IMPACT OF ELECTRICAL VEHICLE CHARGING ON DISTRIBUTION NETWORK

This report submitted in accordance with requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Electrical Engineering (Industrial Power) with Honours.

By

MOHAMAD TARMIZI BIN MOHD SALEH

B011310149

940223055077

FACULTY OF ELECTRICAL ENGINEERING

2017

“I hereby declare that I have read through this report entitle “Impact of Electrical Vehicle Charging on Distribution Network” and found that it has comply the partial fulfilment for awarding the degree of Bachelor of Electrical Engineering (Industrial Power)”

Signature : …………………………………..

Supervisor’s Name : Assoc. Prof. Dr. Gan Chin Kim

Date : …………………………………...

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A report submitted in partial fulfilment of the requirements for the degree of Bachelor of Electrical Engineering (Industrial Power)

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2017

I declare that this report entitle "Impact of Electrical Vehicle Charging on Distribution Network" is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature	:	…………………………………
Name	:	Mohamad Tarmizi Bin Mohd Saleh
Date	:	…………………………………

Dedicated to my beloved mother and father.

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ABSTRACT

Nowadays, Electrical Vehicle (EV) is getting popular in our daily life to reduce global pollution. It is one of the solution to keep human stay healthy without affect the human life. EV use charging battery as power supply because it does not use fuel directly. It is a new concept to introduce people about economic clean transportation technology. Charging an EV at residential area is one of the distribution network problem that may lead a disturbance of the system. In this studies, it begin to create model the Low Voltage (LV) residential network due to urban, semi urban and rural area. Charging the EV will bring about a few impact through the power grid connection and also for the load. There have several impact such as cable overload and voltage drop to residential network system. Every single related issue had been found and analysed by several countries. The aim of this project is about impact of EV charging on distribution network. Those effects can be determine using simulation software. A simulation case was considered to analyse several parameter contains voltage drop and energy losses. Some essential reviews had been done identified with the current framework components and EV characteristic. In simulation software, there have 5 stages with 20%, 40%, 60%, 80% and 100% of EV penetration. This project will divided into two part which are results without EV penetration and results with EV penetration. All information acquired was processed and analysed.

ABSTRAK

Pada masa kini, kenderaan elektrik (EV) semakin terkenal dalam kehidupan seharian kita untuk mengurangkan pencemaran global. Ia adalah salah satu cara penyelesaian untuk manusia kekal sihat tanpa menjejaskan kehidupan seharian. EV menggunakan pengecasan bateri sebagai bekalan kuasa kerana ia tidak menggunakan bahan api secara langsung. Ia merupakan satu konsep baru untuk diperkenalkan kepada orang ramai mengenai teknologi pengangkutan yang bersih dan ekonomi. Mengecas EV di kawasan perumahan merupakan salah satu masalah rangkaian pengagihan yang boleh membawa kepada gangguan sistem. Dalam kajian ini, ia bermula dengan membuat model rangkaian voltan rendah kesan terhadap kediaman di bandar, pinggir bandar dan luar bandar. Mengecas EV akan memberi beberapa impak malalui sambungan grid kuasa dan juga terhadap beban. Ia mempunyai beberapa kesan seperti beban kabel dan kejatuhan voltan terhadap sistem rangkaian kediaman. Setiap isu yang berkaitan telah dijumpai dan dianalisis oleh beberapa buah negara. Tujuan projek ini adalah mengenai kesan pengecasan EV pada rangkaian pengagihan. Kesan-kesan tersebut boleh ditentukan dengan menggunakan perisian simulasi. Satu simulasi telah dijalankan untuk menyiasat parameter seperti kejatuhan voltan dan kehilangan tenaga. Beberapa ulasan penting telah dilakukan seperti komponen rangka kerja semasa dan ciri-ciri EV. Dalam perisian simulasi, terdapat 5 peringkat penembusan EV iaitu sebanyak 20%, 40%, 60%, 80% dan 100%. Projek ini akan dibahagikan kepada dua bahagian iaitu keputusan tanpa penembusan EV dan keputusan dengan penembusan EV. Semua maklumat yang diperolehi telah diproses dan dianalisis.

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LIST OF ABBREVIATIONS

AC	-	Alternative Current
BEV	-	Battery EV
DC	-	Direct Current
DSO	-	Distribution System Operation
EV	-	Electric Vehicle
G2V	-	Grid-To-Vehicles
HEV	-	Hybrid EV
ICE	-	Internal Combustion Engine
Km/h	-	Kilometres Per Hour
LV	-	Low Voltage
MD	-	Maximum Demand
NEV	-	Neighbourhood EV
OpenDSS	-	Open Distribution Simulation Software
PEV	-	Plug-in Electric Vehicle
PHEV	-	Plug-in Hybrid EV
SCADA	-	Supervisory Control and Data Acquisition
TNB	-	Tenaga Nasional Berhad
T_x	-	Transformer

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CHAPTER 1

INTRODUCTION

1.1 Introduction

The transportation sector has been identified about 25% of global carbon emissions from fossil fuels [1]. This situation is getting worse by the inefficiency of the transportation sector. To achieve a sustainable and green economy development towards a green transportation sector, the government must have several strategies for it. For example, introducing electrical – based vehicle towards the Malaysia consumer is the alternative to reduce CO_2 emission and the dependency on petroleum. According to the government statistics, car ownership in Malaysia is the third highest in the world at a whopping 93% with 53% of households having more than one car. By using electric cars, it is one of the ways to support the government's initiative to achieve a reduction of 40% towards the greenhouse gas emissions by the year 2030 and reduces the reliance on fossil fuels as the resources are depleting. According to Malaysian Green Technology Corporation (MGTC), switching to EV could save up to 69% in fuel and 64% in maintenance. Using EV as the battery and also acts as the power supply, it can be charged at home or public locations through standard electrical power outlets [2]. Moreover, the phenomena of charging EV battery in the houses in this country is still new. In this project, it will focuses on the impact of EV charging on the distribution of network.

1.2 Research Background

An Electrical Vehicle (EV) is also known as an electric drive vehicle. An EV is more energy efficient as compared with an Internal Combustion Engine (ICE) vehicle as it does not have any transmission losses. The increasing price of fuel and cares about the environment issue encourage the citizens to buy EV. An EV contains low carbon emission during operation that led to the reducing of air pollution and less contribution towards the greenhouse gases. Besides that, sales of EV is growing fast nowadays [3]. These EVs are available in the Malaysia market with the purpose of green technology and energy saving. The use of green technology and renewable energy is an integral part of the government agendas. Power source for an EV comes from the electricity collector system which is self – contained with battery or a generator to convert fuel to electricity. Consumers can charge at any location that provides electrical socket. This charging location is most common at home and in the workplace. Furthermore, during a critical situation, it may be a challenge in Malaysia to charge an EV because there are just few of the electrical charging stations only such as in Johor, Melaka, Penang and Klang Valley. In addition, installing Electrical Vehicle (EV) charging at Malaysia residential locations which consists of the urban, semi urban and rural area will give some impacts such as voltage drop or energy losses. The modelling network system for their impact of EV charging in residential areas are based on local power utility which is Tenaga Nasional Berhad (TNB) standard [4]. Due to the popularity of EV charging on electricity distribution network, it will give impacts on the planning and operation of the power system network. However, high penetrations of Electrical Vehicle (EV) may lead to technical impacts on connections to the residential system networks [5].

1.3 Problem Statement

In the modern days, the EV is getting popular as a transportation because it is one of the environmental friendly automobiles. The battery acts as a power supply for moving the EV. The energy of the EV battery can be added through swapping the battery or getting it recharged through grid connected charger. In the morning, during the working hour period from 8 am to 5 pm, the residential consumer demand is low as compared to the evening hour until midnight. This scenario occurs when people are out from their home for school or work. Residential consumer demand begin to rise in the evening at 5 pm until midnight due to the high demand occurs at that time when people go back from work and charge their EV at home. When extra load is used to charge the EV, it will affect the distribution network system. To reduce the grid network issues such as voltage unbalance, cable limit or transformer limit, are needed to be discuss to ensure stable grid distribution network.

1.4 Objectives

The objectives of this project are:

i. To model and determine the technical parameters of the low voltage (LV) distribution network in Malaysia.
ii. To determine the impacts of Electrical Vehicle (EV) integration of Malaysia's distribution network.

1.5 Scope

This project will focus on the impacts of Electrical Vehicle (EV) charging on the distribution network based on LV network for the Malaysian power distribution system. It involves the simulation of software studies. A software simulation has been developed in DIgSILENT Power Factory of 15.1 software. It is to model LV network for their impacts of EV charging in semi – urban residential area. In this project, those impacts comprises of voltage drop, cable thermal limit, transformer loading and energy losses.

1.6 Report Outline

This report will cover 5 chapters with its own content. Hopefully this report can show the ideas and understanding of the whole system designed to the reader after reviewing each chapter.

Chapter 1 gives a briefing about the introduction of this project, the research background, the problem statement, the objective, the scope and report outline for each chapter in this report.

Chapter 2 will discuss about all the literature reviews needed. In the literature review, it will elaborate about the theory and basic concepts of the project and comparison between previous researchers. This chapter also explains the previous project that are related about the impacts of Electrical Vehicle (EV) charging on the distribution network.

Chapter 3 explains the methodology used in this project. All the parameters and types of modelling will be explained in detail. It also includes the project’s progress that considers simulation modelling and flow chart.

In chapter 4, it highlights the result and analysis for this project. The analysis includes the existing system and the improved ones on the proposed system.

Chapter 5 explains the conclusion of this project about impacts of Electrical Vehicle (EV) charging on the distribution network. It also includes the future recommendations of the project.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter will describe the literature review based on the information from lecturers, reference book, information from internet web page and previous researches that are relevant to this project. This chapter consists of several sub – topics such as Electrical Vehicle (EV) charging theory, review of related work and summary of the related work.

2.2 System and Theory of Electrical Vehicle

Electrical Vehicle produce less pollution than Internal Combustion Engine (ICE). So, EV are an environmentally friendly especially in urban area. EV depend only on electricity to charge batteries compared with conventional and hybrid vehicles. EV technology which is regenerative braking help energy to flow back to the battery when brakes. Moreover, the harder the pedal pressed will make the motor rotate faster because EV does not need to change the gear. EV get power from the rechargeable batteries installed inside the vehicle. These batteries are not only used for power vehicles but also used for the functioning of radio, light, air conditioning and others. Since the EV has controller inside, it acts as a regulator to control the amount of energy received from the batteries so the motor does not damage or burn when the motor was running. However, the EV power source battery acts like a “gas tank” and give energy to the electrical motor vehicle rotate [6].

Battery EV (BEV), hybrid EV (HEV), plug-in hybrid EV (PHEV) and neighbourhood EV (NEV) are several types of EV available in the market. BEV is a type of EV that must need energy by connecting to an electrical source to drive the vehicle. It is also known as the pure EV. Battery electric motor of BEVs can move about 100 to 200 miles on the road. Combination between an electrical motor for the propulsion system and an internal combustion engine (ICE) is known as HEV. The electric power-train is better fuel economy compared with a conventional gasoline vehicle. HEV can save our electrical bills because it does not need to be recharged through electric grid. The electric motor improves the HEV to drive in urban area for over 600 miles per tank of gasoline with average 88.5 km/h. Vehicle that use rechargeable batteries connecting with electric power source is called PHEV. A PHEV and HEV is same because it has both of electric motor and combustion engine. PHEVs have an expected mileage range from 30 to 40 miles on electric power for shorter trips compared with ICE for long journey. NEV is an EV have a 48.5 km/h maximum speed and 3000 pounds maximum loaded. NEV is typically designed for usage in neighbourhood as stated in the name [7].

There are three types electric motor in the market such as DC brushless with top speed, permanent magnet motor and AC induction with the good performance. Besides that, there are three main component in EV which is battery, controller and electric motor. When the vehicle are turn on, the current will flow from the battery and the controller will take energy from the battery to send energy to the electric motor. Table 2.1 shows types of EV batteries [8].

Table 2.1: Types of EV batteries.

Types of Batteries	Description
Lithium ion batteries.	• Gives extra performances, range and carries highest price tag. • Lighter than lead acid and nickel metal. • Also used to store data in smart phone.
Lead acid batteries.	• Most popular. • Cheapest and 97% recyclable.
Nickle metal hydride batteries.	• Cost much more than lead acid but provides higher output and better performances.

There are many environmental benefits and personal benefits for having an EV such as no oil consumption. Next, creates less noise pollution. These because EV engine made low noise compared with combustion engine. Besides that, the maintenance of EV are more easy and cheaper. Since EV is giving affordable price to maintenance, they have fewer moving parts compared to conventional vehicle which using ICE. Moreover, EV very suitable for urban driving since it is not using conventional gear system and it so practical to handle. Furthermore, most electric motors can travel up to 150 until 180 km at full charge of battery.

2.3 Review of Related Work

Objective of paper [9] is to explore the affect proportion of residential LV distribution networks in Ireland by EV. Besides that, this study consists of two main issues which are excessive voltage drops and overloading of networks components. For example, large over load of transformer and power lines. Since, residential household in single phase connection, the voltage asymmetry will occurs on distribution network. Choose suitable levels of EV penetration for point connection of EV. Besides that, 28% penetration will over the limit when connecting end of feeder while 42% for start of feeder for point connection of EV. Then, 25% and 30% penetration will over the limit of transformer and the cable limit respectively. Distribution System Operation (DSO) cut down the power supply for EV charging, since 20% to 40% of EV penetration will over the limit for components safety. It can be conclude that installed smart metering device will upgrade impact for EV charging.

Paper [10] study the impacts of electric vehicle charging on the power distribution network in the Danish island of Bornholm. On the other hand, this study consist of five parameters to increase EV penetration such as system losses, peak demand, transformer loading, distribution line loading and voltage profile. Furthermore, EV charging have two modes consists controlled and uncontrolled are analysed for 0% until 50% EV penetration. These uncontrolled charging made the voltage drop below the limit more than 10% while controlled charging can increase EV penetration up more than 40%. It was obvious that the controlled charging is the best performance in EV penetration compared with the uncontrolled charging.

Numerous studies have attempted to explain about impact of EV charging on distribution network. Paper [11] found that the network sample was done on a residential area supplied by local Distribution System Operation (DSO). This studies aim to investigate the case study about newly developed and matured networks. For this studies, matured network has ten years experienced compared to newly developed network. This studies also research about safe penetration level for EV charging network. For example, penetration level on grid limit consist of voltage drop, transformer limit and voltage unbalanced. On the other hand, this studies consist of three scenarios such as unbalance EV charging, evenly distributed EV charging and controlled EV charging. For the first scenario, which also considered as a worst case. Transformer does not be over limit with 80% for new network and 30% for matured network. For voltage limit, penetration for new network is 40% while matured network is 20% can be safely restrain by residential grid. Both network, new and mature network was considered 20% of penetration level was safe for voltage unbalance. 30% and 10% of penetration level for new and matured network respectively due to cable thermal limit. Next, for the second scenario, which acted as balanced load. 100% penetration for newly developed network will constant for save minimum voltage unbalance and voltage limit while for matured network same penetration level can supported for voltage unbalance. Lastly, the third scenario is the best charging method among the others. It control the charging time with higher penetration level. Newly developed network can provide full EV penetration. It was obvious that potential of using different charging pattern.

Voltage unbalance create by uneven distribution network of EV penetration level among the stage were concentrates in paper [12]. 3 levels of battery charging technique such as Level 1, Level 2 and Level 3 to recharge the PEV batteries. Level 1 and Level 2 are single phase while Level 3 is 3 phase. In United State, Level 2 charger was use in this studies. It typically charges 208V to 240V and drawn many current up to 80A. PEV charging used high loads demand that influence energy consumption increase and can bring power losses and voltage unbalanced. Voltage unbalance increased by 0.181% for off-peak and 0.165% for on-peak demand due to 10% penetration of EV. Next, increased by 0.277% for off-peak and 0.262% for on-peak demand due to 30% EV penetration. Furthermore, for 50% penetration, voltage unbalance increased by 0.404% and 0.38% for off-peak demand and on-peak demand respectively. Last EV penetration is 80%. Voltage unbalance increased by 0.926% for off-peak demand and for on-peak demand increased by 0.917%. Since the higher EV penetration contribute voltage unbalance increase. Smart or coordinate charging, grid reinforcements, grid optimization are the new technologies method without give more impact on the EV charging system.

Three types of EV charging such as dumb charging, delayed charging, and smart charging were involved in paper [13]. Dumb charging means that EVs are charged like battery depleted without concerning any constraints. Delayed charging is like grid-to-vehicle (G2V) where the grid operator control the EV charging either by ripple control or by financial. Financial instrument motivates EV owners to charge their vehicles during off peak hours with a lower tariff rated. Smart charging needs continuous bidirectional communication between EV battery management system and distribution system operator (DSO) supervisory control and data acquisition (SCADA). Dumb charging had been using in the simulation for investigating a worst case scenario in Hungary. Dumb charging was used because no smart metering infrastructure in Hungary yet. Some assumption has been made in this study such as the customer amount in the network is very large, all customers are independent to decide the time for charging EV, and a single customer only consumes very small percentage on the network performance. Thus, paper concluded that dumb charging causes on increase in transformer loading. When 100% penetration was applied on transformer it may cause serious overloading. Furthermore, dump charging also cause voltage drop but it does not exceed the permissible limits which states 7.5% according to Hungary Standard MSZ EN 50160.

When large value penetration on EVs on the network system it will cause impact toward transformer and cable loading as stated in paper [14]. However, the percentage of overloaded network system instruments can be alleviated by implementing some kind of controlled charging. This study is focused in the Netherlands and also researches about the financial value of controlled charging of EVs. For the 10KW uncontrolled charging, it yields approximately 50% for transformer, 13% for cables due to overloading and 5% for cables due to voltage drop for the out of limit value. After used controlled charging, the percentage of exceeded threshold value had been improved compared to the 10KW uncontrolled scenario. It improve to approximately 25% for transformers, 5% for cables due to overloading and 2% for cables due to voltage drop.

All the paper studied had involved with the impact of EV charging. The EV charging will bring impact such as transformer overload, voltage drop or line losses. Table 2.2 shows the summary of previous research.

Table 2.2: Summary of previous research.

Authors	Field of Study	Project Description	Research Gap
P. Richardson, D Flynn, and A. Keane.	Impact Assessment of Varying Penetrations of Electric Vehicles on Low Voltage Distribution Systems.	This paper explores the potential effect to EV when charging on distribution network. This project was used DIgSILENT Power Factory to build a model of LV distribution network. Using unbalanced load flow calculations method to explore details about steady-state performance by changing the thermal loading levels and voltage at different parts of the system. Then the data was collected.	This research does not consider tap-changing capabilities for LV substation transformer in Ireland.
J. R. Pillai and B. Bak-Jensen.	Impact of Electric Vehicle Loads on Power Distribution Systems.	The main purpose in this project is to examine the impact of EV charging on the power distribution network in the Danish island of Bornholm due to voltage profile, transformer loading, distribution line loading, peak demand and line losses. Using DIgSILENT software to model EV charging profile and load flow analysis performance. 2 types of plug-in EV (uncontrolled & controlled).	The network data that has been analyse is difficult to find in the Danish Island of Bornholm.
Csaba Farkas, Kristof I. Szabo, Laszlo Prikler.	Impact assessment of electric vehicle charging on a LV distribution system.	Focus on dumb charging type of EV charging in Hungary. DigSILENT had been using in the simulation for investigating a worst case scenario in Hungary. This paper conclude that dumb charging causes on increase in transformer loading and voltage drop.	The analysis on this paper only shows the standard parameters which are relevant to the Hungary setting.

C.Tie, C.Gan, and K. Ibrahim.	The impact of electric vehicle charging on a residential low voltage distribution network in Malaysia.	This studies aim to investigate the case study about newly developed and matured networks. The Open Distribution Simulation Software (OpenDSS) was used to model the network. Three scenario such as unbalance EV charging, evenly distribution EV charging and controlled EV charging.	The research does not consider demand patterns in Malaysia. It totally different compared to the European and US setting.
S. K. Bunga, A. H. Eltom,and N. Sisworahardjo.	Impact of Plug-in-Electric Vehicle battery charging on a distribution system	This studies focuses on voltage unbalance caused uneven distribution of EV penetration among the phases. Modelled and tested distribution system using Matlab/Simulink/SimPowerSystem (Version 7.12 R2011b). In this case study consist four part such as model testing without PEV penetration, unbalanced voltage calculation, model testing with PEV penetration and impact of PEV penetration on simulation system.	The research does not consider Level 3 for charging level in residential areas because it may draw extra-large current will give more impact to the distribution network.
R.A.Verzijlbergh, Z.Lukszo, J.G.Slootweg, M.D.Ilic	The impact of controlled electric vehicle charging on residential low voltage networks.	This paper investigates the impact of electric vehicle charging on residential low-voltage networks. This study also researches about the financial value of controlled charging of EVs. This study focused on the Netherlands impact toward transformer and cable loadings if large amount EVs are penetrated.	The research does not consider demand patterns in Malaysia. The analysis on this paper only shows the standard parameters which are relevant to the Netherlands setting.

2.4 Summary and Discussion of the Reviews

This chapter has been summarized the previous studies relevant to the impact of EV charging on distribution network. All information or theory from journals, books and papers can be used to improve the system. According to previous research, the impact for EV charging had been carried out in United State, Malaysia and some countries of Europe. There have discussed that EV charging is influenced the electricity grid in the country. There are few key parameters which involve in those studies such as cable thermal limit, transformer overloading limit, voltage asymmetry, power losses and voltage profile. Voltage limit will be violated when load is too heavy. Thermal limit is happened when cable overheating due to overload. Voltage unbalanced happened because loads are not balance for three phases. Losses will increased when current is increasing by heavy load. Those are the impacts of EV charging for the electricity network. Some countermeasures had been suggested and few of them had been investigated such as smart charging, EV battery management, financial instrument, grid reinforcement and others. By concluding the previous studies, the efficient approach for overcoming issue brought by 100% EV penetration is combination a few methods as stated in [13].

CHAPTER 3

METHODOLOGY

3.1 Introduction

Most of the previous studies collected the load profile data before doing analysis. Then some assumption will be made according to personal demand. The analysis will after that showing by simulation, graph or table. Apart from those software which can show graphical result directly, data obtained from other software had to process by using Microsoft Excel to plot into graph.

3.2 Network Losses

Power losses come from many factors such as cables, transformer, overhead lines and other equipment. It possible to achieve 100% efficiency due to power transmitting system. Equation (1) below represent power losses equation [15].

$$P_{loss} = I^2R = \frac{(P_G-P_L)^2+(Q_G-Q_L)^2}{V^2}R \quad (1)$$

P_{loss} = Loss power
V = Voltage
I = Current
R = Resistance
P_G = Real power (KW) at grid

P_L = Real power (KW) at load

Q_G = Reactive power (KVAR) at grid

Q_L = Reactive power (KVAR) at load

3.3 Transformer Loading

The reverse power flow can overload the transformer by huge production and small consumption in LV grid. The transformer loading occurs when the reverse power flow is too high. To avoid the transformer overloading is necessary to estimate the limit for distribute generation-free capacity($P_{\max}$). Figure 3.1 shows the measured trend of transformer loading during one day [16].

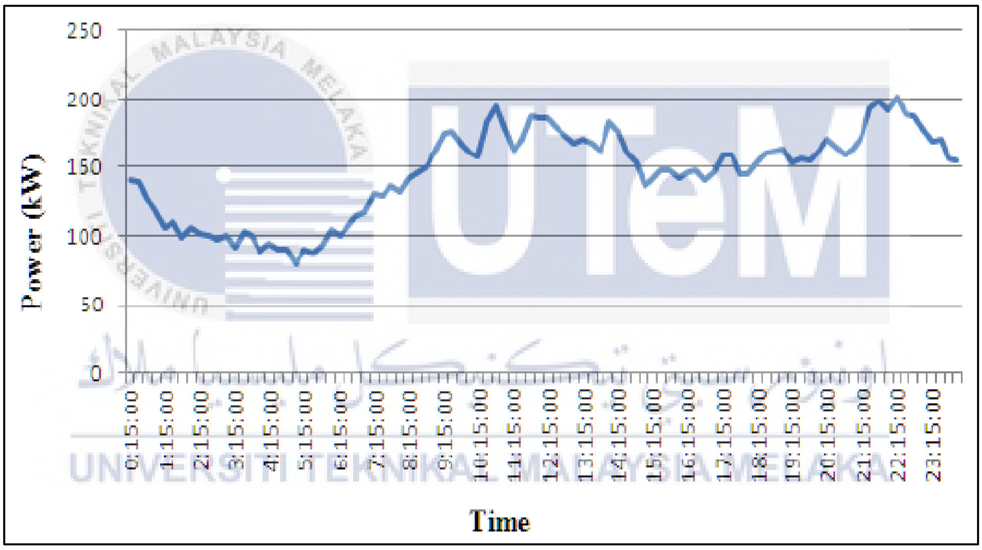

Figure 3.1: Transformer loading pattern in one day.

Equation (2) until (5) below represent transformer loading (proposed method) [17].

$$KVA_{r1}(inductive) = \sqrt{(KVA_2)^2 - (KW)^2} \tag{2}$$

$$KVA_{r3} = KVA_{r1} - KVA_{r2} \tag{3}$$

$$KVA_3 = \sqrt{(KVA_{r3})^2 + (KW)^2} \tag{4}$$

$$Transformer\ Loading\ (\%) = \frac{KVA_3}{KVA_1} \times 100\% \tag{5}$$

KVA_1 = Transformer rated capacity

KVA_{r1} = Existing reactive power at PCC (in general, it is inductive)

KVA_{r2} = Reactive power compensated with capacitors at PCC

KVA_{r3} = Reactive power at PCC after compensation

KW = Measured full load active power (adding active of all feeder values)

KVA_2 = Measured full load apparent power (adding apparent all of feeder values)

KVA_3 = Apparent power at PCC after reactive power compensation

3.4 Voltage Drop

Voltage drop calculation is necessary in designing electrical system in order to keep our equipment operate normally. Failure to calculate voltage drop property would result into under-voltage that can damage equipment. Furthermore, an overhead distribution conductor has a considerably higher current carrying capacity than an underground cable conductor of the same material and cross-section [18]. On the other hand, underground cable conductor has much lower inductive reactance than that of an overhead conductor because of closer spacing of conductors.

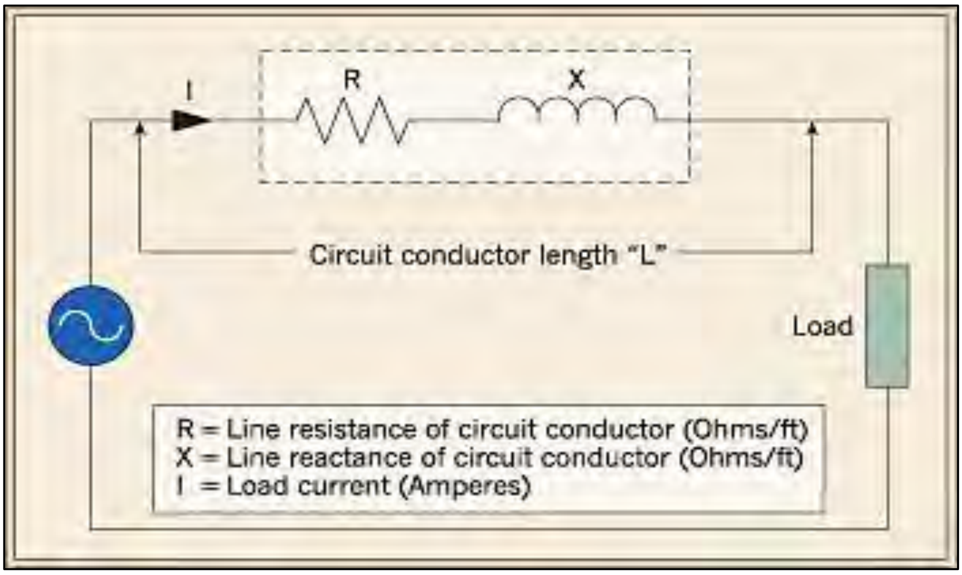

Figure 3.2: Simple two-wire AC circuit.

Calculate the voltage drop of the simple two-wire AC circuit in the Figure 3.2 by using following equation (6) [19].

$$V_d = \frac{2 \times K \times Q \times L \times I}{D} \tag{6}$$

V_d = Voltage drop (Volt)

K = The resistivity constant of conductor metal (Circular mil-ohm per feet)

Q = The alternating current adjustment factor for skin effect

L = Length (In feet)

I = Load current (Amps)

D = The cross sectional area of conductor (In circular mils)

3.5 Flow Chart

Step by step for this methodology were shown in a flow chart drawing. Firstly, collect the data about grid characteristics and EV characteristics. A residential area (semi urban) was chosen for this case study. After collecting the data, line impedance, size of cables, transformer rating was calculate. Next step, the modelling simulations were done for different cases. All the data take from previous research. All cases simulated can be divided into five penetration levels. After that, the simulation data was present into graphical image and plotted into graph for each feeder. Combined all graph for each case. Last step for this case study was analysed the graphs. Figure 3.3 shows the flow chart of DIgSILENT software.

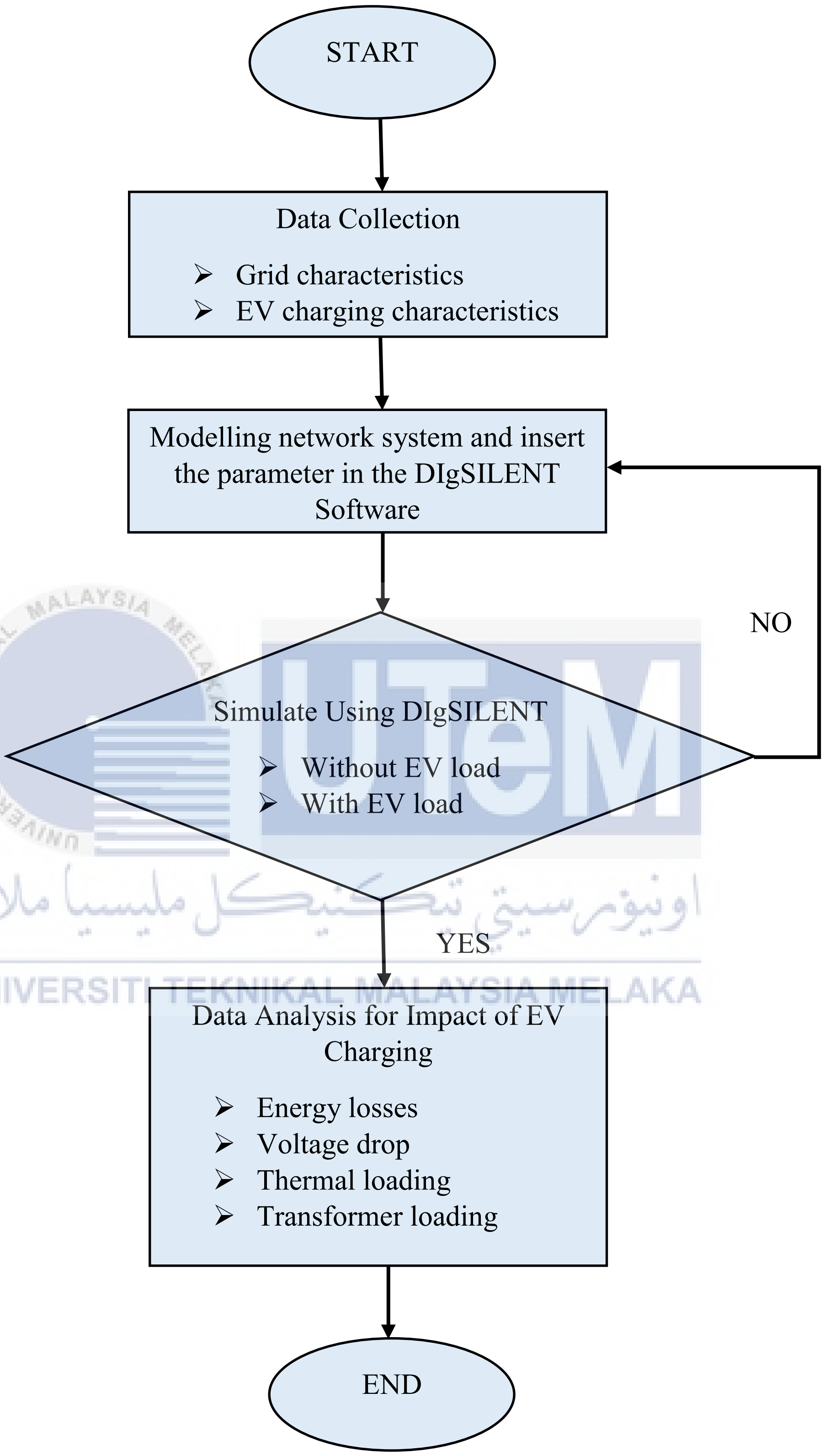

Figure 3.3: Flow chart of DIgSILENT software.

3.6 DIgSILENT Modelling

DIgSILENT Power Factory software consists tool for the analysis of distribution, transmission and industrial electrical power system [20]. This power system software has been designed which related to the control and power analysis to achieve the fundamental targets of the planning. Design the new modelling of generation and distribution network system can reduce the unbalanced network. All over the world using DIgSILENT Power Factory software because of the high accuracy in power analysis results. This software has been recommended by organizations who is involved in planning and design of power distribution network system. DIgSILENT Power Factory simulation software is appropriate to examining the impact of EV charging load on the distribution network systems consist of calculation voltage drop, unbalance network system, generation and EV load model. Local power utility in Malaysia which is TNB also use this software to simulate and analysis in Malaysia distribution networks. Figure 3.4 shows the logo of DIgSILENT Power Factory software.

Figure 3.4: DIgSILENT Power Factory logo.

3.6.1 Network Modelling

This project was carried out by utilizing DigSILENT Power Factory simulation software as simulator and Microsoft Excel as data processor. 3.3KW EV load of Nissan Leaf and additional EV load which is 6.6KW and 9.9KW was chosen as EV charging load in all the simulations. The battery capacity for Nissan Leaf was 24KWh and on board charger chosen was 3.3KW charger [21]. The time taken for charging from 0% to 100% was approximately 8 hours. However, 20% was the minimum level of power needed to be reserve in the battery. For charging from 20% to 100% time taken was approximately 6 hours which was used in EV charging profile. EV were assumed to charge through the direct plug in socket which same with other daily appliances. Each EV charging load was set 3.3KW constant power demand for 6 hours continuously and then change with 6.6KW and 9.9KW constant power demand. The simulation was done based on a real grid network. A residential area was chosen for this project. Figure 3.5 shows the single line diagram of the area.

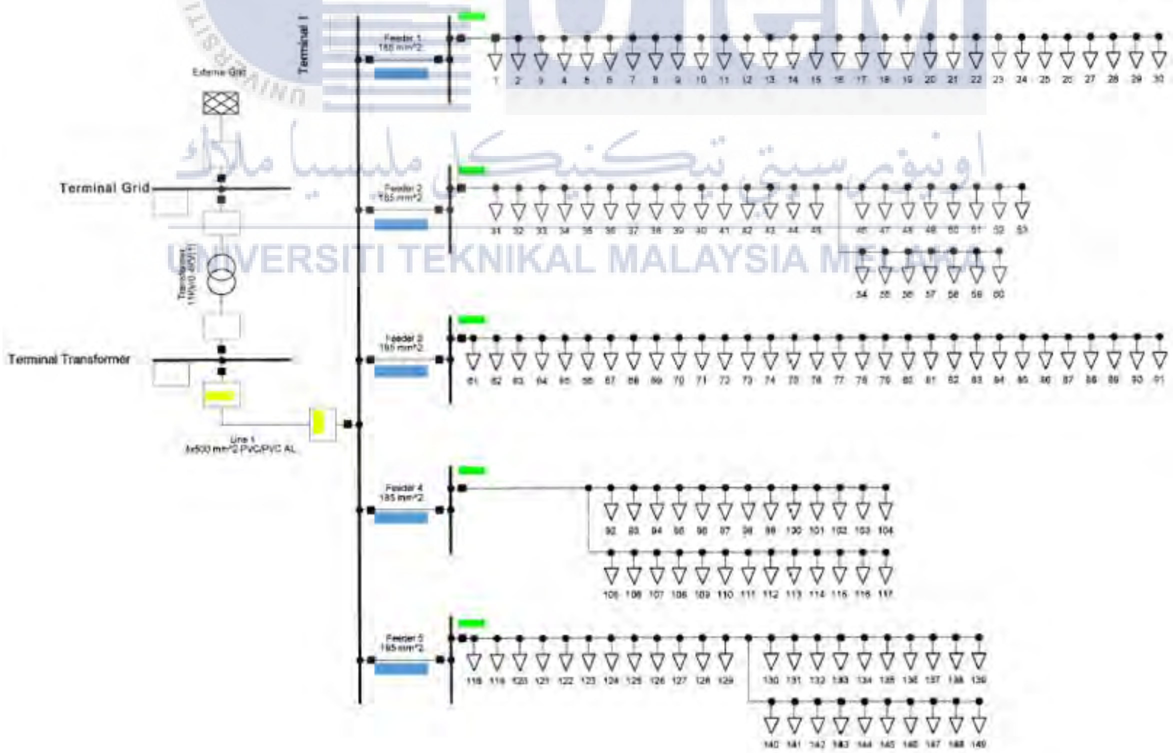

Figure 3.5: Single line diagram of chosen residential area.

Table 3.1: Characteristic of network.

Characteristic	Quantity/Rating
No. of houses	149
Total demand (KW)	596
Total network length (KM)	1.5
Transformer rating (KVA)	500

Table 3.2: Cable Size of the network.

Colour	Cable size
	4 x 500 mm^2 PVC/PVC AL
	185 mm^2 4C XLPE AL
	ABC 3 x 185 mm^2 + 120 mm^2

3.6.2 Transformer Modelling

The network consists of one transformer, five feeder pillars and one hundred and forty nine houses. There is 11KV/400V delta-wye transformer with 500KVA rating. Five feeder were connected to transformer through busbar. Cable 500 mm^2 aluminium cable was used between terminal transformer and busbar. Feeder pillar 1, 2, 3, 4, and 5 were connected to busbar by 185mm^2 cable.

Table 3.3: Characteristic of transformer.

Characteristic of Transformer	Rating
Rated power (MVA)	0.5
Nominal frequency (Hz)	50
Rated voltage – HV side/LV side (KV)	11/0.4
Vector group – HV side/LV side	Delta-Wye connection

3.6.3 Cable Modelling

- 4x500 mm^2PVC/PVC Aluminium (Al)

Using size cable 4x500 mm^2PVC/PVC Aluminium (Al) connected between transformer and main feeder. This cable has 4 wires consist of 3 phase wires with neutral wire. Table 3.4 shows the rating of 4x500 mm^2PVC/PVC Aluminium (Al) cable.

Table 3.4: The rating of the 4x500 mm^2PVC/PVC Aluminium (Al) cable.

Characteristic of cable size	Value
Rated voltage (KV)	0.4
Rated current (KA)	1
AC-Resistance R' 20°C (ohm/km)	0.11
Reactance X' (ohm/km)	0.14
AC-Resistance R0' (ohm/km)	0.12
Reactance X0' (ohm/km)	0.15

- 185 mm^2 4C Al XLPE

Using size cable 185 mm^2 4C Al XLPE connected between main feeder and distribution feeder. This cable also has 4 wires consist of 3 phase wires with neutral wire. Rated voltage and rated current are 0.4KV and 1KA respectively. Table 3.5 shows the rating of the 185 mm^2 4C Al XLPE cable.

Table 3.5: The rating of the 185 mm^2 4C Al XLPE cable.

Characteristic of cable size	Value
Rated voltage (KV)	0.4
Rated current (KA)	1
AC-Resistance R’ 20°C (ohm/km)	0.165
Reactance X’ (ohm/km)	0.076
AC-Resistance R0’ (ohm/km)	0.12
Reactance X0’ (ohm/km)	0.15

- (ABC) 3 x 185mm^2 + 120mm^2

Power source from feeder distribute separately to every house by using cable (ABC) 3 x 185mm^2 + 120mm^2 due to durability of the cable. Table 3.6 below shows the rating of the (ABC) 3 x 185mm^2 + 120mm^2 cable.

Table 3.6: The rating of the (ABC) 3 x 185mm^2 + 120mm^2 cable.

Characteristic of cable size	Value
Rated voltage (KV)	0.4
Rated current (KA)	1
AC-Resistance R’ 20°C (ohm/km)	0.165
Reactance X’ (ohm/km)	0.076
AC-Resistance R0’ (ohm/km)	0.18
Reactance X0’ (ohm/km)	0.03

3.6.4 Load Estimation

In Malaysia, local utility name TNB provides the typical value of maximum demand (MD) for houses. All the data based on survey by TNB due to demand from customer. Table 3.7 below shows value of maximum demand (MD) for houses [22]. 4KW of double storey terrace at suburban area was used as reference demand for this project.

Table 3.7: Maximum demand for houses [22].

No.	**Type of Premises**	**Rural (KW)**	**Suburban (KW)**	**Urban (KW)**
1	Low cost flats, single storey terrace, studio apartment (<600 sq ft)	1.5	2.0	3.0
2	Double storey terrace or apartment	3.0	4.0	5.0
3	Single storey, semi-detached	3.0	5.0	7.0
4	Double storey, semi-detached	5	7.0	10
5	Single storey bungalow & three-room condominium	5	7.0	10
6	Double storey bungalow & luxury condominium	8.0	12	15

3.6.5 Load Modelling

All the houses were connected to five feeder pillar. Those houses were distributed evenly in terms of power demand. Table 3.8 and 3.9 shows total load demand and load modelling characteristic respectively.

- No. of house = 149
- Power demand each house = 4KW
- Total power demand = 596KW

Table 3.8: Total load demand.

Feeder	No. of House	Total Demand (KW)
1	30	120
2	30	120
3	31	124
4	26	104
5	32	128
Total	149	596

Table 3.9: Load modelling characteristic.

Parameter	Value
Voltage, U (L-L) (KV)	0.4
Active power, P (KW)	4
Power factor, cos (phi)	0.95
Scaling factor	0.1

Besides that, load demand profile for Malaysia residential usage was plotted and referred. All the houses were assumed to have that kind of power consumption daily. The pattern was recorded in KW unit where 160KW represent maximum full load demand. The load demand pattern was shown in figure 3.6.

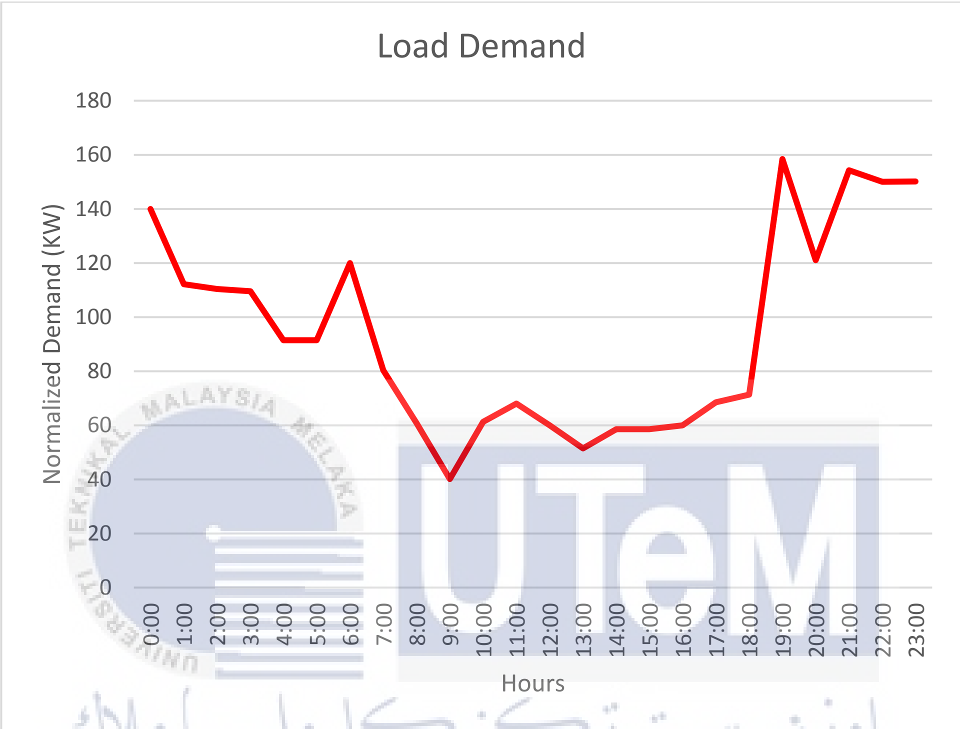

Figure 3.6: Typical Malaysia residential load demand pattern.

There were different cases done for simulation to ease the analysis work. There were comparison between without EV load penetration and with EV load penetration. For each type of case, there were also divided into several penetration levels. Penetration level can be defined as percentage of EV amount charging among all houses. 20%, 40%, 60%, 80%, and 100% penetration level simulation cases were done for most scenarios. There were used three different type of EV load demand which is 3.3KW, 6.6KW, and 9.9KW.

The EV load demand patterns for both peak and off peak time were shown in figure 3.7 and 3.8. The pattern was recorded in per unit where 1 represent full load.

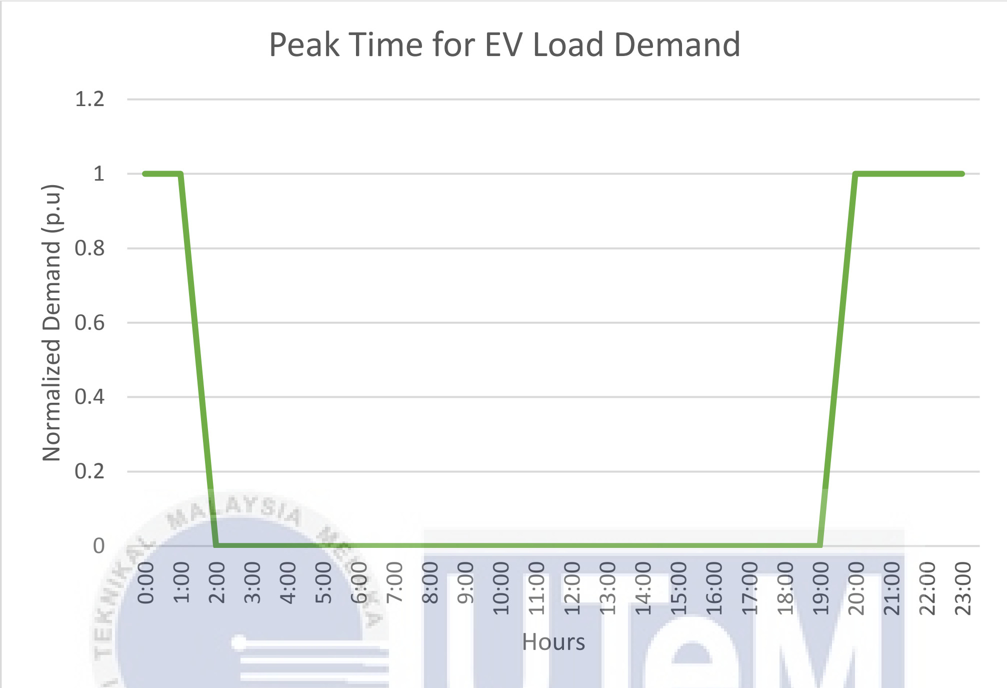

Figure 3.7: Peak time for EV load demand charging pattern.

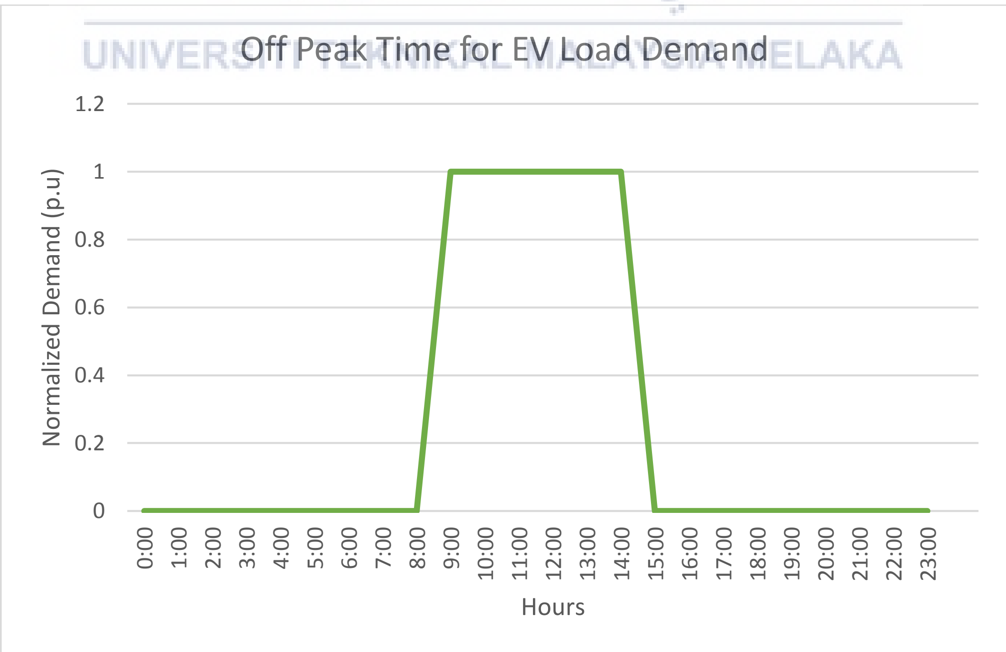

Figure 3.8: Off peak time for EV load demand charging pattern.

The load profile of EV charging overnight was simulated in DigSILENT and graph plotted using Microsoft Excel. Different penetration level for EV was investigated. Without exceeding the grid limits, only limited amount of EV can be charge simultaneously for a low voltage (LV) distribution network. The penetration level which did not violate any grid limit was indicated for each case. Controlled charging was a method proposed that more EV can be charge daily without replacing the existing grid equipment. All the data simulated was recorded in csv file and had been processes into graphical data by Microsoft Excel. Four parameters which are voltage drop, feeder thermal limit, transformer loading and energy losses were involved in the data analysis part. All the analyses of data had been included into this report.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

There were two simulation cases done for this research. Each parameter for each case was simulate and plotted into graph using Microsoft Excel such as current, voltage, power and energy. Maximum current used to determine the thermal limit of feeder. Total power was calculated to carry out the transformer loading. Energy consumed daily was obtained to get the energy losses in percentage for the system. Two simulation case are without EV load and with EV load with three different types of EV which is 3.3KW, 6.6KW, and 9.9KW. For thermal limit there have a limit current for a cable to carry. In this case, $185mm^2$ size cable was used for each feeder. According to Tenaga Nasional Berhad (TNB), 320A was the current limit for $185mm^2$ cable to carry [22]. Total power consumed by three phases should not exceed the rating of the transformer connected.

4.2 Case 1: Without EV Load

A case without any EV load was simulated. That case can also be defined as 0% penetration of EV among the residential area. Voltage and current for each feeder were measured and plotted. There were one line indicating three phases for both current and voltage graph. The minimum voltage for all feeders was shown at hours 19:00. At 7p.m is the time for people back from work and reached home. People may use water heater to bath or switch on the air conditioner due to hot weather. Those reason made 7p.m become the peak demand hour. All feeder from feeder 1 until feeder 5 which made up of double storey terrace house were consuming three phase load. The load demand will be supplied evenly by three phases. Figure 4.1 shows the voltage without EV for feeder 1 until 5. The minimum voltage which occurred at 7p.m was use to plot another graph afterwards. Feeder 5 was facing the highest voltage drop because it consists of highest amount of houses. Even the load was approximately same, but the cable will be longer when there are more houses. The line impedance of the cable will cause the voltage drop to enlarge when length of the cable is longer. The feeder 2 had minimum voltage of less than 220V which is lower than feeder 1. Feeder 3 was balance among three phases since house load in three phase connected. While feeder 4 had similar condition with feeder 5 but feeder 5 had face lower voltage drop than feeder 4.

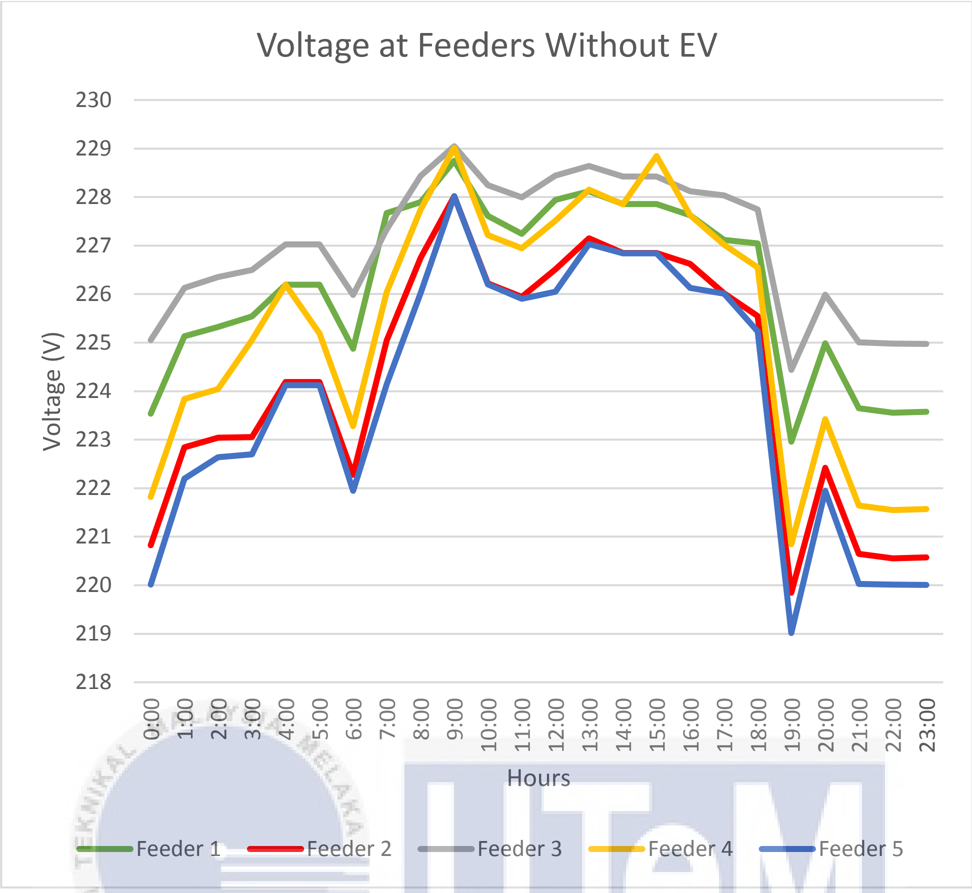

Figure 4.1: Voltage at feeder without EV load.

Figure 4.2 shows the current for feeder 1 until 5. The highest current drawn for all feeder was on 7p.m. Since 7p.m was peak load demand, most power will consumed at that hour and thus current drawn will also increase. Since, all feeder using three phase, the current drawn was balanced among three phases indicated by the graphs. Feeder 2 drawn the highest current for about 162A and lowest current for less than 40A. Feeder 3 had balanced among three phase with highest current less than 180A. Furthermore, feeder 4 was also balanced in current drawn with same reason but the highest current drawn was lower than feeder 3. While feeder 5 was similar with feeder 2 in current drawn since amount of houses for both feeders were nearly same.

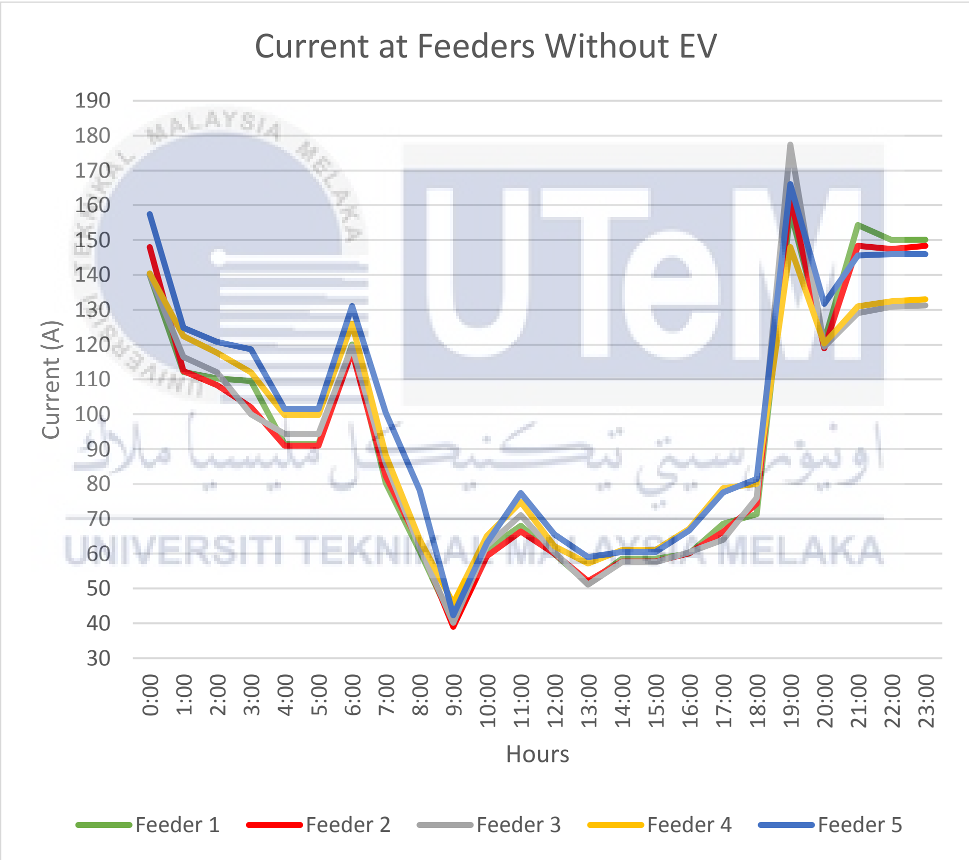

Figure 4.2: Current at feeder without EV load.

Figure 4.3 shows the graph of transformer loading. This graph are illustrated in unit of apparent power in KVA. Rating for transformer is 500KVA. Transformer can function normally within its own rating. Not even the transformer loading graph, voltage and current graph will also show the similar pattern since there are no EV load injected to the network. Maximum power used for transformer was about 238KVA and minimum power was slightly more than 100KVA.

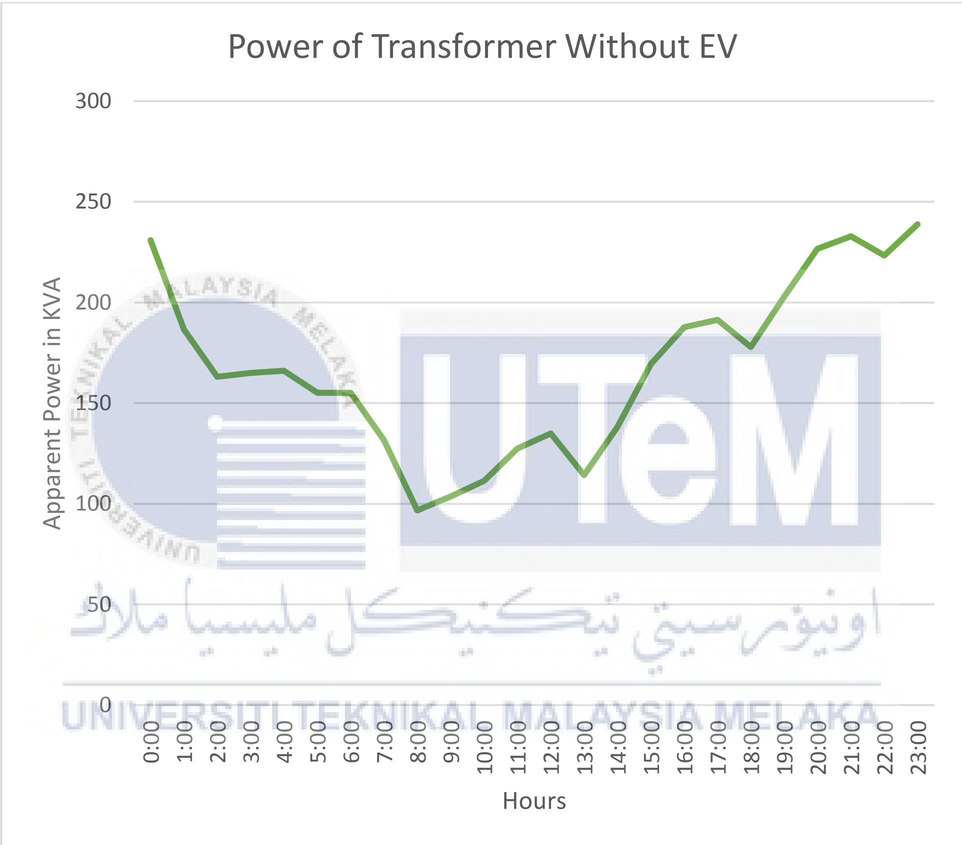

Figure 4.3: Power for transformer without EV load.

4.3 Case 2: With EV Load

100% penetration EV charging with different type of EV load which is 3.3KW, 6.6KW, and 9.9KW can be declared as the worst case because it would make voltage drop to lowest value and highest current drawn by all feeder. For case 2, all feeder which is feeder 1 until 5 will be shown since all penetration level have similar pattern of graph. Figure 4.4 until 4.8 are voltage graph for five feeder. When compared with 0% penetration, the gap between off peak hour and peak hour become larger because all EV were assumed to charge at peak hour.

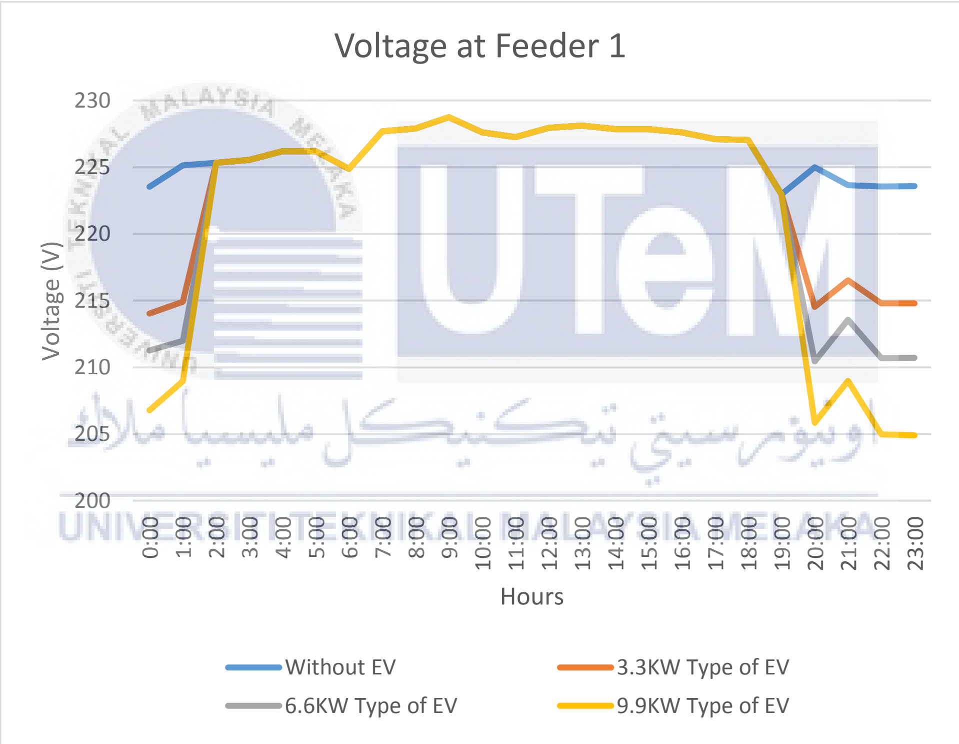

Figure 4.4: Voltage at feeder 1 with EV load.

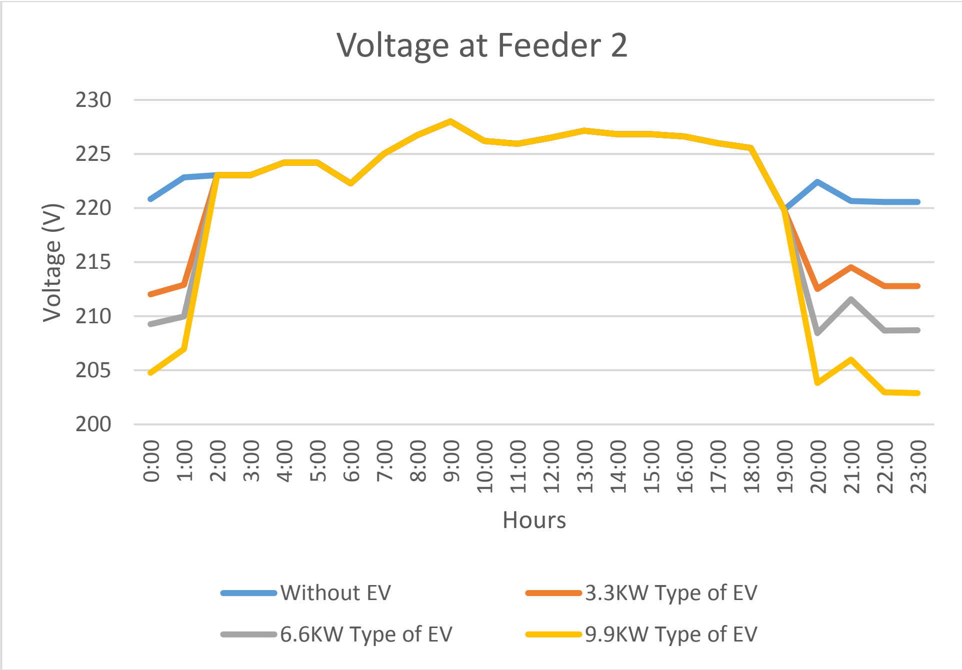

Figure 4.5: Voltage at feeder 2 with EV load.

Feeder 2 was three phase feeder and all EV were charged through a same phase in this case. The impact of voltage drop can be seen obviously from figure 4.5 and 4.6 where different type of EV load was injected.

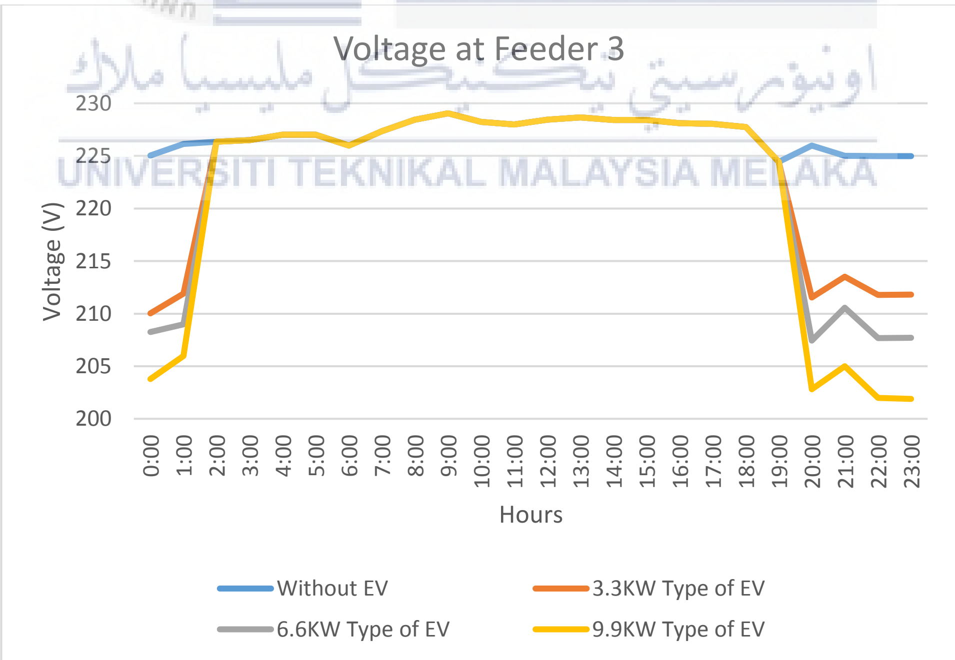

Figure 4.6: Voltage at Feeder 3 with EV load.

All feeder showed same voltage pattern at graph but different value in magnitude when charging on peak hour. The six hours peak time had used to charge the EV and consumed large power. When all houses charge the EV on peak hour, the EV charging load was lower than residential peak demand. The peak demand hours was changed from 8p.m to 1a.m. When comparing voltage drop for three type of EV load inject, some different can be spotted. The voltage drop had change the magnitude due to penetration of EV load according figure 4.7 and 4.8 below.

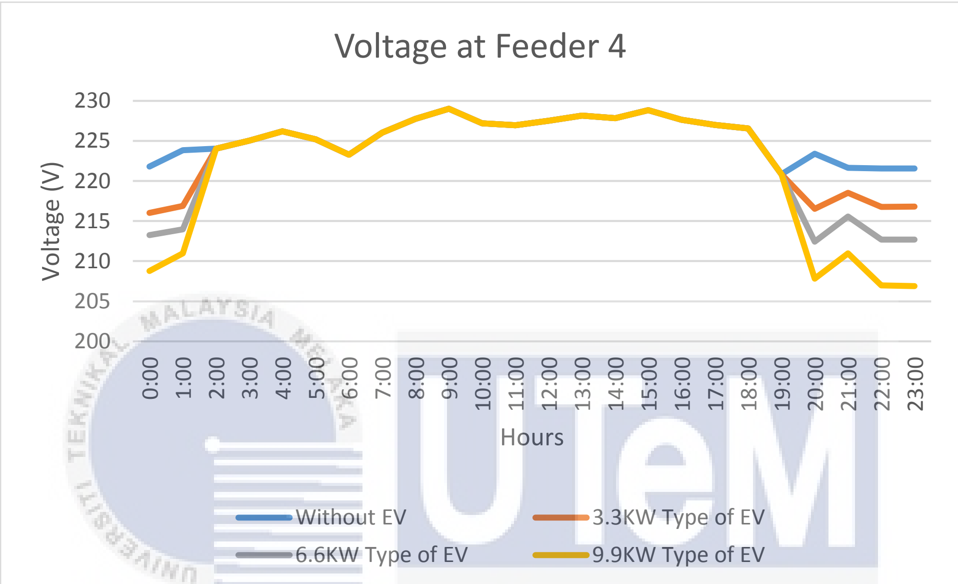

Figure 4.7: Voltage at feeder 4 with EV load.

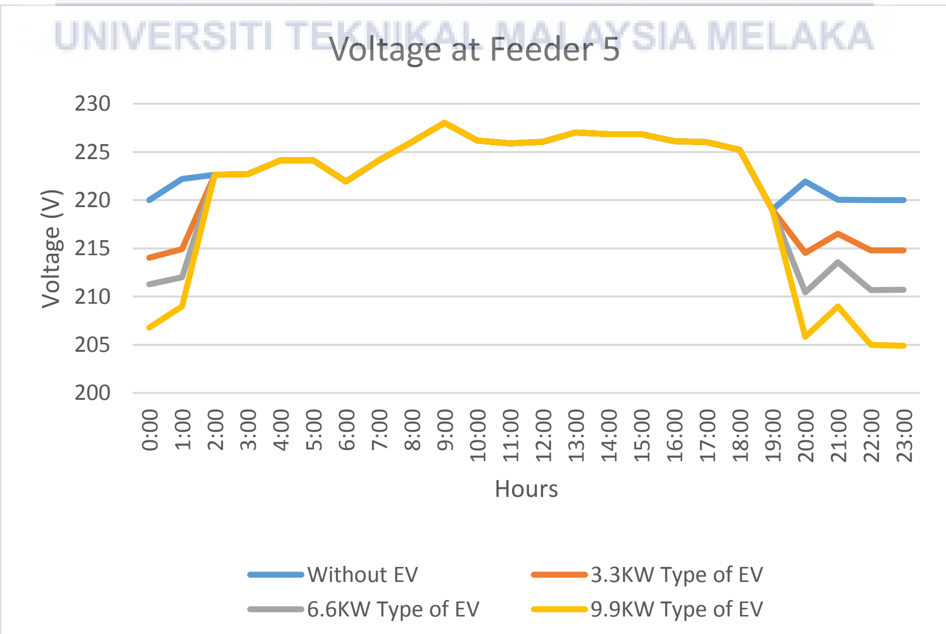

Figure 4.8: Voltage at feeder 5 with EV load.

100% penetration EV charging with different type of EV load which is 3.3KW, 6.6KW, and 9.9KW can be declared as the worst case because it would make highest current drawn by all feeder. For this case, all feeder which is feeder 1 until 5 will be shown since all penetration level have similar pattern of graph. Figure 4.9 until 4.13 are current graph for five feeder. When compared with 0% penetration, the gap between off peak hour and peak hour become larger because all EV were assumed to charge at peak hour. Graph for case 2 which was fully penetration were shown below.

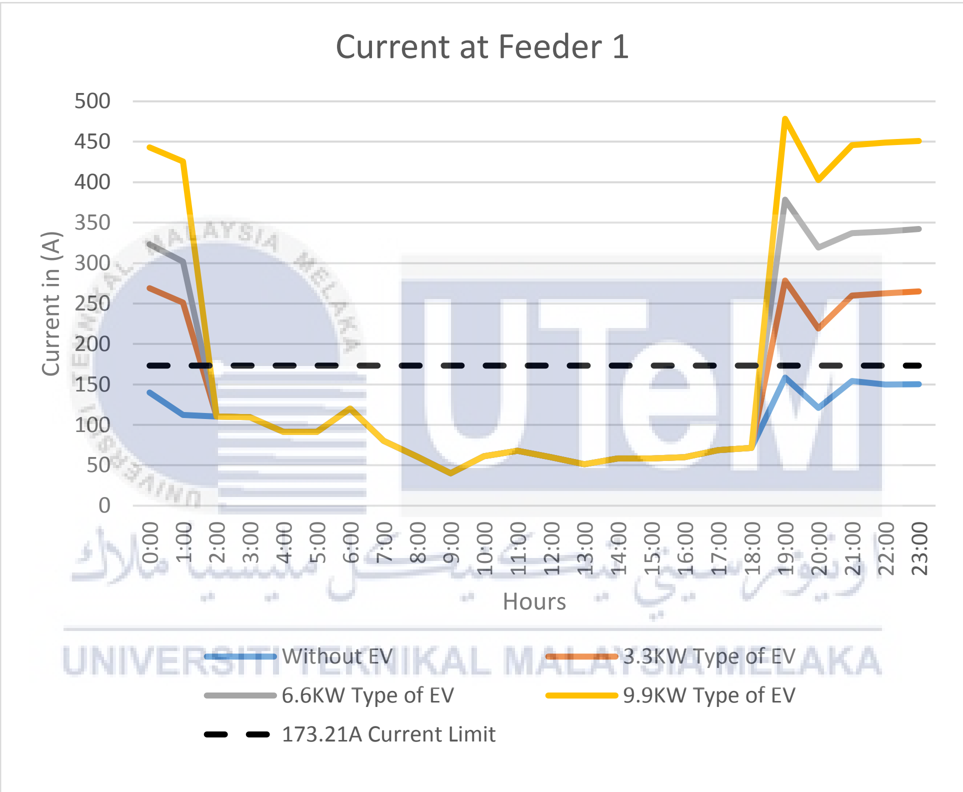

Figure 4.9: Current at feeder 1 with EV load.

Different type of EV load penetration would bring significant changes to load pattern since most feeder almost fully loaded. For Feeder 1 and 2 have same current limit for load without EV penetration which is 173.21A. Meanwhile, for feeder 3, 4 and 5 have different current limit for load without EV penetration which is 178.98A, 150.11A, and 184.75A respectively.

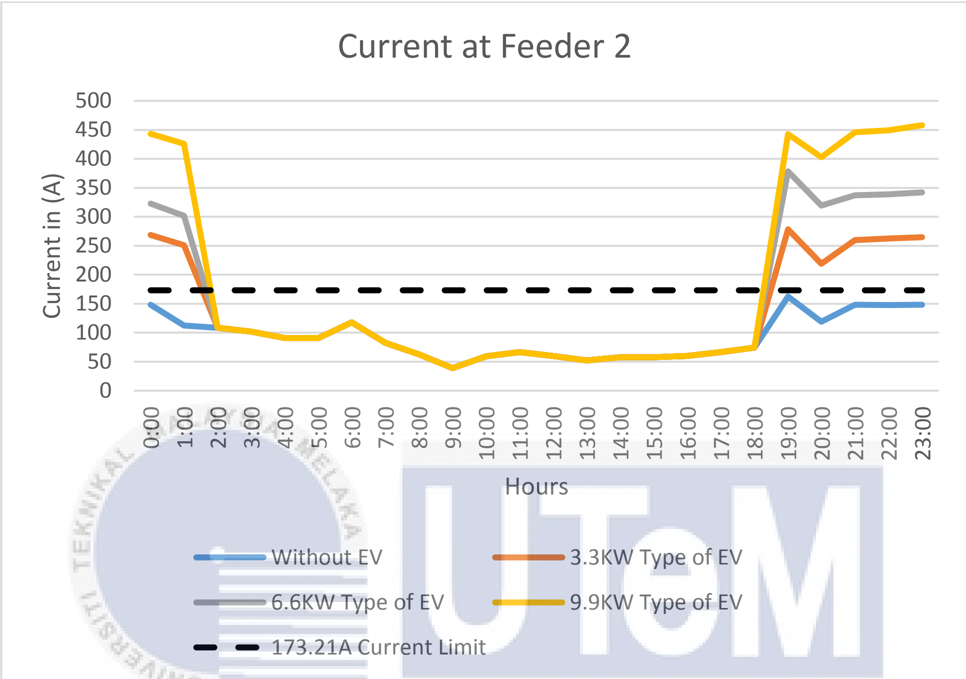

Figure 4.10: Current at feeder 2 with EV load.

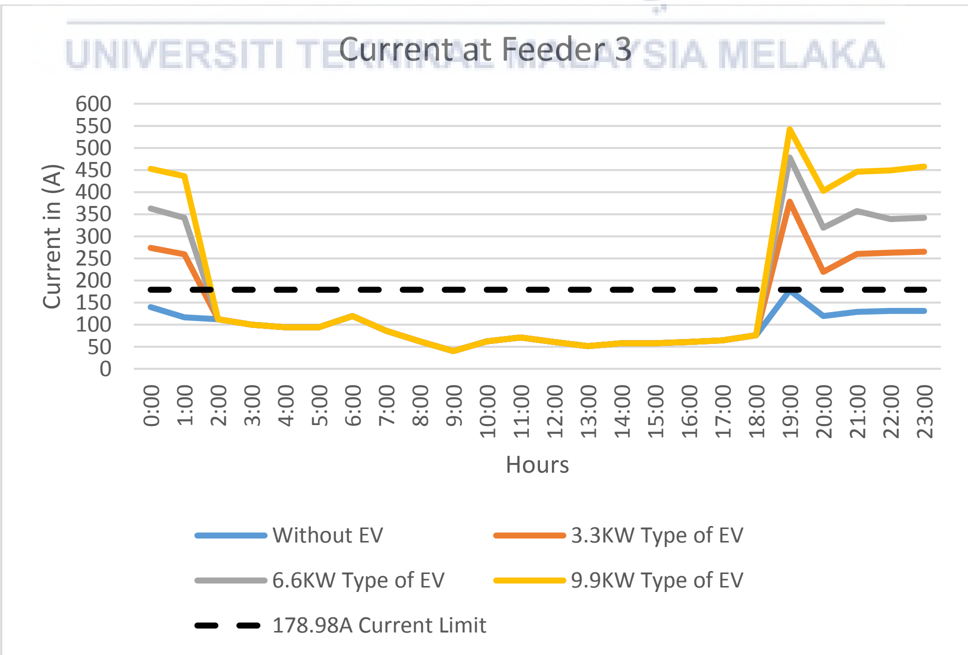

Figure 4.11: Current at feeder 3 with EV load.

When EV load start charging at 7p.m until 1a.m, the current of EV load increase compared without EV load. As the maximum current without EV occur at 10p.m, the maximum current drawn with EV penetration also change to 10p.m. Feeder 5 reach almost 550A maximum current for 9.9KW type of EV load because connected with 32 houses compared with feeder 4 connected with only 26 houses.

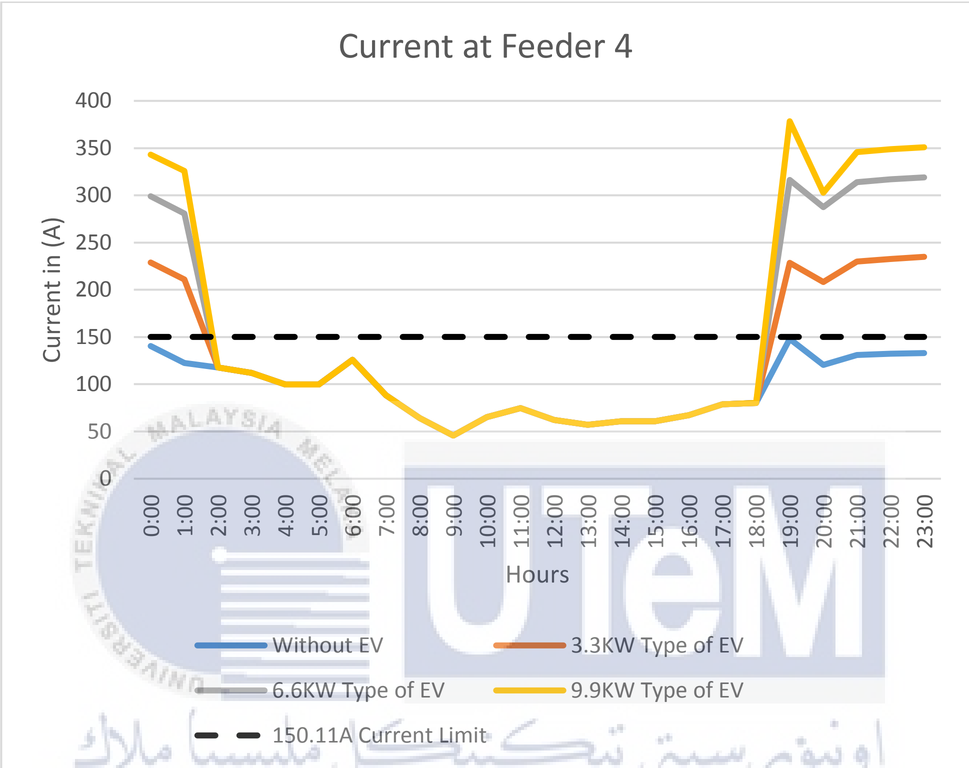

Figure 4.12: Current at feeder 4 with EV load.

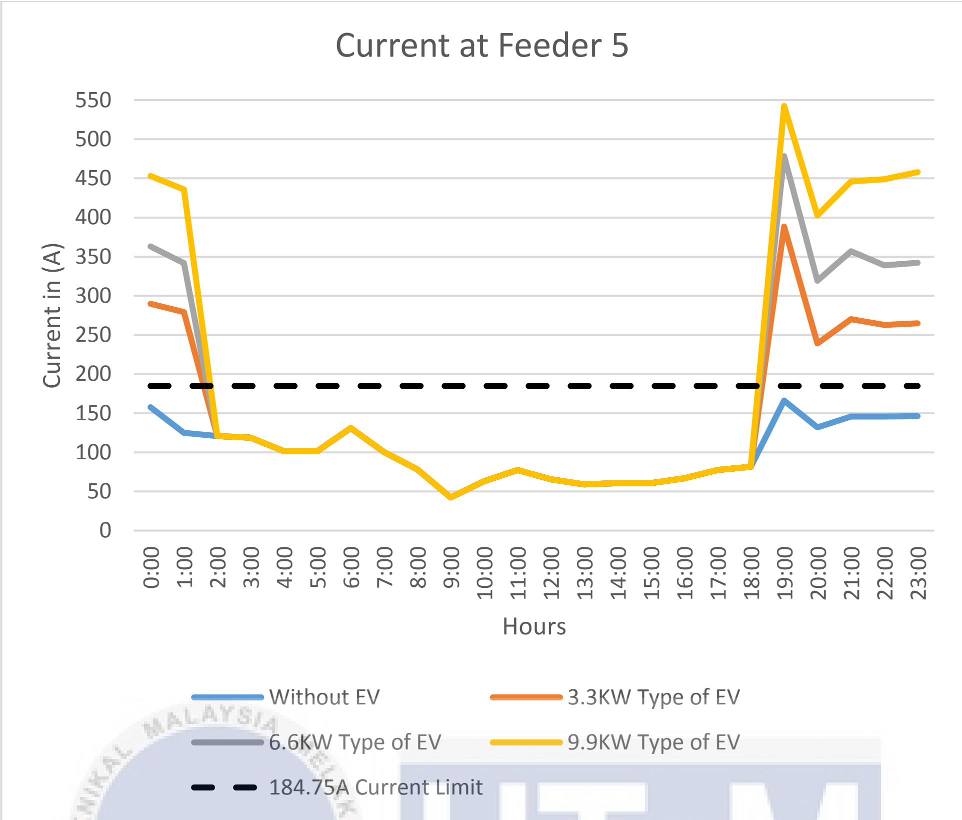

Figure 4.13: Current at feeder 5 with EV load.

Figure 4.14 shows the power of transformer with EV load. The pattern for transformer loading is still similar. When compared with 0%penetration, the peak hour consumed more power because of EV charging. Transformer had exceed the rating of 500KVA when 9.9KW type of EV load was injected while for 3.3KW and 6.6KW still operated within the limit. It means that transformer can still function normally even all houses had change EV on the same time. Since transformer had rating of 500KVA, it can operate safely with full penetration but transformer will burst when 9.9KW type of EV load used.

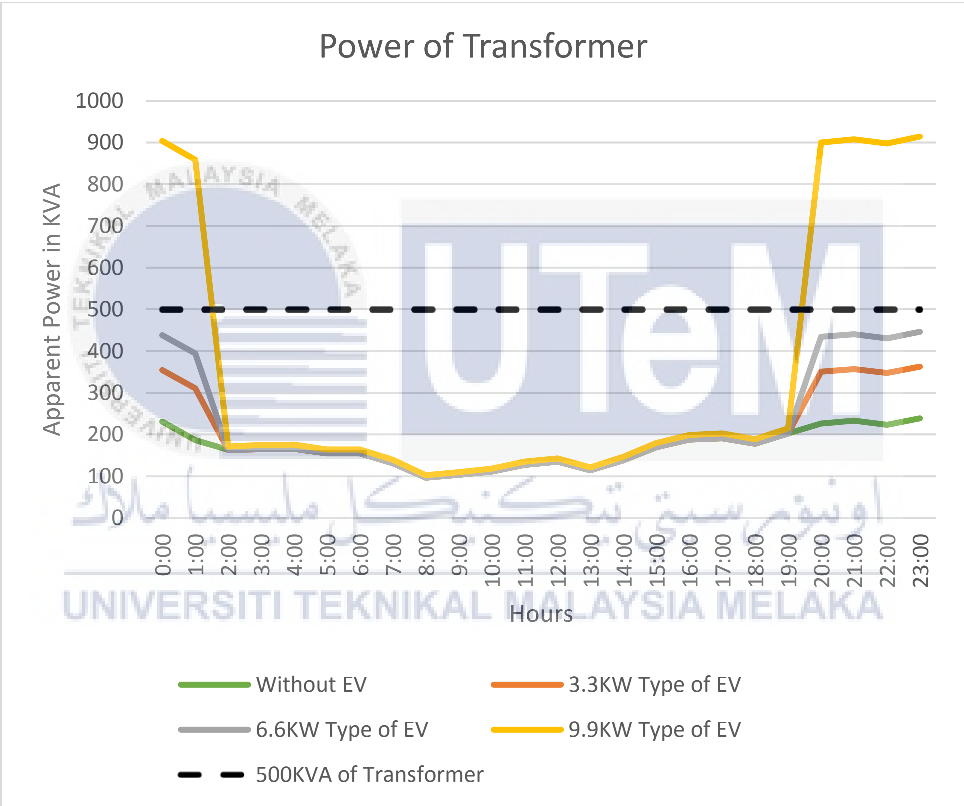

Figure 4.14: Power of transformer with EV load.

Figure 4.15 shows cable thermal limit for all feeder of the network system with several penetration of EV. In terms of thermal limit, no feeder in this case can withstand full penetration of EV load. Feeder 4 can withstand 80% penetration of EV load. Feeder 2 and 3 can withstand 60% penetration of EV load and remaining feeder, feeder 1 and 5 can only withstand 40% penetration of EV load. In other meaning, 40% penetration of EV can be accepted by whole network system if only considering cable thermal limit.

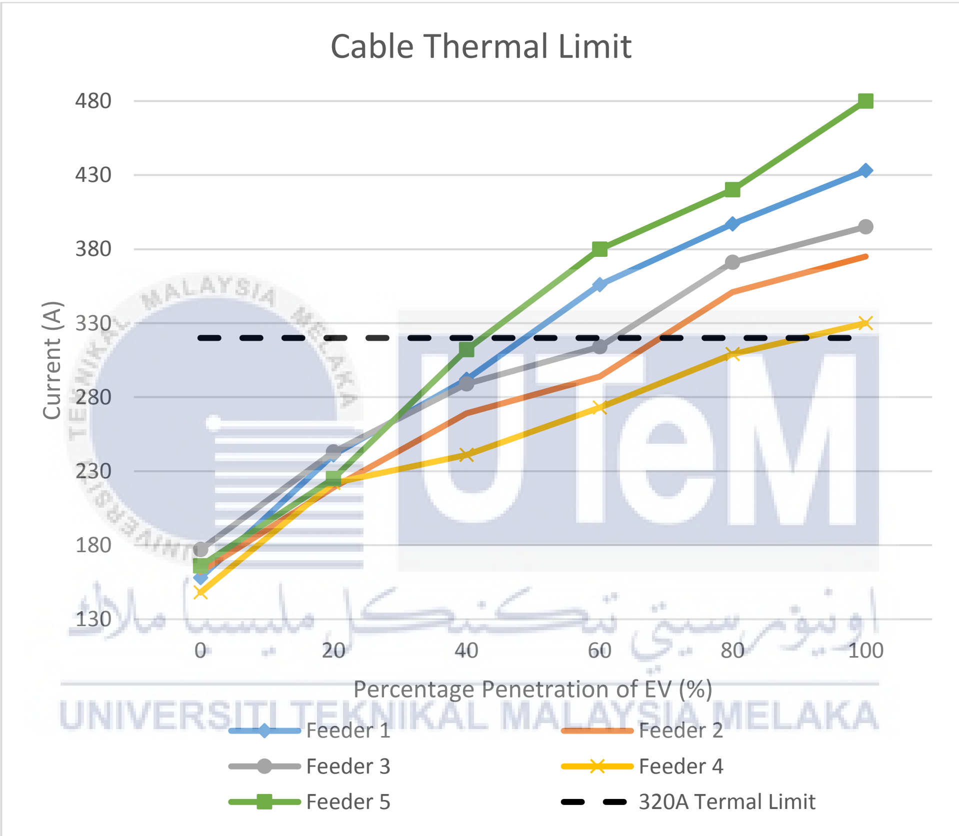

Figure 4.15: Cable thermal limit. .

4.4 Losses of the System

For the 0% penetration of EV at figure 4.16, the system have 1.24%, 2.43%, and 2.99% of losses for the 3.3KW, 6.6KW, and 9.9KW type of EV load respectively. Result show losses were increase starting 20% penetration of EV until 100%. The penetration of EV load may influence the losses because it included total load demand for each houses. Hence, current flow at the load was increase along the line each house. So losses due to heating or impedance at the line will increase.

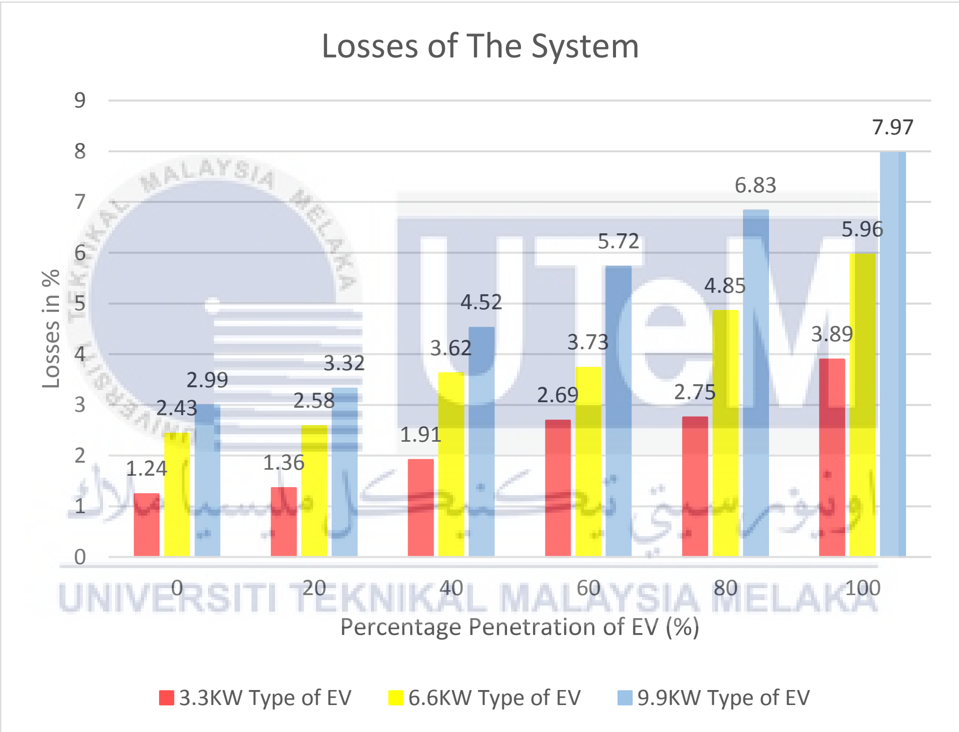

Figure 4.16: Losses of the system.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

EV is needed to preserve the environment. Gas pollution can be reduced by introducing and implement EV in public. EV which need recharging battery for propulsion would bring some impacts to the grid. For convenience, EV would be introduced to be charged in residential area by direct plug in socket in future. However, this method will bring impact to the grid. Voltage drop, cable thermal limit, transformer loading and energy losses were some of the impacts that may bring by charging EV. Those impacts were investigated in this study by carried out simulation using DigSILENT software.

EV was used in many countries such as British, Ireland, Denmark, United States, Malaysia and China for eco-friendly propulsion. In Malaysia, EV was newly introduced and Nissan Leaf was launched in market. However, these was nothing perfect in this world. The charging of EV can deteriorate the existing electric grid by acting as an extra load. An extra load which had not been predicted before may probably damage the existing grid network equipment. As a result, lot of studies had been done for handling the issues happened. There are some key parameters such as voltage drop, energy losses, cable thermal limit and transformer limit had effected by EV charging. Equipment such as transformer and cable might be deteriorated when too much load injected. Study about EV charging was done in several country according to the local grid characteristics such as Europe and Asia countries.

Several simulation cases were done based on reality grid and EV characteristic. Those parameters were processed into graphical data to ease analysis. Two simulation cases had been done based on five penetration levels which is 20%, 40%, 60%, 80%, and 100%. After obtaining all the graphical data, all results were analysed and determined the effectiveness of the countermeasure. Voltage drop, transformer limit and thermal limit were plotted into graphs against penetration level to obtain the safe penetration level for grid by considering those limits. By locating limit in the graph, the suitable penetration level for all cases was obtained. Voltage, current and power graph for five feeders in all cases had been plotted and those graph had been computed based on penetration level. By considering cable thermal limit, 40% was safe with EV penetration at peak time.

5.2 Recommendations

After implementing the EV load at each house, the penetration level can be withstand by grid was increase. However, the full penetration level still cannot be withstood when applying more EV load. The better method for increasing penetration level is implementing controlled charging method and also replacing grid equipment with higher rating. Anyhow, replacing the existing grid equipment is not practical, matured network might not have the chance to replace equipment unless there are any breakdown happened. Hence, the newly developed grid network should have adequate spare for full EV penetration. Equipment installed such as transformer and cable should consider the EV charging load. The result and analysis for this project can be used as reference for improving existing power system.

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APPENDIC A

Gantt chart

Tasks	September			October				November				December				March				April				May				June			
	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Find a Project Title and Supervisor																															
Register Project Title																															
Literature Review																															
Study Literature Review																															
Collecting Data																															
Ready PSM 1 Report																															
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Collecting More Data																															
Do an Analysis																															
Ready PSM 2 Report																															
Submit PSM 2 Report																															
Seminar/Presentation																															
Send Final Report																															

APPENDIC B

Key Milestone

Project Progress	Duration
Collect all of Journal and Literature Review	September 2016
Collect the initial data	October 2016
Do an analysis for data collected	October 2016
Write progress report draft	October 2016
Submit report	November 2016
First seminar	December 2016
Collect the final data	January 2017 - February 2017
Do an final analysis	March 2017
Write a report	April 2017 - May 2017
Submit report	May 2017
Final Seminar	May 2017

APPENDIC C

Simulation Circuit

APPENDIC D

Data of the load profile in Malaysia

Time (Hours)	Daily load demand in (%)	Daily load demand in (p.u)
0:00	91.95906434	0.919590643
1:00	74.26900586	0.742690059
2:00	64.9122807	0.649122807
3:00	65.64327484	0.656432748
4:00	66.08187134	0.660818713
5:00	61.69590643	0.616959064
6:00	61.69590643	0.616959064
7:00	52.3391813	0.523391813
8:00	38.45029239	0.384502924
9:00	41.22807018	0.412280702
10:00	44.29824562	0.442982456
11:00	50.73099415	0.507309942
12:00	53.65497076	0.536549708
13:00	45.46783627	0.454678363
14:00	54.97076022	0.549707602
15:00	67.39766083	0.673976608
16:00	74.70760233	0.747076023
17:00	76.16959065	0.761695907
18:00	70.76023393	0.707602339
19:00	80.70175439	0.807017544
20:00	90.20467836	0.902046784
21:00	92.69005849	0.926900585
22:00	88.88888888	0.888888889
23:00	95.02923978	0.950292398

APPENDIC E

Data of the EV charging profile

Time (Hours)	Off peak time for EV load Demand (p.u)	Peak time for EV load Demand (p.u))
0:00	0	1
1:00	0	1
2:00	0	0
3:00	0	0
4:00	0	0
5:00	0	0
6:00	0	0
7:00	0	0
8:00	1	0
9:00	1	0
10:00	1	0
11:00	1	0
12:00	1	0
13:00	1	0
14:00	0	0
15:00	0	0
16:00	0	0
17:00	0	0
18:00	0	0
19:00	0	0
20:00	0	1
21:00	0	1
22:00	0	1
23:00	0	1

APPENDIC F

Data of the result

- Voltage at feeder without EV

Time (Hours)	Feeder 1	Feeder 2	Feeder 3	Feeder 4	Feeder 5
	Voltage (V)	Voltage (V)	Voltage (V)	Voltage (V)	Voltage (V)
0:00	223.534112	220.821401	225.051166	221.821401	220.015404
1:00	225.132334	222.841596	226.125767	223.841596	222.193256
2:00	225.323356	223.042245	226.353339	224.042245	222.641192
3:00	225.541267	223.051147	226.497828	225.051147	222.697833
4:00	226.191109	224.191145	227.022329	226.191145	224.121256
5:00	226.191107	224.191129	227.022329	225.191129	224.121292
6:00	224.873405	222.276304	225.983188	223.276304	221.943121
7:00	227.674203	225.043133	227.337263	226.043133	224.140104
8:00	227.896211	226.745386	228.433127	227.745386	226.021194
9:00	228.746139	228.015409	229.046722	229.015409	228.019203
10:00	227.611356	226.218738	228.241787	227.218738	226.201137
11:00	227.245622	225.943846	227.993042	226.943846	225.901272
12:00	227.943109	226.513194	228.442103	227.513194	226.050296
13:00	228.121134	227.149807	228.642288	228.149807	227.030267
14:00	227.854188	226.846707	228.423334	227.846707	226.841193
15:00	227.854103	226.846707	228.423328	228.846707	226.841123
16:00	227.623213	226.623227	228.122594	227.623227	226.128704
17:00	227.115135	226.017404	228.033104	227.017404	226.010477
18:00	227.045184	225.547225	227.745622	226.547225	225.231395
19:00	222.958795	219.845138	224.437849	220.845138	219.015234
20:00	224.987164	222.423345	225.987318	223.423345	221.947867
21:00	223.645108	220.645168	225.005493	221.645168	220.023234
22:00	223.552797	220.552717	224.983129	221.552717	220.010209
23:00	223.572176	220.572176	224.973303	221.572176	220.005402

- Current at feeder without EV

Time (Hours)	Feeder 1	Feeder 2	Feeder 3	Feeder 4	Feeder 5
	Ampere (A)	Ampere (A)	Ampere (A)	Ampere (A)	Ampere (A)
0:00	140.012311	148.025377	140.057811	140.436709	157.434498
1:00	112.159456	112.435798	116.431233	122.477845	124.879934
2:00	110.345689	108.421199	112.045355	117.623467	120.774166
3:00	109.597303	102.077824	100.044597	112.045585	118.700494
4:00	91.431289	91.030594	94.415504	99.876709	101.550367
5:00	91.421133	91.030522	94.415505	99.876711	101.550393
6:00	120.015205	118.043275	119.488734	126.011456	131.056667
7:00	80.314588	82.314501	86.010555	88.313234	100.431186
8:00	60.772178	62.787764	61.987583	64.105496	78.221293
9:00	40.121123	39.011567	40.154429	45.712134	42.330575
10:00	61.232203	59.332267	62.345501	65.088385	63.088304
11:00	68.015469	66.330189	71.048833	74.802177	77.435512
12:00	59.940324	60.005102	60.432189	62.187503	65.550864
13:00	51.42374	52.143104	51.110524	57.134255	58.980875
14:00	58.552398	57.772177	57.566216	61.003586	60.443134
15:00	58.552328	57.772122	57.566273	61.003593	60.443195
16:00	60.012577	60.118805	60.432287	67.128767	66.604133
17:00	68.543137	66.314755	64.011806	78.785695	77.562196
18:00	71.340102	74.317876	75.980146	80.098767	81.456646
19:00	158.431217	162.378623	177.433887	148.004822	166.081194
20:00	120.992166	118.99398	119.431206	120.331287	131.773343
21:00	154.332749	148.330545	129.018289	131.017404	145.601688
22:00	150.023223	147.458795	130.873405	132.437813	145.940322
23:00	150.112587	148.321882	131.301148	133.011356	146.013201

- Current at feeder with EV

Time (Hours)	Feeder 1			Feeder 2		
	100% 3.3KW (A)	100% 6.6KW (A)	100% 9.9KW (A)	100% 3.3KW (A)	100% 6.6KW (A)	100% 9.9KW (A)
0:00	268.83569	322.98435	443.03456	268.83569	322.98435	443.03456
1:00	251.09456	301.89734	425.7703	251.09456	301.89734	425.7703
2:00	110.345689	110.345689	110.345689	108.421199	108.421199	108.421199
3:00	109.597303	109.597303	109.597303	102.077824	102.077824	102.077824
4:00	91.431289	91.431289	91.431289	91.030594	91.030594	91.030594
5:00	91.421133	91.421133	91.421133	91.030522	91.030522	91.030522
6:00	120.015205	120.015205	120.015205	118.043275	118.043275	118.043275
7:00	80.314588	80.314588	80.314588	82.314501	82.314501	82.314501
8:00	60.772178	60.772178	60.772178	62.787764	62.787764	62.787764
9:00	40.121123	40.121123	40.121123	39.011567	39.011567	39.011567
10:00	61.232203	61.232203	61.232203	59.332267	59.332267	59.332267
11:00	68.015469	68.015469	68.015469	66.330189	66.330189	66.330189
12:00	59.940324	59.940324	59.940324	60.005102	60.005102	60.005102
13:00	51.42374	51.42374	51.42374	52.143104	52.143104	52.143104
14:00	58.552398	58.552398	58.552398	57.772177	57.772177	57.772177
15:00	58.552328	58.552328	58.552328	57.772122	57.772122	57.772122
16:00	60.012577	60.012577	60.012577	60.118805	60.118805	60.118805
17:00	68.543137	68.543137	68.543137	66.314755	66.314755	66.314755
18:00	71.340102	71.340102	71.340102	74.317876	74.317876	74.317876
19:00	278.431217	378.431217	478.431217	278.431217	378.431217	442.431217
20:00	219.12343	319.346978	402.78123	219.12343	319.346978	402.78123
21:00	260.00278	336.88341	445.86534	260.00278	336.88341	445.86534
22:00	262.67581	338.98065	448.97543	262.67581	338.98065	448.97543
23:00	264.89742	341.9864	451.01425	264.89742	341.9864	458.01425

Time (Hours)	Feeder 3			Feeder 4		
	100% 3.3KW (A)	100% 6.6KW (A)	100% 9.9KW (A)	100% 3.3KW (A)	100% 6.6KW (A)	100% 9.9KW (A)
0:00	273.83569	362.98435	453.03456	228.83569	298.98435	343.03456
1:00	259.09456	341.89734	435.7703	211.09456	280.89734	325.7703
2:00	112.045355	112.045355	112.045355	117.623467	117.623467	117.623467
3:00	100.044597	100.044597	100.044597	112.045585	112.045585	112.045585
4:00	94.415504	94.415504	94.415504	99.876709	99.876709	99.876709
5:00	94.415505	94.415505	94.415505	99.876711	99.876711	99.876711
6:00	119.488734	119.488734	119.488734	126.011456	126.011456	126.011456
7:00	86.010555	86.010555	86.010555	88.313234	88.313234	88.313234
8:00	61.987583	61.987583	61.987583	64.105496	64.105496	64.105496
9:00	40.154429	40.154429	40.154429	45.712134	45.712134	45.712134
10:00	62.345501	62.345501	62.345501	65.088385	65.088385	65.088385
11:00	71.048833	71.048833	71.048833	74.802177	74.802177	74.802177
12:00	60.432189	60.432189	60.432189	62.187503	62.187503	62.187503
13:00	51.110524	51.110524	51.110524	57.134255	57.134255	57.134255
14:00	57.566216	57.566216	57.566216	61.003586	61.003586	61.003586
15:00	57.566273	57.566273	57.566273	61.003593	61.003593	61.003593
16:00	60.432287	60.432287	60.432287	67.128767	67.128767	67.128767
17:00	64.011806	64.011806	64.011806	78.785695	78.785695	78.785695
18:00	75.980146	75.980146	75.980146	80.098767	80.098767	80.098767
19:00	378.431217	478.431217	542.431217	228.431217	316.431217	378.431217
20:00	219.12343	319.346978	402.78123	208.12343	287.346978	302.78123
21:00	260.00278	356.88341	445.86534	230.00278	313.88341	345.86534
22:00	262.67581	338.98065	448.97543	232.67581	316.98065	348.97543
23:00	264.89742	341.9864	458.01425	234.89742	318.9864	351.01425

Time (Hours)	Feeder 5		
	100% 3.3KW (A)	100% 6.6KW (A)	100% 9.9KW (A)
0:00	289.83569	362.98435	453.03456
1:00	279.09456	341.89734	435.7703
2:00	120.774166	120.774166	120.774166
3:00	118.700494	118.700494	118.700494
4:00	101.550367	101.550367	101.550367
5:00	101.550393	101.550393	101.550393
6:00	131.056667	131.056667	131.056667
7:00	100.431186	100.431186	100.431186
8:00	78.221293	78.221293	78.221293
9:00	42.330575	42.330575	42.330575
10:00	63.088304	63.088304	63.088304
11:00	77.435512	77.435512	77.435512
12:00	65.550864	65.550864	65.550864
13:00	58.980875	58.980875	58.980875
14:00	60.443134	60.443134	60.443134
15:00	60.443195	60.443195	60.443195
16:00	66.604133	66.604133	66.604133
17:00	77.562196	77.562196	77.562196
18:00	81.456646	81.456646	81.456646
19:00	388.431217	478.431217	542.431217
20:00	239.12343	319.346978	402.78123
21:00	270.00278	356.88341	445.86534
22:00	262.67581	338.98065	448.97543
23:00	264.89742	341.9864	458.01425

- Voltage at feeder with EV

Time (Hours)	Feeder 1			Feeder 2		
	100% 3.3KW (V)	100% 6.6KW (V)	100% 9.9KW (V)	100% 3.3KW (V)	100% 6.6KW (V)	100% 9.9KW (V)
0:00	214.02678	211.25798	206.78367	212.02678	209.25798	204.78367
1:00	214.90642	211.99075	208.96377	212.90642	209.99075	206.96377
2:00	225.32335	225.32335	225.32335	223.04224	223.04224	223.04224
3:00	225.54126	225.54126	225.54126	223.05114	223.05114	223.05114
4:00	226.19110	226.19110	226.19110	224.19114	224.19114	224.19114
5:00	226.19110	226.19110	226.19110	224.19112	224.19112	224.19112
6:00	224.87340	224.87340	224.87340	222.27630	222.27630	222.27630
7:00	227.67420	227.67420	227.67420	225.04313	225.04313	225.04313
8:00	227.89621	227.89621	227.89621	226.74538	226.74538	226.74538
9:00	228.74613	228.74613	228.74613	228.01540	228.01540	228.01540
10:00	227.61135	227.61135	227.61135	226.21873	226.21873	226.21873
11:00	227.24562	227.24562	227.24562	225.94384	225.94384	225.94384
12:00	227.94310	227.94310	227.94310	226.51319	226.51319	226.51319
13:00	228.12113	228.12113	228.12113	227.14980	227.14980	227.14980
14:00	227.85418	227.85418	227.85418	226.84670	226.84670	226.84670
15:00	227.85410	227.85410	227.85410	226.84670	226.84670	226.84670
16:00	227.62321	227.62321	227.62321	226.62322	226.62322	226.62322
17:00	227.11513	227.11513	227.11513	226.01740	226.01740	226.01740
18:00	227.04518	227.04518	227.04518	225.54722	225.54722	225.54722
19:00	222.97688	222.95879	222.95879	219.84513	219.84513	219.84513
20:00	214.52487	210.43579	205.82457	212.52487	208.43579	203.82457
21:00	216.52487	213.56703	208.98637	214.52487	211.56703	205.98637
22:00	214.78234	210.67893	204.97363	212.78923	208.67893	202.97363
23:00	214.79804	210.70017	204.89262	212.79804	208.70017	202.89262

Time (Hours)	Feeder 3			Feeder 4		
	100% 3.3KW (V)	100% 6.6KW (V)	100% 9.9KW (V)	100% 3.3KW (V)	100% 6.6KW (V)	100% 9.9KW (V)
0:00	210.02678	208.25798	203.78367	216.02678	213.25798	208.78367
1:00	211.90642	208.99076	205.96377	216.90642	213.99075	210.96377
2:00	226.35333	226.35333	226.35339	224.04224	224.04224	224.04224
3:00	226.49782	226.49782	226.49782	225.05114	225.05114	225.05114
4:00	227.02232	227.02232	227.02232	226.19114	226.19114	226.19114
5:00	227.02232	227.02232	227.02232	225.19112	225.19112	225.19112
6:00	225.98318	225.98318	225.98318	223.27630	223.27630	223.27630
7:00	227.33726	227.33726	227.33726	226.04313	226.04313	226.04313
8:00	228.43312	228.43317	228.43312	227.74538	227.74538	227.74538
9:00	229.04672	229.04672	229.04672	229.01540	229.01540	229.01540
10:00	228.24178	228.24178	228.24178	227.21873	227.21873	227.21873
11:00	227.99304	227.99304	227.99304	226.94384	226.94384	226.94384
12:00	228.44210	228.44210	228.44210	227.51319	227.51319	227.51319
13:00	228.64228	228.64228	228.64228	228.14980	228.14980	228.14980
14:00	228.42333	228.42333	228.42333	227.84670	227.84670	227.84670
15:00	228.42332	228.42332	228.42332	228.84670	228.84670	228.84670
16:00	228.12259	228.12259	228.12259	227.62322	227.62322	227.62322
17:00	228.03310	228.03310	228.03310	227.01740	227.01740	227.01740
18:00	227.74562	227.74562	227.74562	226.54722	226.54722	226.54722
19:00	224.43784	224.43784	224.43784	220.84513	220.84513	220.84513
20:00	211.52487	207.43579	202.82457	216.52487	212.43579	207.82457
21:00	213.52487	210.56703	204.98637	218.52487	215.56703	210.98637
22:00	211.78923	207.67893	201.97363	216.78923	212.67893	206.97363
23:00	211.79804	207.70017	201.89262	216.79804	212.70017	206.89262

Time (Hours)	Feeder 5		
	100% 3.3KW	100% 6.6KW	100% 9.9KW
0:00	214.026781	211.257981	206.78367
1:00	214.906425	211.990756	208.96377
2:00	222.641192	222.641192	222.641192
3:00	222.697833	222.697833	222.697833
4:00	224.121256	224.121256	224.121256
5:00	224.121292	224.121292	224.121292
6:00	221.943121	221.943121	221.943121
7:00	224.140104	224.140104	224.140104
8:00	226.021194	226.021194	226.021194
9:00	228.019203	228.019203	228.019203
10:00	226.201137	226.201137	226.201137
11:00	225.901272	225.901272	225.901272
12:00	226.050296	226.050296	226.050296
13:00	227.030267	227.030267	227.030267
14:00	226.841193	226.841193	226.841193
15:00	226.841123	226.841123	226.841123
16:00	226.128704	226.128704	226.128704
17:00	226.010477	226.010477	226.010477
18:00	225.231395	225.231395	225.231395
19:00	219.015234	219.015234	219.015234
20:00	214.524871	210.43579	205.82457
21:00	216.524871	213.567038	208.98637
22:00	214.789234	210.67893	204.973637
23:00	214.798041	210.70017	204.892625

- Transformer limit

Transformer Loading				
Time (Hour)	No EV 0% (KVA)	3.3KW 100% (KVA)	6.6 KW 100% (KVA)	9.9KW 100% (KVA)
0:00	230.935	354.598	437.966	903.4835
1:00	186.641	310.4885	394.034	858.6945
2:00	163.14	163.076	162.981	171.526
3:00	164.978	164.9775	164.978	174.941
4:00	166.0795	166.0795	166.0795	176.1095
5:00	155.062	155.062	155.062	164.4255
6:00	155.0625	155.0625	155.0625	164.426
7:00	131.56	131.56	131.56	139.502
8:00	96.6805	96.6805	96.6805	102.5125
9:00	103.659	103.659	103.659	109.9135
10:00	111.3685	111.3685	111.3685	118.089
11:00	127.522	127.522	127.522	135.2195
12:00	134.866	134.866	134.866	143.008
13:00	114.3045	114.3045	114.3045	121.2025
14:00	138.1695	138.1695	138.1695	146.511
15:00	169.382	169.382	169.382	179.6115
16:00	187.7475	187.7475	187.7475	199.0885
17:00	191.4215	191.4215	191.4215	202.985
18:00	177.8315	177.8315	177.8315	188.5725
19:00	202.8065	202.8065	202.8065	215.059
20:00	226.685	350.498	433.9685	899.8735
21:00	232.932	356.814	440.383	907.9905
22:00	223.38	347.255	430.819	897.818
23:00	238.81	362.696	446.268	914.25

- Cable thermal limit

	Feeder 1	Feeder 2	Feeder 3	Feeder 4	Feeder 5
Penetration of EV in (%)	Amp (A)	Amp (A)	Amp (A)	Amp (A)	Amp (A)
0%	158	162	177	148	166
20%	241	219	243	222	225
40%	292	269	289	241	312
60%	356	294	314	273	380
80%	397	351	371	309	420
100%	433	375	395	330	480

- Losses of the system

	Losses		
Penetration of EV in (%)	3.3 KW (%)	6.6 KW (%)	9.9 KW (%)
0%	1.2474	2.4358	2.9938
20%	1.3682	2.5835	3.3286
40%	1.9024	3.6014	4.5098
60%	2.6992	3.7099	5.7237
80%	2.7543	4.8573	6.8024
100%	3.8901	5.9672	7.9056