dec-19**	**4-Dec-19**	**5-Dec-19**	
94,00	94,00	94,80	93,00	91,00	98,20	97,20	94,20	97,20	102,00	97,00		
90,40	94,40	94,80	91,20	90,40	99,20	96,80	93,80	95,80	100,60	96,60		
90,40	95,00	94,80	91,60	89,40	96,20	98,80	94,40	97,00	97,00	93,80		
91,40	94,40	93,60	93,80	91,40	96,40	97,60	94,00	95,60	95,60	96,80		
90,40	93,20	93,20	93,20	91,20	96,00	96,60	95,00	96,80	99,20	95,60		
89,40	93,60	94,60	94,00	89,40	95,20	96,40	96,60	93,60	98,80	95,80		
89,40	92,60	93,80	93,40	88,20	95,20	96,60	96,60	94,00	99,60	94,20		
87,80	93,80	94,80	93,20	88,20	95,00	96,00	94,80	93,00	96,00	93,80		
87,60	93,80	96,60	93,20	88,40	95,00	97,20	95,80	93,00	96,60	88,40		
89,60	93,60	95,40	67,20	89,20	95,00	96,60	95,40	91,00	95,00	92,20		
87,00	93,00	96,00	61,20	89,60	93,40	96,20	94,40	93,40	94,20	89,20		
87,00	92,00	95,60	83,20	89,80	93,40	96,00	94,80	94,00	93,80	93,40		
87,00	92,60	95,60	89,00	89,60	92,60	95,60	94,00	93,40	96,60	93,80		
88,40	93,20	95,20	90,80	89,20	92,00	94,00	93,20	93,40	93,60	91,60		
86,40	92,60	93,40	89,80	88,60	92,80	94,00	94,00	93,60	96,20	90,40		

Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Average
24-Nov-19	**25-Nov-19**	**26-Nov-19**	**27-Nov-19**	**28-Nov-19**	**29-Nov-19**	**30-Nov-19**	**1-Dec-19**	**2-Dec-19**	**3-Dec-19**	**4-Dec-19**	**5-Dec-19**	
88,40	64,80	93,40	89,60	88,00	92,00	92,60	94,00	93,60	90,40	91,20		
86,40	88,20	93,20	92,00	88,00	91,80	94,00	94,40	92,80	89,20	90,00		
75,60	88,40	91,60	90,00	88,40	91,40	94,20	93,40	91,80	93,00	90,40		
58,00	91,00	91,60	90,60	90,60	90,60	98,00	93,00	92,20	92,80	90,60		
80,00	91,60	93,40	90,80	89,80	91,40	92,80	92,00	92,60	90,00	91,40		
84,40	91,40	91,80	90,20	87,00	90,80	92,80	90,80	92,60	88,40	90,20		
87,80	90,00	95,40	90,00	89,20	90,00	91,40	92,00	92,00	89,00	88,60		
87,60	90,00	98,60	87,80	88,60	89,40	91,00	91,40	91,20	88,80	88,60		
87,60	90,00	98,60	87,80	88,60	89,40	91,00	91,40	91,20	88,80	88,60		
103,60	101,80	99,60	93,20	89,80	102,60	106,80	105,40	91,60	104,80	78,60		
101,00	99,20	101,20	93,40	88,80	101,40	105,80	103,00	90,00	103,20	78,00		
99,80	97,00	99,20	92,40	87,20	98,00	103,00	102,60	89,20	101,80	80,80		
98,40	94,80	96,80	92,20	88,00	96,00	100,00	100,00	89,40	100,00	83,80		
96,40	94,60	95,40	82,20	88,20	93,00	98,80	100,60	89,40	97,80	82,60		
94,80	93,20	95,20	86,40	86,80	93,00	98,60	97,60	90,00	97,20	82,80		

Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Average
24-Nov-19	**25-Nov-19**	**26-Nov-19**	**27-Nov-19**	**28-Nov-19**	**29-Nov-19**	**30-Nov-19**	**1-Dec-19**	**2-Dec-19**	**3-Dec-19**	**4-Dec-19**	**5-Dec-19**	
93,00	94,80	96,40	88,40	87,20	90,60	98,40	96,00	89,40	95,80	82,20		
93,20	89,20	95,60	88,60	87,80	93,40	93,60	96,00	90,20	95,40	83,40		
92,80	90,00	94,40	88,00	88,00	92,40	93,00	94,00	89,40	93,60	81,20		
4,20	90,60	92,60	87,60	88,00	90,20	96,00	93,20	89,40	93,00	80,60		
91,60	89,80	93,60	91,40	89,00	90,40	94,40	92,40	89,20	92,80	80,40		
92,20	88,60	82,60	90,20	78,20	91,40	94,20	91,80	87,60	91,80	89,80		
91,20	88,60	93,00	91,40	88,20	91,40	92,80	91,20	85,20	92,40	89,80		
91,40	90,80	91,80	90,60	87,60	90,60	92,40	91,60	87,40	92,00	89,40		
91,20	90,40	92,20	90,00	87,20	90,60	92,80	91,00	86,60	90,60	89,00		
90,20	89,40	91,00	90,80	86,60	90,20	92,60	90,20	86,60	91,20	90,20		
89,20	89,40	91,00	91,80	84,60	89,20	88,20	89,60	86,80	90,80	90,00		
89,20	90,00	90,00	91,00	88,40	90,00	91,60	90,20	86,40	90,20	89,80		
85,00	81,60	87,20	88,40	82,00	85,00	87,00	86,40	83,40	85,60	86,80		
85,00	83,00	87,20	86,40	82,00	85,00	87,40	85,00	83,40	86,00	86,40		
83,60	82,00	87,60	87,00	82,20	84,80	86,80	85,40	83,20	86,00	87,80		

Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Average
24-Nov-19	**25-Nov-19**	**26-Nov-19**	**27-Nov-19**	**28-Nov-19**	**29-Nov-19**	**30-Nov-19**	**1-Dec-19**	**2-Dec-19**	**3-Dec-19**	**4-Dec-19**	**5-Dec-19**	
84,20	80,40	86,80	85,20	81,20	85,60	88,20	86,80	82,40	85,00	86,80		
84,80	81,40	85,20	86,40	80,40	85,20	88,00	87,00	81,60	87,20	86,60		
84,60	80,80	86,00	86,60	80,40	84,60	87,20	87,00	81,60	87,00	85,20		
84,80	80,00	85,60	87,20	84,00	84,80	87,40	85,40	81,40	87,20	86,00		
84,60	81,00	85,40	85,60	85,20	84,20	87,00	85,40	81,20	87,00	84,80		
86,00	81,00	84,60	83,60	84,80	84,20	87,80	84,20	82,20	86,40	85,20		
84,60	79,40	84,20	82,20	85,80	84,40	87,20	85,40	82,60	86,40	84,40		
85,40	79,40	85,20	82,40	84,00	83,60	86,40	85,60	83,00	86,80	85,00		
85,00	83,00	85,20	85,00	79,60	83,40	87,40	85,80	82,80	86,20	85,40		
84,80	83,80	85,60	87,60	79,80	81,40	86,20	86,00	82,80	84,00	78,40		
85,20	83,40	85,60	87,00	79,20	82,00	86,80	86,40	83,60	84,00	80,20		
84,00	83,40	86,60	87,20	79,40	80,20	85,80	86,60	83,40	85,00	80,00		
84,80	83,20	85,00	88,20	78,40	82,00	84,80	85,60	82,20	85,40	82,80		
83,60	83,40	86,60	86,80	82,60	83,20	85,80	84,60	83,00	86,80	85,40		
82,80	82,80	83,80	86,60	79,20	84,40	78,20	85,60	83,20	86,20	83,60		

Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Average
24-Nov-19	**25-Nov-19**	**26-Nov-19**	**27-Nov-19**	**28-Nov-19**	**29-Nov-19**	**30-Nov-19**	**1-Dec-19**	**2-Dec-19**	**3-Dec-19**	**4-Dec-19**	**5-Dec-19**	
82,80	82,00	85,80	85,60	82,20	83,20	78,20	85,80	83,00	85,40	85,20		
84,40	81,80	84,60	84,40	82,40	80,40	78,00	85,20	83,00	85,60	85,40		

APPENDIX 3:
TURNITIN CERTIFICATE

Dissertation 6 November

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APPENDIX 4:
DECLARATION OF PROFESSIONAL EDIT

ANGY MOOI
PROFESSIONAL ENGLISH LANGUAGE EDITOR

23 April 2022

Mr. Phil P. Nonyane
Email address: PhilN@tshwane.gov.za
Contact number: 081 840 7762/079 177 880

Dear Mr. Nonyane

This letter serves to confirm that I have completed an English Language edit of your Master's dissertation entitled *"Adaptive scheme for improvement of load factor of water heater loads in residential buildings"*.

The edit included spelling, grammar, vocabulary, punctuation, sentence structure, correcting of acronyms and abbreviations according to your supplied list, captions and labels for tables and figures, formatting of document styles and headings to create a Table of Contents and List of Tables and Figures, correction of page and section breaks and general presentation of the document.

The edit did not include content, correctness of truth or information, technical terms and words, unfamiliar names and proper nouns, specific formulae, symbols, or illustrations.

Sincerely

Mrs. Angy Mooi

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