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SARJANA MUDA

IMPACT OF EV CHARGING ON LV NETWORKS

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Bachelor of Electrical Engineering (Industrial Power)

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"I hereby declare that I have read through this report entitle "*Impact of EV Charging on LV Networks"* and found that it has comply the partial fulfilment for awarding the degree of *Bachelor of Electrical Engineering (Industrial Power)*"

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IMPACT OF EV CHARGING ON LV NETWORKS

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

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2014

I declare that this report entitle "*Impact of EV Charging on LV Networks"* 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.

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ABSTRACT

Global pollution is increasing tremendously which will affect human life. Electric Vehicle (EV) is one of the methods which can reduce pollution. EV does not consume fuel directly for propulsion, but charging battery for power supplying. Charging EV by connecting through power grid will cause some problems. Those problems such as voltage drop and cable overheat will bring some impacts to residential. A residential area may face power shortage when exceeding EVs are charging simultaneously. All related problems had been found and studied by some countries. This project will focus on EV charging impact towards residential LV distribution network. Those EV was considered to be charged using same supply with house load. Simulations were carried out for studying those impacts. Five simulation cases had been carried out for investigating parameters such as voltage drop, thermal limit, transformer limit and energy losses. Some prerequisite studies had been done related to the existing grid features and EV characteristic. Five levels of EV penetration, 20%, 40%, 60%, 80% and 100% were done for simulation and obtained a series of data. The method proposed to alleviate the impact of EV charging on distribution grid was controlled charging method. The simulation involving the method had been carried out as one of five cases. All data obtained was processed and analyzed.

ABSTRAK

Pencemaran global yang mempengaruhi kehidupan manusia semakin bertambah. Kenderaan Elektrik (EV) merupakan salah satu cara yang boleh mengurangkan pencemaran. EV tidak memerlukan bahan api secara langsung untuk pergerakan, tetapi perlu mengecaskan bateri untuk bekalan tenaga. Pengecasan bateri melalui gird kuasa akan menimbulkan masalah. Masalah seperti kejatuhan voltan dan keterlalupanasan kabel akan membawa impak kepada kediaman. Sesuatu kawasan kediaman mungkin menghadapi kekurangan kuasa apabila terlampau banyak EV dicaskan pada masa yang sama. Masalah berkenaan telah dijumpai dan dikaji oleh beberapa negara. Projek ini akan menumpu kepada impak pengecasan EV terhadap rangkaian pengagihan voltan rendah kediaman. Semua EV dianggap mengecas dengan bekalan yang sama dengan beban rumah. Impak tersebut dikaji dengan mengadakan simulasi. Lima kes simulasi telah dijalankan untuk menyiasat parameter seperti kejatuhan voltan, had terma, had alat pengubah dan kehilangan tenaga. Beberapa pembelajaran awal berkaitan dengan ciri-ciri grid dan EV telah dihabiskan. Lima tahap penembusan telah digunakan untuk mejalankan simulasi dan sesiri data telah didapati. Cara pengecasan secara kawalan merupakan cara yang dikemukakan untuk mengurangkan impak pengecasan EV terhadap grid pengaihan. Simulasi yang merangkumi cara tersebut telah dijalankan sebagai salah satu daripada 5 kes simulasi. Kesemua data yang didapati telah diproseskan dan dianalisasikan.

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	ACKNOWLEDGEMENT	**iv**
	ABSTRACT	**v**
	TABLE OF CONTENTS	**vii**
	LIST OF TABLES	**ix**
	LIST OF FIGURES	**x**
	LIST OF ABBREVIATIONS	**xiv**
	LIST OF APPENDICES	**xv**
1	**INTRODUCTION**	**1**
	1.1 Research Background	1
	1.2 Problem Statement	2
	1.3 Objectives	3
	1.4 Scope	3
2	**LITERATURE REVIEW**	**4**
	2.1 Theory and Basic Principles	4
	2.2 Review of Previous Related Works	6
	2.3 Summary and Discussion of the Review	12

3	**METHODOLOGY**	**13**
	3.1 Methods used in the Previous Work	13
	3.2 Flowchart	15
	3.3 OpenDSS Modelling	16
	3.3.1 Source Modelling	17
	3.3.2 Transformer Modelling	17
	3.3.3 Line Modelling	18
	3.3.4 Load Modelling	19
	3.3.5 Monitors and Meters Modelling	19
	3.3.6 30 Bus Modelling	20
	3.4 Case Study	22
4	**RESULT AND DISCUSSION**	**32**
	4.1 Case 1: without EV load	33
	4.2 Case 2: uncontrolled unbalanced charging	42
	4.3 Case 3: controlled unbalanced charging	55
	4.4 Case 4: uncontrolled balanced charging	60
	4.5 Case 5: controlled balanced charging	63
	4.6 Energy Losses for All Cases	67
5	**CONCLUSION**	**68**
	REFERENCES	**70**
	APPENDICES	**72**

LIST OF TABLES

TABLE	TITLE	PAGE
Table 1.1	Percentage reduction in global warming emissions of EV	2
Table 2.1	Impacts of EV charging studied	11
Table 3.1	Amount and load demand for each type of house	24
Table 3.2	Distribution of houses over 7 feeders	24
Table 3.3	Simulation cases	27
Table 3.4	Controlled charging pattern	29

LIST OF FIGURES

FIGURE	TITLE	PAGE
Figure 3.1	Model of the distribution grid in DIgSILENT	14
Figure 3.2	Model of the distribution system in Matlab	14
Figure 3.3	Flowchart of project	16
Figure 3.4	Single line diagram for 30 bus	21
Figure 3.5	Magnitude of v1 for 30 bus case	21
Figure 3.6	Power for 30 bus case	22
Figure 3.7	Single line diagram of the chosen residential area	23
Figure 3.8	Typical Malaysia residential load demand pattern	25
Figure 3.9	Configuration for different cables	25
Figure 3.10	EV load demand pattern for peak time	28
Figure 3.11	EV load demand for off peak time	28
Figure 3.12	EV load demand pattern for period 1	29
Figure 3.13	EV load demand pattern for period 2	30
Figure 3.14	EV load demand pattern for period 3	30
Figure 4.1	Voltage for feeder A in case 1	33
Figure 4.2	Voltage for feeder B in case 1	34
Figure 4.3	Voltage for feeder C in case 1	34

Figure 4.4	Voltage for feeder D in case 1	35
Figure 4.5	Voltage for feeder E in case 1	35
Figure 4.6	Voltage for feeder F in case 1	36
Figure 4.7	Voltage for feeder G in case 1	36
Figure 4.8	Current for feeder A in case 1	37
Figure 4.9	Current for feeder B in case 1	38
Figure 4.10	Current for feeder C in case 1	38
Figure 4.11	Current for feeder D in case 1	39
Figure 4.12	Current for feeder E in case 1	39
Figure 4.13	Current for feeder F in case 1	40
Figure 4.14	Current for feeder G in case 1	40
Figure 4.15	Power for transformer 1 in case 1	41
Figure 4.16	Power for transformer 2 in case 1	42
Figure 4.17	Voltage for feeder A in case 2 for peak time	43
Figure 4.18	Voltage for feeder E in case 2 for peak time	43
Figure 4.19	Current for feeder C in case 2 for peak time	44
Figure 4.20	Current for feeder G in case 2 for peak time	44
Figure 4.21	Voltage for feeder D in case 2 for off peak time	45
Figure 4.22	Voltage for feeder F in case 2 for off peak time	46
Figure 4.23	Current for feeder D in case 2 for off peak time	46
Figure 4.24	Current for feeder G in case 2 for off peak time	47
Figure 4.25	Power for transformer 1 in case 2 for peak time	48
Figure 4.26	Power for transformer 2 in case 2 for peak time	48
Figure 4.27	Power for transformer 1 in case 2 for off peak time	49

Figure 4.28	Power for transformer 2 in case 2 for off peak time	50
Figure 4.29	Voltage drop for case 2 during peak time	51
Figure 4.30	Thermal loading for case 2 during peak time	52
Figure 4.31	Transformer loading for case 2 during peak	52
Figure 4.32	Voltage drop for case 2 during off peak time	53
Figure 4.33	Thermal loading for case 2 during off peak time	54
Figure 4.34	Transformer loading for case 2 during off peak time	54
Figure 4.35	Voltage for feeder B in case 3	55
Figure 4.36	Voltage for feeder G in case 3	56
Figure 4.37	Current for feeder D in case 3	56
Figure 4.38	Current for feeder E in case 3	57
Figure 4.39	Power for transformer 2 in case 3	57
Figure 4.40	Voltage drop in case 3	58
Figure 4.41	Thermal loading in case 3	59
Figure 4.42	Transformer loading in case 3	59
Figure 4.43	Voltage for feeder E in case 4	60
Figure 4.44	Current for feeder E in case 4	60
Figure 4.45	Voltage drop in case 4	61
Figure 4.46	Thermal loading in case 4	62
Figure 4.47	Transformer loading in case 4	62
Figure 4.48	Voltage for feeder G in case 5	63
Figure 4.49	Current for feeder F in case 5	64
Figure 4.50	Voltage drop in case 5	65
Figure 4.51	Thermal loading in case 5	65

Figure 4.52 Transformer loading in case 5 66

Figure 4.53 Energy losses for all cases 67

LIST OF ABBREVIATIONS

BEV	-	Battery EV
DSO	-	Distribution system operator
EV	-	Electric vehicle
EREV	-	Extended range electric vehicles
G2V	-	Grid-to-vehicle
HEV	-	Hybrid EV
ICE	-	Internal combustion engine
km/h	-	Kilometers per hour
LV	-	Low voltage
mGen	-	Micro generator
mpg	-	Miles per gallon
NEV	-	Neighborhood EV
OpenDSS	-	Open Distribution System Simulator
PHEV	-	Plug-in hybrid EV
SCADA	-	Supervisory control and data acquisition

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	Coding for 30 bus case	72
B	Coding of simulation for some cases	77
C	Graphs for some cases	110
D	Table of EVs amount for each case	115

CHAPTER 1

INTRODUCTION

1.1 Research Background

Automotive is using fossil fuel to be functioned in transportation. However, fuel will produce a lot of unwanted gas and particles which may pollute the air and eventually results in global warming. As concern for global warming keep growing, several countermeasures to reduce global warming are proposed. Electric vehicle (EV) is mentioned as one of the feasible solutions among all. EVs are battery powered. Thus, pollution and global warming can be reduced since fuel is no longer been used for EV. Reduced in fossil fuel demand will extend fuel reserved. When EV is fully replaced conventional vehicles, fossil fuel will not consume directly for transportation. Table 1.1 shows the percentage reduction in global warming emissions between EV and conventional vehicles. Some EV in markets such as Toyota Prius and Honda Civic Hybrid are estimated to reduce global warming emissions for about 40% when compared to 27 mpg gasoline vehicle [1].

Table 1.1: Percentage reduction in global warming emissions for EV [1]

	Good	**Better**	**Best**
mpg of a gasoline vehicle with equivalent global warming emissions	31 – 40 mpg	41 – 50 mpg	51+ mpg
Implication of ratings about EVs' global warming emissions	EVs have emissions comparable to the best gasoline non-hybrid models available	EVs have emissions comparable to the best gasoline hybrid models available	EVs outperform the best gasoline hybrid models available
Percent reduction in global warming emissions compared with 27 mpg gasoline vehicle	11 – 33%	33 – 46%	>46%
Examples of model year 2012 gasoline and hybrid vehicle in each range	Ford Fiesta (34 mpg) Hyundai Elantra (33 mpg) Chevrolet Cruze Eco (31 mpg)	Toyota Prius (50 mpg) Honda Civic Hybrid (44 mpg) Lexus CT200h (42 mpg)	No gasoline comparisons

1.2 Problem Statement

EV is the new trend for transportation since it is environmental friendly. However, there are some constraints for EV penetration. EV will be functioned based on the battery worked as power supply. The battery can be recharged through grid connected charger. For recent grid, charging of EV is an extra load which is huge enough to affect the entire system.

To fully charge an EV battery, grid network may face issues such as voltage unbalance, cable limit or transformer limit. All those aspects need to be deliberated to ensure stable grid networks.

1.3 Objectives

EV battery can be recharged through grid connected charger which becoming an extra load that may affect the entire grid system. To fully charge an EV battery, grid network may face issues such as voltage drop, cable limit and transformer loading need to be deliberated for stable grid network. This project is carried out:

i. To investigate impacts of EV charging on low voltage (LV) networks such as voltage drop, cable thermal limit, transformer loading and energy losses.
ii. To propose and study about countermeasure for moderating impacts.

1.4 Scope

This project is expected to study about effects on LV network in Malaysia brought by EV charging for different penetration levels based on several charging patterns. EV was assumed to be charged connecting through residential grid which also considered as house load. The residential area will only use Low Voltage (LV) which is lower than 1kV. Those impacts comprise voltage drop, cable thermal limit, transformer loading and energy losses. Methods for moderating EV charging impacts are proposed and investigated. Open Distribution System Simulator (OpenDSS) was used to simulate all cases.

CHAPTER 2

LITERATURE REVIEW

2.1 Theory and Basic Principles

Electric vehicle (EV) is type of vehicle which driven by electric, uses an onboard battery as supply for electric motor to build propulsion. Differ from conventional and hybrid vehicles, EV depend totally on electricity to charge batteries. Regenerative braking is technology that help energy to flow back to the battery when brakes. EV does not need to change gear because the harder the pedal pressed, the motor turns faster and hence drive the vehicle forward. Electric delivery vehicles accelerate faster than conventional vehicles because electric motor produces high torque at any load. Moreover, EV has no gear changes which made it comparable for urban driving and sometimes even better than diesel vehicles. EV is ready for a 10-hour working time after charging for overnight. Electric vehicles involve in transportation applications presently are able to move for 100 miles before charging required [2].

There are several types of EV available in the market recently. There include battery EV (BEV), hybrid EV (HEV), plug-in hybrid EV (PHEV) and neighborhood EV (NEV). BEV, also known as the pure electric vehicle, is a type of electric vehicle that must acquire energy by connecting to an electrical source to drive the vehicle. BEVs typically move for a mileage range of 100 to 200 miles powered by batteries-fed electric motor. HEV is combination of an internal combustion engine with an electric motor for the propulsion system. The electric power-train needs for achieving better fuel economy than a conventional gasoline vehicle. HEV does not need to be recharged through electric grid. The vehicle changes to the electric motor from the ICE once vehicle is warmed; but it will remain on electric power at low speeds for less than 15 mph or about 24 km per hour. The electric motor improves the HEV to drive in urban for over 600 miles per tank of gasoline with average 88.5 km/h. PHEV is hybrid vehicle that use rechargeable batteries which can be charging by connecting to an electric power source. A PHEV is similar with HEV because it contains both internal combustion engine and electric motor. PHEV referred as “extended range electric vehicles” or EREV at times. Most PHEVs have an expected mileage range from 30 to 40 miles on electric power especially for shorter trips and ICE are appropriate for long journey. NEV is an EV which limited to speed less than 72.5 km/h speed, depending on the local law. NEV is built to have a 48.5 km/h maximum speed and 3000 pounds maximum loaded weight. It is typically designed for usage in neighborhood as stated in the name [3].

There are a lot of the benefits brought by EV. First, it does not have emissions at the point of use. It means that none of the unwanted gases release while driving an EV. Next, it brings a quiet driving experience. Since EV is giving a quiet and smooth operation, it has less noise and vibration compared to conventional vehicle which using ICE. Moreover, EV is also practical and easy to drive since it is not using conventional gear system. Thus, EV is suitable for urban driving. The traffic in urban which comprise a lot of start and stop will definitely lead regenerative braking of EV in full use. Last but not least, EV can be charged in home with electrical supply, thus avoids driver for queuing at petrol stations and save time [4].

2.2 Review of Previous Related Works

Paper [5] involves 3 types of EV charging which are dumb charging, delayed charging and smart charging. Dumb charging means that EVs are charged as soon as battery depleted without concerning any constraints. Delayed charging is often referred as grid-to-vehicle (G2V) which means that the grid operator controls the EV charging either by financial or by ripple control. Financial instrument which comprise multi tariff motivates EV owners to charge their cars during off peak hours with a lower rate. Smart charging is part of the smart grid concept. This type of charging needs continuous bidirectional communication between the EV battery management system and distribution system operator (DSO) supervisory control and data acquisition (SCADA). Since there is no smart metering infrastructure in Hungary yet, dumb charging had been using in the simulation for investigating a worst case scenario. Some assumption had been made in this study. First, the customer amount in the network is very large. Then, a single customer only consumes very tiny percentage on the performance of the network. Last, all customers are independent to decide the time for charging EV. This paper concludes that dumb charging causes an increase in transformer loading. A serious overloading may happened on transformer for 100% penetration. In addition, dumb charging also causes voltage drop. However, the voltage drop does not exceed the permissible limits which states 7.5% according to Hungarian Standard MSZ EN 50160.

Paper [6] studies the effect of EV battery charging on distribution network voltage, thermal loading and electrical line losses. A case study for different penetration levels for British distribution network had been made. The penetration levels divided into 12.5%, 33% and 71% correspond to low, medium and high EV penetration levels. Deterministic and probabilistic were used as the 2 approaches for the study. For deterministic approach, there were four findings highlighted. Voltage was out of limits for the medium and high EV penetration levels but remain normal for low level. Next, the cable supplying 96 households from LV distribution grid was found to over its nominal rating for the medium and high EV penetration levels and also normal for low penetration level. After that, the distribution transformer was found to be overloaded for all EV penetration levels. Lastly, electrical line losses in the LV cables were found to increase by 6% for the high EV penetration level.

Besides deterministic approach, there was also probabilistic approach used in this study. The first finding was voltage was out of limits for the medium and high EV penetration levels while low penetration level has 4% probability to violate limit. Besides that, the cable supplying 96 households from LV distribution grid was found to over its nominal rating for all penetration levels. Moreover, the distribution transformer was found to be overloaded for all EV penetration levels with only less than 5% probability for it to operate normally. Last finding for probabilistic approach was electrical line losses in the LV cables were found to increase by 10% for the high EV penetration level. It was obvious that deterministic approach was obtaining a better penetration level for EV charging when comparing with probabilistic approach. On the other hand, this study consists of two charging methods which are dumb and smart charging. For smart charging, the results showed that the probability of voltage violations for the low EV penetration maybe eliminated and the transformer overload probability would be reduce from 85% to 5%. Besides that, distribution network reinforcement method was investigated. The low EV penetration level may not crash any cable or voltage limit by upgrading the underground cables and the distribution transformers. However, this solution was found not sufficient for medium and high EV penetration levels. All the constraints for the medium EV penetration level can be endured by installing micro generator (mGen). When both reinforcement and installing methods applied, high EV penetration level can keep the transformer loading and the voltage limits within boundary. This paper concludes that a high EV penetration level in distribution networks needs a combination of network reinforcement, mGen installation and EV battery management.

The main questions stated in paper [7] is the impact toward transformers and cable loadings if large amount EVs are penetrated. In addition, the percentage of overloaded network components can be alleviated by implementing some kind of controlled charging is investigated. This study also researches about the financial value of controlled charging of EVs. This study is focused on the Netherlands but the research approach and conclusions are generally applicable. For the 10kW uncontrolled charging, it yields approximately 50% for transformers, 13% for cables due to overloading and 5% for cables due to voltage drop for the out of limit value. After implementing controlled charging, the percentage of exceeded threshold value had been improved compared to the 10kW uncontrolled scenario. It improves to approximately 25% for transformers, 5% for cables due to overloading and 2% for cables due to voltage drop.

Paper [8] investigates the proportion of residential LV distribution networks could be impacted by EV in Ireland. The main issues that can be predicted are excessive voltage drops and overloading of networks components such as power lines and transformers due to huge extra load. The sensitivity of these impacts to be changed in the point of connection of EVs is also analyzed for determining affordable levels of EV penetration. The voltage asymmetry also may happen since residential household connecting single phase with distribution network. For point of connection of EV, 28% penetration will violate the limit when connecting end of feeder while 42% for start of feeder. 25% penetration will violate the transformer limit and 30% penetration will violate the cable thermal limit. Since 20 to 40% of EV penetration will break the limit for components, DSO would needs to cut down the power supply for EV charging for secure reason. This paper proposed advanced metering device to be installed for alleviating the impact for EV charging with considering cost for network upgrade.

Objective of paper [9] is to investigate the impacts of electric vehicle charging on the power distribution network in the Danish island of Bornholm. The parameters involved such as voltage profile, distribution line loading, transformer loading, peak demand and system losses are analyzed for increasing in EV penetration. Two modes of EV charging which including controlled and uncontrolled are analyzed for 0 to 50% EV penetration. Uncontrolled charging made the voltage falls below the limit for more than 10% EV penetration while controlled charging can afford penetration up to more than 40%. For 50% EV penetration, uncontrolled and controlled charging shows 40% and 30% increasing in power losses respectively. For same penetration, uncontrolled had 31% higher in peak demand compared to controlled charging. For overall, only 10% of EV integration is allowed for the uncontrolled charging for the studied test distribution network. Undeniably the controlled charging is more effective than the uncontrolled charging for more EV penetration.

Paper [10] analyzed the reactive power characteristics and impact of charging stations accessing to typical distribution networks. Two types of charging method are available in charging stations which are normal-charge and fast-charge. The characteristic of charging stations accessing to four types of networks is simulated for each charging mode and charging time. In China, 4 main distribution networks comprise radial distribution networks with overhead lines, “hand in hand” distribution networks with overhead lines, radial distribution networks with cables and ring networks with cables. It can be conclude that the higher the voltage at access point is, the less the reactive power absorbed by charging stations is for reactive power characteristics analysis. Besides that, voltage level at related nodes will dip when charging power increasing. The simulation of charging stations for different network structures and charging modes shows that voltage levels at night are higher than during the day. Moreover, voltage fluctuate more for fast-charge compared to normal-charge.

Paper [11] focuses on voltage unbalance caused by uneven distribution of EV penetration among the phases. Level 2 charger with typically 208 to 240 V and draws current up to 80 A is used for study the impact on residential grid of United State. PEVs charging act as an extra-large load which led to impermissible peaks in the energy consumption. These extra single phase electrical loads can bring power losses and voltage unbalances [12]. The power losses, transformer and feeder overloads are reliability and safety concern for DSO [13]. For 10% EV penetration, voltage unbalance increased by 0.165% for on-peak and 0.181% for off-peak demand. For 30% EV penetration, voltage unbalance increased by 0.262% for on-peak and 0.277% for off-peak demand. For 50% EV penetration, voltage unbalance increased by 0.38% for on-peak and 0.404% for off-peak demand. For 80% EV penetration, voltage unbalance increased by 0.917% for on-peak and 0.926% for off-peak demand. Since the voltage unbalance increase with PEVs penetration, methods like smart or coordinated charging, grid reinforcements, grid optimization will become essential for future electricity usage.

Paper [14] investigates the maximum voltage deviation for both uncoordinated and coordinated charging schemes and providing corrective strategy. The uncoordinated charging of PHEV gives a maximum deviation of 12.53% while the coordinated charging provides a better result which is 11.4 % for maximum voltage deviation in worst case scenario. When compared to the normal operating voltage, even coordinated charging gives a high deviation. Hence, the coordinated charging cannot provide the desired voltage regulation needed alone. Thus, corrective strategy is proposed and investigated. Local individual injection, local weighted compensation and remote compensation are 3 types strategies studied in this paper. The maximum improvement for voltage profile obtained in the local individual compensation case is 2.19%. For the local weighted compensation, 9.47% in term of active and reactive power injections and 3.38% for reactive power injections improvement had been done. The remote compensation gives an improvement of 1.68% for voltage profile. It is obviously that the individual weighted compensation results gives better improvement percentage for voltage profile. The local power injection will improve better than the remote injection. For the local active and reactive power supply, diesel generator was proposed for usage of fleet of EVs.

Paper [15] investigated the impact of EV charging on LV residential network in Malaysia. The study was done on a residential area where the network sample had been supplied by the local DSO. This paper focused on case study which considering newly developed and matured networks. Matured network was assumed as a network which undergone 10 years growth from newly developed network. This study was obtaining the safe penetration level of EV for networks by considering grid limit such as transformer limit, voltage drop and voltage unbalance. 3 scenarios were studied in this paper which were unbalanced EVs charging which also considered as worst case, evenly distributed EVs charging which acted as balanced load and controlled EVs charging which including optimization method. For scenario 1, the worst case, 40% penetration for new network and 20% penetration for matured network can be safely withstand by residential grid where minimum voltage limit would not been violated. 20% penetration level was safe by considering voltage unbalanced for both networks. 30% for new and 10% for matured can be sustained for cable thermal limit. Transformer would not overload with 80% for new and 30% for matured network. For scenario 2, all EVs were assumed to be charged evenly among three phases in the residential area. Penetration levels for comply all limits were increased in this scenario compared with scenario 1. For a newly developed network, full penetration can be maintained for safe minimum voltage limit and voltage unbalance. Same penetration level can be supported for voltage unbalance and half penetration can be withstood for minimum voltage limit when matured network was considered. 75% for cable thermal limit and 80% for transformer loading were safe for new network, while cable thermal limit and transformer loading for matured network would not be violated by 30% penetration level. Lastly, the scenario 3 can know as best charging method among 3 scenarios. By controlling the charging time by dividing into 3 periods, all limits could be preserved by higher penetration level. Newly develop network can provide full penetration level for EV charging without crashing any limits. Voltage unbalance and minimum voltage limit can be kept for full penetration in matured network, while 70% and 60% penetration level were safe for cable thermal limit and transformer limit respectively in same network. This study indicated the effectiveness of applying different charging pattern. By distributing all EVs to be charged at 3 different time, a newly developed network can withstand full penetration which means all houses had their own EV charging. For new network, compared to scenario 1 which can only withstand 20% penetration, an alleviating method was useful to have more EV penetrated.

All the paper studied had involved with the impacts of EV charging. The EV charging will bring impacts such as transformer overload, voltage drop or line losses. All the impacts studied had been categorized with the paper studied on them. Table 2.1 shows the impacts and the paper studied on them. Voltage drop was studied by most paper since it is easily happened and affect significantly.

Table 2.1: Impacts of EV charging studied

Paper	**Impact**
[5][6][7][8][15]	Transformer overload
[5][6][7][8][9][15]	Voltage drop
[6][7][8][15]	Cable overload
[6][9][15]	Line losses
[10][14]	Voltage fluctuation
[11][15]	Voltage unbalance

2.3 Summary and Discussion of the Review

According to [4] to [15], the impact for EV charging had been carried out in China, 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 unbalance happened because loads are not balance for three phases. Losses will be increased when current is increasing by heavy load. Those are the impacts of EV charging for the electricity network. Several studies had predicted that scale of EV penetration will be increased tremendously for the future [6,11,16]. Those issues had to be alleviated for future delivery trend. Some countermeasures had been suggested and few of them had been investigated. The approaches proposed were financial instrument, smart charging, local power injection, upgrading network components, grid reinforcements, grid optimization, EV battery management and others. By concluding the previous studies, the efficient approach for overcoming issue brought by 100% EV penetration is combination of few methods as stated in [6].

CHAPTER 3

METHODOLOGY

3.1 Methods used in the Previous Work

Most of 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 softwares which can show graphical result directly, data obtained from other softwares had to process by using Microsoft Excel to plot into graph.

Paper [5] used DIgSILENT Power Factoty simulation software to simulate the model of a real distribution grid in city of Budapest for examining the impact of EV charging on the distribution grid. The model is shown in Figure 3.1.

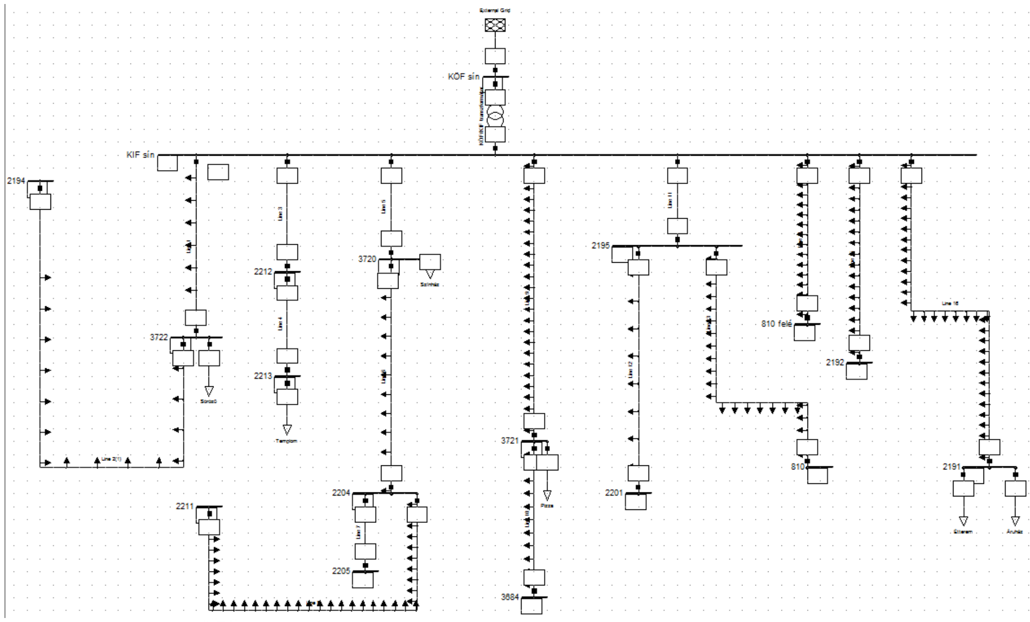

Figure 3.1: Model of the distribution grid in DIgSILENT [5]

Besides the DigSILENT software, a 12.47kV distribution system had been modeled and tested using Matlab/Simulink/SimPowerSystem in paper [11]. All the components involved are modeled and simulate for results. Components modeled are overhead and underground cables, level 2 charger and service transformers. The model of studied system is as shown in Figure 3.2.

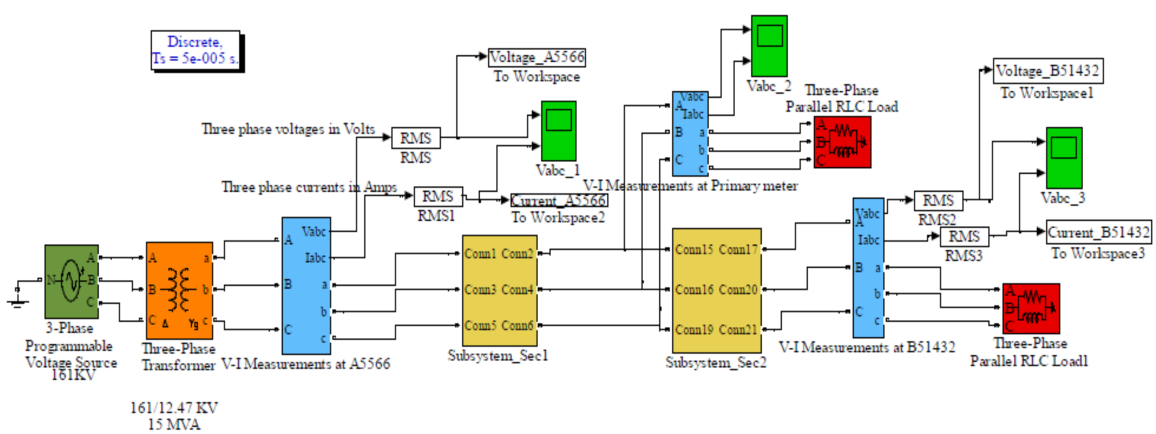

Figure 3.2: Model of the distribution system in Matlab [11]

Paper [14] using IEEE-13 bus network in this research which is a thirteen bus distribution network modeled on Open Distribution Simulation Software (OpenDSS). IEEE-13 bus test feeder values which stored in OpenDSS repository are used as reference for simulation. Code is developed for the various scenarios and conditions involving the PHEV penetration to perform the desired operation. The system uses a twenty four hours daily load data and simulates PHEV load in order to study the effect on distribution grid. Results are obtained in form of output bus voltage. Results are processed and conditioned to obtain graphs to support the improvement claimed.

3.2 Flowchart

The steps of whole project were illustrated in a flow chart. First, collect data such as EV charging characteristics and grid characteristics. A type of EV and a residential area had been chosen for case study. After obtaining those data, some calculations were done for getting the line impedance for different size of cables. Different cable had been used to connect different equipment. Next, the simulations were done for different cases by considering all data obtained previously. All cases simulated can be divided into five penetration levels. Then, data simulated was processed into graphical image which is easier to be analyzed. All those data were plotted into graph for every single feeder and also compiled graph for each case. Last part of the project was analyzed the graphs which obtained from several reality-based simulation cases. Flow chart was shown below in Figure 3.3.

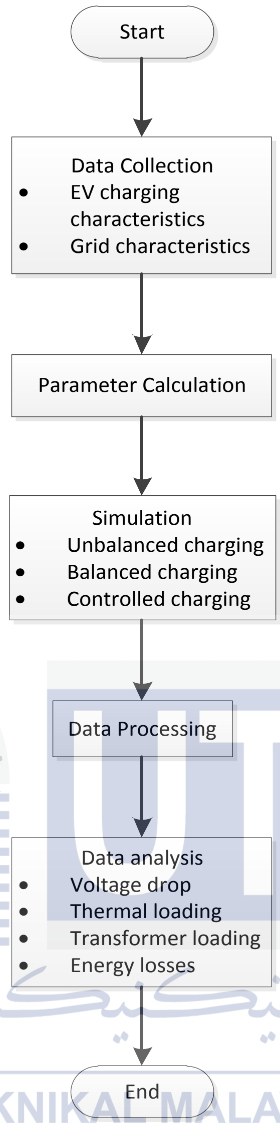

Figure 3.3: Flowchart of project

3.3 OpenDSS Modelling

The Open Distribution Simulation Software (OpenDSS) is a software that created by Electric Power Research Institute. It was familiar used as simulation tool to model the distribution network for different cases to carry out analysis. This software can model most networks as long as data for the network was collected. Different part of network had to be modeled by using different coding. The main concern in this software was the sequence of coding where the upstream equipment had to be modeled earlier than downstream. Example, source had to be modeled earlier than other equipment such as transformer. Syntax for different equipment involved in this study was shown in below.

3.3.1 Source Modelling

Before modeled a source for network, frequency for the network had to be preset. The frequency can be set by typing syntax below.

```
Set DefaultBaseFrequency=50
```

After that, source bus can be modeled by using syntax as shown below. "example" was the name of the circuit and base voltage set for the source was 132kV.

```
New circuit.example basekV=132 pu=1.0 angle=0 frequency=50 phases=3
```


3.3.2 Transformer Modelling

The equipment after sourcebus was a power transformer. A transformer can be modeled by using coding below. "SS" was name for the transformer and was located between sourcebus and bus A. SS was a 30MVA rating transformer which step-down 132kV to 33kV by wye-wye connection. xhl was short circuit reactance and SS was assumed to be lossless.

```
new transformer.SS phases=3 windings=2 buses=(sourcebus, A) conns=(wye, wye)
kvs=(132, 33) kvas=(30000, 30000) %loadloss=0 xhl=12.5
```

`In this study, two transformers were used for supplying overall seven feeders. 500kVA and 750kVA were rating for the two transformers.500kVA transformer was used to supply houses with single phase load and 750kVA transformer was used to supply three phase load houses. Both transformers were step-down voltage from 11kV to 400V with delta-wye connection.

3.3.3 Line Modelling

After transformer was modeled, line had to be created. For modelling line for connecting two equipment, line code had to be created preliminary. The line code can be type as below. ABC was name for the line code and was set as three phase cable. R1 was positive sequence resistance and X1 was positive sequence reactance. The unit for length of ABC was in kilometer.

```
new linecode.ABC nphases=3 R1=2.13444 X1=1.554003 units=km
```

After creating a line code, corresponding cable can be modeled by typing syntax below. lineA-B was name for the cable and it was connecting bus A and bus B. It was referred to line code ABC and modeled as a one kilometer cable.

```
new line.lineA-B bus1=A bus2=B length=1 phases=3 units=km linecode=ABC
```

There were three sizes of cables used in this study which were 500mm^2, 185mm^2 and 16mm^2 aluminum cables. However, different arrangement of cable will lead to different line code. Five line codes were created by these three sizes cables. Those line codes were 185mm^2, 4 x 500mm^2, 7 x 500mm^2, three phase 16mm^2 and single phase 16mm^2. 185mm^2 was used to connect feeder pillar and bus before entering house. 4 x 500mm^2 was used for 500kVA transformer and 7 x 500mm^2 was used for 750kVA transformer to connect with feeder pillars. Three phase 16mm^2 was used for three phase houses and single phase 16mm^2 was used for single phase houses. All those equipment used in this study was discussed in 3.4.

3.3.4 Load Modelling

The most downstream element was the load. Load named “loadB” was modeled in syntax below. loadB was a three phase load which had rating of 33kV. 5MW and 1.64Mvar was consumed by loadB.

```
new load.loadB bus1=B phases=3 kV=33 kW=5000 kvar=1640 model=1
```

There were four types of houses modeled in this study which represented by four types of load which were two types of single phase load and two types of three phase load. Besides the residential house load, EV charging was also modeled as load. All loads involved was stated in 3.4.

3.3.5 Monitors and Meters Modelling

After modelling all equipment required in a network, monitors and meters had to be placed to obtain the data. Monitor got few modes to choose, mode 0 was used to observe voltage and current, while mode 1 was used to observed power. Monitor SS was connected to front side of transformer SS and monitor Vbb was connected to back side of the transformer.

```
new monitor.SS element=transformer.SS terminal=1 mode=1 ppolar=no

new monitor.Vbb element=transformer.SS terminal=2 mode=0
```

Energy meter was placed to observe the energy flow. “Grid” was connected to front side of transformer SS and will capture the energy flow through SS. It will compute for active energy, reactive energy and energy losses.

```
new energymeter.Grid element=transformer.SS terminal=1
```

After placing the monitors and meters, they needed to be exported to show the data obtained. By typing coding as below, csv file of data obtained for every particular monitor will be created in same folder with coding. However, energy meters only need to be exported once regardless amount of energy meters. The reason was all energy meters will have their data merged in a csv file.

```
export monitors SS

export meters
```

Monitors and meters were needed in this study since there were seven feeders to be observed. The configuration of the monitor and meter was shown in 3.4.

3.3.6 30 Bus Modelling

A case for a network which consists of thirty buses had been done. The single line diagram of the network was shown in figure 3.4. All the equipment such as line and load were modeled separately in different text file. After that, a main simulation file was created and all particular file were redirected in the main coding. The voltage and power within the network were obtained and plotted into graph as shown in figure 3.5 and 3.6. This case was done before the simulation of case study started. Coding for this case was attached as appendix A.

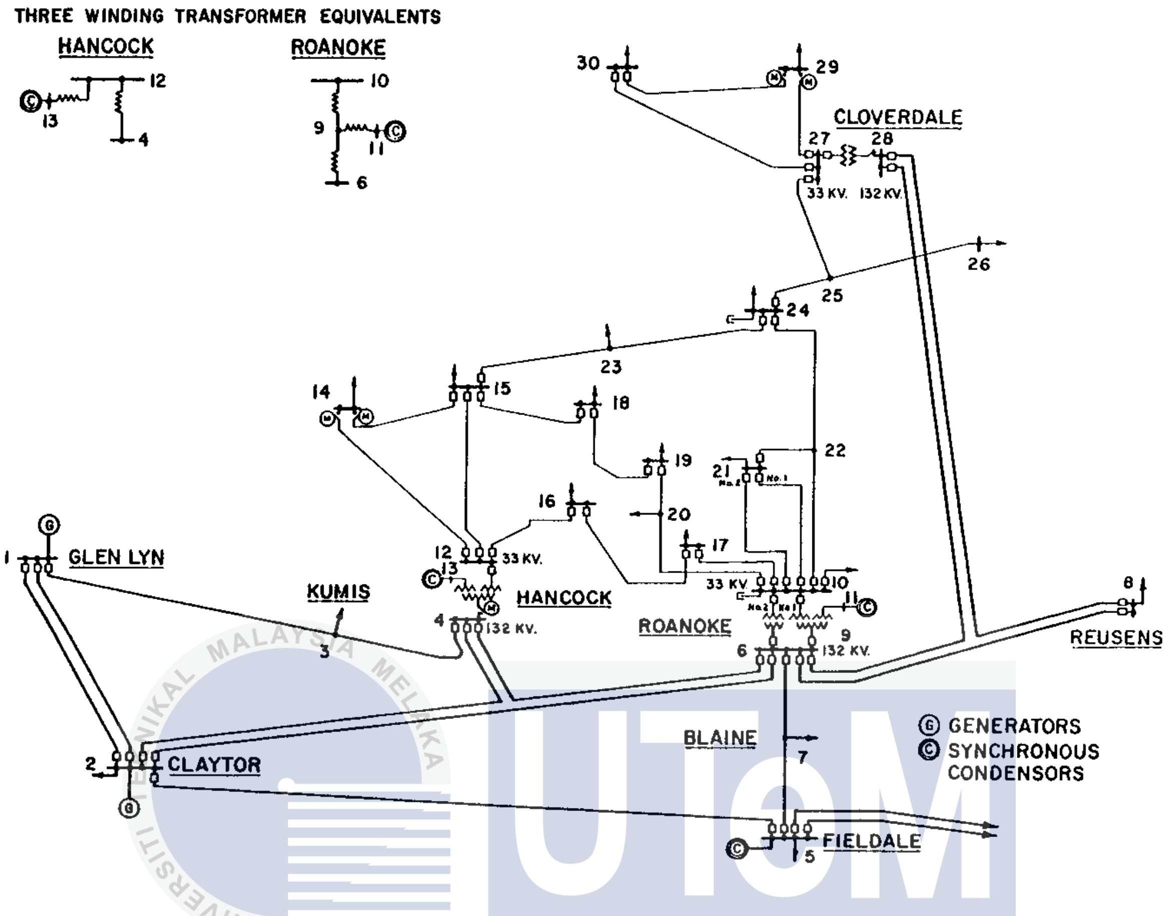

Figure 3.4: Single line diagram for 30 bus

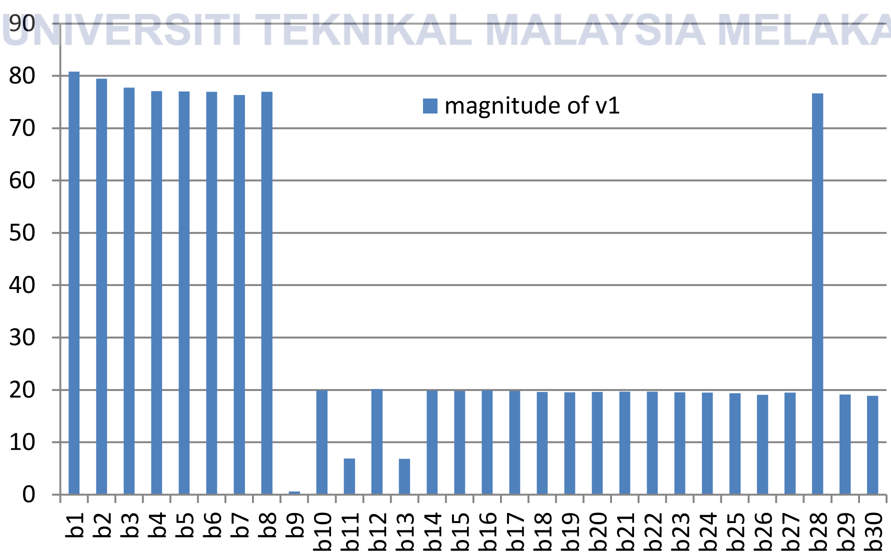

Figure 3.5: Magnitude of v1 for 30 bus case

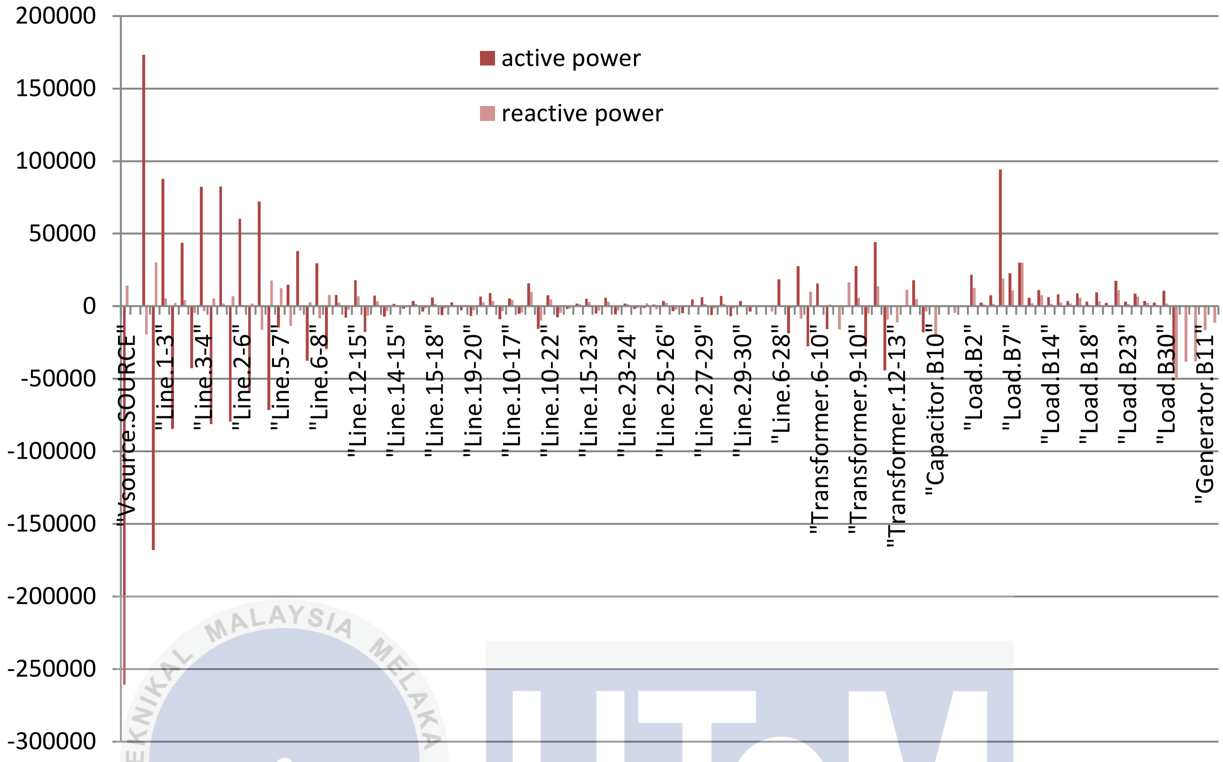

Figure 3.6: Power for 30 bus case

3.4 Case Study

This project was carried out by utilizing Open Distribution System Simulator (OpenDSS) software as simulator and Microsoft Excel as data processor. Nissan Leaf was chosen as EV charging load in all the simulations. It will be the only EV load used in this project. The battery capacity for Leaf was 24kWh and onboard charger chosen was 3.3kW charger [17]. The time taken for charging from 0% to 100% was approximately 8 hours. However, 20% was the minimum level of power needed to be reserved in the battery [12]. For charging from 20% to 100%, time taken was approximately 6 hours which was used in EV charging profile. EVs were assumed to charge through the direct plug in socket which same with other daily appliances. Each EV charging load was set as 3.3kW constant power demand for 6 hours continuously. The simulation was done based on a real grid network. A residential area was chosen for this project, the single line diagram of the area was as shown below.

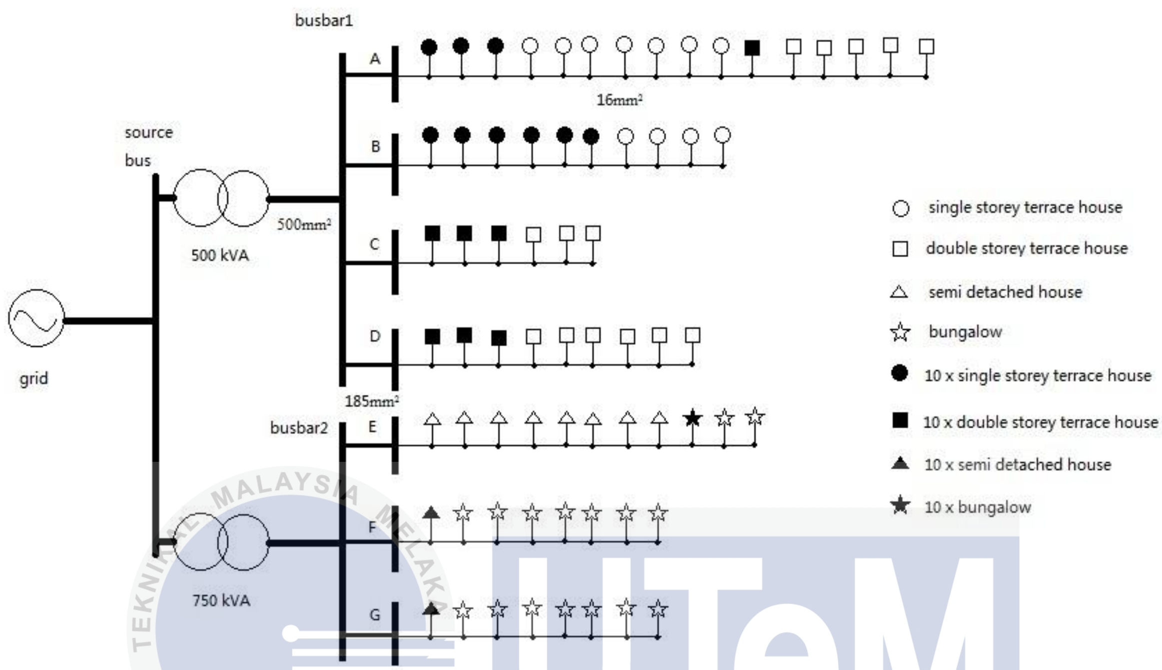

Figure 3.7: Single line diagram of the chosen residential area

The network consists of two transformers, seven feeder pillars and two hundred and thirty nine houses. There were two 11kV/400V delta-wye transformers with 500kVA and 750kVA rating respectively. Seven feeders were connected to two transformers through two busbars. Transformer 1 with 500kVA was connected to busbar1 and transformer 2 with 750kVA was connected to busbar2 where both transformers connecting through $500mm^2$ aluminum cable. Feeder pillars A, B, C and D were connected to busbar1 and feeder pillars E, F and G were connected to busbar2 by $185mm^2$ cable. There were four type houses in the residential area which were single storey terrace house, double storey terrace house, semidetached house and bungalow. The amount of houses and the load demand for the houses were recorded in Table 3.1.

Table 3.1: Amount and load demand for each type of house

Type of houses	Single storey terrace house	Double storey terrace house	Semi detached house	Bungalow
Number of houses	101	84	28	26
Load demand	1.5kW	3kW	5kW	8kW

All the houses were connected to seven feeder pillars by 16mm² cable. Those houses were distributed evenly in terms of power demand. For demand more or equal to 5kW, it was considered as three phase load [18]. Hence, semi detached house and bungalow were considering as three phase load. Combinations of two types of houses were existed on most feeder pillars. The distribution of houses was shown in Table 3.2.

Table 3.2: Distribution of houses over 7 feeders

Type of houses	Single storey terrace house	Double storey terrace house	Semi detached house	Bungalow	Total houses per feeder
Feeder A	37	15	0	0	52
Feeder B	64	0	0	0	64
Feeder C	0	33	0	0	33
Feeder D	0	36	0	0	36
Feeder E	0	0	8	12	20
Feeder F	0	0	10	7	17
Feeder G	0	0	10	7	17
Total houses per type	101	84	28	26	**239**

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 per unit where 1 represent full load. The load demand pattern was shown in figure 3.8.

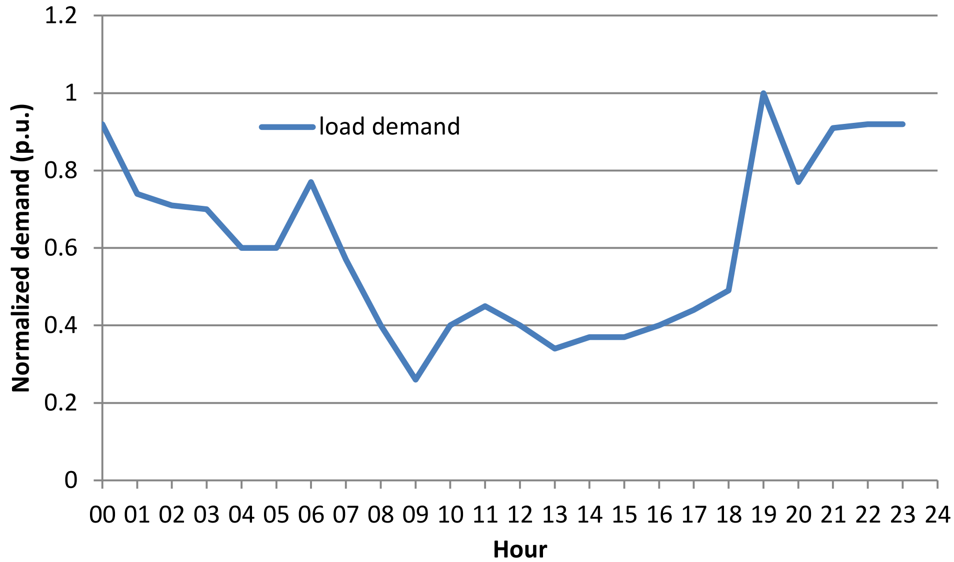

Figure 3.8: Typical Malaysia residential load demand pattern

The line impedance for 185mm^2, 4 x 500mm^2, 7 x 500mm^2, three phase 16mm^2 and single phase 16mm^2. 185mm^2 cables were calculated for simulation usage. All cable had its owned arrangement. All the configurations of the cable were shown in figure 3.9.

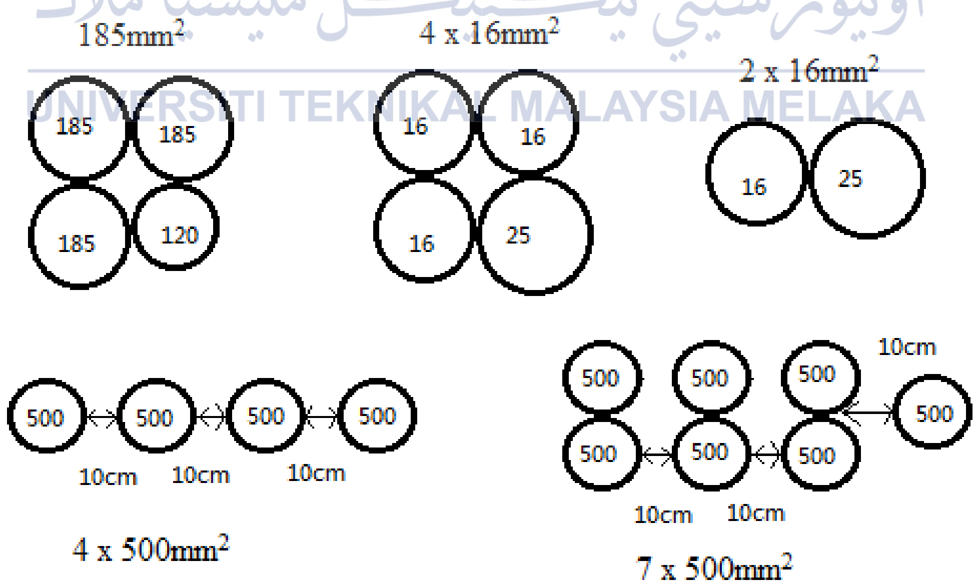

Figure 3.9: Configuration for different cables

Self-impedance and mutual impedance was considered for calculating the line impedance. r represents the radius of cable, GMR is the geometric mean radius and D is the distance between cables. The distances between cables were calculated using formula below.

$$D_{ij} = GMD_{ij} = \sqrt[3]{Dab \cdot Dbc \cdot Dca} \text{ ft} \tag{3.1}$$

$$D_{in} = GMD_{in} = \sqrt[3]{Dan \cdot Dbn \cdot Dcn} \text{ ft} \tag{3.2}$$

Formulas below were computed for frequency of 60Hz.

$$Z_{ii} = r_i + 0.09530 + j0.12134 (\ln GMR_i^{-1} + 7.93402) \ \Omega/\text{mile} \tag{3.3}$$

$$Z_{ij} = 0.09530 + j0.12134 (\ln D_{ij}^{-1} + 7.93402) \ \Omega/\text{mile} \tag{3.4}$$

Malaysia was using 50Hz as frequency, so the formula was corrected. For neutral line, the formula was equivalent to the phase line formula.

$$Z_{ii} = r_i + 0.07942 + j0.10112 (\ln GMR_i^{-1} + 8.02517) \ \Omega/\text{mile} \tag{3.5}$$

$$Z_{ij} = 0.07942 + j0.10112 (\ln D_{ij}^{-1} + 8.02517) \ \Omega/\text{mile} \tag{3.6}$$

$$Z_{nn} = r_n + 0.07942 + j0.10112 (\ln GMR_n^{-1} + 8.02517) \ \Omega/\text{mile} \tag{3.7}$$

$$Z_{in} = 0.07942 + j0.10112 (\ln D_{in}^{-1} + 8.02517) \ \Omega/\text{mile} \tag{3.8}$$

Since 1 mile =1.609344km, the value obtained from formula above was divided by 1.609344 to convert the unit to become Ω/km.

$$[Z_{abc}] = [Z_{ij}] - [Z_{in}] * [Z_{nn}] * [Z_{nj}] \tag{3.9}$$

$$[Z_{012}] = [A_s]^{-1} * [Z_{abc}] * [A_s] \tag{3.10}$$

$$[Z_{012}] = \begin{bmatrix} Z00 & Z01 & Z02 \\ Z10 & Z11 & Z12 \\ Z20 & Z21 & Z22 \end{bmatrix} \tag{3.11}$$

where

$$[A_s] = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \tag{3.12}$$

and

$$a = 1\angle 120° \tag{3.13}$$

Z_{00} is the zero impedance while Z_{11} and Z_{22} are positive and negative impedance. Impedance, Z was separated into resistance and reactance for simulation coding usage.

There were different cases done for simulation to ease the analysis work. There were comparison between balanced and unbalanced charging, controlled and uncontrolled charging. Besides that, charging during peak time and off peak time also done simulated. 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. For the off peak period, only unbalanced charging simulation was done. Hence, unbalanced uncontrolled charging for both peak and off peak hour were set as same case and compared. All cases done were indicated in table 3.3.

Table 3.3: Simulation cases

	Case 1	Case 2	Case 3	Case 4	Case 5
Case a	0%	20%	20%	20%	20%
Case b		40%	40%	40%	40%
Case c		60%	60%	60%	60%
Case d		80%	80%	80%	80%
Case e		100%	100%	100%	100%

Case 1 until case 5 was stated as below.

Case 1: without EV load/ normal house load

Case 2: uncontrolled unbalanced charging

Case 3: controlled unbalanced charging

Case 4: uncontrolled balanced charging

Case 5: controlled balanced charging

The EV load demand patterns for both peak and off peak time were shown in figure 3.10 and 3.11.

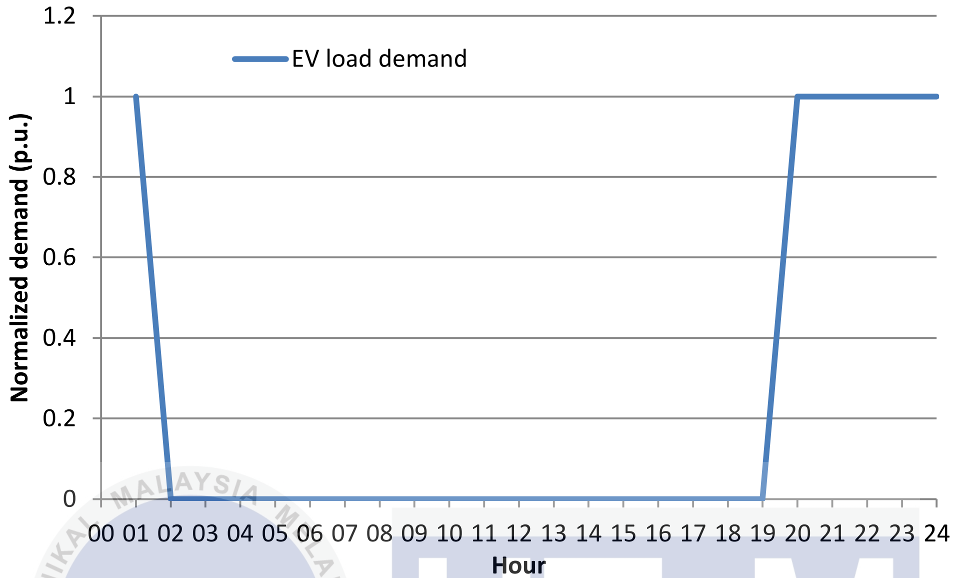

Figure 3.10: EV load demand pattern for peak time

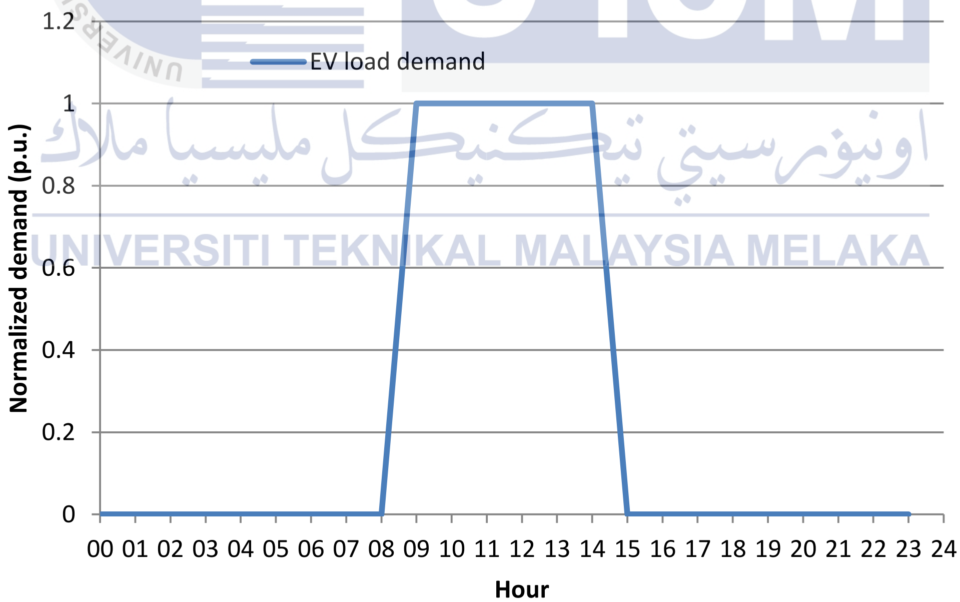

Figure 3.11: EV load demand for off peak time

Uncontrolled charging was assumed that all EV users charge EV on same time. Controlled charging was divided the EV users to charge at three different times. The periods for controlled charging were as shown in Table 3.4. Time for three periods had been stated below. Figure 3.12, 3.13 and 3.14 were indicated the EV load pattern for period 1, period 2 and period 3 respectively.

Table 3.4: Controlled charging pattern

12am-2am	2am-4am	4am-6am	6am-8am	8am-6pm	6pm-8pm	8pm-10pm	10pm-12am

Period 1: 6pm to 12am

Period 2: 10pm to 4am

Period 3: 2am to 8am

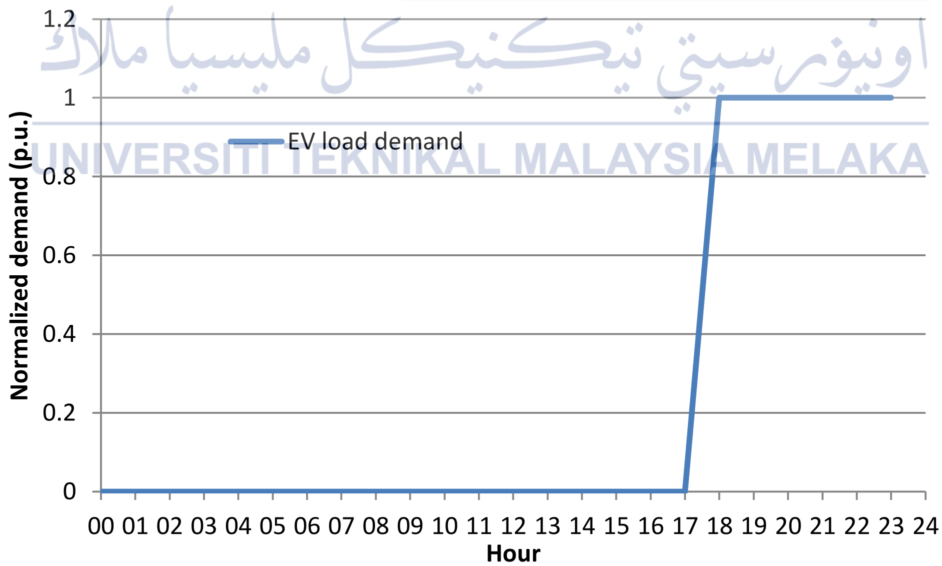

Figure 3.12: EV load demand pattern for period 1

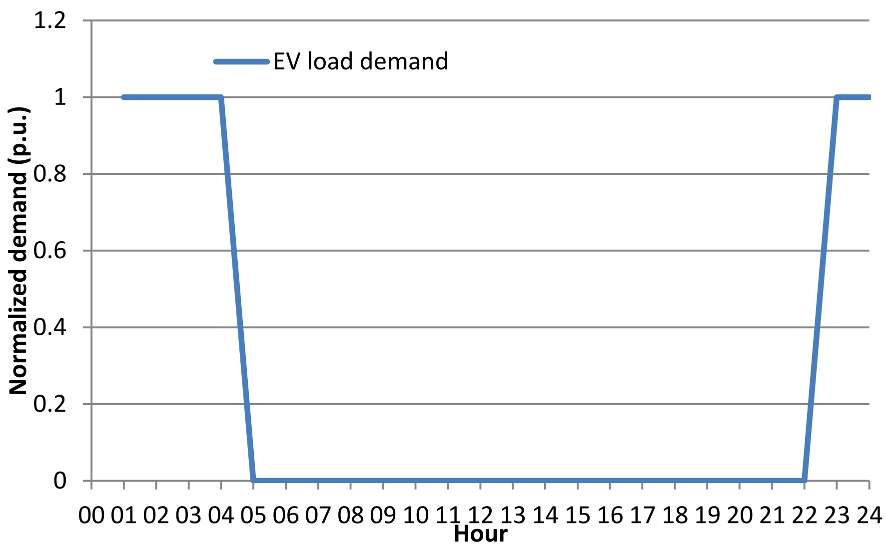

Figure 3.13: EV load demand pattern for period 2

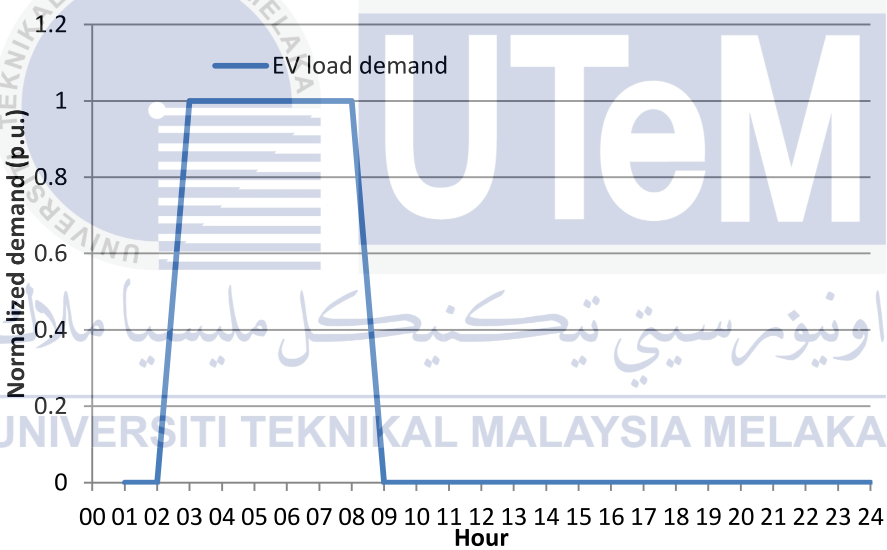

Figure 3.14: EV load demand pattern for period 3

All house load and EV load in OpenDSS will use syntax as below.

new load.evAA1 bus1=AA1.1.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand

where evdemand will refer to syntax below

new loadshape.evdemand npts=24 interval=1.0 csvfile=ev.txt action=normalize

In syntax above, evdemand represents the name of new loadshape where will be used in load modelling. The csvfile will lead OpenDSS to read the txt file which located in same folder and was represented by figure 3.10 until figure 3.14 for different cases.

For the unbalanced charging, only the three phase feeders, E, F and G will face the significant effect. In unbalanced mode, all EV for feeder E, F and G were connected to red phase only. The single phase feeder would not be affected since the houses were distributed evenly among three phases. For the balanced charging, all EV in three phase feeders will be distributed equally among three phases. However, the amount of EV may not be multiple of three which means EV cannot divided evenly. When this situation occurred, the EV would be connected to either one phase by considering the load. Besides that, second pattern for controlled charging also considered when doing modeling of EV and houses. The reason is the second pattern overlap with other two patterns. It may consume the highest power, so if either one phase consists of too many EV charge by second pattern, that phase would facing a great impact. All EV was assuming to be charged by direct plug in socket but EV load would not be sum with normal house load in simulation since they were using different load pattern or loadshape as mentioned before.

The load profile for EV charging overnight was simulated in OpenDSS 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 charged 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 charged daily without replacing the existing grid equipment. All the data simulated was recorded in csv file and had been processed 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. There were different meters used in simulation for getting different parameters. For measuring current, meter was placed at front of feeder. For measuring voltage drop, meter was placed at end of feeder. For measuring power and energy, the meters were placed at transformer. With presence of graphs, the suitable penetration level for each case had been indicated. All the analyses of data had been included into this report. Part of coding for all cases had been attached as appendix B.

CHAPTER 4

RESULT AND DISCUSSION

There were five simulation cases done and parameters such as voltage, current, power and energy were obtained. Each parameter for each case was processed and plotted into graph. Minimum voltage used for ensuring voltage drop limit had not been violated. Maximum current used to determine the thermal limit of feeder. Total power was calculated to find out the transformer loading. Energy consumed daily was obtained to get the energy losses percentage. Five cases are unbalanced uncontrolled charging, balanced controlled charging, unbalanced controlled charging, balanced uncontrolled charging and off peak hour charging. Inside voltage graph got two lines which were upper limit and lower limit. These two limits were set by TNB which stated that tolerance of voltage should within +10% and -6% [18]. In this case, voltage used was 230V, so the upper limit will become 253V and lower limit will become 216.2V. For thermal limit, there was limit for a cable to carry. In this case, feeder was using 185mm^2 cables. According to TNB, 320A was the limit for 185mm^2 cable [18]. Total power consumed by three phases should not exceed the rating of transformer connected. Energy losses were computed in percentage by dividing the total energy losses with total energy consumed.

4.1 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 three lines indicating three phases for both current and voltage graph. The minimum voltage for all feeders was shown at hours 1900. 7pm is the time for peoples back from work and reached home. Peoples may use water heater to bath or switch on the air conditioner due to hot weather. Those reason made 7pm become the peak demand hour. Differ from the terrace house, feeder E, F and G which made up of semi detached house and bungalow were consuming three phase load. The load demand will be supplied evenly by three phases. Hence, there were only 1 single line shown in graphs for feeder E, F and G due to overlapping. Figure 4.1 until 4.7 shows the voltage for feeder A to G respectively. The minimum voltage which occurred at 7pm was used to plot another graph afterwards. Feeder B 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 cable is longer.

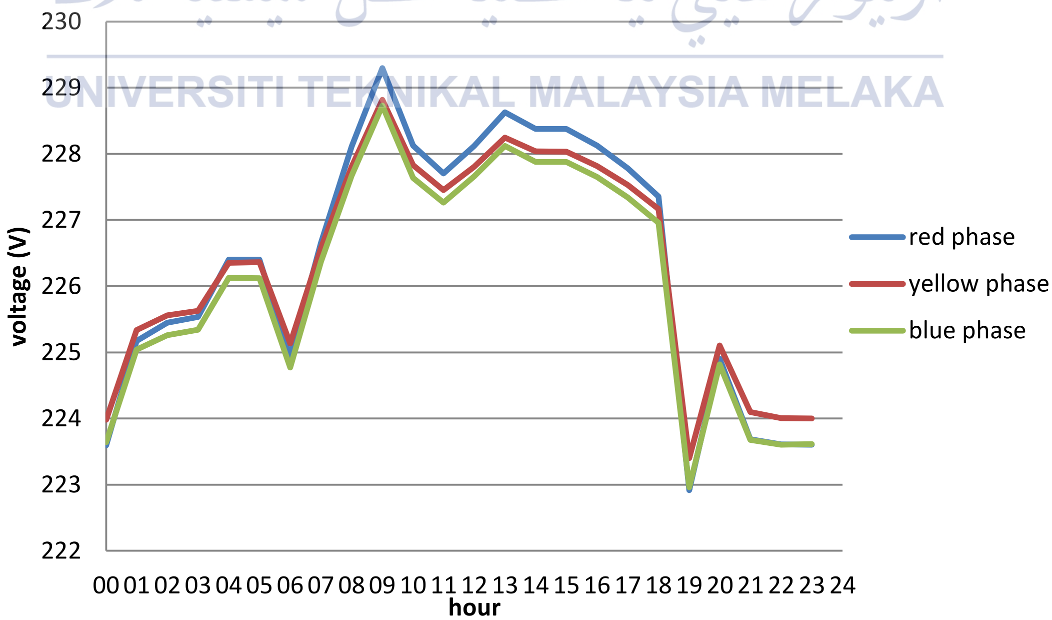

Figure 4.1: Voltage for feeder A in case 1

The feeder B had minimum voltage of less than 220V which is lower than feeder A.

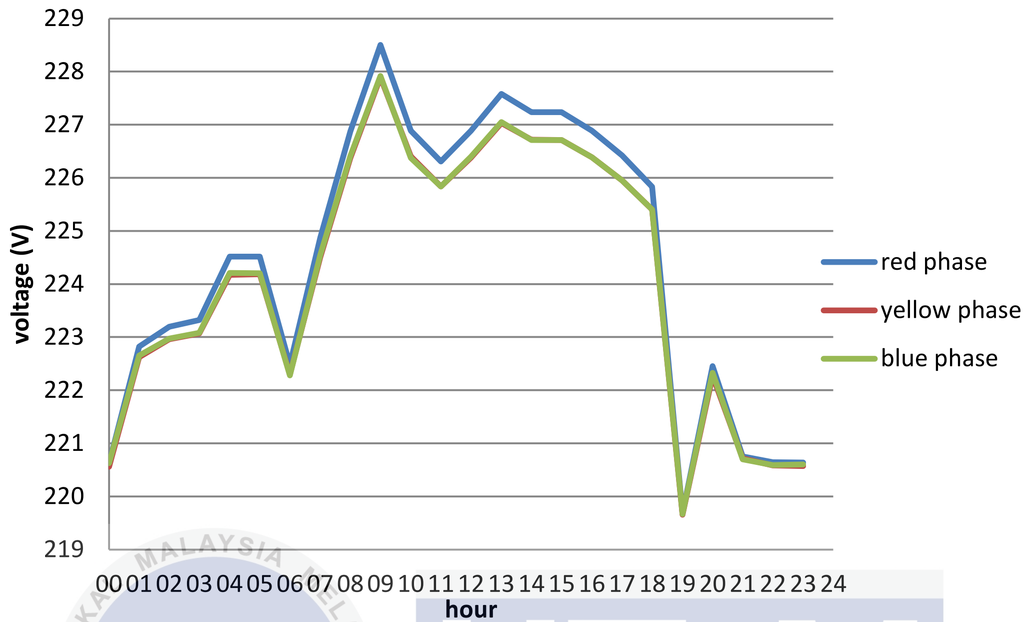

Figure 4.2: Voltage for feeder B in case 1

Feeder C had balanced voltage among three phases since the number of houses was evenly divided by three.

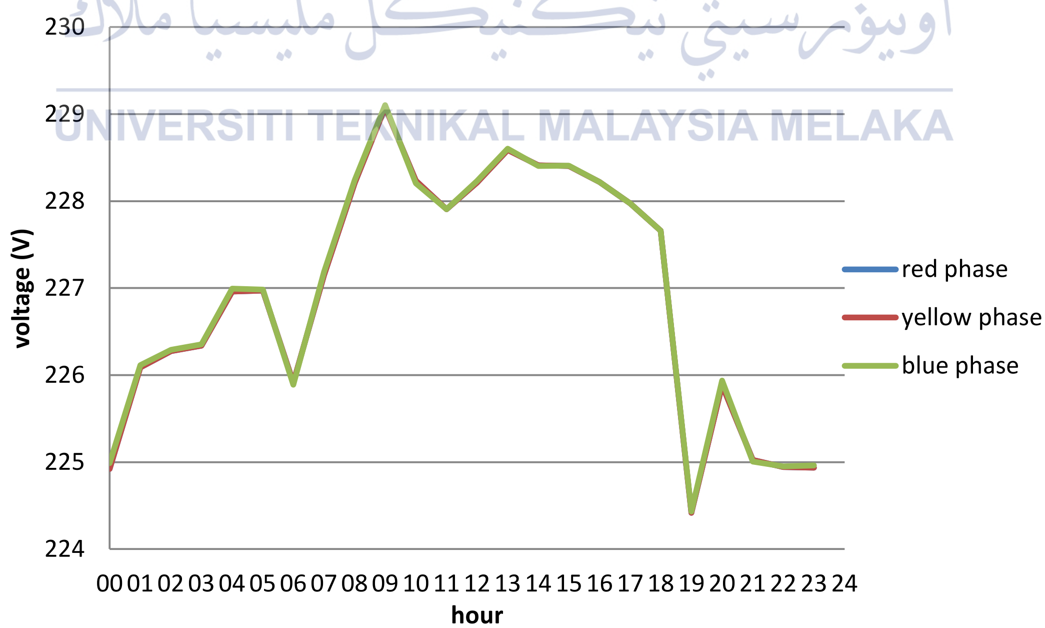

Figure 4.3: Voltage for feeder C in case 1

Feeder D had similar condition with feeder C but feeder D had faced lower voltage drop.

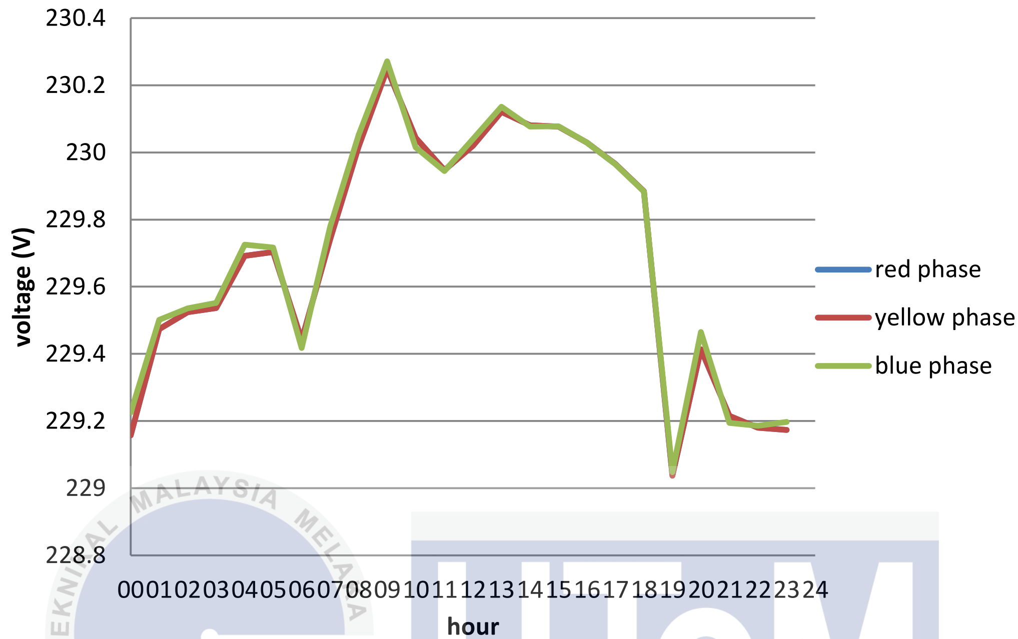

Figure 4.4: Voltage for feeder D in case 1

Feeder E was balanced among three phases since house load was three phase connected.

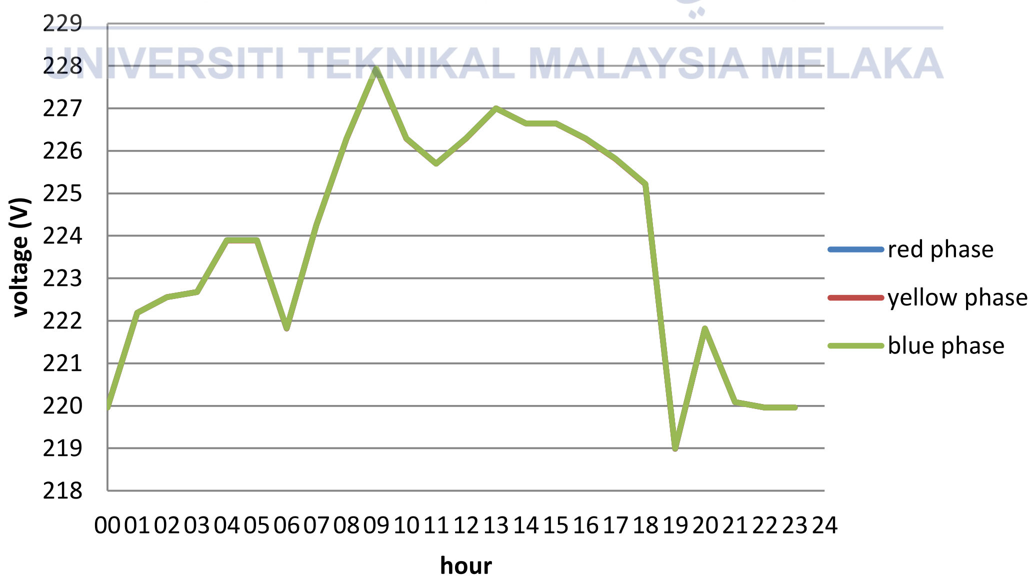

Figure 4.5: Voltage for feeder E in case 1

Feeder F had similar voltage pattern over a day with feeder F but lower minimum voltage.

Figure 4.6: Voltage for feeder F in case 1

Feeder G was similar with feeder F because both feeder have same amount and types of houses.

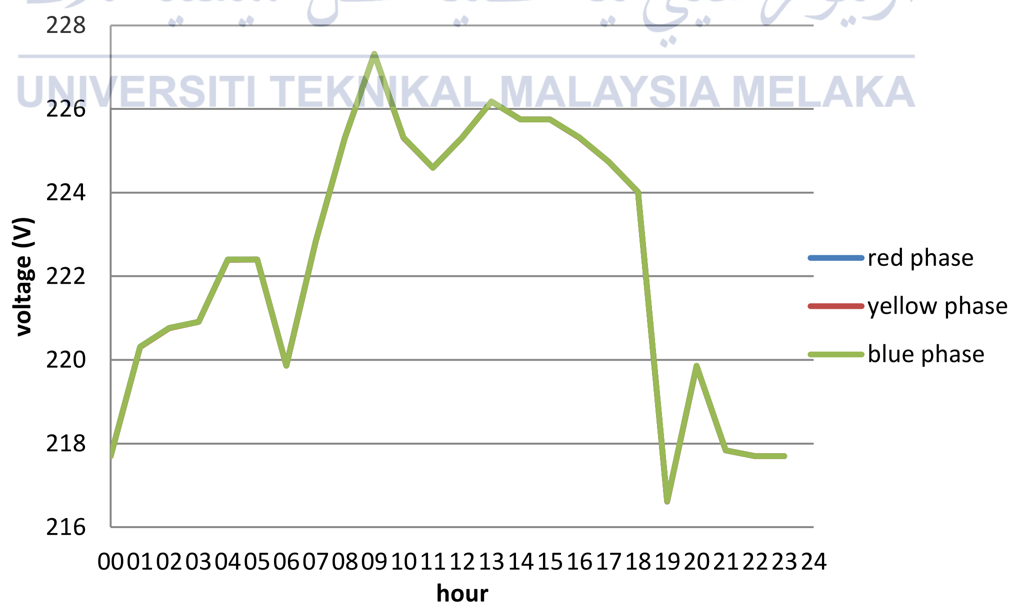

Figure 4.7: Voltage for feeder G in case 1

Figure 4.8 until 4.14 is shows the current for feeder A to G respevtively. The highest current drawn for all feeder was on 7pm. Since 7pm was peak load demand, most power will consumed at that hour and thus current drawn will also increase. Eventhough feeder C and D made up of terrace house which using single phase supply, both feeder drawn current evenly for three phases which can be known from graph which only show a single line. For the three phase feeders, the current drawn was balanced among three phases indicated by the graphs. The highest current drawn also used for plotting other graph afterwards.

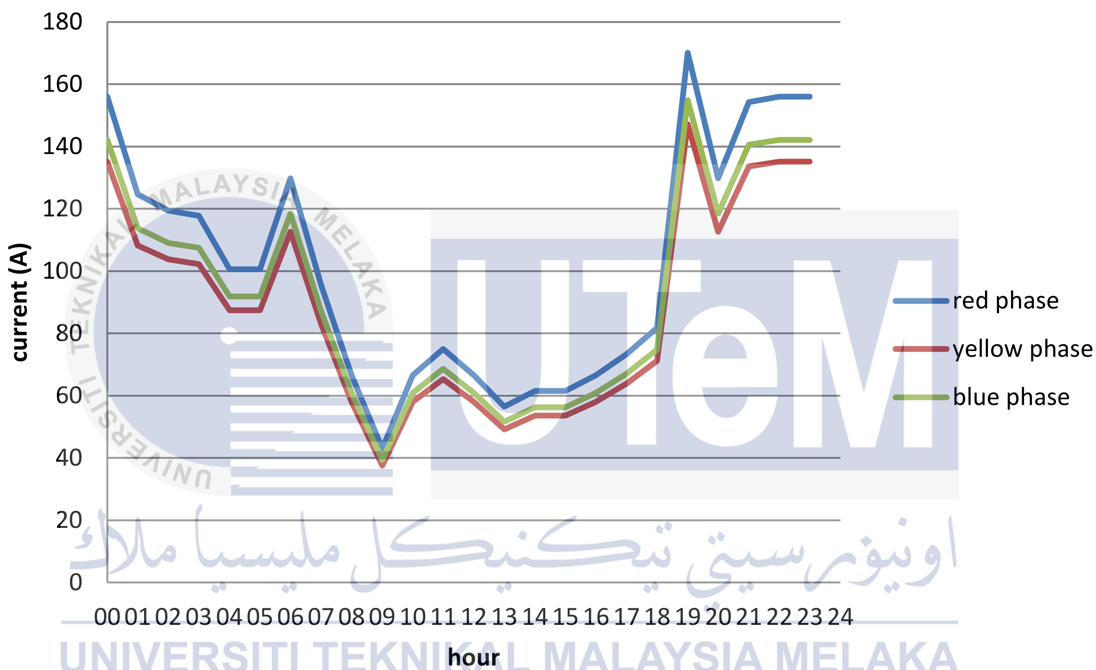

Figure 4.8: Current for feeder A in case 1

Feeder B draws the highest current for about 160A and lowest current for less than 40A.

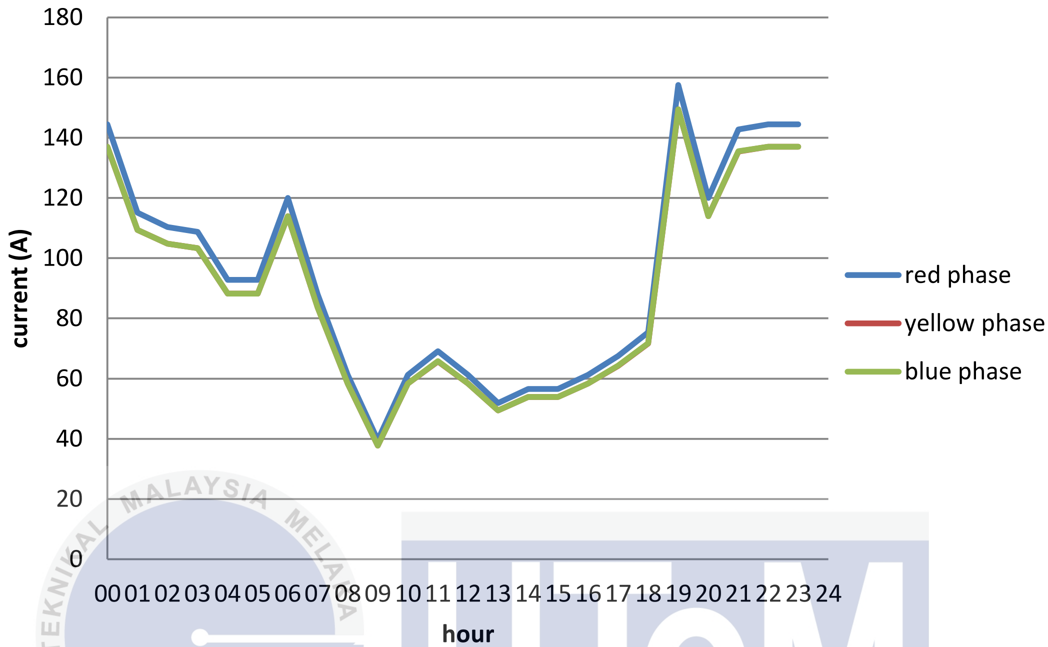

Figure 4.9: Current for feeder B in case 1

Feeder C had balanced among three phases with highest current of less than 160A.

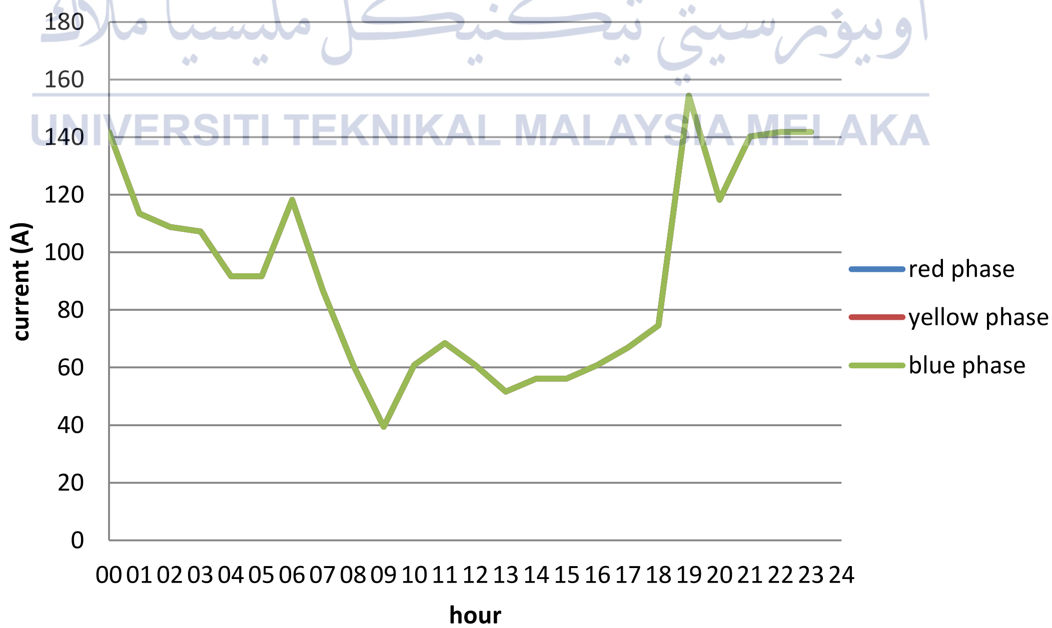

Figure 4.10: Current for feeder C in case 1

Feeder D was similar with feeder C in current drawn since amount of houses for both feeders were nearly same.

Figure 4.11: Current for feeder D in case 1

Feeder E was balanced in current drawn since load is three phase connected.

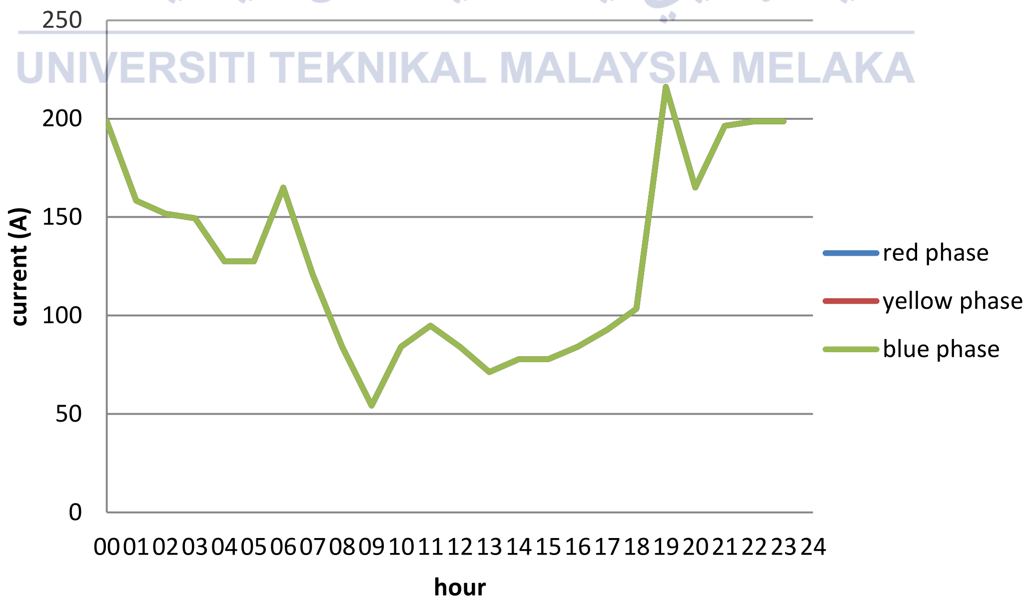

Figure 4.12: Current for feeder E in case 1

Feeder F was also balanced in current drawn with same reason but the highest current drawn was lower than feeder E.

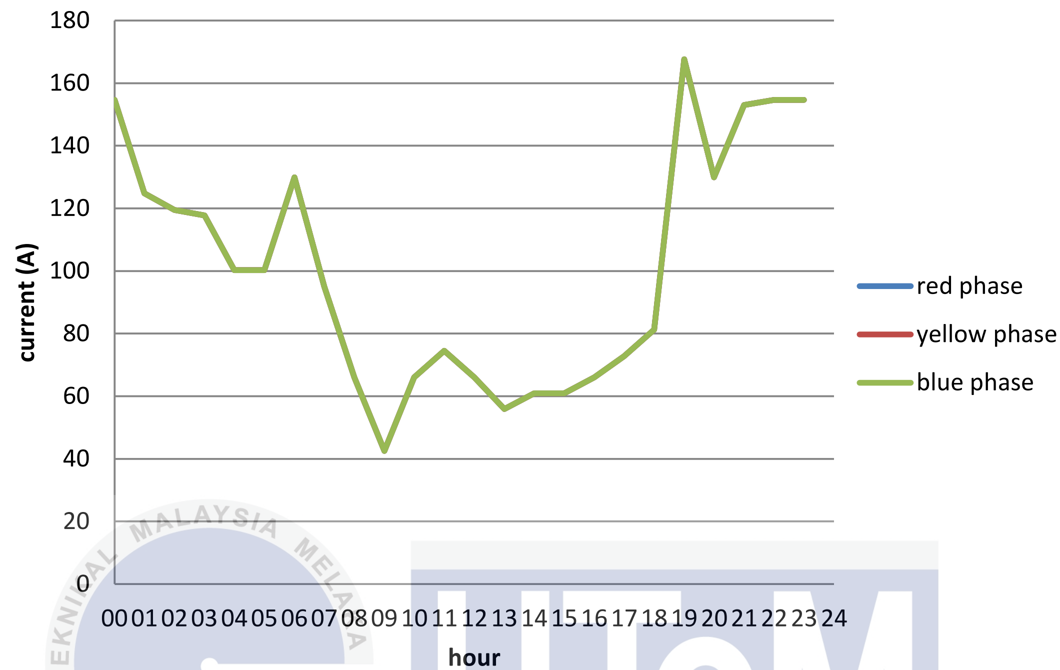

Figure 4.13: Current for feeder F in case 1

Feeder G was almost same with feeder F with the reason of same houses connected.

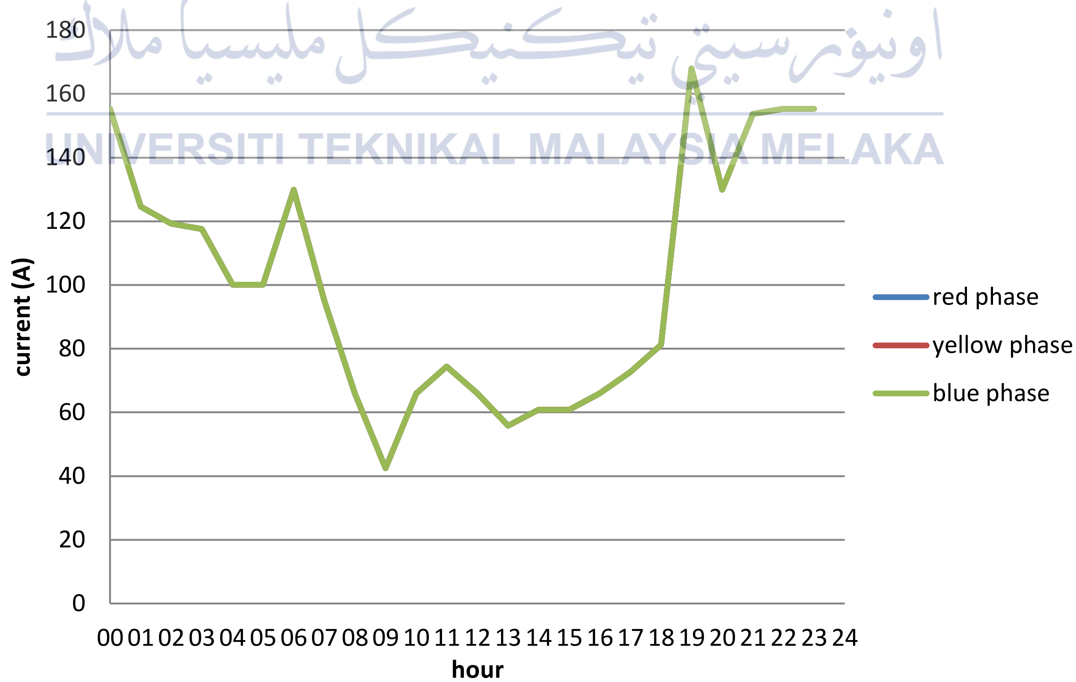

Figure 4.14: Current for feeder G in case 1

Figure 4.15 and 4.16 shows the graph of transformer loading for transformer 1 and 2. Both graphs are illustrated in unit of apparent power, kVA. Both graphs have almost same pattern since the same load demand pattern was used. The only difference between two graphs was the value of power loaded. Transformer 1 which connected to four feeders consumed more power compared to transformer 2 which only connected to three feeders. Rating for transformer 1 is 500kVA and transformer 2 is 750kVA. Transformer can function normally within its own rating. Not even the transformer loading graphs, voltage and current graphs will also show the similar pattern since there are no EV load injected to the network. Maximum power used for transformer 1 was about 450kVA and minimum power was slightly more than 100kVA.

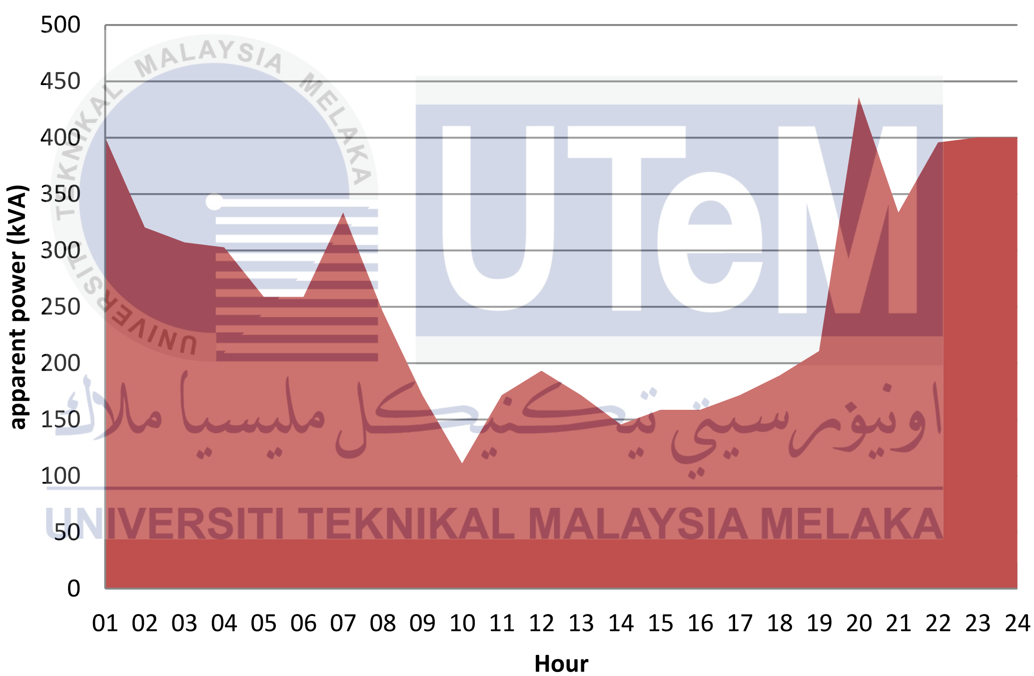

Figure 4.15: Power for transformer 1 in case 1

Maximum power drawn by transformer 2 was about 380kVA while minimum power was about 100kVA.

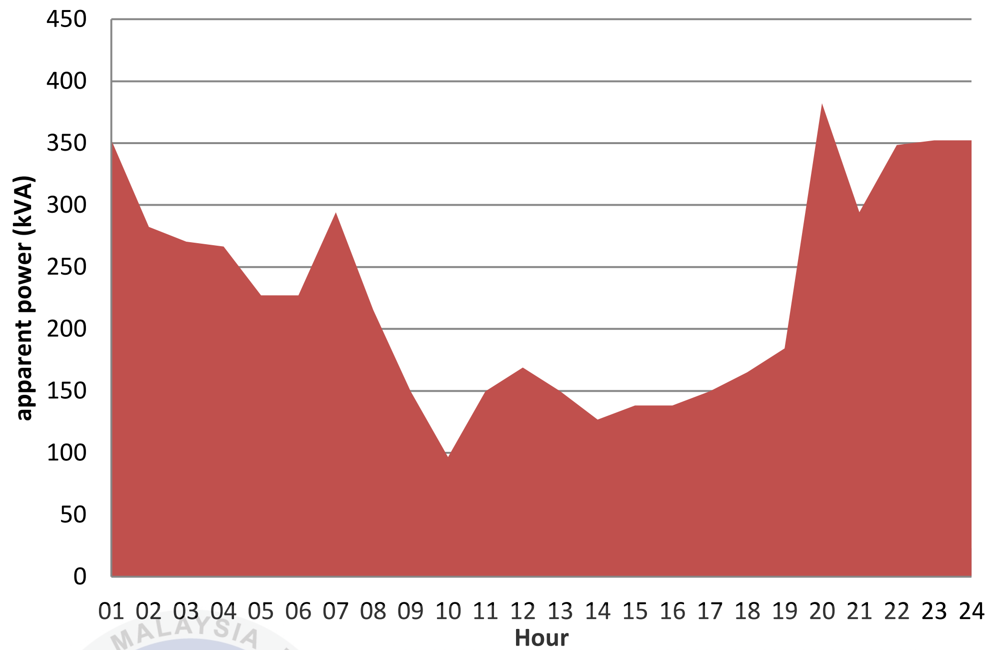

Figure 4.16: Power for transformer 2 in case 1

4.2 Case 2: uncontrolled unbalanced charging

100% penetration unbalanced uncontrolled charging which is case 2e can be declared as the worst case because it would make voltage drop to lowest value and highest current drawn by feeder. For case 2, only case e will be shown since all penetration level will have similar pattern of graphs. Figure 4.17 and 4.18 are voltage graphs for two feeders out of seven. When compared with the 0% penetration, the gap between off peak hour and peak hour become larger because all EV were assumed to charge at peak hour. The unbalance voltage among three phases in feeder A maybe caused by the remaining house when number of total houses is not multiple of three. There is maybe one or two houses exceed after other houses distributed evenly to three phases. The remaining one or two will connect to either one phase and thus caused the unbalanced. The voltage unbalance for three phase feeder alleviated because the minimum voltage decreased when compared to 0% penetration as shown in Figure 4.18.

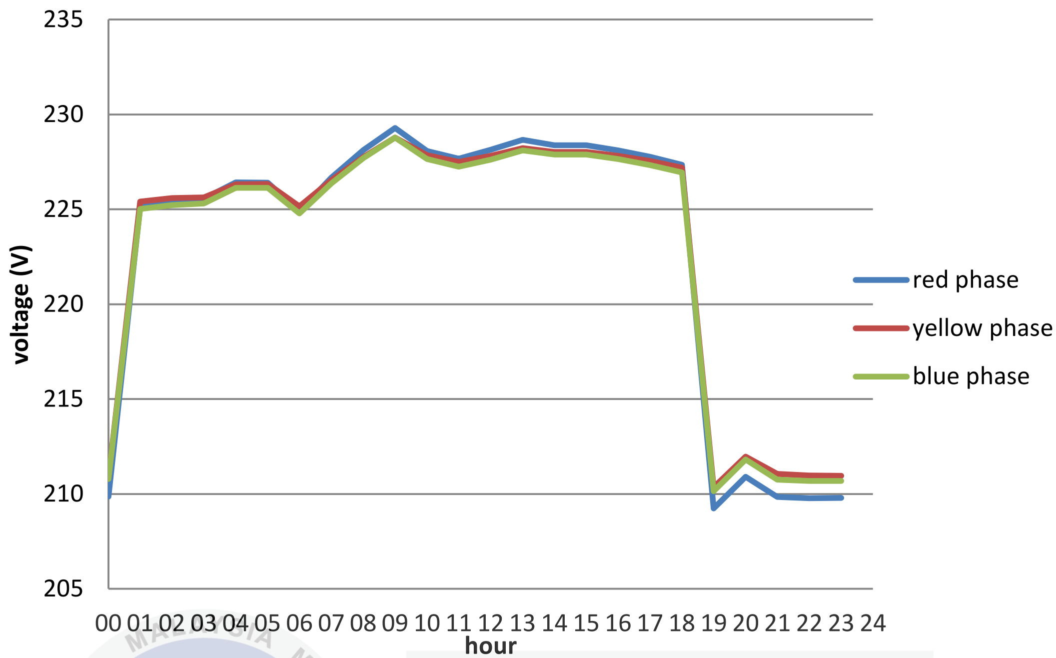

Figure 4.17: Voltage for feeder A in case 2 for peak time

Feeder E was a three phase feeder and all EV were charged through a same single phase which is red phase in this case. The impact of voltage drop can be seen obviously from figure 4.18 where red phase was differ from other two phases.

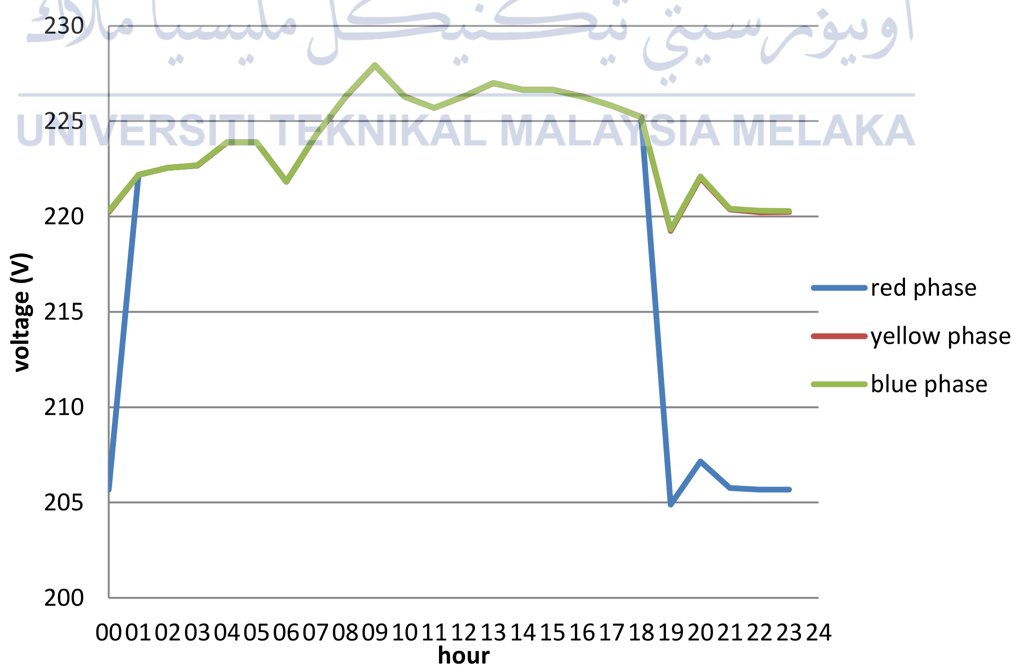

Figure 4.18: Voltage for feeder E in case 2 for peak time

Figure 4.19 and 4.20 show the current for feeder C and feeder G. As stated previously, feeder C which is a single phase feeder did not affected by the unbalanced charging. The maximum current drawn was about 350A.

Figure 4.19: Current for feeder C in case 2 for peak time

Three phase feeder, feeder G shows higher current value difference between red phase and other two phases. The difference between maximum current for red phase and other two phases was about 200A.

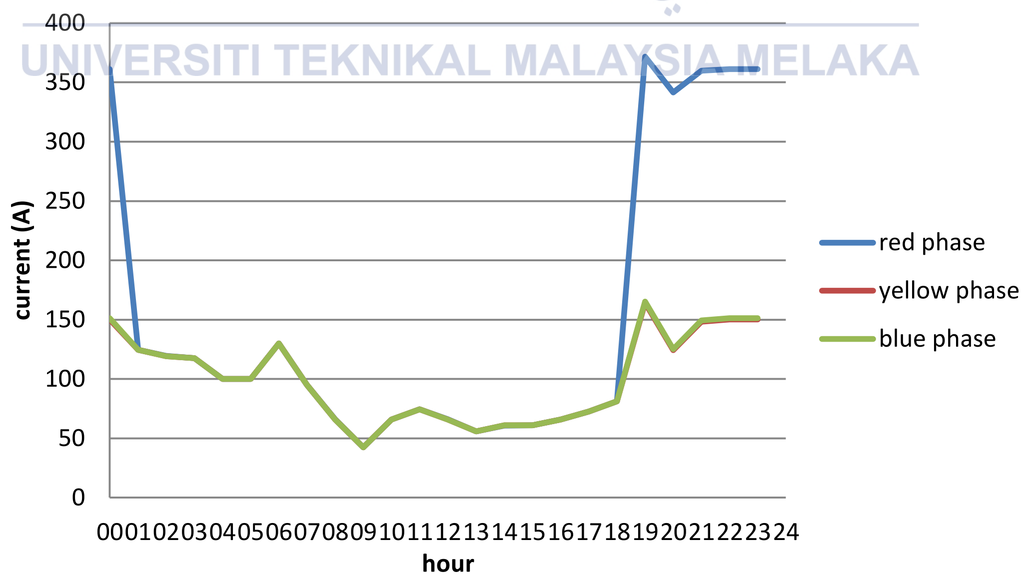

Figure 4.20: Current for feeder G in case 2 for peak time

All feeders showed different voltage and current pattern when compare to previous case which charging on peak hour. The six hours off peak time had used to charge the EV and consumed large power. When all houses charge the EV on off peak hour, the residential peak demand was lower than the EV charging load. The peak demand hour was changed from 7pm to afternoon either 11am or 2pm. When comparing voltage drop and current consumed for both time, some differences can be spotted. The significant change was the overall pattern of the graph.

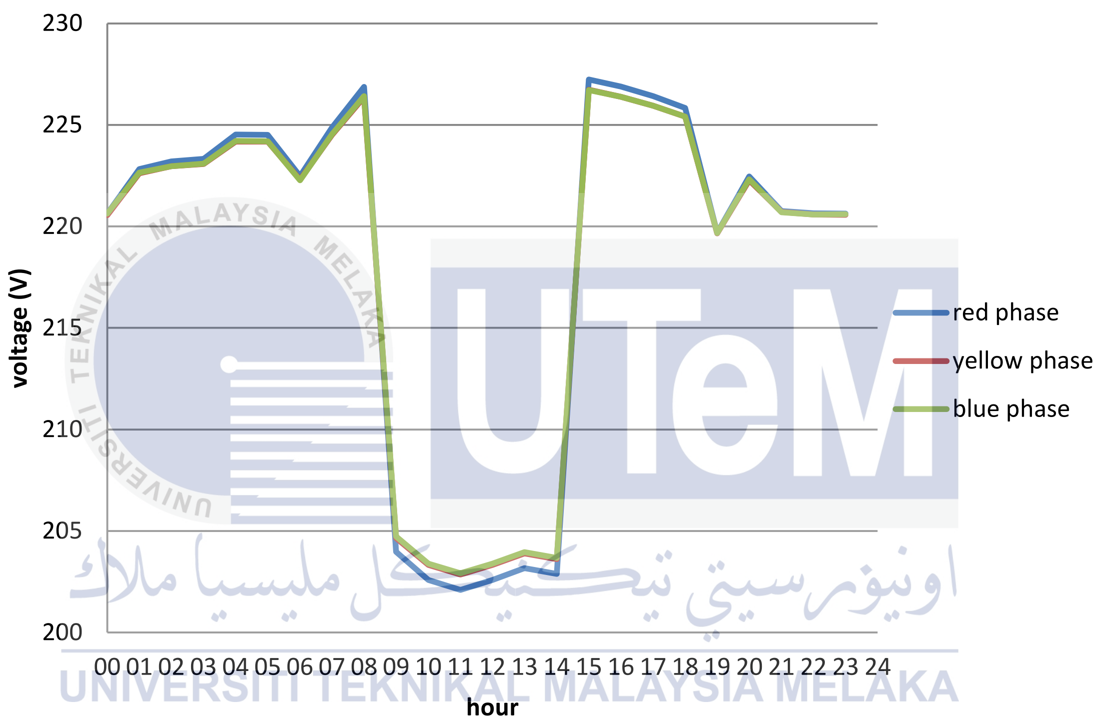

Figure 4.21: Voltage for feeder D in case 2 for off peak time

The three phase feeder still having the same problem where all voltage drops due to EV charging was fell on red phase. Yellow and blue phase were owning same voltage trend since both are balanced.

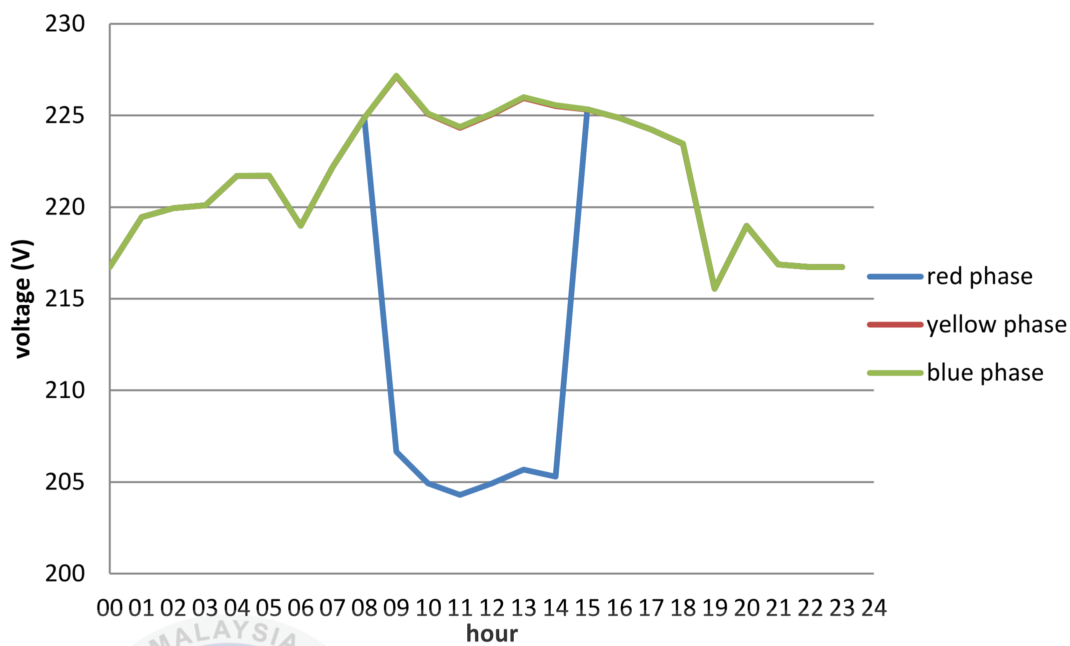

Figure 4.22: Voltage for feeder F in case 2 for off peak time

Feeder D had balanced current drawn while feeder G had unbalanced current. The maximum current drawn was slightly more than 250A.

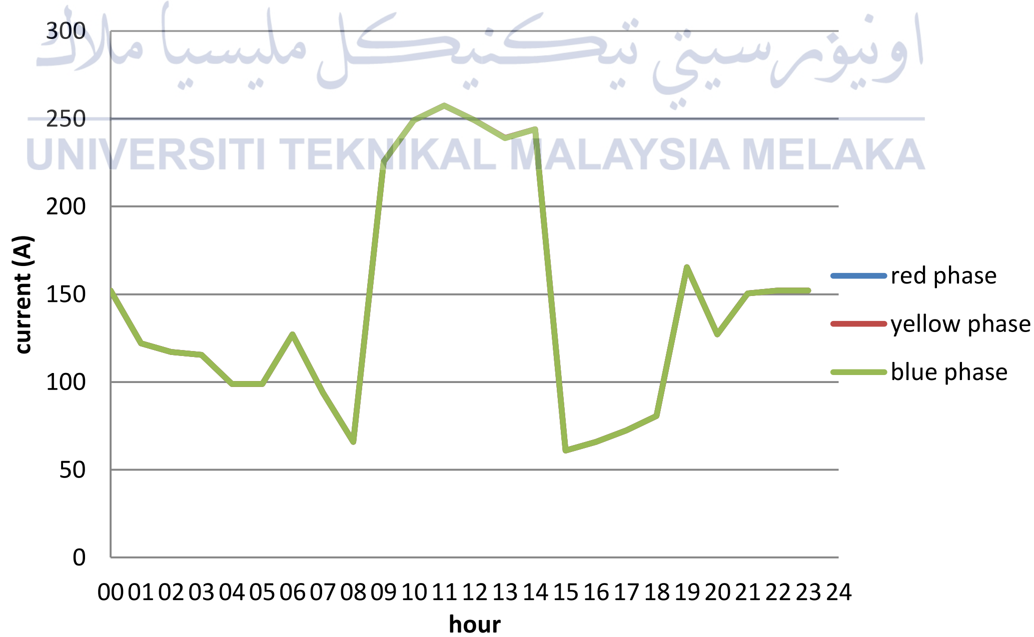

Figure 4.23: Current for feeder D in case 2 for off peak time

Feeder G had unbalanced current drawn among three phases. Red phase had been used for charging EV, thus it carrying the maximum current for feeder. While yellow and blue phase were drawing same current.

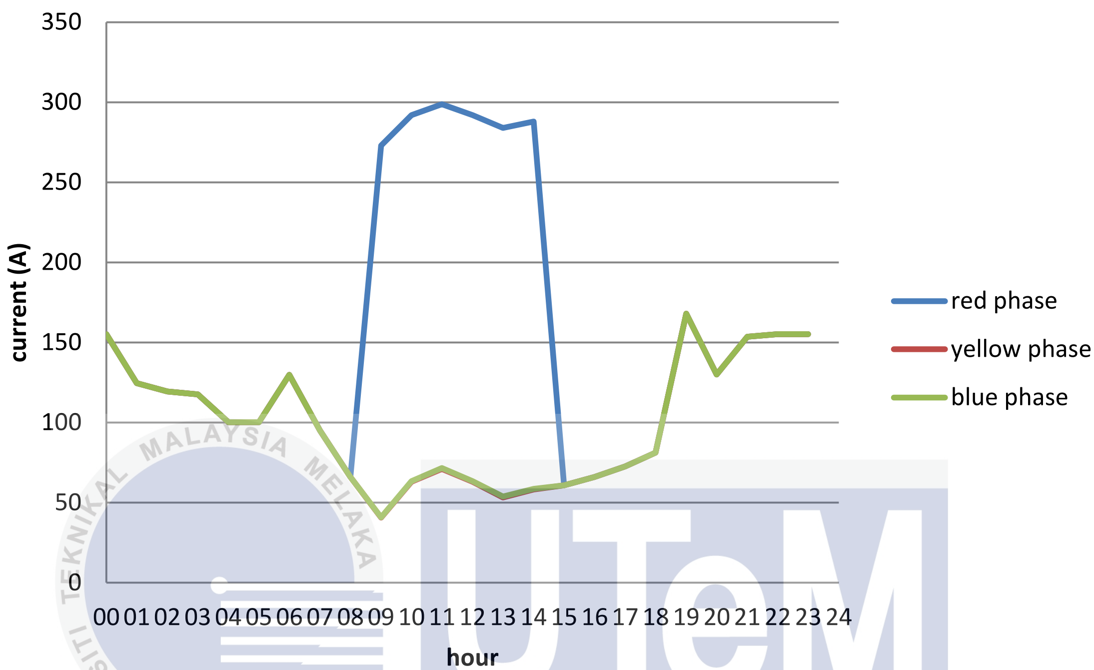

Figure 4.24: Current for feeder G in case 2 for off peak time

The pattern for both transformer loadings are still similar. When compared with 0% penetration, the peak hour consumed more power because of EV charging. Transformer 1 had exceeded the rating of 500kVA while transformer 2 still operated within the limit. It means that transformer 2 can still function normally even all houses had charge EV on same time.

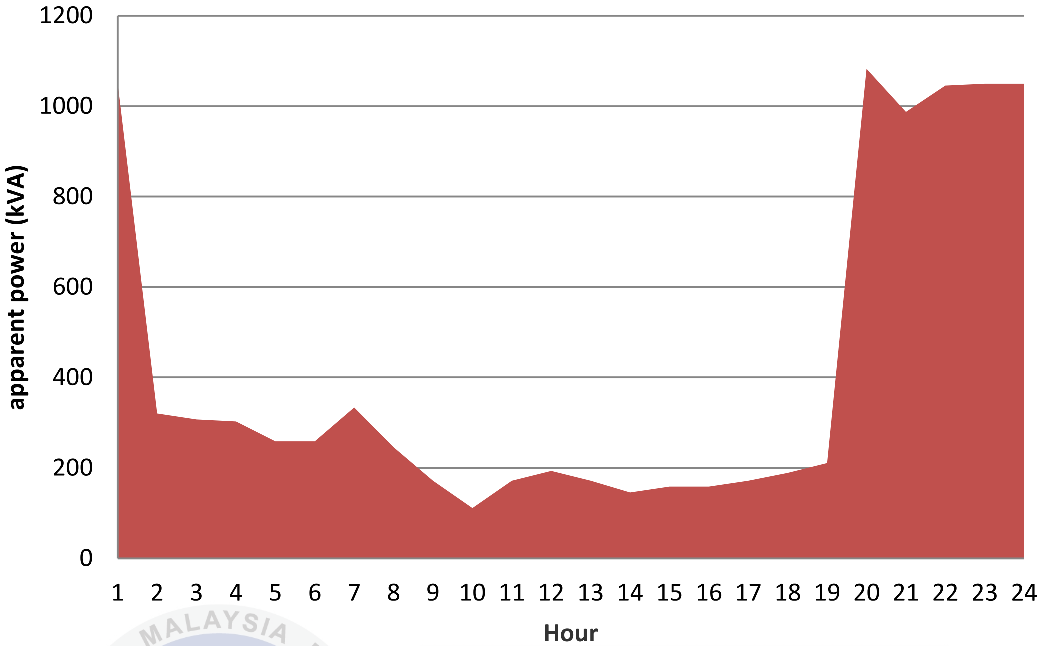

Figure 4.25: Power for transformer 1 in case 2 for peak time

The peak power drawn by transformer 2 was slightly higher than 500kVA but less than 550kVA. Since transformer 2 had rating of 750kVA, it can operate safely with full penetration.

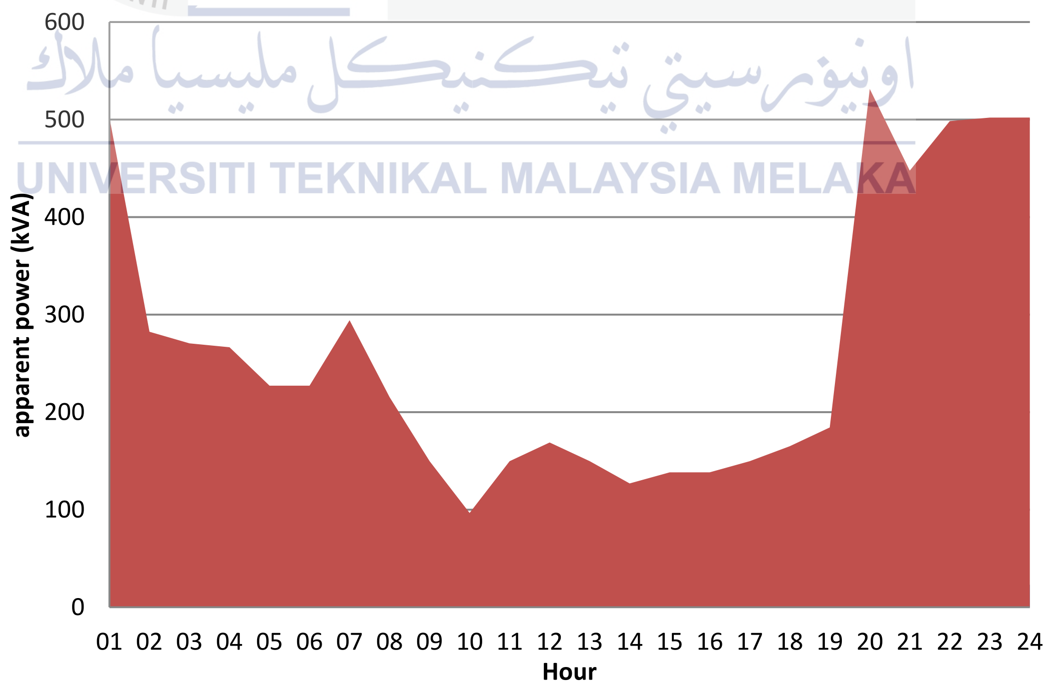

Figure 4.26: Power for transformer 2 in case 2 for peak time

The pattern for transformer 1 was similar with the current graph. The maximum power drawn was about 850kVA which was much higher than the rating of transformer 1 with value of 500kVA.

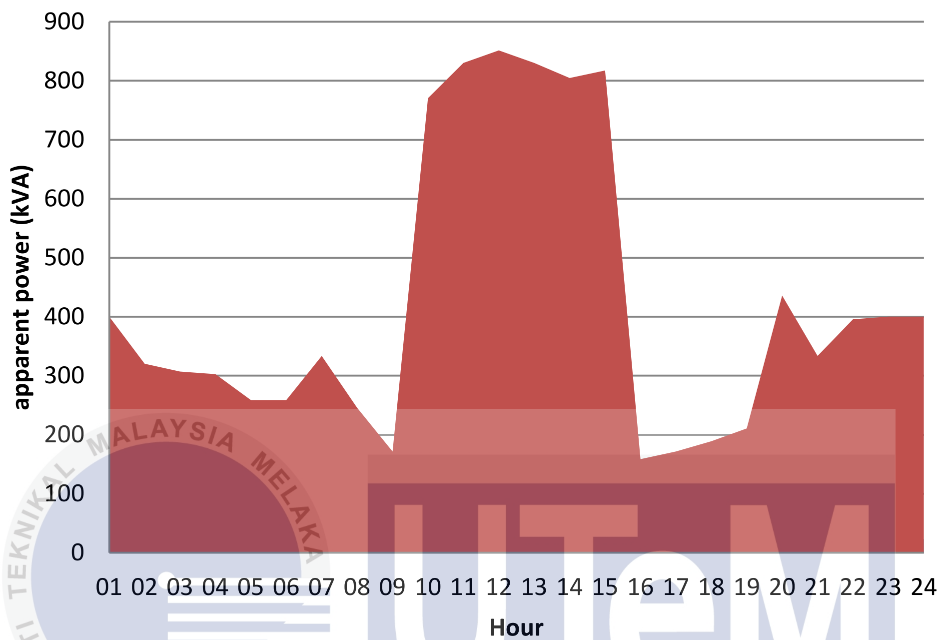

Figure 4.27: Power for transformer 1 in case 2 for off peak time

The residential peak demand for transformer 2 was even higher than the peak demand used for charging EV. It means that the transformer 2 had spared a lot of loading and would not overload easily. However, peak time and off peak time still plotting different pattern of graph. The peak demand hour for off peak time had been changed to afternoon which usually should be off peak time.

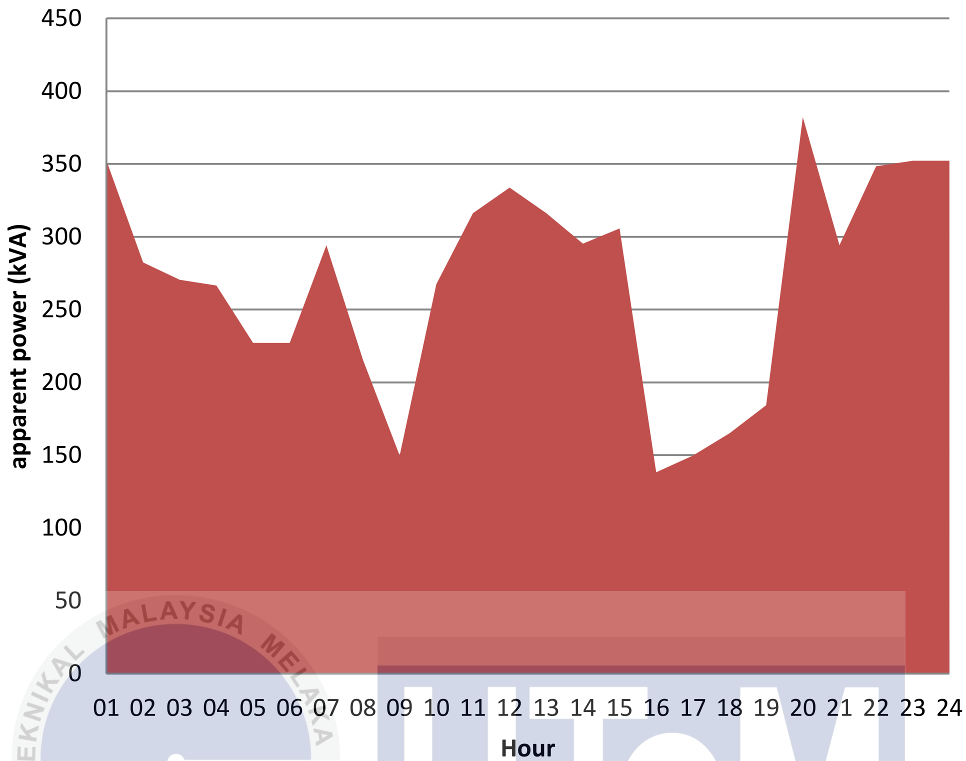

Figure 4.28: Power for transformer 2 in case 2 for off peak time

As shown in graph below, only feeder B and D can withstand full penetration of EV. Feeder A can withstand about 50%, feeder E can withstand more than 10% and feeder B can withstand for 5%. Besides that, feeder F and G cannot withstand any EV because both feeders had quite high voltage drop even without any extra load.

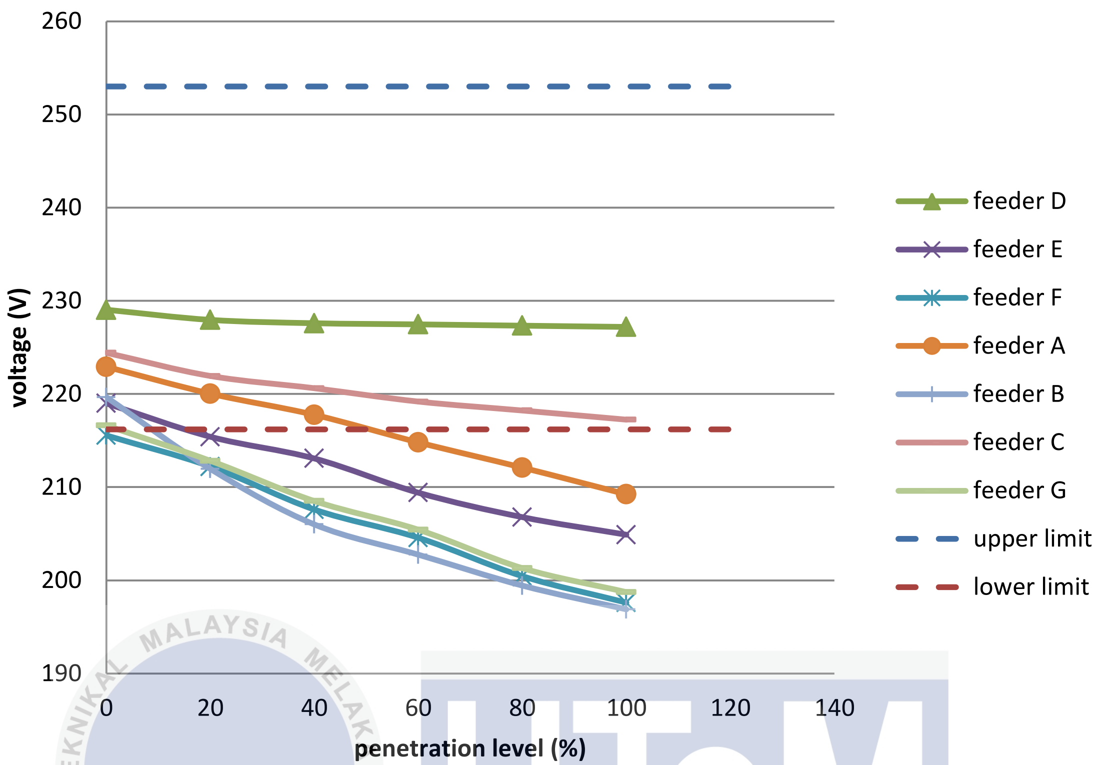

Figure 4.29: Voltage drop for case 2 during peak time

In terms of thermal limit, no feeder in this case can withstand full penetration. Feeder C and D can withstand 80% penetration. Feeder F and G can withstand 60% penetration and the remaining feeders, A, B and C can only withstand 40% of penetration. In other meaning, 40% penetration of EV can be accepted by whole network if only considering cable thermal limit.

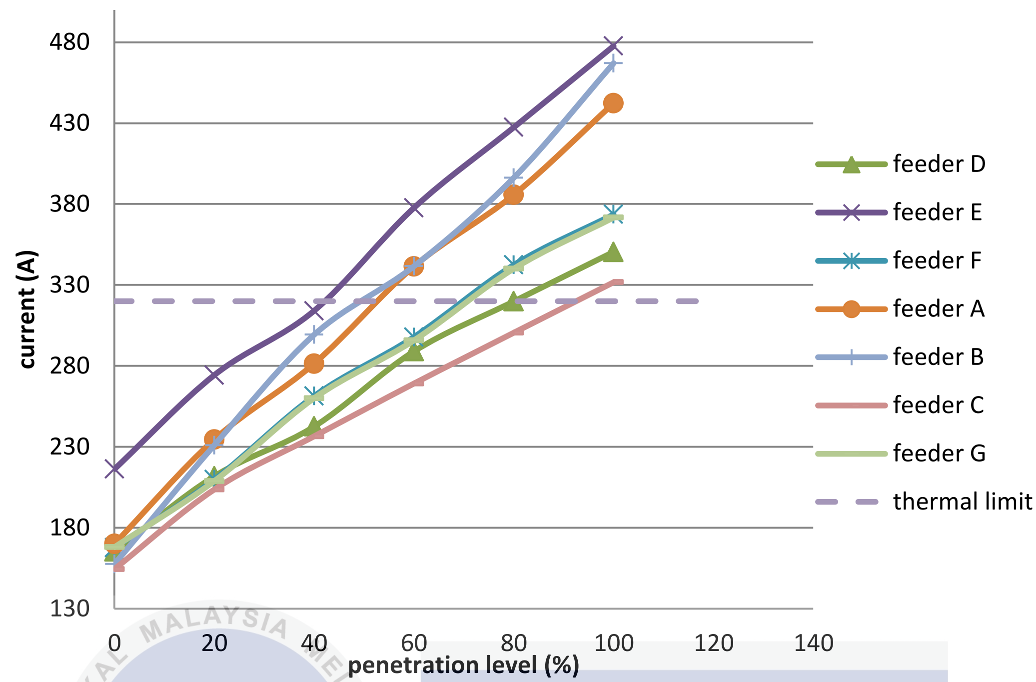

Figure 4.30: Thermal loading for case 2 during peak time

Besides that, transformer 1 can only withstand about 10% penetration of EV while transformer 2 can operate normally even fully penetrated.

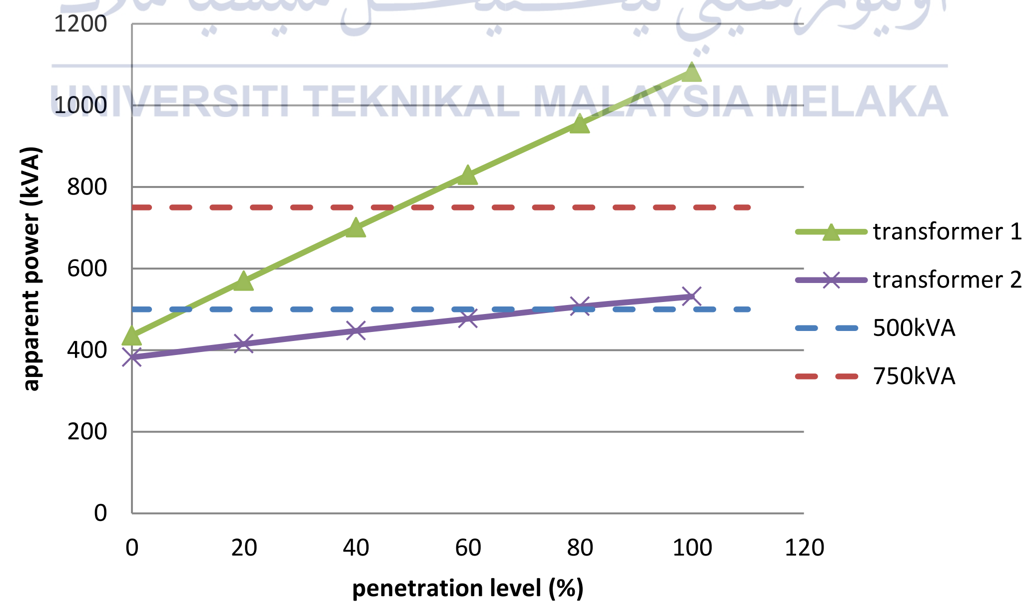

Figure 4.31: Transformer loading for case 2 during peak

Off peak hour charging was the only case which did not charging during the peak demand time. Feeder C and D can withstand 100% penetration and feeder A can loaded up to 80% EV penetration. Feeder E can withstand 50% penetration and feeder B can only withstand 20%. Feeder F and G did not have any spare for EV penetration.

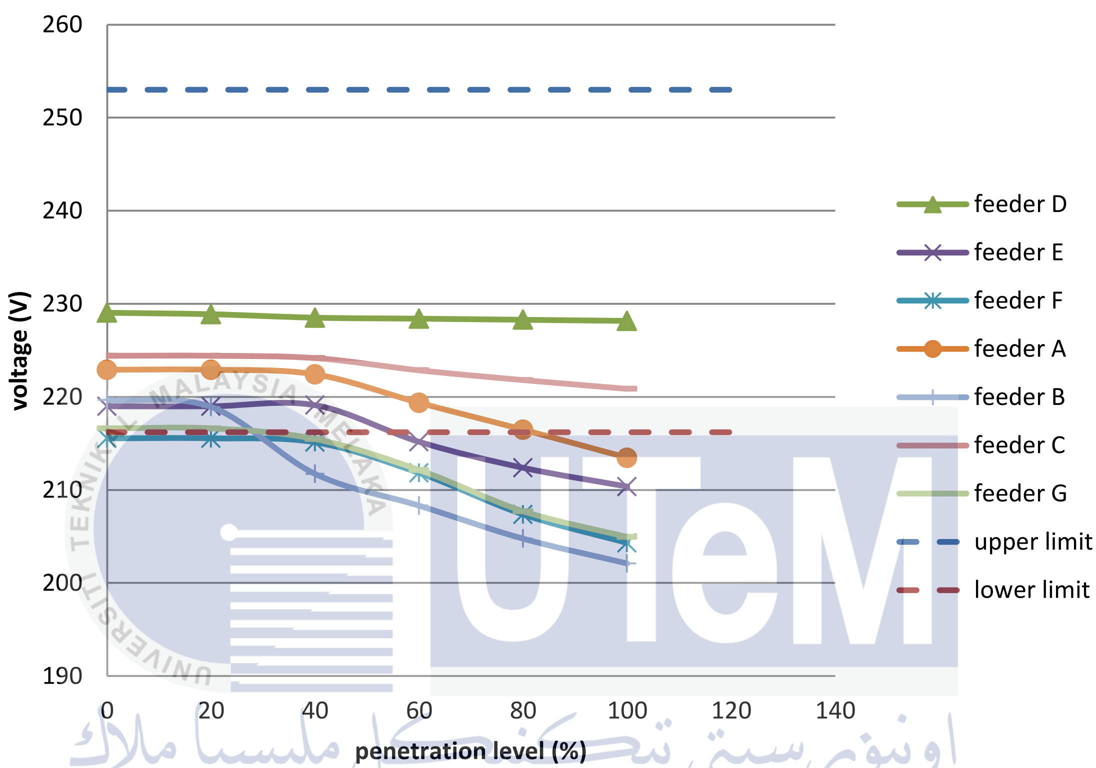

Figure 4.32: Voltage drop for case 2 during off peak time

Feeders B, C, D, and G can supply 100% penetration of EV without overload of any cable. It means cable can withstand the current flow when those feeders charging EV in all houses at the same time. Feeder E and F can withstand 70% penetration while feeder A can supply for 80% penetration.

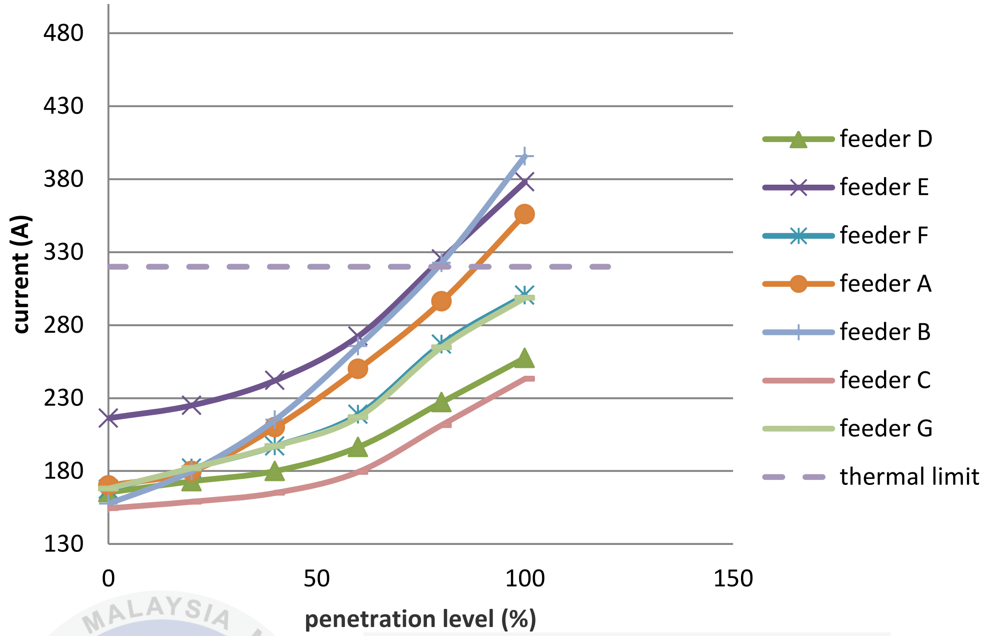

Figure 4.33: Thermal loading for case 2 during off peak time

Power used for charging EV on transformer 2 less than normal residential peak demand, so that highest power used for transformer 2 during full penetration was same with the case without any EV. Transformer 1 rating would not be exceeded for up to 40% penetration.

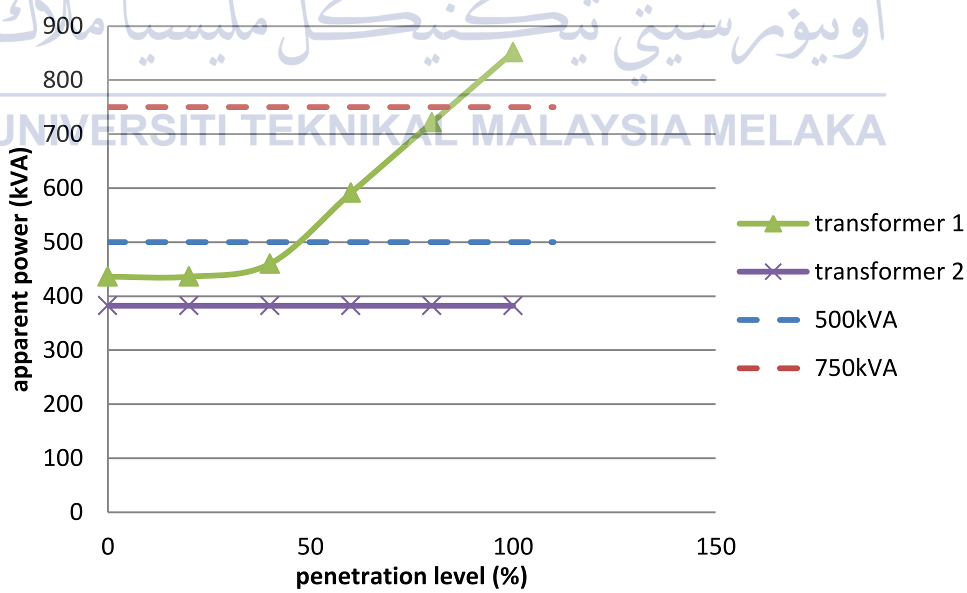

Figure 4.34: Transformer loading for case 2 during off peak time

4.3 Case 3: controlled unbalanced charging

Graphs for case 3e which was fully penetrated were shown below. Different penetration would not bring significant changes to load pattern since most feeder was almost fully loaded. For controlled charging, the load pattern had changed. Minimum voltage at 7pm for uncontrolled charging had changed to 10pm in controlled charging case.

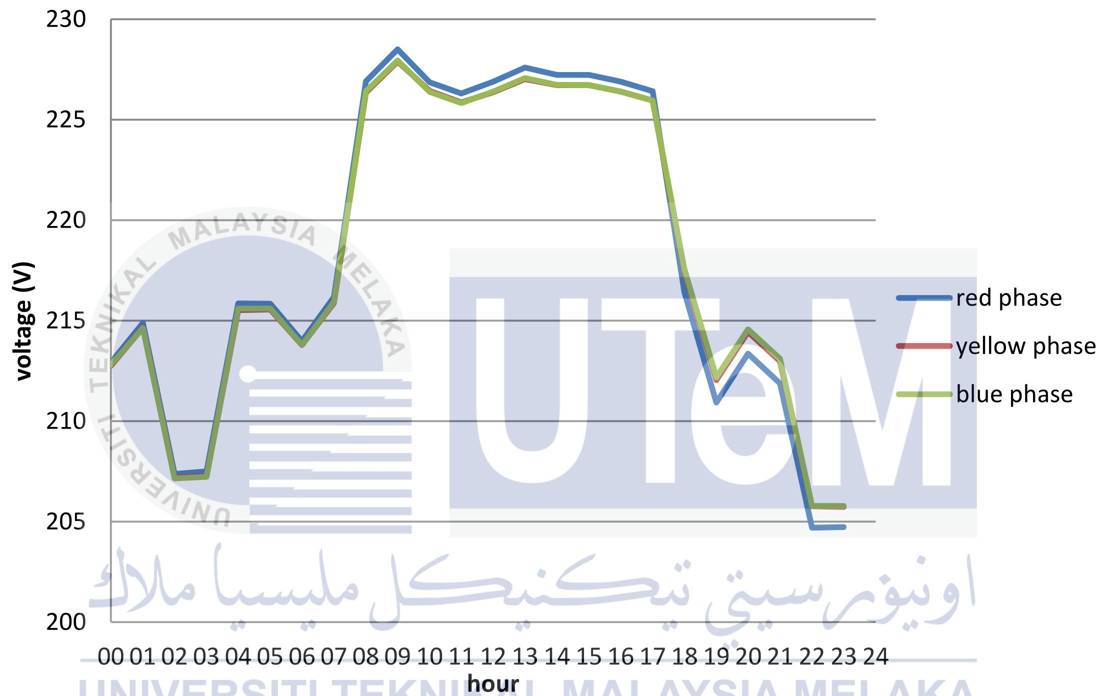

Figure 4.35: Voltage for feeder B in case 3

The three phase feeder still faced the problem of red phase unbalanced. The largest voltage drop for feeder G was fell on red phase.

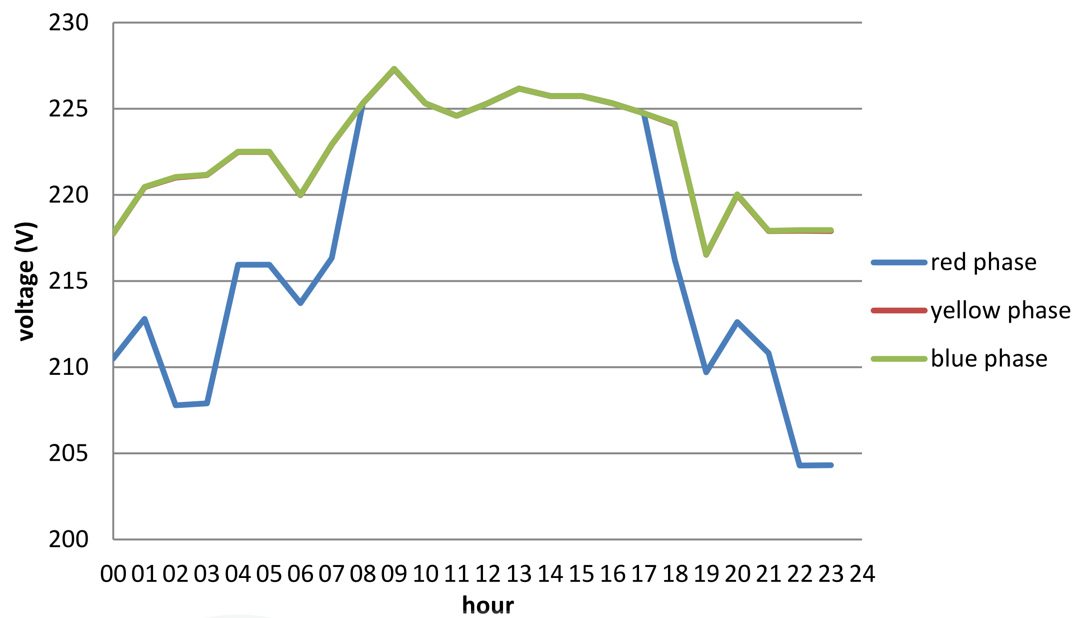

Figure 4.36: Voltage for feeder G in case 3

As the minimum voltage occur at 10pm, the maximum current drawn also changed to 10pm. Feeder D which connecting thirty six terrace houses had equal load for each phase, thus it gave a balance current graph.

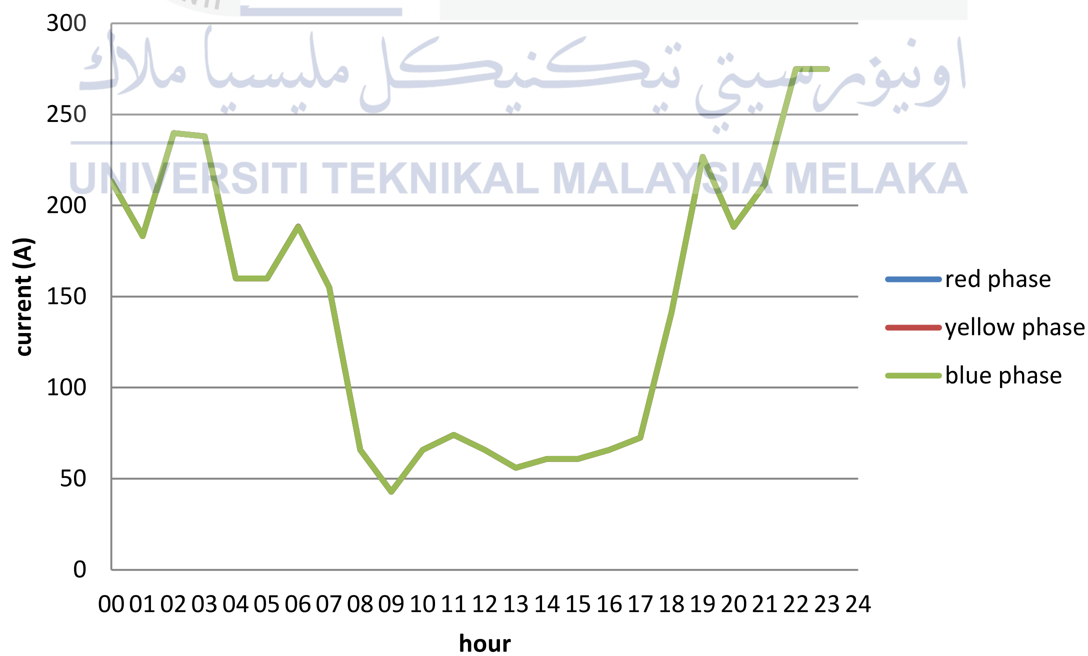

Figure 4.37: Current for feeder D in case 3

The maximum current drawn was about 400A which exceeded the thermal limit of 320A. The current drawn by red phase was higher compared to other two phases since red phase was used to charge EV.

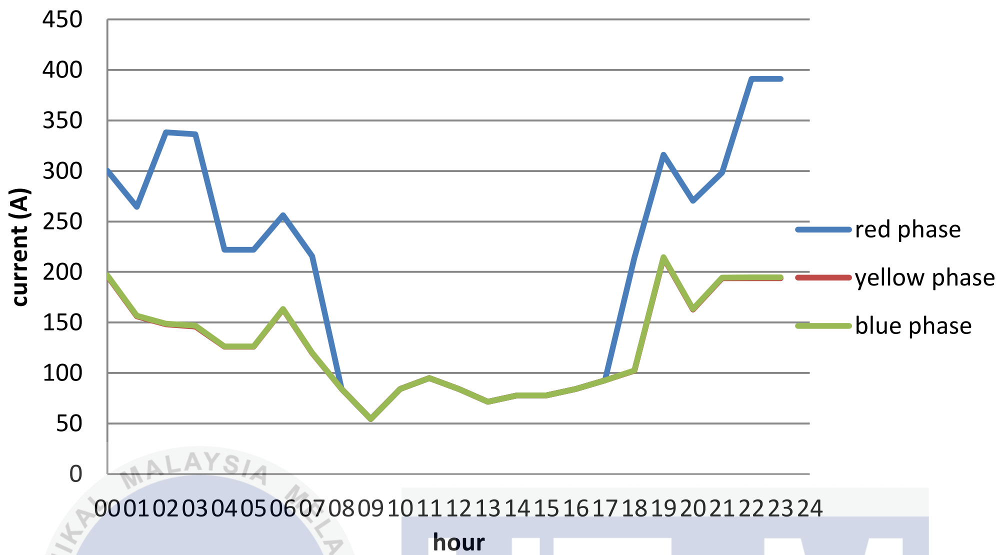

Figure 4.38: Current for feeder E in case 3

The pattern for transformer loading had changed and differed from the usual residential load pattern. The highest power of more than 450kVA was drawn during 10pm because there are two patterns overlapped during 10pm and the normal residential load demand was high.

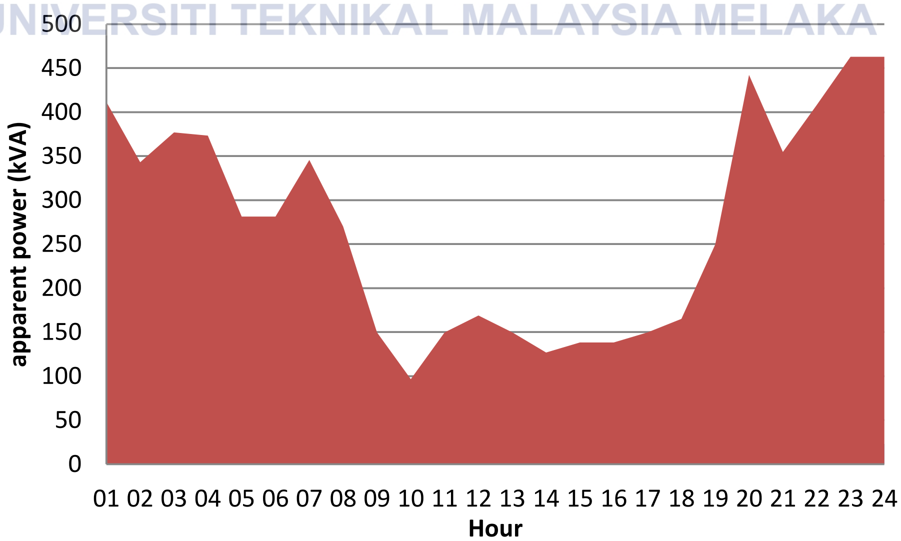

Figure 4.39: Power for transformer 2 in case 3

Similar with the previous case, feeder C and D can withstand full penetration of EV. Feeder A can withstand more than 70% and feeder E can withstand more than 30% penetration. Feeder B can withstand for about 10% penetration while feeders F and G cannot withstand any EV.

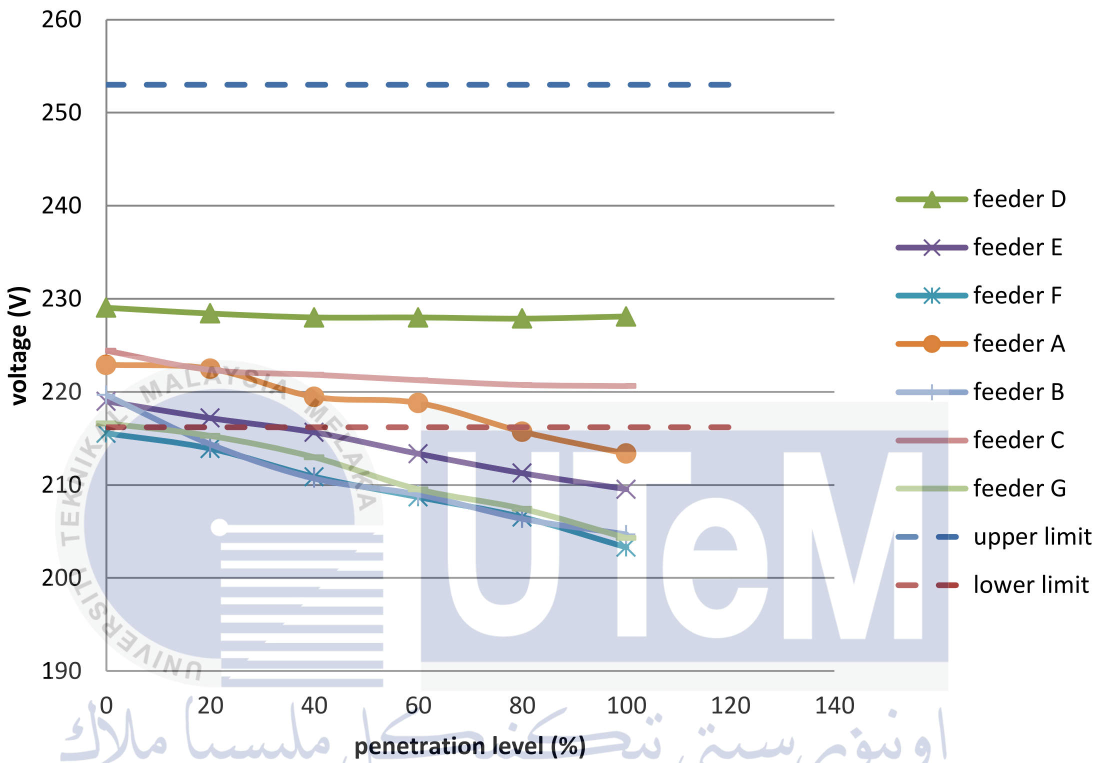

Figure 4.40: Voltage drop in case 3

Feeders C, D, F and G can supply 100% penetration of EV without violating thermal limit of cable. It means cable will not damage even all houses on those feeders charging EV at the same time. Feeder A and B can withstand 80% penetration while feeder E can supply for 60% penetration.

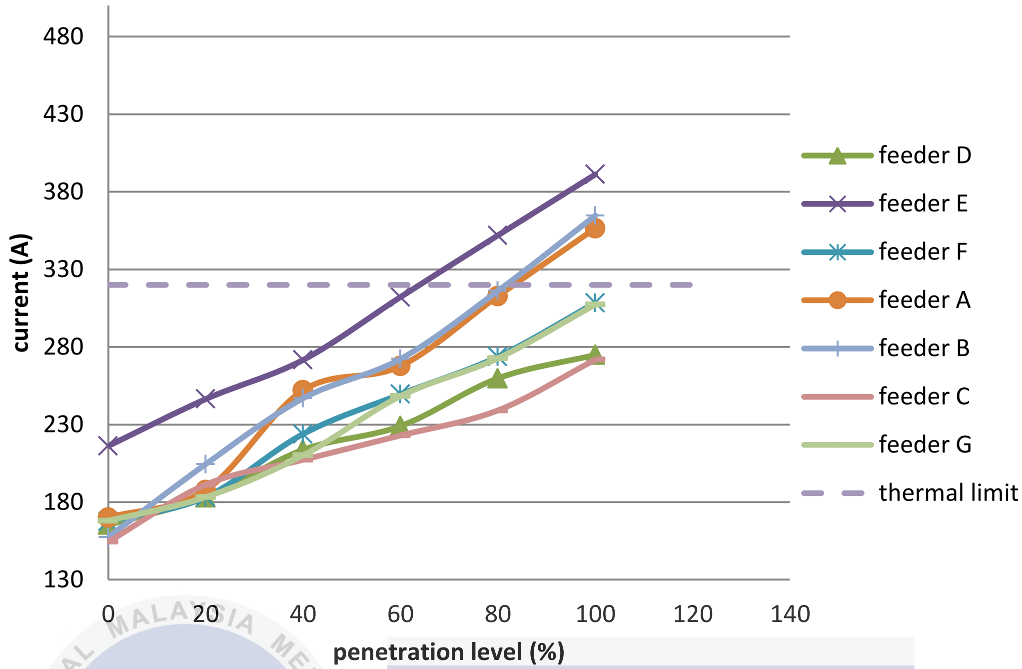

Figure 4.41: Thermal loading in case 3

Transformer 2 even did not reach 500kVA which is rating for transformer 1 while transformer 1 was overloaded for more than 20% penetration.

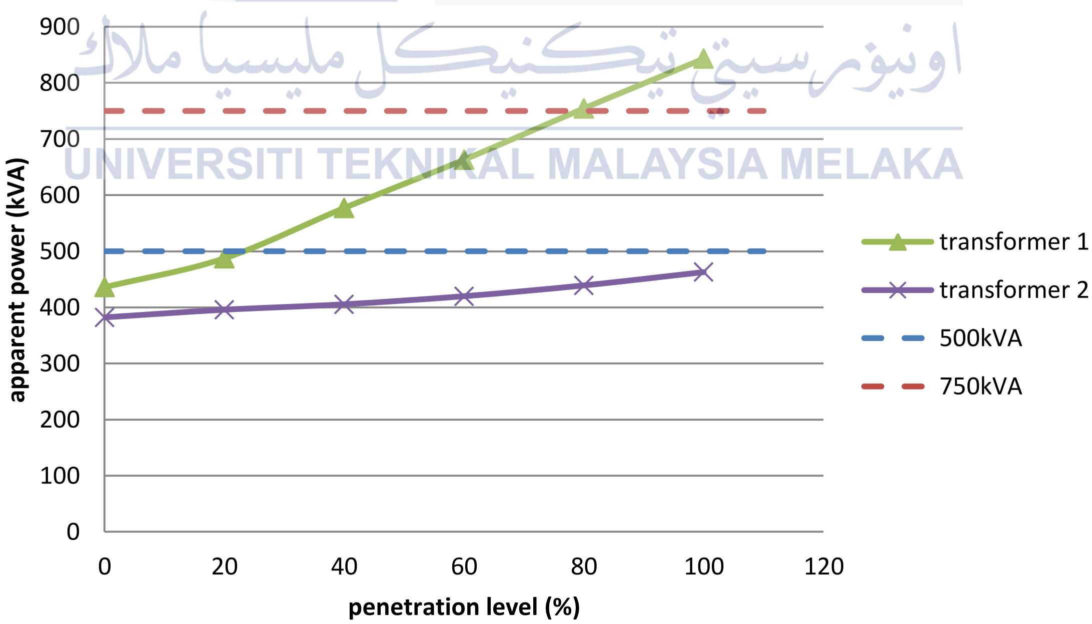

Figure 4.42: Transformer loading in case 3

4.4 Case 4: uncontrolled balanced charging

Case 4e was done for fully penetrating the residential area by EV. The minimum voltage had been increased when compared to case 2 which was unbalance case. Figure 4.34 and 4.35 showed nearly balance voltage and current graph. There was only a tiny difference among three phases during the EV charging time after distributing EV evenly.

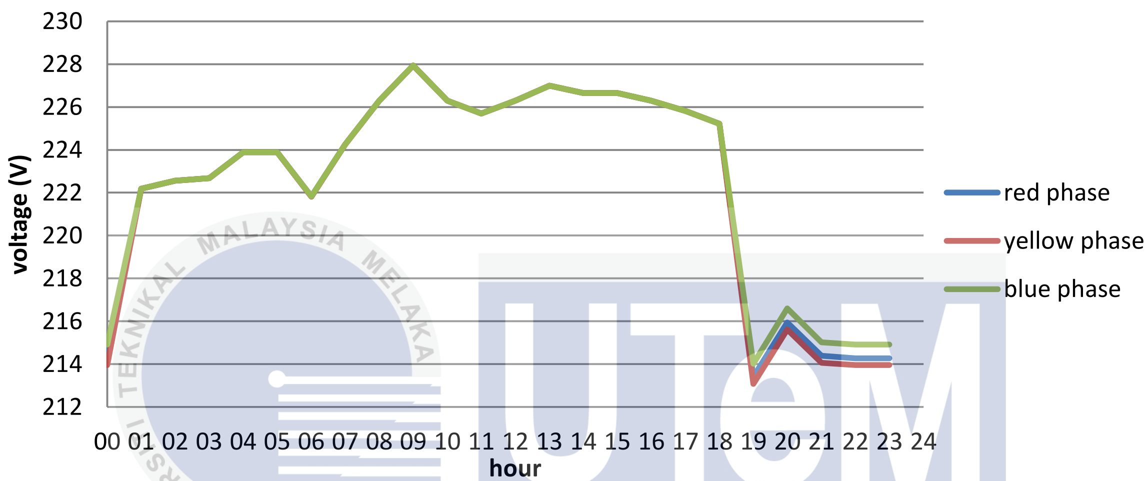

Figure 4.43: Voltage for feeder E in case 4

Feeder E had drawn current for about 320A during the peak load demand. The issue of huge difference between red phase and other two phases had been alleviated.

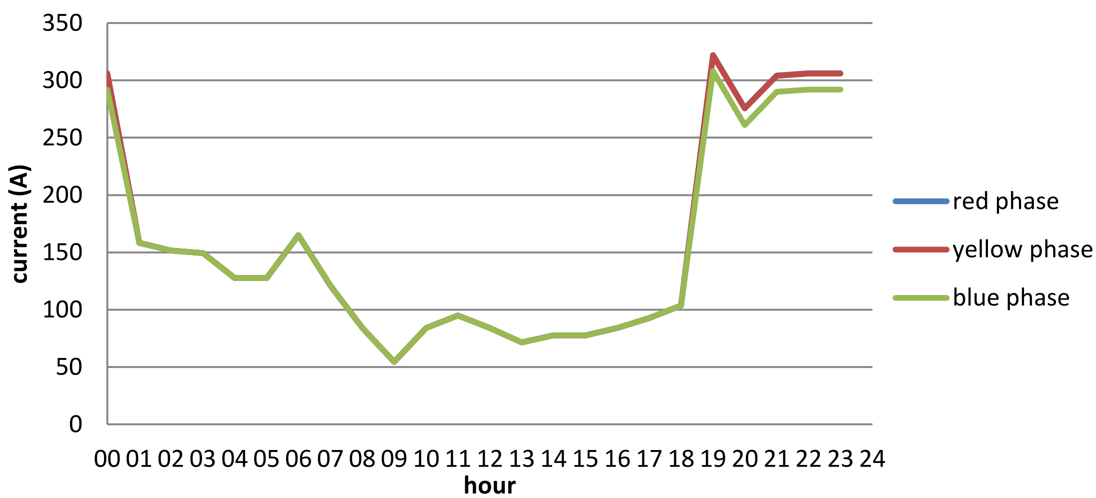

Figure 4.44: Current for feeder E in case 4

Feeders C and D can withstand 100% penetration in this case. Feeder A and E can withstand 40% penetration of EV while the other three feeders were difficult to withstand even 10 % penetration of EV.

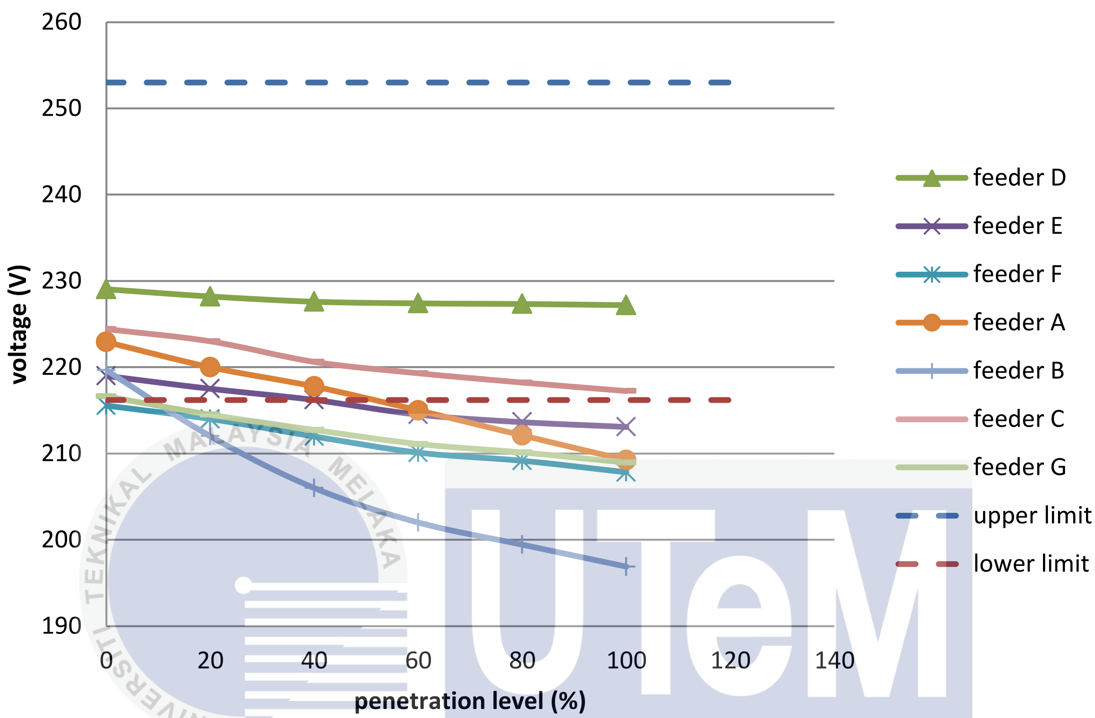

Figure 4.45: Voltage drop in case 4

Feeder F and G can withstand 100% penetration, while feeder C and E can withstand 90% penetration. Feeder D can withstand 80% and feeder A can withstand 50% penetration. The remaining feeder B can only withstand 40% penetration of EV.

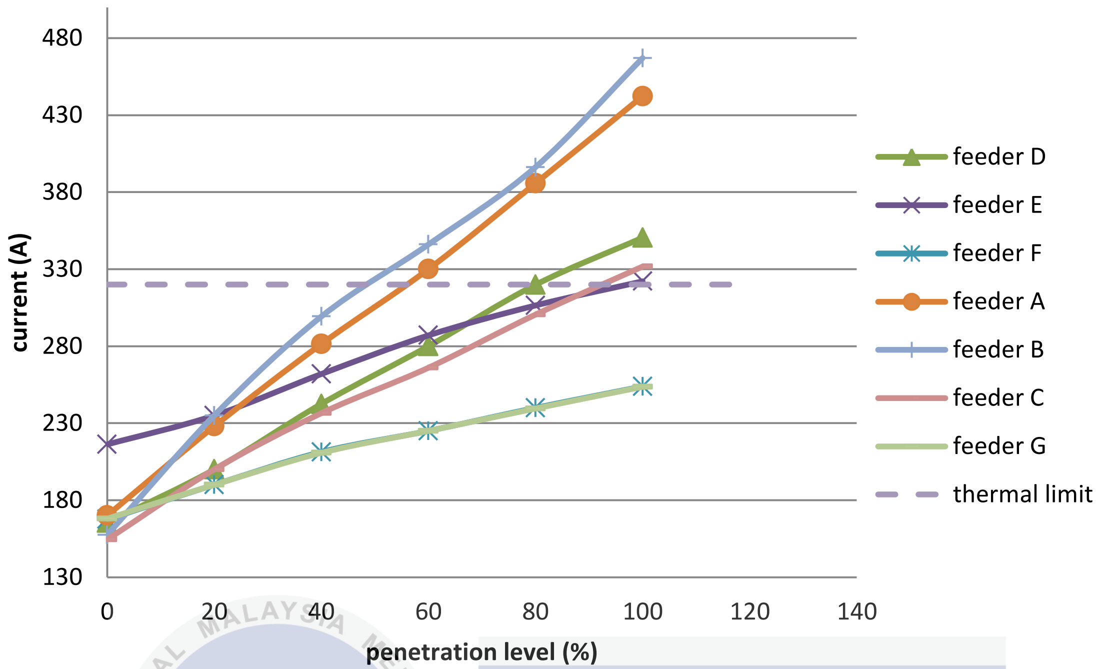

Figure 4.46: Thermal loading in case 4

Transformer 2 still can loaded for full penetration of EV while transformer 1 only can supply about 10% EV penetration.

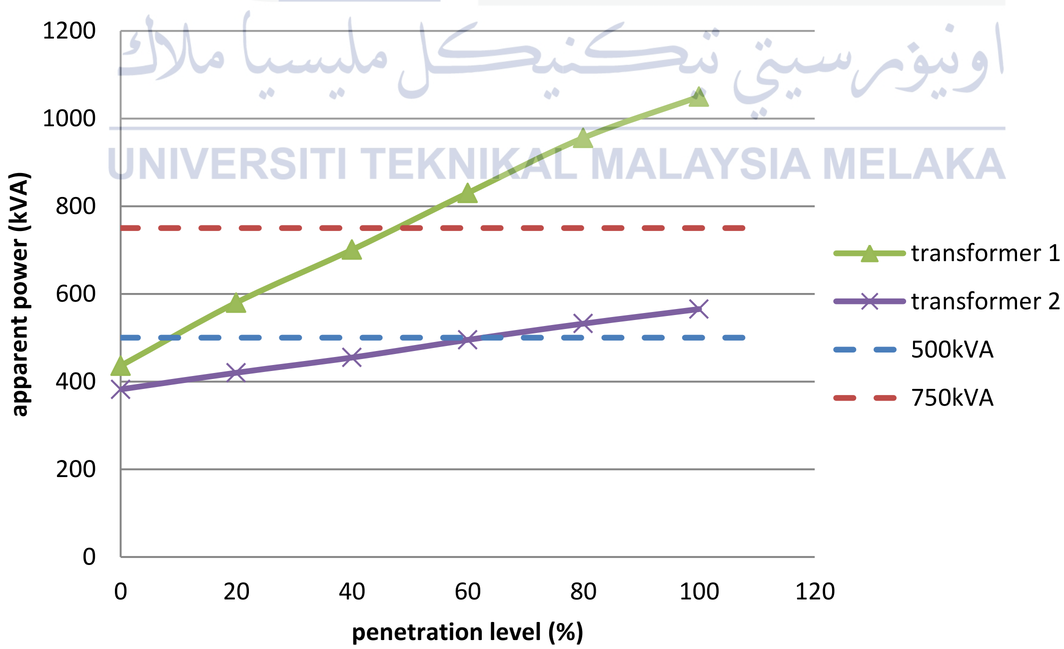

Figure 4.47: Transformer loading in case 4

4.5 Case 5: controlled balanced charging

Both graphs shown below were simulated by considering 100% penetration. For balanced charging case, the EV charging through feeder E, F and G were distributed equally into three phases. The unbalance for three phase feeder was eliminated. The overall pattern was same with the case 3. The only change was no more significant unbalance for three phase houses, feeder E, F and G.

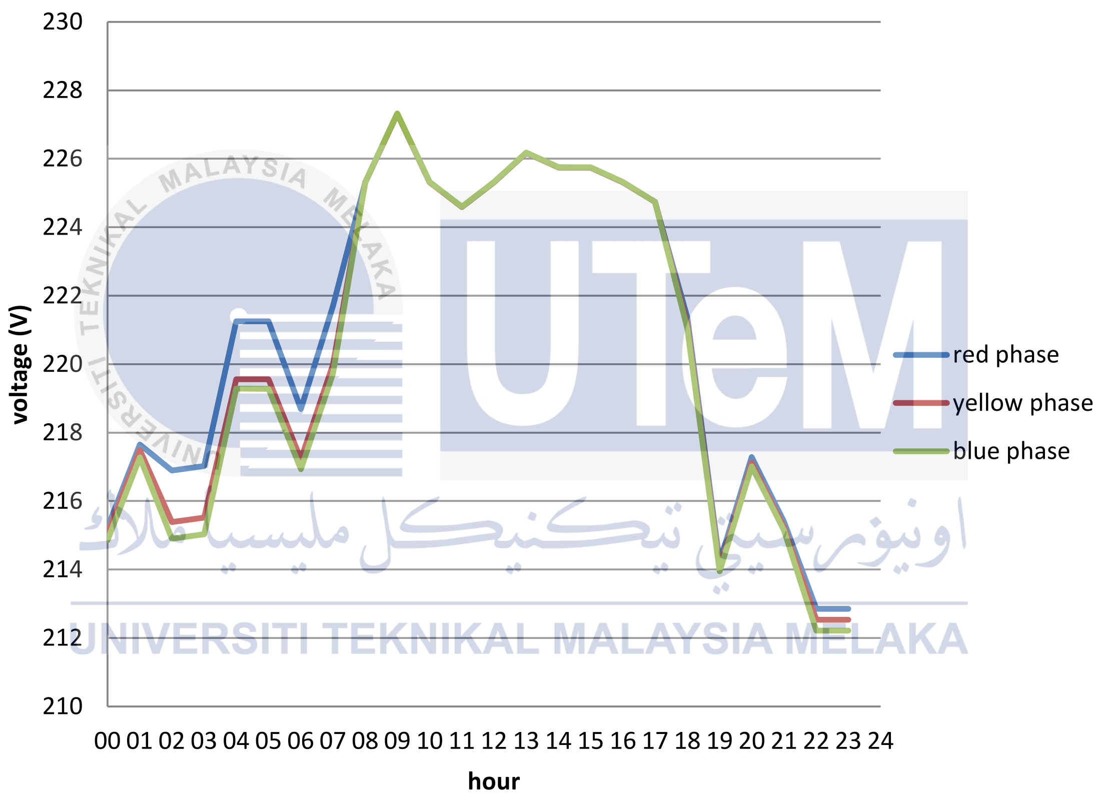

Figure 4.48: Voltage for feeder G in case 5

Feeder F in case 5 had drawn a maximum current of about 220A which can be easily withstand by the existing cable. 10pm was an overlapping point between period 1 and period 2 which means both period charge on that hour, thus lead to maximum current.

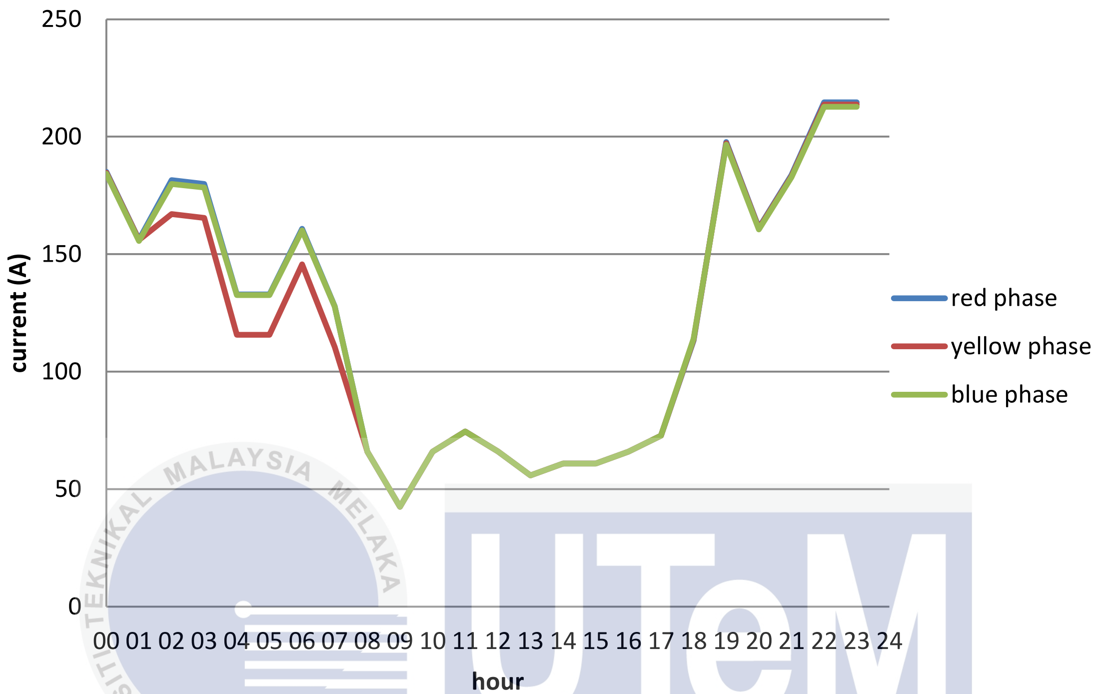

Figure 4.49: Current for feeder F in case 5

Feeder C and D can supply for full EV penetration without violating voltage drop limit. Feeder A and E can withstand for 40% penetration. Remaining feeders B, E and F were unable to supply for even 10% penetration.

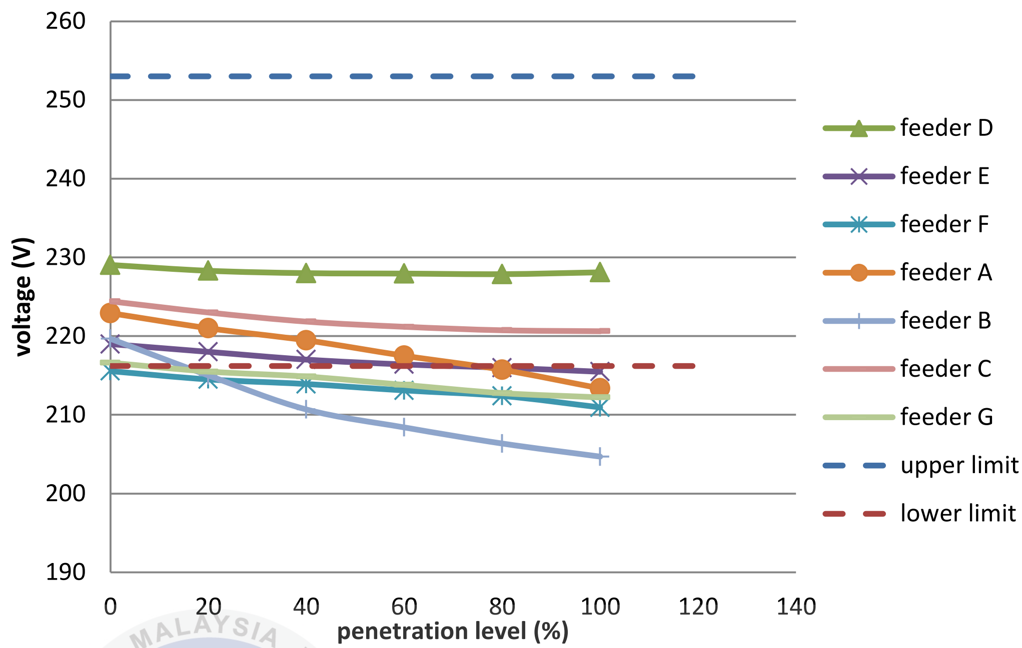

Figure 4.50: Voltage drop in case 5

Feeder C, D, E, F and G can sustained up to 100 % penetration of EV while feeder A and B can withstand for 80% penetration.

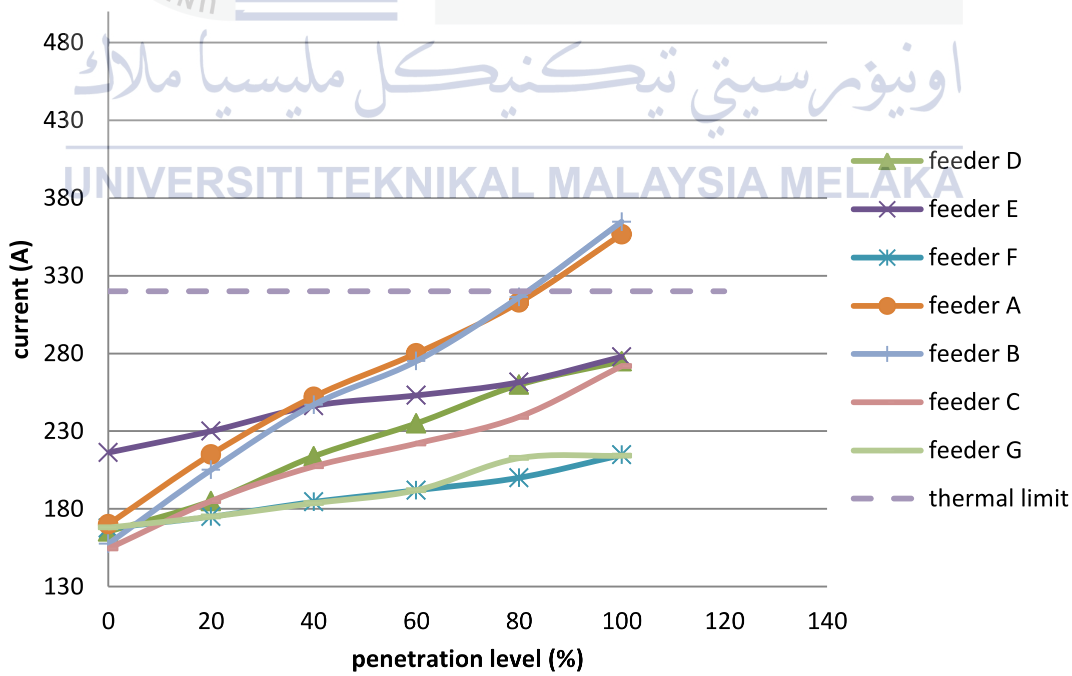

Figure 4.51: Thermal loading in case 5

Transformer 1 can only supply for about 10% EV penetration without overloading, while transformer 2 can easily withstand the supply of all houses charging EV within feeders E, F and G.

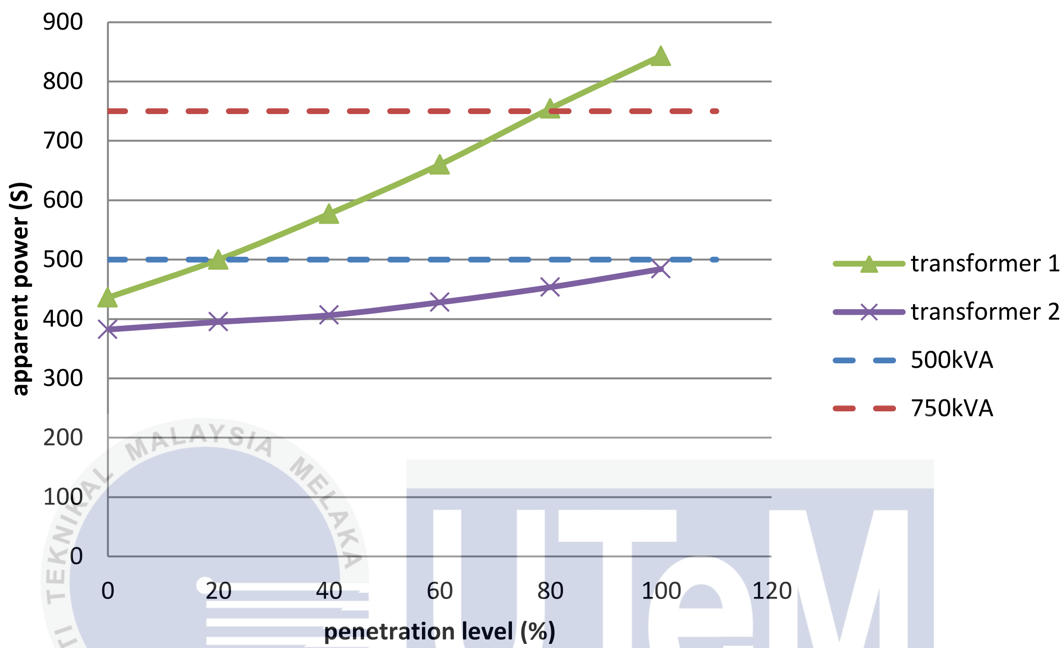

Figure 4.52: Transformer loading in case 5

4.6 Energy Losses for All Cases

The energy losses were obtained from simulation by placing energy meter at transformer side. The energy consumed and energy losses, both with unit of kWh were sum for transformer 1 and transformer 2. After that, total energy losses were divided with total energy consumed and then multiply by 100%. Energy losses percentage for five cases was computed into one single graph as shown below. Unbalanced charging without controlled method gave the highest losses, while balanced charging with controlled method was the best case by giving lowest energy losses percentage.

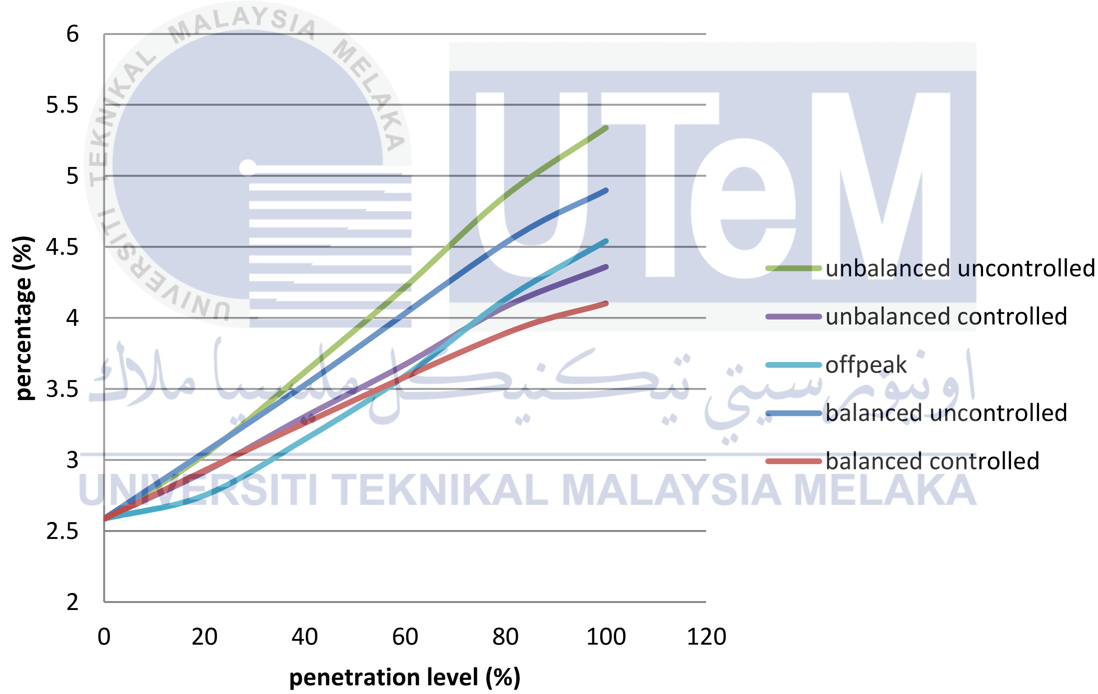

Figure 4.53: Energy losses for all cases

Not all graphs were included in chapter 4. Part of the remaining graphs was attached as appendix C.

CHAPTER 5

CONCLUSION

EV is needed to preserve the environment. Gas pollution can be reduced by introducing and implementing 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 would 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 OpenDSS. Controlled charging would be a method to reduce the impacts and it was investigated by simulation.

EV was used in many countries such as British, Ireland, Denmark, United States, Malaysia and China for the eco-friendly propulsion. In Malaysia, EV was newly introduced and Nissan Leaf was launched in market. However, there 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 affected 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. Before simulation for five cases, a preliminary simulation based on IEEE 30 buses case was done. After considering all situations, five main cases had been fixed which was case 1 until case 5. Case 1 until case 5 would be the cases for either controlled or not controlled and also balanced or unbalanced. Simulation for all cases had been done based on five penetration levels. After obtaining all the graphical data, all results were analyzed 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 seven feeders in all cases had been plotted and those graphs had been computed based on penetration level. By considering cable thermal limit, 40% was safe for case 2 peak and 70% was safe for case 2 off peak. While case 3 would be safe with 60% penetration and 40% was safe for case 4. In addition, the highest penetration level can be implemented was 80% in case 5. With a controlled and balanced charging, the load demand can be divided evenly to reduce the power drawn at particular time. Case 2 peak and case 4 were safe for 10% penetration while 20% was safe for case 3 and case 5 which were controlled. Moreover, the off peak charging was recorded highest penetration level with 40% without transformer overloading. However, all cases cannot afford EV penetration when considering voltage drop since in case 1, some of the feeders had reached the lower limit.

After implementing the controlled charging mode, the penetration level can be withstand by grid was increased. However, the full penetration level still cannot be withstood by only applying controlled charging method. 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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APPENDICES

APPENDIX A

All sub coding was placed in same folder with main coding. When open main coding using OpenDSS, simulator will run Master.DSS for 100 iterations in maximum. Voltages and powers were shown in text file. In the Master.DSS, coding for line, transformer, load, capacitor and generator was redirected. Redirecting was used in OpenDSS because there are limit of coding in a file.

<u>Main coding</u>

```
// Standard IEEE 30-Bus Transmission System Test Case
Compile Master.DSS
! The compile builds the circuit model and sets the voltage bases
! sometimes this model needs more than the default 15 iterations
Set maxiterations=100
! This command solves the base case power flow
Solve
show voltage    ! sequence voltage magnitudes
show voltage  LN Nodes   ! Detailed
show power   ! sequence powers
show power MVA elem   ! show powers in MVA, element by element
```


<u>Master.DSS</u>

```
Clear   ! always have this as the first line before defining a new circuit
New Circuit.IEEE_30
! Define a really stiff 132 kV source for the slack bus
! (continue editing the VSOURCE object created by the New Circuit command)
```

~ BasekV=132 Bus1=B1   pu=1.06 MVASC3=5000000 5000000

! Define the circuit elements

Redirect Lines.DSS

Redirect Transformers.DSS

Redirect Loads.DSS

Redirect Capacitors.DSS

Redirect Generators.DSS

! Let the openDSS estimate the voltage bases

Set Voltagebases=[132, 33, 11, 1]   ! legal bases for this problem

Calcvoltagebases

<u>Capacitors.DSS</u>

! Shunt Capacitor definitions

New Capacitor.B10 Bus1=B10 kV= 33 kvar=19000

New Capacitor.B24 Bus1=B24 kV= 33 kvar=4300

<u>Generators.DSS</u>

! Generator Definitions

New Generator.B2 Bus1=B2 kV= 132 kW=40000 Model=3 Vpu=1.045 Maxkvar=50000 Minkvar=-40000 ! kvar=50000

! The following buses just have a voltage target and kvar limits defined.

! The kW value is defined as zero, but this is illegal in the OpenDSS Generator model

! So we just put a small value (1 kW) here and use model 3 to regulate the bus.

New Generator.B5 Bus1=B5 kV= 132 kW=1   Model=3 Vpu=1.01 Maxkvar=40000 Minkvar=-40000 ! kvar=37000

New Generator.B8 Bus1=B8 kV= 132 kW=1   Model=3 Vpu=1.01 Maxkvar=40000 Minkvar=-10000 ! kvar=37300

New Generator.B11 Bus1=B11 kV= 11 kW=1   Model=3 Vpu=1.082 Maxkvar=24000 Minkvar=-6000 ! kvar=16200

New Generator.B13 Bus1=B13 kV= 11 kW=1   Model=3 Vpu=1.071 Maxkvar=24000 Minkvar=-6000 ! kvar=10600

Lines.DSS

! Note, the line data are given in pu. The per unit values are converted to ohms using 100 MVA base and the voltage base of the first bus

! No capacitance was defined for the 33 and 11 kv lines.

```
New line.1-2   Bus1=B1  Bus2=B2  R1=3.345408  X1=10.0188   R0=10.036224 X0=30.0564
C1=803.793907242183 C0=267.931302414061 Length=1

New line.1-3   Bus1=B1  Bus2=B3  R1=7.875648  X1=28.784448 R0=23.626944
X0=86.353344  C1=621.113473778051 C0=207.037824592684 Length=1

New line.2-4   Bus1=B2  Bus2=B4  R1=9.93168   X1=30.265488 R0=29.79504
X0=90.796464  C1=560.219995956673 C0=186.739998652224 Length=1

New line.3-4   Bus1=B3  Bus2=B4  R1=2.299968  X1=6.603696  R0=6.899904
X0=19.811088  C1=127.876303424893 C0=42.6254344749642 Length=1

New line.2-5   Bus1=B2  Bus2=B5  R1=8.224128  X1=34.551792 R0=24.672384
X0=103.655376 C1=636.336843233395 C0=212.112281077798 Length=1

New line.2-6   Bus1=B2  Bus2=B6  R1=10.123344 X1=30.718512 R0=30.370032
X0=92.155536  C1=569.35401762988  C0=189.784672543293 Length=1

New line.4-6   Bus1=B4  Bus2=B6  R1=2.073456  X1=7.213536  R0=6.220368
X0=21.640608  C1=137.010325098099 C0=45.6701083660331 Length=1

New line.5-7   Bus1=B5  Bus2=B7  R1=8.01504   X1=20.21184  R0=24.04512  X0=60.63552
C1=310.556736889025 C0=103.518912296342 Length=1

New line.6-7   Bus1=B6  Bus2=B7  R1=4.652208  X1=14.28768  R0=13.956624
X0=42.86304   C1=258.797280740854 C0=86.2657602469515 Length=1

New line.6-8   Bus1=B6  Bus2=B8  R1=2.09088   X1=7.31808   R0=6.27264   X0=21.95424
C1=137.010325098099 C0=45.6701083660331 Length=1

New line.12-14 Bus1=B12 Bus2=B14 R1=1.340559  X1=2.786751  R0=4.021677
X0=8.360253   C1=0            C0=0            Length=1

New line.12-15 Bus1=B12 Bus2=B15 R1=0.720918  X1=1.420056  R0=2.162754
X0=4.260168   C1=0            C0=0            Length=1

New line.12-16 Bus1=B12 Bus2=B16 R1=1.029105  X1=2.163843  R0=3.087315
X0=6.491529   C1=0            C0=0            Length=1

New line.14-15 Bus1=B14 Bus2=B15 R1=2.40669   X1=2.174733  R0=7.22007
X0=6.524199   C1=0            C0=0            Length=1

New line.16-17 Bus1=B16 Bus2=B17 R1=0.570636  X1=2.094147  R0=1.711908
X0=6.282441   C1=0            C0=0            Length=1

New line.15-18 Bus1=B15 Bus2=B18 R1=1.168497  X1=2.379465  R0=3.505491
X0=7.138395   C1=0            C0=0            Length=1
```

New line.18-19 Bus1=B18 Bus2=B19 R1=0.695871 X1=1.406988 R0=2.087613 X0=4.220964 C1=0 C0=0 Length=1

New line.19-20 Bus1=B19 Bus2=B20 R1=0.37026 X1=0.74052 R0=1.11078 X0=2.22156 C1=0 C0=0 Length=1

New line.10-20 Bus1=B10 Bus2=B20 R1=1.019304 X1=2.27601 R0=3.057912 X0=6.82803 C1=0 C0=0 Length=1

New line.10-17 Bus1=B10 Bus2=B17 R1=0.352836 X1=0.920205 R0=1.058508 X0=2.760615 C1=0 C0=0 Length=1

New line.10-21 Bus1=B10 Bus2=B21 R1=0.378972 X1=0.815661 R0=1.136916 X0=2.446983 C1=0 C0=0 Length=1
New line.10-22 Bus1=B10 Bus2=B22 R1=0.791703 X1=1.632411 R0=2.375109 X0=4.897233 C1=0 C0=0 Length=1
New line.21-22 Bus1=B21 Bus2=B22 R1=0.126324 X1=0.257004 R0=0.378972 X0=0.771012 C1=0 C0=0 Length=1
New line.15-23 Bus1=B15 Bus2=B23 R1=1.089 X1=2.19978 R0=3.267 X0=6.59934 C1=0 C0=0 Length=1
New line.22-24 Bus1=B22 Bus2=B24 R1=1.25235 X1=1.94931 R0=3.75705 X0=5.84793 C1=0 C0=0 Length=1
New line.23-24 Bus1=B23 Bus2=B24 R1=1.43748 X1=2.9403 R0=4.31244 X0=8.8209 C1=0 C0=0 Length=1
New line.24-25 Bus1=B24 Bus2=B25 R1=2.052765 X1=3.584988 R0=6.158295 X0=10.754964 C1=0 C0=0 Length=1
New line.25-26 Bus1=B25 Bus2=B26 R1=2.770416 X1=4.1382 R0=8.311248 X0=12.4146 C1=0 C0=0 Length=1
New line.25-27 Bus1=B25 Bus2=B27 R1=1.190277 X1=2.272743 R0=3.570831 X0=6.818229 C1=0 C0=0 Length=1
New line.27-29 Bus1=B27 Bus2=B29 R1=2.393622 X1=4.522617 R0=7.180866 X0=13.567851 C1=0 C0=0 Length=1
New line.27-30 Bus1=B27 Bus2=B30 R1=3.486978 X1=6.563403 R0=10.460934 X0=19.690209 C1=0 C0=0 Length=1
New line.29-30 Bus1=B29 Bus2=B30 R1=2.612511 X1=4.936437 R0=7.837533 X0=14.809311 C1=0 C0=0 Length=1
New line.8-28 Bus1=B8 Bus2=B28 R1=11.081664 X1=34.848 R0=33.244992 X0=104.544 C1=651.560212688739 C0=217.186737562913 Length=1
New line.6-28 Bus1=B6 Bus2=B28 R1=2.944656 X1=10.436976 R0=8.833968 X0=31.310928 C1=197.903802919477 C0=65.9679343064923 Length=1

<u>Load.DSS</u>
New Load.B2 Bus1=B2 kV=132 kW=21700 kvar=12700 vminpu=0.9 vmaxpu=1.10
New Load.B3 Bus1=B3 kV=132 kW=2400 kvar=1200 vminpu=0.9 vmaxpu=1.10
New Load.B4 Bus1=B4 kV=132 kW=7600 kvar=1600 vminpu=0.9 vmaxpu=1.10
New Load.B5 Bus1=B5 kV=132 kW=94200 kvar=19000 vminpu=0.9 vmaxpu=1.10
New Load.B7 Bus1=B7 kV=132 kW=22800 kvar=10900 vminpu=0.9 vmaxpu=1.10
New Load.B8 Bus1=B8 kV=132 kW=30000 kvar=30000 vminpu=0.9 vmaxpu=1.10
New Load.B10 Bus1=B10 kV=33 kW=5800 kvar=2000 vminpu=0.9 vmaxpu=1.10

```
New Load.B12 Bus1=B12 kV=33  kW=11200 kvar=7500  vminpu=0.9 vmaxpu=1.10
New Load.B14 Bus1=B14 kV=33  kW=6200  kvar=1600  vminpu=0.9 vmaxpu=1.10
New Load.B15 Bus1=B15 kV=33  kW=8200  kvar=2500  vminpu=0.9 vmaxpu=1.10
New Load.B16 Bus1=B16 kV=33  kW=3500  kvar=1800  vminpu=0.9 vmaxpu=1.10
New Load.B17 Bus1=B17 kV=33  kW=9000  kvar=5800  vminpu=0.9 vmaxpu=1.10
New Load.B18 Bus1=B18 kV=33  kW=3200  kvar=900   vminpu=0.9 vmaxpu=1.10
New Load.B19 Bus1=B19 kV=33  kW=9500  kvar=3400  vminpu=0.9 vmaxpu=1.10
New Load.B20 Bus1=B20 kV=33  kW=2200  kvar=700   vminpu=0.9 vmaxpu=1.10
New Load.B21 Bus1=B21 kV=33  kW=17500 kvar=11200 vminpu=0.9 vmaxpu=1.10
New Load.B23 Bus1=B23 kV=33  kW=3200  kvar=1600  vminpu=0.9 vmaxpu=1.10
New Load.B24 Bus1=B24 kV=33  kW=8700  kvar=6700  vminpu=0.9 vmaxpu=1.10
New Load.B26 Bus1=B26 kV=33  kW=3500  kvar=2300  vminpu=0.9 vmaxpu=1.10
New Load.B29 Bus1=B29 kV=33  kW=2400  kvar=900   vminpu=0.9 vmaxpu=1.10
New Load.B30 Bus1=B30 kV=33  kW=10600 kvar=1900  vminpu=0.9 vmaxpu=1.10
```

Transformer.DSS

```
! Transformer definitions
New Transformer.6-9 kVAs=[100000 100000] XHL=20.8 PPM=0
~ Wdg=1 R=0 kV=132 Bus=B6 Tap=0.978
~ Wdg=2 R=0 kV=1 Bus=B9
~ %loadloss=0
New Transformer.6-10 kVAs=[100000 100000] XHL=55.6 PPM=0
~ Wdg=1 R=0 kV=132 Bus=B6 Tap=0.969
~ Wdg=2 R=0 kV=33 Bus=B10
~ %loadloss=0
New Transformer.9-11 kVAs=[100000 100000] XHL=20.8 PPM=0
~ Wdg=1 R=0 kV=1 Bus=B9 Tap=1
~ Wdg=2 R=0 kV=11 Bus=B11
~ %loadloss=0
New Transformer.9-10 kVAs=[100000 100000] XHL=11 PPM=0
~ Wdg=1 R=0 kV=1 Bus=B9 Tap=1
~ Wdg=2 R=0 kV=33 Bus=B10
~ %loadloss=0
New Transformer.4-12 kVAs=[100000 100000] XHL=25.6 PPM=0
~ Wdg=1 R=0 kV=132 Bus=B4 Tap=0.932
~ Wdg=2 R=0 kV=33 Bus=B12
~ %loadloss=0
New Transformer.12-13 kVAs=[100000 100000] XHL=14 PPM=0
~ Wdg=1 R=0 kV=33 Bus=B12 Tap=1
~ Wdg=2 R=0 kV=11 Bus=B13
~ %loadloss=0
New Transformer.28-27 kVAs=[100000 100000] XHL=39.6 PPM=0
~ Wdg=1 R=0 kV=132 Bus=B28 Tap=0.968
~ Wdg=2 R=0 kV=33 Bus=B27
~ %loadloss=0
```

APPENDIX B

The coding under Case 1 was the main coding for case 1. The main coding will redirect the coding for each feeder and also the EV load if available. All house load and EV load for each feeder was separated in different text files. After simulating, the result of voltage, power, current and energy in csv file will be created in same folder with main coding.

Case 1

```
Clear
set datapath=C:\Users\PigPig\Desktop\EV\timeseriesload
new circuit.LV basekv=11 pu=1.0 angle=0 frequency=50 phases=3
new transformer.T1  windings=2  buses=(Sourcebus, busbar1.1.2.3.4)  conns=(delta, wye)  kvs=(11, 0.4)
kvas=(500, 500) %loadloss=0 xhl=0.001
new transformer.T2  windings=2  buses=(Sourcebus, busbar2.1.2.3.4)  conns=(delta, wye)  kvs=(11, 0.4)
kvas=(750, 750) %loadloss=0 xhl=0.001
new linecode.500mm-4  nphases=4 R1=0.0366   X1=0.1679 R0=0.10595 X0=0.65681 units=km
new linecode.500mm-7 nphases=4 R1=0.0366   X1=0.1679 R0=0.10595 X0=0.65681 units=km
new linecode.185mm     nphases=4 R1=0.16404 X1=0.0665 R0=0.74388 X0=0.44864 units=km
new linecode.16mm-2    nphases=2 R1=1.91       X1=0.0664 R0=2.86387 X0=1.64887 units=km
new linecode.16mm-4  nphases=4 R1=1.91       X1=0.0664 R0=2.86387 X0=1.64887 units=km
new loadshape.demand npts=24 interval=1.0 csvfile=residential.txt action=normalize
redirect feederA.txt
redirect feederB.txt
redirect feederC.txt
redirect feederD.txt
redirect feederE.txt
redirect feederF.txt
redirect feederG.txt
new monitor.HEAD1_POWER element=transformer.T1   terminal=2 mode=1 ppolar=no
new monitor.HEAD2_POWER element=transformer.T2   terminal=2 mode=1 ppolar=no
new monitor.HEADa_IV          element=line.pillarA-AA  terminal=1 mode=0
new monitor.HEADb_IV          element=line.pillarB-BA  terminal=1 mode=0
new monitor.HEADc_IV          element=line.pillarC-CA  terminal=1 mode=0
new monitor.HEADd_IV          element=line.pillarD-DA  terminal=1 mode=0
new monitor.HEADe_IV          element=line.pillarE-EA  terminal=1 mode=0
new monitor.HEADf_IV          element=line.pillarF-FA  terminal=1 mode=0
new monitor.HEADg_IV          element=line.pillarG-GA  terminal=1 mode=0
new monitor.ENDa_IV          element=line.pillarA-AR terminal=2 mode=0
new monitor.ENDb_IV          element=line.pillarB-BV  terminal=2 mode=0
new monitor.ENDc_IV          element=line.pillarC-CK  terminal=2 mode=0
new monitor.ENDd_IV          element=line.pillarD-DL  terminal=2 mode=0
new monitor.ENDe_IV          element=line.pillarE-ET  terminal=2 mode=0
new monitor.ENDf_IV          element=line.pillarF-FQ  terminal=2 mode=0
new monitor.ENDg_IV          element=line.pillarG-GQ  terminal=2 mode=0
new energymeter.METER1      element=transformer.T1   terminal=1
```

```
new energymeter.METER2      element=transformer.T2   terminal=1
set controlmode=TIME
set mode=daily stepsize=1h number=24
set voltagebases=[11 0.4]
calcvoltagebases
solve
export monitors HEAD1_POWER
export monitors HEAD2_POWER
export monitors HEADa_IV
export monitors HEADb_IV
export monitors HEADc_IV
export monitors HEADd_IV
export monitors HEADe_IV
export monitors HEADf_IV
export monitors HEADg_IV
export monitors ENDa_IV
export monitors ENDb_IV
export monitors ENDc_IV
export monitors ENDd_IV
export monitors ENDe_IV
export monitors ENDf_IV
export monitors ENDg_IV
export meters
```

feederA.txt

```
new line.T1-pillarA    bus1=busbar1.1.2.3.4  bus2=pillarA.1.2.3.4  length=0.01   phases=4  units=km
linecode=500mm-4

new line.pillarA-AA   bus1=pillarA.1.2.3.4  bus2=AA.1.2.3.4   length=0.12  phases=4  units=km
linecode=185mm

new line.pillarA-AB   bus1=AA.1.2.3.4   bus2=AB.1.2.3.4   length=0.02  phases=4  units=km
linecode=185mm

new line.pillarA-AC   bus1=AB.1.2.3.4   bus2=AC.1.2.3.4   length=0.02  phases=4  units=km
linecode=185mm

new line.pillarA-AD   bus1=AC.1.2.3.4   bus2=AD.1.2.3.4   length=0.03  phases=4  units=km
linecode=185mm

new line.pillarA-AE   bus1=AD.1.2.3.4   bus2=AE.1.2.3.4   length=0.02  phases=4  units=km
linecode=185mm

new line.pillarA-AF   bus1=AE.1.2.3.4   bus2=AF.1.2.3.4   length=0.02  phases=4  units=km
linecode=185mm

new line.pillarA-AG   bus1=AF.1.2.3.4   bus2=AG.1.2.3.4   length=0.03  phases=4  units=km
linecode=185mm

new line.pillarA-AH   bus1=AG.1.2.3.4   bus2=AH.1.2.3.4   length=0.02  phases=4  units=km
linecode=185mm

new line.pillarA-AI   bus1=AH.1.2.3.4   bus2=AI.1.2.3.4   length=0.02  phases=4  units=km
linecode=185mm
```

new line.pillarA-AJ bus1=AI.1.2.3.4 bus2=AJ.1.2.3.4 length=0.03 phases=4 units=km linecode=185mm

new line.pillarA-AK bus1=AJ.1.2.3.4 bus2=AK.1.2.3.4 length=0.02 phases=4 units=km linecode=185mm

new line.pillarA-AL bus1=AK.1.2.3.4 bus2=AL.1.2.3.4 length=0.02 phases=4 units=km linecode=185mm

new line.pillarA-AM bus1=AL.1.2.3.4 bus2=AM.1.2.3.4 length=0.02 phases=4 units=km linecode=185mm

new line.pillarA-AN bus1=AM.1.2.3.4 bus2=AN.1.2.3.4 length=0.02 phases=4 units=km linecode=185mm

new line.pillarA-AO bus1=AN.1.2.3.4 bus2=AO.1.2.3.4 length=0.02 phases=4 units=km linecode=185mm

new line.pillarA-AP bus1=AJ.1.2.3.4 bus2=AP.1.2.3.4 length=0.05 phases=4 units=km linecode=185mm

new line.pillarA-AQ bus1=AP.1.2.3.4 bus2=AQ.1.2.3.4 length=0.02 phases=4 units=km linecode=185mm

new line.pillarA-AR bus1=AQ.1.2.3.4 bus2=AR.1.2.3.4 length=0.03 phases=4 units=km linecode=185mm

new line.AA-AA1 bus1=AA.1.4 bus2=AA1.1.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.AA-AA2 bus1=AA.2.4 bus2=AA2.2.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.AA-AA3 bus1=AA.3.4 bus2=AA3.3.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.AB-AB1 bus1=AB.1.4 bus2=AB1.1.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.AB-AB2 bus1=AB.2.4 bus2=AB2.2.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.AB-AB3 bus1=AB.3.4 bus2=AB3.3.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.AC-AC1 bus1=AC.1.4 bus2=AC1.1.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.AC-AC2 bus1=AC.2.4 bus2=AC2.2.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.AC-AC3 bus1=AC.3.4 bus2=AC3.3.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.AD-AD1 bus1=AD.1.4 bus2=AD1.1.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.AD-AD2 bus1=AD.2.4 bus2=AD2.2.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.AD-AD3 bus1=AD.3.4 bus2=AD3.3.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.AE-AE1 bus1=AE.1.4 bus2=AE1.1.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.AE-AE2 bus1=AE.2.4 bus2=AE2.2.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.AE-AE3 bus1=AE.3.4 bus2=AE3.3.4 length=0.01 phases=2 units=km linecode=16mm-2

```
new line.AF-AF1    bus1=AF.1.4    bus2=AF1.1.4     length=0.01 phases=2 units=km linecode=16mm-2
new line.AF-AF2    bus1=AF.2.4    bus2=AF2.2.4     length=0.01 phases=2 units=km linecode=16mm-2
new line.AF-AF3    bus1=AF.3.4    bus2=AF3.3.4     length=0.01 phases=2 units=km linecode=16mm-2
new line.AG-AG1    bus1=AG.1.4    bus2=AG1.1.4     length=0.01 phases=2 units=km linecode=16mm-2
new line.AG-AG2    bus1=AG.2.4    bus2=AG2.2.4     length=0.01 phases=2 units=km linecode=16mm-2
new line.AG-AG3    bus1=AG.3.4    bus2=AG3.3.4     length=0.01 phases=2 units=km linecode=16mm-2
new line.AH-AH1    bus1=AH.1.4    bus2=AH1.1.4     length=0.01 phases=2 units=km linecode=16mm-2
new line.AH-AH2    bus1=AH.2.4    bus2=AH2.2.4     length=0.01 phases=2 units=km linecode=16mm-2
new line.AH-AH3    bus1=AH.3.4    bus2=AH3.3.4     length=0.01 phases=2 units=km linecode=16mm-2
new line.AI-AI1    bus1=AI.1.4    bus2=AI1.1.4     length=0.01 phases=2 units=km linecode=16mm-2
new line.AI-AI2    bus1=AI.2.4    bus2=AI2.2.4     length=0.01 phases=2 units=km linecode=16mm-2
new line.AI-AI3    bus1=AI.3.4    bus2=AI3.3.4     length=0.01 phases=2 units=km linecode=16mm-2
new line.AJ-AJ1    bus1=AJ.1.4    bus2=AJ1.1.4     length=0.01 phases=2 units=km linecode=16mm-2
new line.AJ-AJ2    bus1=AJ.2.4    bus2=AJ2.2.4     length=0.01 phases=2 units=km linecode=16mm-2
new line.AJ-AJ3    bus1=AJ.3.4    bus2=AJ3.3.4     length=0.01   phases=2 units=km linecode=16mm-2
new line.AK-AK1    bus1=AK.1.4    bus2=AK1.1.4     length=0.01 phases=2 units=km linecode=16mm-2
new line.AK-AK2    bus1=AK.2.4    bus2=AK2.2.4     length=0.01 phases=2 units=km linecode=16mm-2
new line.AK-AK3    bus1=AK.3.4    bus2=AK3.3.4     length=0.01 phases=2 units=km linecode=16mm-2
new line.AL-AL1    bus1=AL.1.4    bus2=AL1.1.4     length=0.01 phases=2 units=km linecode=16mm-2
new line.AL-AL2    bus1=AL.2.4    bus2=AL2.2.4     length=0.01 phases=2 units=km linecode=16mm-2
new line.AL-AL3    bus1=AL.3.4    bus2=AL3.3.4     length=0.01 phases=2 units=km linecode=16mm-2
new line.AM-AM1    bus1=AM.1.4    bus2=AM1.1.4     length=0.01 phases=2 units=km linecode=16mm-2
new line.AM-AM2    bus1=AM.2.4    bus2=AM2.2.4     length=0.01 phases=2 units=km linecode=16mm-2
new line.AM-AM3    bus1=AM.3.4    bus2=AM3.3.4     length=0.01 phases=2 units=km linecode=16mm-2
new line.AN-AN1    bus1=AN.1.4    bus2=AN1.1.4     length=0.01 phases=2 units=km linecode=16mm-2
new line.AN-AN2    bus1=AN.2.4    bus2=AN2.2.4     length=0.01 phases=2 units=km linecode=16mm-2
new line.AN-AN3    bus1=AN.3.4    bus2=AN3.3.4     length=0.01 phases=2 units=km linecode=16mm-2
new line.AO-AO1    bus1=AO.1.4    bus2=AO1.1.4     length=0.01 phases=2 units=km linecode=16mm-2
new line.AO-AO2    bus1=AO.2.4    bus2=AO2.2.4     length=0.01 phases=2 units=km linecode=16mm-2
new line.AO-AO3    bus1=AO.3.4    bus2=AO3.3.4     length=0.01 phases=2 units=km linecode=16mm-2
```

```
new line.AP-AP1   bus1=AP.1.4   bus2=AP1.1.4    length=0.01 phases=2 units=km linecode=16mm-2
new line.AP-AP2   bus1=AP.2.4   bus2=AP2.2.4    length=0.01 phases=2 units=km linecode=16mm-2
new line.AP-AP3   bus1=AP.3.4   bus2=AP3.3.4    length=0.01 phases=2 units=km linecode=16mm-2
new line.AQ-AQ1   bus1=AQ.1.4   bus2=AQ1.1.4    length=0.01 phases=2 units=km linecode=16mm-2
new line.AQ-AQ2   bus1=AQ.2.4   bus2=AQ2.2.4    length=0.01 phases=2 units=km linecode=16mm-2
new line.AQ-AQ3   bus1=AQ.3.4   bus2=AQ3.3.4    length=0.01 phases=2 units=km linecode=16mm-2
new line.AR-AR1   bus1=AR.1.4   bus2=AR1.1.4    length=0.01 phases=2 units=km linecode=16mm-2

new load.AA1   bus1=AA1.1.4   phases=1  kV=0.23 kW=3 pf=0.95 model=1 conn=wye status=variable daily=demand
new load.AA2   bus1=AA2.2.4   phases=1  kV=0.23 kW=3 pf=0.95 model=1 conn=wye status=variable daily=demand
new load.AA3   bus1=AA3.3.4   phases=1  kV=0.23 kW=3 pf=0.95 model=1 conn=wye status=variable daily=demand
new load.AB1   bus1=AB1.1.4   phases=1  kV=0.23 kW=3 pf=0.95 model=1 conn=wye status=variable daily=demand
new load.AB2   bus1=AB2.2.4   phases=1  kV=0.23 kW=3 pf=0.95 model=1 conn=wye status=variable daily=demand
new load.AB3   bus1=AB3.3.4   phases=1  kV=0.23 kW=3 pf=0.95 model=1 conn=wye status=variable daily=demand
new load.AC1   bus1=AC1.1.4   phases=1  kV=0.23 kW=3 pf=0.95 model=1 conn=wye status=variable daily=demand
new load.AC2   bus1=AC2.2.4   phases=1  kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand
new load.AC3   bus1=AC3.3.4   phases=1  kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand
new load.AD1   bus1=AD1.1.4   phases=1  kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand
new load.AD2   bus1=AD2.2.4   phases=1  kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand
new load.AD3   bus1=AD3.3.4   phases=1  kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand
new load.AE1   bus1=AE1.1.4   phases=1  kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand
new load.AE2   bus1=AE2.2.4   phases=1  kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand
```

new load.AE3 bus1=AE3.3.4 phases=1 kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.AF1 bus1=AF1.1.4 phases=1 kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.AF2 bus1=AF2.2.4 phases=1 kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.AF3 bus1=AF3.3.4 phases=1 kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.AG1 bus1=AG1.1.4 phases=1 kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.AG2 bus1=AG2.2.4 phases=1 kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.AG3 bus1=AG3.3.4 phases=1 kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.AH1 bus1=AH1.1.4 phases=1 kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.AH2 bus1=AH2.2.4 phases=1 kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.AH3 bus1=AH3.3.4 phases=1 kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.AI1 bus1=AI1.1.4 phases=1 kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.AI2 bus1=AI2.2.4 phases=1 kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.AI3 bus1=AI3.3.4 phases=1 kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.AJ1 bus1=AJ1.1.4 phases=1 kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.AJ2 bus1=AJ2.2.4 phases=1 kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.AJ3 bus1=AJ3.3.4 phases=1 kV=0.23 kW=3 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.AK1 bus1=AK1.1.4 phases=1 kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.AK2 bus1=AK2.2.4 phases=1 kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.AK3 bus1=AK3.3.4 phases=1 kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.AL1 bus1=AL1.1.4 phases=1 kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand new load.AL2 bus1=AL2.2.4 phases=1 kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.AL3 bus1=AL3.3.4 phases=1 kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.AM1 bus1=AM1.1.4 phases=1 kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.AM2 bus1=AM2.2.4 phases=1 kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.AM3 bus1=AM3.3.4 phases=1 kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.AN1 bus1=AN1.1.4 phases=1 kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.AN2 bus1=AN2.2.4 phases=1 kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.AN3 bus1=AN3.3.4 phases=1 kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.AO1 bus1=AO1.1.4 phases=1 kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.AO2 bus1=AO2.2.4 phases=1 kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.AO3 bus1=AO3.3.4 phases=1 kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.AP1 bus1=AP1.1.4 phases=1 kV=0.23 kW=3 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.AP2 bus1=AP2.2.4 phases=1 kV=0.23 kW=3 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.AP3 bus1=AP3.3.4 phases=1 kV=0.23 kW=3 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.AQ1 bus1=AQ1.1.4 phases=1 kV=0.23 kW=3 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.AQ2 bus1=AQ2.2.4 phases=1 kV=0.23 kW=3 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.AQ3 bus1=AQ3.3.4 phases=1 kV=0.23 kW=3 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.AR1 bus1=AR1.1.4 phases=1 kV=0.23 kW=3 pf=0.95 model=1 conn=wye status=variable daily=demand

Case 2a peak time

```
clear

set datapath=C:\Users\PigPig\Desktop\EV\twentypercent

new circuit.LV basekv=11 pu=1.0 angle=0 frequency=50 phases=3

new transformer.T1  windings=2  buses=(Sourcebus, busbar1.1.2.3.4)  conns=(delta, wye)  kvs=(11, 0.4) kvas=(500, 500) %loadloss=0 xhl=0.001

new transformer.T2  windings=2  buses=(Sourcebus, busbar2.1.2.3.4)  conns=(delta, wye)  kvs=(11, 0.4) kvas=(750, 750) %loadloss=0 xhl=0.001

new linecode.500mm-4  nphases=4 R1=0.0366   X1=0.1679 R0=0.10595 X0=0.65681 units=km

new linecode.500mm-7 nphases=4 R1=0.0366   X1=0.1679 R0=0.10595 X0=0.65681 units=km

new linecode.185mm     nphases=4 R1=0.16404 X1=0.0665 R0=0.74388 X0=0.44864 units=km

new linecode.16mm-2    nphases=2 R1=1.91       X1=0.0664 R0=2.86387 X0=1.64887 units=km

new linecode.16mm-4   nphases=4 R1=1.91       X1=0.0664 R0=2.86387 X0=1.64887 units=km

new loadshape.demand     npts=24 interval=1.0 csvfile=residential.txt action=normalize

new loadshape.evdemand npts=24 interval=1.0 csvfile=ev.txt            action=normalize

redirect feederA.txt

redirect feederB.txt

redirect feederC.txt

redirect feederD.txt

redirect feederE.txt

redirect feederF.txt

redirect feederG.txt

redirect evA.txt

redirect evB.txt

redirect evC.txt

redirect evD.txt

redirect evE.txt

redirect evF.txt

redirect evG.txt

new monitor.HEAD1_POWER element=transformer.T1   terminal=2 mode=1 ppolar=no

new monitor.HEAD2_POWER element=transformer.T2   terminal=2 mode=1 ppolar=no
```

```
new monitor.HEADa_IV        element=line.pillarA-AA  terminal=1 mode=0
new monitor.HEADb_IV        element=line.pillarB-BA  terminal=1 mode=0
new monitor.HEADc_IV        element=line.pillarC-CA  terminal=1 mode=0
new monitor.HEADd_IV        element=line.pillarD-DA  terminal=1 mode=0
new monitor.HEADe_IV        element=line.pillarE-EA  terminal=1 mode=0
new monitor.HEADf_IV        element=line.pillarF-FA  terminal=1 mode=0
new monitor.HEADg_IV        element=line.pillarG-GA  terminal=1 mode=0
new monitor.ENDa_IV         element=line.pillarA-AR terminal=2 mode=0
new monitor.ENDb_IV         element=line.pillarB-BV  terminal=2 mode=0
new monitor.ENDc_IV         element=line.pillarC-CK  terminal=2 mode=0
new monitor.ENDd_IV         element=line.pillarD-DL  terminal=2 mode=0
new monitor.ENDe_IV         element=line.pillarE-ET  terminal=2 mode=0
new monitor.ENDf_IV         element=line.pillarF-FQ  terminal=2 mode=0
new monitor.ENDg_IV         element=line.pillarG-GQ  terminal=2 mode=0
new energymeter.METER1      element=transformer.T1   terminal=1
new energymeter.METER2      element=transformer.T2   terminal=1
set controlmode=TIME
set mode=daily stepsize=1h number=24
set voltagebases=[11 0.4]
calcvoltagebases
solve
export monitors HEAD1_POWER
export monitors HEAD2_POWER
export monitors HEADa_IV
export monitors HEADb_IV
export monitors HEADc_IV
export monitors HEADd_IV
export monitors HEADe_IV
export monitors HEADf_IV
export monitors HEADg_IV
```

```
export monitors ENDa_IV
export monitors ENDb_IV
export monitors ENDc_IV
export monitors ENDd_IV
export monitors ENDe_IV
export monitors ENDf_IV
export monitors ENDg_IV
export meters
```

feederB.txt

```
new line.T1-pillarB bus1=busbar1.1.2.3.4 bus2=pillarB.1.2.3.4 length=0.01 phases=4 units=km linecode=500mm-4

new line.pillarB-BA bus1=pillarB.1.2.3.4 bus2=BA.1.2.3.4 length=0.18 phases=4 units=km linecode=185mm

new line.pillarB-BB bus1=BA.1.2.3.4 bus2=BB.1.2.3.4 length=0.02 phases=4 units=km linecode=185mm

new line.pillarB-BC bus1=BB.1.2.3.4 bus2=BC.1.2.3.4 length=0.02 phases=4 units=km linecode=185mm

new line.pillarB-BD bus1=BC.1.2.3.4 bus2=BD.1.2.3.4 length=0.02 phases=4 units=km linecode=185mm

new line.pillarB-BE bus1=BD.1.2.3.4 bus2=BE.1.2.3.4 length=0.02 phases=4 units=km linecode=185mm

new line.pillarB-BF bus1=BE.1.2.3.4 bus2=BF.1.2.3.4 length=0.06 phases=4 units=km linecode=185mm

new line.pillarB-BG bus1=BF.1.2.3.4 bus2=BG.1.2.3.4 length=0.02 phases=4 units=km linecode=185mm

new line.pillarB-BH bus1=BG.1.2.3.4 bus2=BH.1.2.3.4 length=0.02 phases=4 units=km linecode=185mm

new line.pillarB-BI bus1=BH.1.2.3.4 bus2=BI.1.2.3.4 length=0.03 phases=4 units=km linecode=185mm

new line.pillarB-BJ bus1=BI.1.2.3.4 bus2=BJ.1.2.3.4 length=0.02 phases=4 units=km linecode=185mm

new line.pillarB-BK bus1=BJ.1.2.3.4 bus2=BK.1.2.3.4 length=0.02 phases=4 units=km linecode=185mm

new line.pillarB-BL bus1=BK.1.2.3.4 bus2=BL.1.2.3.4 length=0.02 phases=4 units=km linecode=185mm
```

```
new line.pillarB-BM bus1=BL.1.2.3.4 bus2=BM.1.2.3.4 length=0.04 phases=4 units=km linecode=185mm

new line.pillarB-BN bus1=BM.1.2.3.4 bus2=BN.1.2.3.4 length=0.02 phases=4 units=km linecode=185mm

new line.pillarB-BO bus1=BN.1.2.3.4 bus2=BO.1.2.3.4 length=0.02 phases=4 units=km linecode=185mm

new line.pillarB-BP bus1=BO.1.2.3.4 bus2=BP.1.2.3.4 length=0.02 phases=4 units=km linecode=185mm

new line.pillarB-BQ bus1=BP.1.2.3.4 bus2=BQ.1.2.3.4 length=0.02 phases=4 units=km linecode=185mm

new line.pillarB-BR bus1=BM.1.2.3.4 bus2=BR.1.2.3.4 length=0.06 phases=4 units=km linecode=185mm

new line.pillarB-BS bus1=BR.1.2.3.4 bus2=BS.1.2.3.4 length=0.02 phases=4 units=km linecode=185mm

new line.pillarB-BT bus1=BS.1.2.3.4 bus2=BT.1.2.3.4 length=0.02 phases=4 units=km linecode=185mm

new line.pillarB-BU bus1=BT.1.2.3.4 bus2=BU.1.2.3.4 length=0.02 phases=4 units=km linecode=185mm

new line.pillarB-BV bus1=BU.1.2.3.4 bus2=BV.1.2.3.4 length=0.02 phases=4 units=km linecode=185mm

new line.BA-BA1 bus1=BA.1.4 bus2=BA1.1.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.BA-BA2 bus1=BA.2.4 bus2=BA2.2.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.BA-BA3 bus1=BA.3.4 bus2=BA3.3.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.BB-BB1 bus1=BB.1.4 bus2=BB1.1.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.BB-BB2 bus1=BB.2.4 bus2=BB2.2.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.BB-BB3 bus1=BB.3.4 bus2=BB3.3.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.BC-BC1 bus1=BC.1.4 bus2=BC1.1.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.BC-BC2 bus1=BC.2.4 bus2=BC2.2.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.BC-BC3 bus1=BC.3.4 bus2=BC3.3.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.BD-BD1 bus1=BD.1.4 bus2=BD1.1.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.BD-BD2 bus1=BD.2.4 bus2=BD2.2.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.BD-BD3 bus1=BD.3.4 bus2=BD3.3.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.BE-BE1 bus1=BE.1.4 bus2=BE1.1.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.BE-BE2 bus1=BE.2.4 bus2=BE2.2.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.BE-BE3 bus1=BE.3.4 bus2=BE3.3.4 length=0.01 phases=2 units=km linecode=16mm-2
```

```
new line.BF-BF1   bus1=BF.1.4   bus2=BF1.1.4    length=0.01 phases=2 units=km linecode=16mm-2
new line.BF-BF2   bus1=BF.2.4   bus2=BF2.2.4    length=0.01 phases=2 units=km linecode=16mm-2
new line.BF-BF3   bus1=BF.3.4   bus2=BF3.3.4    length=0.01 phases=2 units=km linecode=16mm-2
new line.BG-BG1   bus1=BG.1.4   bus2=BG1.1.4    length=0.01 phases=2 units=km linecode=16mm-2
new line.BG-BG2   bus1=BG.2.4   bus2=BG2.2.4    length=0.01 phases=2 units=km linecode=16mm-2
new line.BG-BG3   bus1=BG.3.4   bus2=BG3.3.4    length=0.01 phases=2 units=km linecode=16mm-2
new line.BH-BH1   bus1=BH.1.4   bus2=BH1.1.4    length=0.01 phases=2 units=km linecode=16mm-2
new line.BH-BH2   bus1=BH.2.4   bus2=BH2.2.4    length=0.01 phases=2 units=km linecode=16mm-2
new line.BH-BH3   bus1=BH.3.4   bus2=BH3.3.4    length=0.01 phases=2 units=km linecode=16mm-2
new line.BI-BI1   bus1=BI.1.4   bus2=BI1.1.4    length=0.01 phases=2 units=km linecode=16mm-2
new line.BI-BI2   bus1=BI.2.4   bus2=BI2.2.4    length=0.01 phases=2 units=km linecode=16mm-2
new line.BI-BI3   bus1=BI.3.4   bus2=BI3.3.4    length=0.01 phases=2 units=km linecode=16mm-2
new line.BJ-BJ1   bus1=BJ.1.4   bus2=BJ1.1.4    length=0.01 phases=2 units=km linecode=16mm-2
new line.BJ-BJ2   bus1=BJ.2.4   bus2=BJ2.2.4    length=0.01 phases=2 units=km linecode=16mm-2
new line.BJ-BJ3   bus1=BJ.3.4   bus2=BJ3.3.4    length=0.01 phases=2 units=km linecode=16mm-2
new line.BK-BK1   bus1=BK.1.4   bus2=BK1.1.4    length=0.01 phases=2 units=km linecode=16mm-2
new line.BK-BK2   bus1=BK.2.4   bus2=BK2.2.4    length=0.01 phases=2 units=km linecode=16mm-2
new line.BK-BK3   bus1=BK.3.4   bus2=BK3.3.4    length=0.01 phases=2 units=km linecode=16mm-2
new line.BL-BL1   bus1=BL.1.4   bus2=BL1.1.4    length=0.01 phases=2 units=km linecode=16mm-2
new line.BL-BL2   bus1=BL.2.4   bus2=BL2.2.4    length=0.01 phases=2 units=km linecode=16mm-2
new line.BL-BL3   bus1=BL.3.4   bus2=BL3.3.4    length=0.01 phases=2 units=km linecode=16mm-2
new line.BM-BM1   bus1=BM.1.4   bus2=BM1.1.4    length=0.01 phases=2 units=km linecode=16mm-2
new line.BM-BM2   bus1=BM.2.4   bus2=BM2.2.4    length=0.01 phases=2 units=km linecode=16mm-2
new line.BM-BM3   bus1=BM.3.4   bus2=BM3.3.4    length=0.01 phases=2 units=km linecode=16mm-2
new line.BN-BN1   bus1=BN.1.4   bus2=BN1.1.4    length=0.01 phases=2 units=km linecode=16mm-2
new line.BN-BN2   bus1=BN.2.4   bus2=BN2.2.4    length=0.01 phases=2 units=km linecode=16mm-2
new line.BN-BN3   bus1=BN.3.4   bus2=BN3.3.4    length=0.01 phases=2 units=km linecode=16mm-2
new line.BO-BO1   bus1=BO.1.4   bus2=BO1.1.4    length=0.01 phases=2 units=km linecode=16mm-2
new line.BO-BO2   bus1=BO.2.4   bus2=BO2.2.4    length=0.01 phases=2 units=km linecode=16mm-2
new line.BO-BO3   bus1=BO.3.4   bus2=BO3.3.4    length=0.01 phases=2 units=km linecode=16mm-2
```

new line.BP-BP1 bus1=BP.1.4 bus2=BP1.1.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.BP-BP2 bus1=BP.2.4 bus2=BP2.2.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.BP-BP3 bus1=BP.3.4 bus2=BP3.3.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.BQ-BQ1 bus1=BQ.1.4 bus2=BQ1.1.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.BQ-BQ2 bus1=BQ.2.4 bus2=BQ2.2.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.BQ-BQ3 bus1=BQ.3.4 bus2=BQ3.3.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.BR-BR1 bus1=BR.1.4 bus2=BR1.1.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.BR-BR2 bus1=BR.2.4 bus2=BR2.2.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.BR-BR3 bus1=BR.3.4 bus2=BR3.3.4 length=0.01 phases=2 units=km linecode=16mm-2

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new line.BS-BS2 bus1=BS.2.4 bus2=BS2.2.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.BS-BS3 bus1=BS.3.4 bus2=BS3.3.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.BT-BT1 bus1=BT.1.4 bus2=BT1.1.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.BT-BT2 bus1=BT.2.4 bus2=BT2.2.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.BT-BT3 bus1=BT.3.4 bus2=BT3.3.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.BU-BU1 bus1=BU.1.4 bus2=BU1.1.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.BU-BU2 bus1=BU.2.4 bus2=BU2.2.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.BU-BU3 bus1=BU.3.4 bus2=BU3.3.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.BV-BV1 bus1=BV.1.4 bus2=BV1.1.4 length=0.01 phases=2 units=km linecode=16mm-2

new load.BA1 bus1=BA1.1.4 phases=1 kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.BA2 bus1=BA2.2.4 phases=1 kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.BA3 bus1=BA3.3.4 phases=1 kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand

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new load.BB2 bus1=BB2.2.4 phases=1 kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.BB3 bus1=BB3.3.4 phases=1 kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.BC1 bus1=BC1.1.4 phases=1 kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand new load.BC2 bus1=BC2.2.4 phases=1 kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.BC3 bus1=BC3.3.4 phases=1 kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand

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new load.BD2 bus1=BD2.2.4 phases=1 kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.BD3 bus1=BD3.3.4 phases=1 kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand

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new load.BE2 bus1=BE2.2.4 phases=1 kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand

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new load.BK2 bus1=BK2.2.4 phases=1 kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.BK3 bus1=BK3.3.4 phases=1 kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand

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new load.BL2 bus1=BL2.2.4 phases=1 kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand

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new load.BM2 bus1=BM2.2.4 phases=1 kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand

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new load.BN2 bus1=BN2.2.4 phases=1 kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.BN3 bus1=BN3.3.4 phases=1 kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand

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new load.BO2 bus1=BO2.2.4 phases=1 kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.BO3 bus1=BO3.3.4 phases=1 kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand

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new load.BP2 bus1=BP2.2.4 phases=1 kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand new load.BP3 bus1=BP3.3.4 phases=1 kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.BQ1 bus1=BQ1.1.4 phases=1 kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.BQ2 bus1=BQ2.2.4 phases=1 kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.BQ3 bus1=BQ3.3.4 phases=1 kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand

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new load.BR2 bus1=BR2.2.4 phases=1 kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand

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new load.BS2 bus1=BS2.2.4 phases=1 kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand

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new load.BT2 bus1=BT2.2.4 phases=1 kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.BT3 bus1=BT3.3.4 phases=1 kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.BU1 bus1=BU1.1.4 phases=1 kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.BU2 bus1=BU2.2.4 phases=1 kV=0.23 kW=1.5 pf=0.95 model=1 conn=wye status=variable daily=demand

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evA.txt

!new load.evAA1 bus1=AA1.1.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand

!new load.evAA2 bus1=AA2.2.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand

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new load.evAR1 bus1=AR1.1.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand

Case 3b

clear

set datapath=C:\Users\PigPig\Desktop\EV\control40

new circuit.LV basekv=11 pu=1.0 angle=0 frequency=50 phases=3

new transformer.T1 windings=2 buses=(Sourcebus, busbar1.1.2.3.4) conns=(delta, wye) kvs=(11, 0.4) kvas=(500, 500) %loadloss=0 xhl=0.001

new transformer.T2 windings=2 buses=(Sourcebus, busbar2.1.2.3.4) conns=(delta, wye) kvs=(11, 0.4) kvas=(750, 750) %loadloss=0 xhl=0.001

new linecode.500mm-4 nphases=4 R1=0.0366 X1=0.1679 R0=0.10595 X0=0.65681 units=km

```
new linecode.500mm-7 nphases=4 R1=0.0366   X1=0.1679 R0=0.10595 X0=0.65681 units=km
new linecode.185mm     nphases=4 R1=0.16404 X1=0.0665 R0=0.74388 X0=0.44864 units=km
new linecode.16mm-2    nphases=2 R1=1.91       X1=0.0664 R0=2.86387 X0=1.64887 units=km
new linecode.16mm-4   nphases=4 R1=1.91       X1=0.0664 R0=2.86387 X0=1.64887 units=km
new loadshape.demand     npts=24 interval=1.0 csvfile=residential.txt action=normalize
new loadshape.ev1       npts=24 interval=1.0 csvfile=ev1.txt          action=normalize
new loadshape.ev2       npts=24 interval=1.0 csvfile=ev2.txt          action=normalize
new loadshape.ev3       npts=24 interval=1.0 csvfile=ev3.txt          action=normalize
redirect feederA.txt
redirect feederB.txt
redirect feederC.txt
redirect feederD.txt
redirect feederE.txt
redirect feederF.txt
redirect feederG.txt
redirect evA.txt
redirect evB.txt
redirect evC.txt
redirect evD.txt
redirect evE.txt
redirect evF.txt
redirect evG.txt
new monitor.HEAD1_POWER element=transformer.T1   terminal=2 mode=1 ppolar=no
new monitor.HEAD2_POWER element=transformer.T2   terminal=2 mode=1 ppolar=no
new monitor.HEADa_IV          element=line.pillarA-AA  terminal=1 mode=0
new monitor.HEADb_IV          element=line.pillarB-BA  terminal=1 mode=0
new monitor.HEADc_IV          element=line.pillarC-CA  terminal=1 mode=0
new monitor.HEADd_IV          element=line.pillarD-DA  terminal=1 mode=0
new monitor.HEADe_IV          element=line.pillarE-EA  terminal=1 mode=0
new monitor.HEADf_IV          element=line.pillarF-FA  terminal=1 mode=0
```

```
new monitor.HEADg_IV        element=line.pillarG-GA  terminal=1 mode=0
new monitor.ENDa_IV         element=line.pillarA-AR terminal=2 mode=0
new monitor.ENDb_IV         element=line.pillarB-BV  terminal=2 mode=0
new monitor.ENDc_IV         element=line.pillarC-CK  terminal=2 mode=0
new monitor.ENDd_IV         element=line.pillarD-DL  terminal=2 mode=0
new monitor.ENDe_IV         element=line.pillarE-ET  terminal=2 mode=0
new monitor.ENDf_IV         element=line.pillarF-FQ  terminal=2 mode=0
new monitor.ENDg_IV         element=line.pillarG-GQ  terminal=2 mode=0
new energymeter.METER1      element=transformer.T1   terminal=1
new energymeter.METER2      element=transformer.T2   terminal=1
set controlmode=TIME
set mode=daily stepsize=1h number=24
set voltagebases=[11 0.4]
calcvoltagebases
solve
export monitors HEAD1_POWER
export monitors HEAD2_POWER
export monitors HEADa_IV
export monitors HEADb_IV
export monitors HEADc_IV
export monitors HEADd_IV
export monitors HEADe_IV
export monitors HEADf_IV
export monitors HEADg_IV
export monitors ENDa_IV
export monitors ENDb_IV
export monitors ENDc_IV
export monitors ENDd_IV
export monitors ENDe_IV
export monitors ENDf_IV
```

export monitors ENDg_IV

export meters

feederC.txt

new line.T1-pillarC bus1=busbar1.1.2.3.4 bus2=pillarC.1.2.3.4 length=0.01 phases=4 units=km linecode=500mm-4

new line.pillarC-CA bus1=pillarC.1.2.3.4 bus2=CA.1.2.3.4 length=0.14 phases=4 units=km linecode=185mm

new line.pillarC-CB bus1=CA.1.2.3.4 bus2=CB.1.2.3.4 length=0.02 phases=4 units=km linecode=185mm

new line.pillarC-CC bus1=CB.1.2.3.4 bus2=CC.1.2.3.4 length=0.02 phases=4 units=km linecode=185mm

new line.pillarC-CD bus1=CC.1.2.3.4 bus2=CD.1.2.3.4 length=0.02 phases=4 units=km linecode=185mm

new line.pillarC-CE bus1=CD.1.2.3.4 bus2=CE.1.2.3.4 length=0.02 phases=4 units=km linecode=185mm

new line.pillarC-CF bus1=CE.1.2.3.4 bus2=CF.1.2.3.4 length=0.02 phases=4 units=km linecode=185mm

new line.pillarC-CG bus1=CF.1.2.3.4 bus2=CG.1.2.3.4 length=0.02 phases=4 units=km linecode=185mm

new line.pillarC-CH bus1=CG.1.2.3.4 bus2=CH.1.2.3.4 length=0.02 phases=4 units=km linecode=185mm

new line.pillarC-CI bus1=CE.1.2.3.4 bus2=CI.1.2.3.4 length=0.05 phases=4 units=km linecode=185mm

new line.pillarC-CJ bus1=CI.1.2.3.4 bus2=CJ.1.2.3.4 length=0.02 phases=4 units=km linecode=185mm

new line.pillarC-CK bus1=CJ.1.2.3.4 bus2=CK.1.2.3.4 length=0.02 phases=4 units=km linecode=185mm

new line.CA-CA1 bus1=CA.1.4 bus2=CA1.1.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.CA-CA2 bus1=CA.2.4 bus2=CA2.2.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.CA-CA3 bus1=CA.3.4 bus2=CA3.3.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.CB-CB1 bus1=CB.1.4 bus2=CB1.1.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.CB-CB2 bus1=CB.2.4 bus2=CB2.2.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.CB-CB3 bus1=CB.3.4 bus2=CB3.3.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.CC-CC1 bus1=CC.1.4 bus2=CC1.1.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.CC-CC2 bus1=CC.2.4 bus2=CC2.2.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.CC-CC3 bus1=CC.3.4 bus2=CC3.3.4 length=0.01 phases=2 units=km linecode=16mm-2 new line.CD-CD1 bus1=CD.1.4 bus2=CD1.1.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.CD-CD2 bus1=CD.2.4 bus2=CD2.2.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.CD-CD3 bus1=CD.3.4 bus2=CD3.3.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.CE-CE1 bus1=CE.1.4 bus2=CE1.1.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.CE-CE2 bus1=CE.2.4 bus2=CE2.2.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.CE-CE3 bus1=CE.3.4 bus2=CE3.3.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.CF-CF1 bus1=CF.1.4 bus2=CF1.1.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.CF-CF2 bus1=CF.2.4 bus2=CF2.2.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.CF-CF3 bus1=CF.3.4 bus2=CF3.3.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.CG-CG1 bus1=CG.1.4 bus2=CG1.1.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.CG-CG2 bus1=CG.2.4 bus2=CG2.2.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.CG-CG3 bus1=CG.3.4 bus2=CG3.3.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.CH-CH1 bus1=CH.1.4 bus2=CH1.1.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.CH-CH2 bus1=CH.2.4 bus2=CH2.2.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.CH-CH3 bus1=CH.3.4 bus2=CH3.3.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.CI-CI1 bus1=CI.1.4 bus2=CI1.1.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.CI-CI2 bus1=CI.2.4 bus2=CI2.2.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.CI-CI3 bus1=CI.3.4 bus2=CI3.3.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.CJ-CJ1 bus1=CJ.1.4 bus2=CJ1.1.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.CJ-CJ2 bus1=CJ.2.4 bus2=CJ2.2.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.CJ-CJ3 bus1=CJ.3.4 bus2=CJ3.3.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.CK-CK1 bus1=CK.1.4 bus2=CK1.1.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.CK-CK2 bus1=CK.2.4 bus2=CK2.2.4 length=0.01 phases=2 units=km linecode=16mm-2

new line.CK-CK3 bus1=CK.3.4 bus2=CK3.3.4 length=0.01 phases=2 units=km linecode=16mm-2

new load.CA1 bus1=CA1.1.4 phases=1 kV=0.23 kW=3 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.CA2 bus1=CA2.2.4 phases=1 kV=0.23 kW=3 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.CA3 bus1=CA3.3.4 phases=1 kV=0.23 kW=3 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.CB1 bus1=CB1.1.4 phases=1 kV=0.23 kW=3 pf=0.95 model=1 conn=wye status=variable daily=demand new load.CB2 bus1=CB2.2.4 phases=1 kV=0.23 kW=3 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.CB3 bus1=CB3.3.4 phases=1 kV=0.23 kW=3 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.CC1 bus1=CC1.1.4 phases=1 kV=0.23 kW=3 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.CC2 bus1=CC2.2.4 phases=1 kV=0.23 kW=3 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.CC3 bus1=CC3.3.4 phases=1 kV=0.23 kW=3 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.CD1 bus1=CD1.1.4 phases=1 kV=0.23 kW=3 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.CD2 bus1=CD2.2.4 phases=1 kV=0.23 kW=3 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.CD3 bus1=CD3.3.4 phases=1 kV=0.23 kW=3 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.CE1 bus1=CE1.1.4 phases=1 kV=0.23 kW=3 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.CE2 bus1=CE2.2.4 phases=1 kV=0.23 kW=3 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.CE3 bus1=CE3.3.4 phases=1 kV=0.23 kW=3 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.CF1 bus1=CF1.1.4 phases=1 kV=0.23 kW=3 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.CF2 bus1=CF2.2.4 phases=1 kV=0.23 kW=3 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.CF3 bus1=CF3.3.4 phases=1 kV=0.23 kW=3 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.CG1 bus1=CG1.1.4 phases=1 kV=0.23 kW=3 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.CG2 bus1=CG2.2.4 phases=1 kV=0.23 kW=3 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.CG3 bus1=CG3.3.4 phases=1 kV=0.23 kW=3 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.CH1 bus1=CH1.1.4 phases=1 kV=0.23 kW=3 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.CH2 bus1=CH2.2.4 phases=1 kV=0.23 kW=3 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.CH3 bus1=CH3.3.4 phases=1 kV=0.23 kW=3 pf=0.95 model=1 conn=wye status=variable daily=demand new load.CI1 bus1=CI1.1.4 phases=1 kV=0.23 kW=3 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.CI2 bus1=CI2.2.4 phases=1 kV=0.23 kW=3 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.CI3 bus1=CI3.3.4 phases=1 kV=0.23 kW=3 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.CJ1 bus1=CJ1.1.4 phases=1 kV=0.23 kW=3 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.CJ2 bus1=CJ2.2.4 phases=1 kV=0.23 kW=3 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.CJ3 bus1=CJ3.3.4 phases=1 kV=0.23 kW=3 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.CK1 bus1=CK1.1.4 phases=1 kV=0.23 kW=3 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.CK2 bus1=CK2.2.4 phases=1 kV=0.23 kW=3 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.CK3 bus1=CK3.3.4 phases=1 kV=0.23 kW=3 pf=0.95 model=1 conn=wye status=variable daily=demand

evB.txt

!new load.evBA1 bus1=BA1.1.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand

!new load.evBA2 bus1=BA2.2.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand

!new load.evBA3 bus1=BA3.3.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand

!new load.evBB1 bus1=BB1.1.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand

!new load.evBB2 bus1=BB2.2.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand

!new load.evBB3 bus1=BB3.3.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand

!new load.evBC1 bus1=BC1.1.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand

!new load.evBC2 bus1=BC2.2.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand

!new load.evBC3 bus1=BC3.3.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand

!new load.evBD1 bus1=BD1.1.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand

!new load.evBD2 bus1=BD2.2.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand

!new load.evBD3 bus1=BD3.3.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand

!new load.evBE1 bus1=BE1.1.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand

!new load.evBE2 bus1=BE2.2.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand

!new load.evBE3 bus1=BE3.3.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand

!new load.evBF1 bus1=BF1.1.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand

!new load.evBF2 bus1=BF2.2.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand

!new load.evBF3 bus1=BF3.3.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand

!new load.evBG1 bus1=BG1.1.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand

!new load.evBG2 bus1=BG2.2.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand

!new load.evBG3 bus1=BG3.3.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand

!new load.evBH1 bus1=BH1.1.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand

!new load.evBH2 bus1=BH2.2.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand

!new load.evBH3 bus1=BH3.3.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand

!new load.evBI1 bus1=BI1.1.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand

!new load.evBI2 bus1=BI2.2.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand

!new load.evBI3 bus1=BI3.3.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand

!new load.evBJ1 bus1=BJ1.1.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand

!new load.evBJ2 bus1=BJ2.2.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand

!new load.evBJ3 bus1=BJ3.3.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand

!new load.evBK1 bus1=BK1.1.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand

!new load.evBK2 bus1=BK2.2.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand

!new load.evBK3 bus1=BK3.3.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand

!new load.evBL1 bus1=BL1.1.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand

!new load.evBL2 bus1=BL2.2.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand

!new load.evBL3 bus1=BL3.3.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand

new load.evBM1 bus1=BM1.1.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=ev3

!new load.evBM2 bus1=BM2.2.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand

!new load.evBM3 bus1=BM3.3.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand

new load.evBN1 bus1=BN1.1.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=ev1

new load.evBN2 bus1=BN2.2.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=ev1

new load.evBN3 bus1=BN3.3.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=ev1

new load.evBO1 bus1=BO1.1.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=ev2

new load.evBO2 bus1=BO2.2.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=ev2

new load.evBO3 bus1=BO3.3.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=ev2

new load.evBP1 bus1=BP1.1.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=ev3

new load.evBP2 bus1=BP2.2.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=ev3

new load.evBP3 bus1=BP3.3.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=ev3

new load.evBQ1 bus1=BQ1.1.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=ev1 new load.evBQ2 bus1=BQ2.2.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=ev1

new load.evBQ3 bus1=BQ3.3.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=ev1

new load.evBR1 bus1=BR1.1.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=ev2

new load.evBR2 bus1=BR2.2.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=ev2

new load.evBR3 bus1=BR3.3.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=ev2

new load.evBS1 bus1=BS1.1.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=ev3

new load.evBS2 bus1=BS2.2.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=ev3

new load.evBS3 bus1=BS3.3.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=ev3

new load.evBT1 bus1=BT1.1.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=ev1

new load.evBT2 bus1=BT2.2.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=ev1

new load.evBT3 bus1=BT3.3.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=ev2

new load.evBU1 bus1=BU1.1.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=ev2

new load.evBU2 bus1=BU2.2.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=ev3

new load.evBU3 bus1=BU3.3.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=ev3

new load.evBV1 bus1=BV1.1.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=ev1

Case 4d

feederE.txt

new line.T2-pillarE bus1=busbar2.1.2.3.4 bus2=pillarE.1.2.3.4 length=0.01 phases=4 units=km linecode=500mm-7

new line.pillarE-EA bus1=pillarE.1.2.3.4 bus2=EA.1.2.3.4 length=0.21 phases=4 units=km linecode=185mm

new line.pillarE-EB bus1=EA.1.2.3.4 bus2=EB.1.2.3.4 length=0.015 phases=4 units=km linecode=185mm

new line.pillarE-EC bus1=EB.1.2.3.4 bus2=EC.1.2.3.4 length=0.015 phases=4 units=km linecode=185mm

new line.pillarE-ED bus1=EC.1.2.3.4 bus2=ED.1.2.3.4 length=0.015 phases=4 units=km linecode=185mm

new line.pillarE-EE bus1=ED.1.2.3.4 bus2=EE.1.2.3.4 length=0.015 phases=4 units=km linecode=185mm

new line.pillarE-EF bus1=EE.1.2.3.4 bus2=EF.1.2.3.4 length=0.015 phases=4 units=km linecode=185mm

new line.pillarE-EG bus1=EF.1.2.3.4 bus2=EG.1.2.3.4 length=0.015 phases=4 units=km linecode=185mm

new line.pillarE-EH bus1=EG.1.2.3.4 bus2=EH.1.2.3.4 length=0.015 phases=4 units=km linecode=185mm

new line.pillarE-EI bus1=EH.1.2.3.4 bus2=EI.1.2.3.4 length=0.015 phases=4 units=km linecode=185mm

new line.pillarE-EJ bus1=EA.1.2.3.4 bus2=EJ.1.2.3.4 length=0.03 phases=4 units=km linecode=185mm

new line.pillarE-EK bus1=EJ.1.2.3.4 bus2=EK.1.2.3.4 length=0.015 phases=4 units=km linecode=185mm

new line.pillarE-EL bus1=EK.1.2.3.4 bus2=EL.1.2.3.4 length=0.03 phases=4 units=km linecode=185mm

new line.pillarE-EM bus1=EI.1.2.3.4 bus2=EM.1.2.3.4 length=0.06 phases=4 units=km linecode=185mm

new line.pillarE-EN bus1=EM.1.2.3.4 bus2=EN.1.2.3.4 length=0.015 phases=4 units=km linecode=185mm

new line.pillarE-EO bus1=EN.1.2.3.4 bus2=EO.1.2.3.4 length=0.015 phases=4 units=km linecode=185mm

new line.pillarE-EP bus1=EO.1.2.3.4 bus2=EP.1.2.3.4 length=0.015 phases=4 units=km linecode=185mm

new line.pillarE-EQ bus1=EI.1.2.3.4 bus2=EQ.1.2.3.4 length=0.06 phases=4 units=km linecode=185mm

new line.pillarE-ER bus1=EQ.1.2.3.4 bus2=ER.1.2.3.4 length=0.015 phases=4 units=km linecode=185mm

new line.pillarE-ES bus1=ER.1.2.3.4 bus2=ES.1.2.3.4 length=0.02 phases=4 units=km linecode=185mm

new line.pillarE-ET bus1=ES.1.2.3.4 bus2=ET.1.2.3.4 length=0.015 phases=4 units=km linecode=185mm new line.EA-EA1 bus1=EA.1.2.3.4 bus2=EA1.1.2.3.4 length=0.01 phases=4 units=km linecode=16mm-4

new line.EB-EB1 bus1=EB.1.2.3.4 bus2=EB1.1.2.3.4 length=0.01 phases=4 units=km linecode=16mm-4

new line.EC-EC1 bus1=EC.1.2.3.4 bus2=EC1.1.2.3.4 length=0.01 phases=4 units=km linecode=16mm-4

new line.ED-ED1 bus1=ED.1.2.3.4 bus2=ED1.1.2.3.4 length=0.01 phases=4 units=km linecode=16mm-4

new line.EE-EE1 bus1=EE.1.2.3.4 bus2=EE1.1.2.3.4 length=0.01 phases=4 units=km linecode=16mm-4

new line.EF-EF1 bus1=EF.1.2.3.4 bus2=EF1.1.2.3.4 length=0.01 phases=4 units=km linecode=16mm-4

new line.EG-EG1 bus1=EG.1.2.3.4 bus2=EG1.1.2.3.4 length=0.01 phases=4 units=km linecode=16mm-4

new line.EH-EH1 bus1=EH.1.2.3.4 bus2=EH1.1.2.3.4 length=0.01 phases=4 units=km linecode=16mm-4

new line.EI-EI1 bus1=EI.1.2.3.4 bus2=EI1.1.2.3.4 length=0.01 phases=4 units=km linecode=16mm-4

new line.EJ-EJ1 bus1=EJ.1.2.3.4 bus2=EJ1.1.2.3.4 length=0.01 phases=4 units=km linecode=16mm-4

new line.EK-EK1 bus1=EK.1.2.3.4 bus2=EK1.1.2.3.4 length=0.01 phases=4 units=km linecode=16mm-4

new line.EL-EL1 bus1=EL.1.2.3.4 bus2=EL1.1.2.3.4 length=0.04 phases=4 units=km linecode=16mm-4

new line.EM-EM1 bus1=EM.1.2.3.4 bus2=EM1.1.2.3.4 length=0.015 phases=4 units=km linecode=16mm-4

new line.EN-EN1 bus1=EN.1.2.3.4 bus2=EN1.1.2.3.4 length=0.01 phases=4 units=km linecode=16mm-4

new line.EO-EO1 bus1=EO.1.2.3.4 bus2=EO1.1.2.3.4 length=0.01 phases=4 units=km linecode=16mm-4

new line.EP-EP1 bus1=EP.1.2.3.4 bus2=EP1.1.2.3.4 length=0.01 phases=4 units=km linecode=16mm-4

new line.EQ-EQ1 bus1=EQ.1.2.3.4 bus2=EQ1.1.2.3.4 length=0.015 phases=4 units=km linecode=16mm-4

new line.ER-ER1 bus1=ER.1.2.3.4 bus2=ER1.1.2.3.4 length=0.01 phases=4 units=km linecode=16mm-4

new line.ES-ES1 bus1=ES.1.2.3.4 bus2=ES1.1.2.3.4 length=0.01 phases=4 units=km linecode=16mm-4

new line.ET-ET1 bus1=ET.1.2.3.4 bus2=ET1.1.2.3.4 length=0.01 phases=4 units=km linecode=16mm-4

new load.EA1 bus1=EA1.1.2.3.4 phases=3 kV=0.4 kW=8 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.EB1 bus1=EB1.1.2.3.4 phases=3 kV=0.4 kW=5 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.EC1 bus1=EC1.1.2.3.4 phases=3 kV=0.4 kW=5 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.ED1 bus1=ED1.1.2.3.4 phases=3 kV=0.4 kW=5 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.EE1 bus1=EE1.1.2.3.4 phases=3 kV=0.4 kW=5 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.EF1 bus1=EF1.1.2.3.4 phases=3 kV=0.4 kW=5 pf=0.95 model=1 conn=wye status=variable daily=demand new load.EG1 bus1=EG1.1.2.3.4 phases=3 kV=0.4 kW=5 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.EH1 bus1=EH1.1.2.3.4 phases=3 kV=0.4 kW=5 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.EI1 bus1=EI1.1.2.3.4 phases=3 kV=0.4 kW=5 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.EJ1 bus1=EJ1.1.2.3.4 phases=3 kV=0.4 kW=8 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.EK1 bus1=EK1.1.2.3.4 phases=3 kV=0.4 kW=8 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.EL1 bus1=EL1.1.2.3.4 phases=3 kV=0.4 kW=8 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.EM1 bus1=EM1.1.2.3.4 phases=3 kV=0.4 kW=8 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.EN1 bus1=EN1.1.2.3.4 phases=3 kV=0.4 kW=8 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.EO1 bus1=EO1.1.2.3.4 phases=3 kV=0.4 kW=8 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.EP1 bus1=EP1.1.2.3.4 phases=3 kV=0.4 kW=8 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.EQ1 bus1=EQ1.1.2.3.4 phases=3 kV=0.4 kW=8 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.ER1 bus1=ER1.1.2.3.4 phases=3 kV=0.4 kW=8 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.ES1 bus1=ES1.1.2.3.4 phases=3 kV=0.4 kW=8 pf=0.95 model=1 conn=wye status=variable daily=demand

new load.ET1 bus1=ET1.1.2.3.4 phases=3 kV=0.4 kW=8 pf=0.95 model=1 conn=wye status=variable daily=demand

evD.txt

!new load.evDA1 bus1=DA1.1.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand

!new load.evDA2 bus1=DA2.2.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand

!new load.evDA3 bus1=DA3.3.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand

!new load.evDB1 bus1=DB1.1.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand

```
!new load.evDB2 bus1=DB2.2.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand
!new load.evDB3 bus1=DB3.3.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand
new load.evDC1 bus1=DC1.1.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand
new load.evDC2 bus1=DC2.2.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand
!new load.evDC3 bus1=DC3.3.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand
new load.evDD1 bus1=DD1.1.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand
new load.evDD2 bus1=DD2.2.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand
new load.evDD3 bus1=DD3.3.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand
new load.evDE1 bus1=DE1.1.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand
new load.evDE2 bus1=DE2.2.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand
new load.evDE3 bus1=DE3.3.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand
new load.evDF1 bus1=DF1.1.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand
new load.evDF2 bus1=DF2.2.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand
new load.evDF3 bus1=DF3.3.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand
new load.evDG1 bus1=DG1.1.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand
new load.evDG2 bus1=DG2.2.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand
new load.evDG3 bus1=DG3.3.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand
new load.evDH1 bus1=DH1.1.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand
new load.evDH2 bus1=DH2.2.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand
new load.evDH3 bus1=DH3.3.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand
```

new load.evDI1 bus1=DI1.1.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand

new load.evDI2 bus1=DI2.2.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand

new load.evDI3 bus1=DI3.3.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand

new load.evDJ1 bus1=DJ1.1.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand

new load.evDJ2 bus1=DJ2.2.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand

new load.evDJ3 bus1=DJ3.3.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand

new load.evDK1 bus1=DK1.1.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand

new load.evDK2 bus1=DK2.2.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand

new load.evDK3 bus1=DK3.3.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand

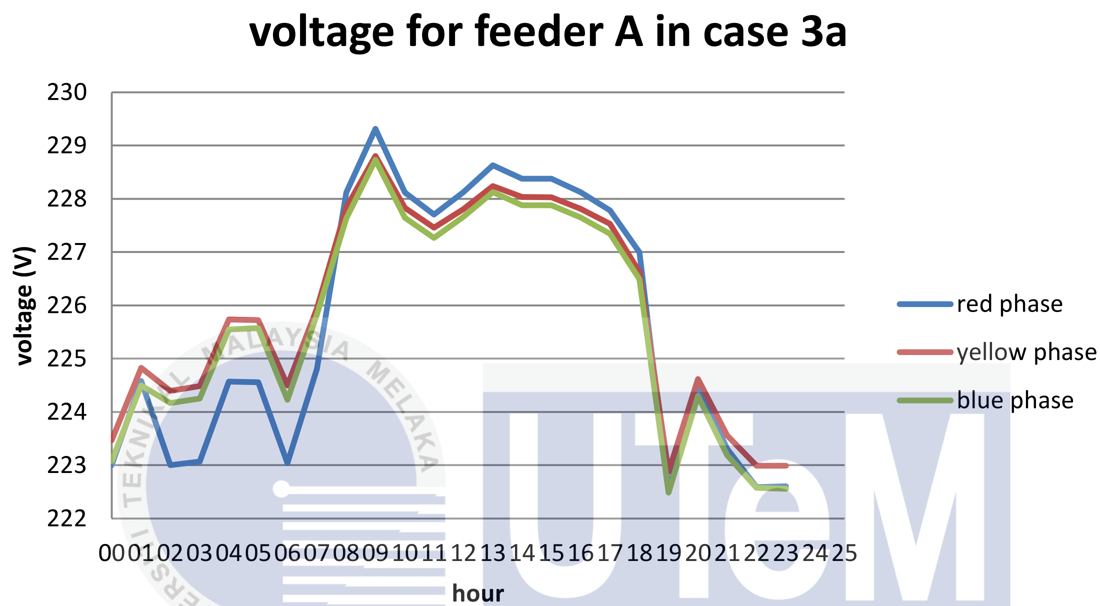
new load.evDL1 bus1=DL1.1.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand

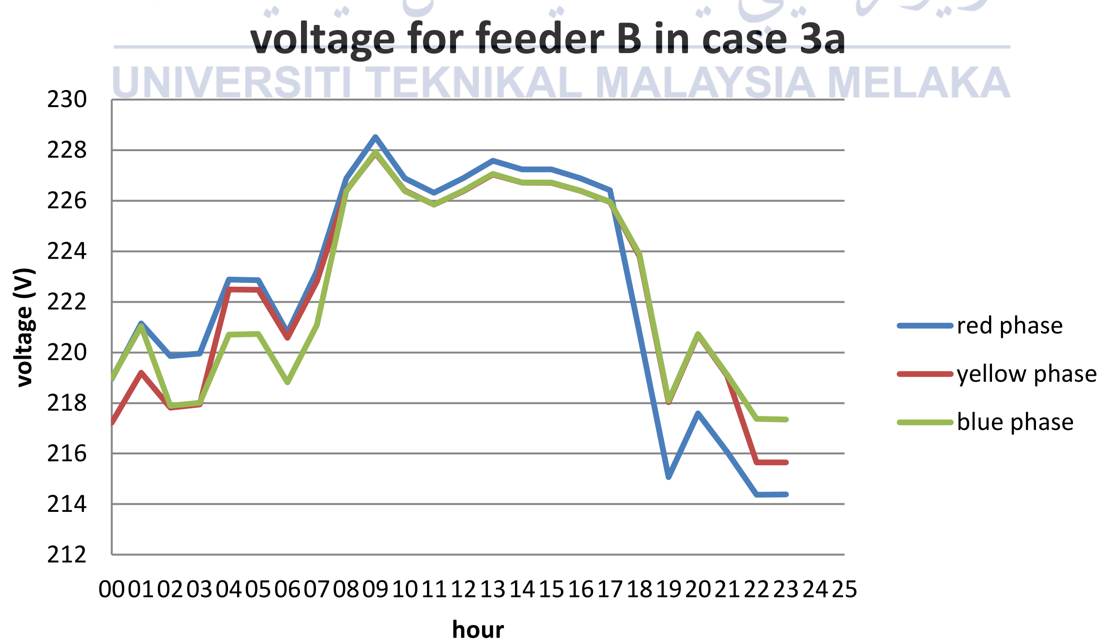
new load.evDL2 bus1=DL2.2.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand

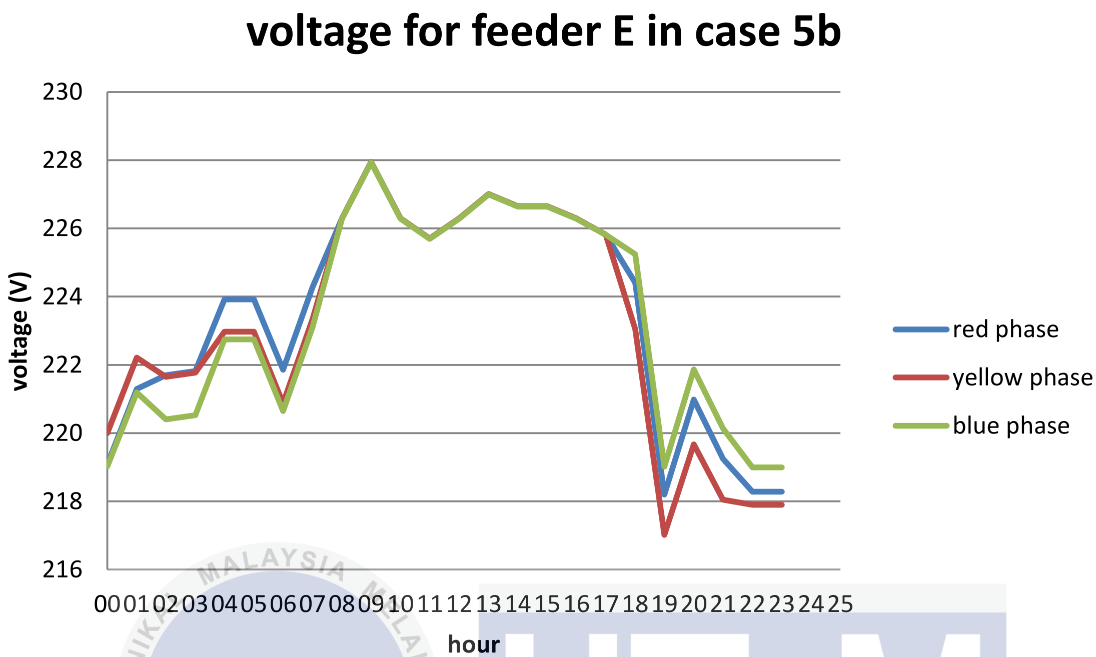
new load.evDL3 bus1=DL3.3.4 phases=1 kV=0.23 kW=3.3 pf=0.95 model=1 conn=wye status=variable daily=evdemand

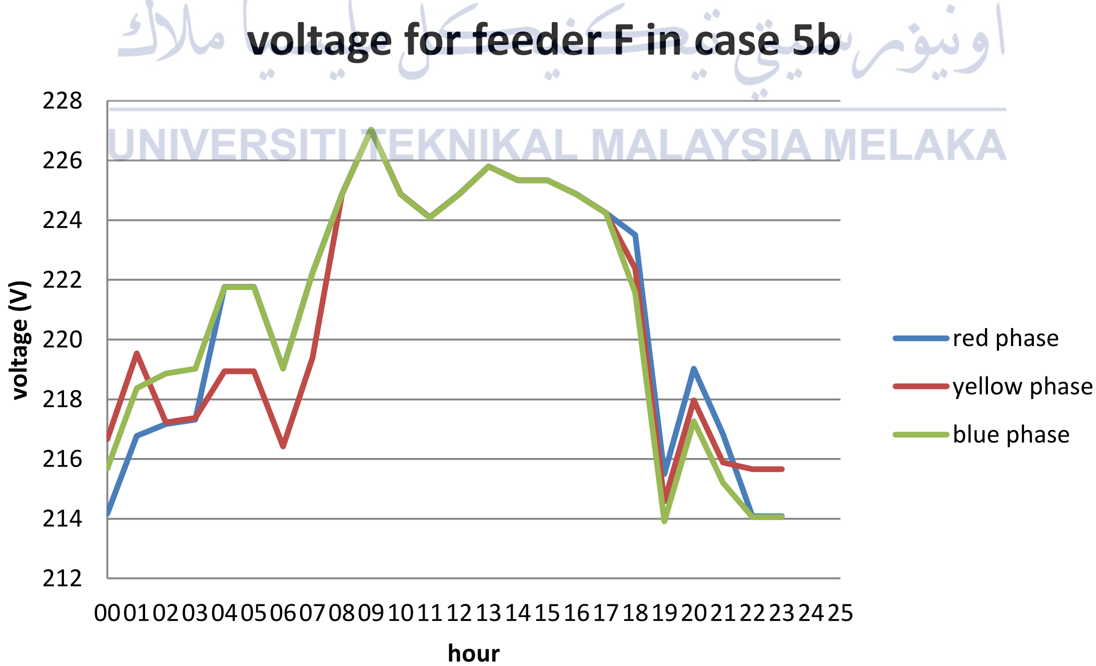
APPENDIX C

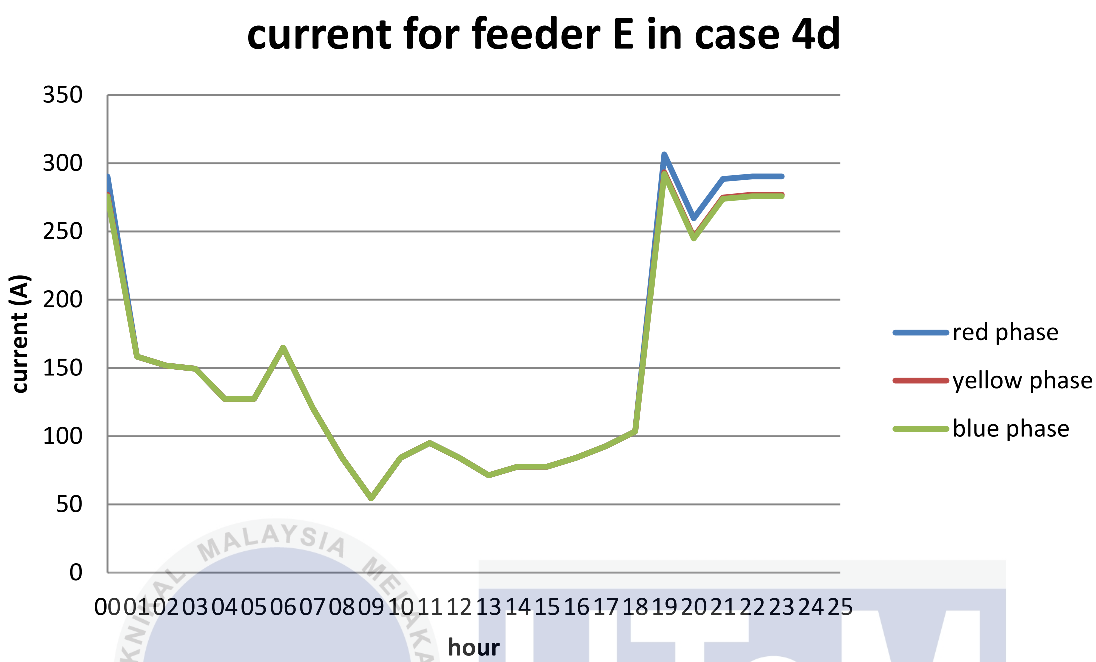
There was seven feeders in network, each feeder will have its own voltage, current and power graph. There were total more than two hundred graphs for all cases. Ten graphs from different cases for voltage and current were attached below.

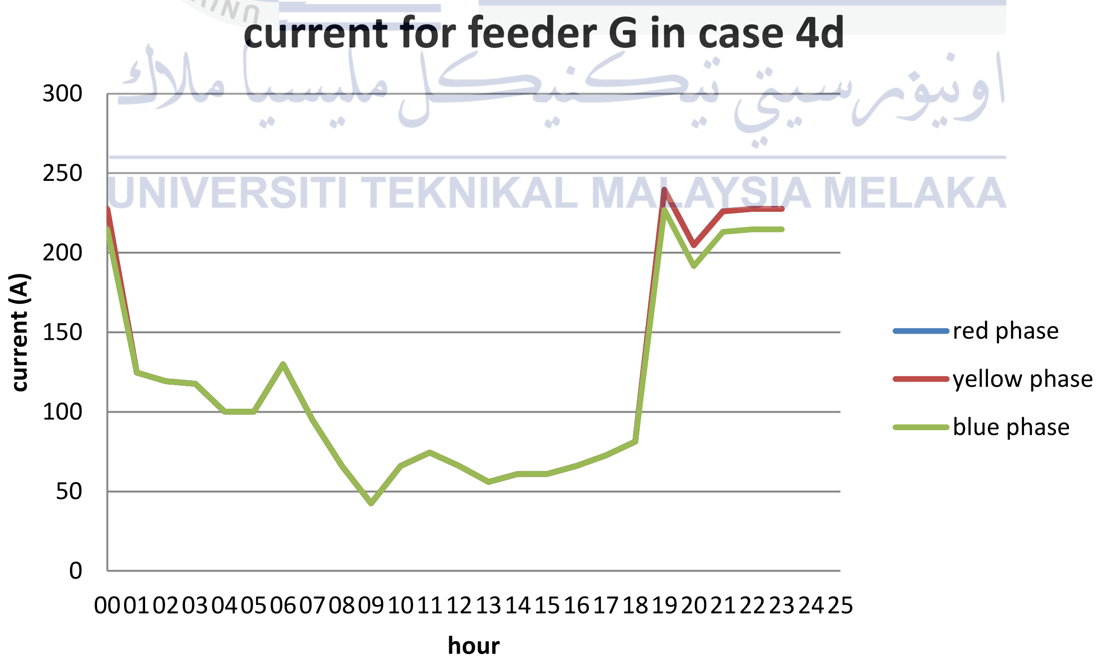


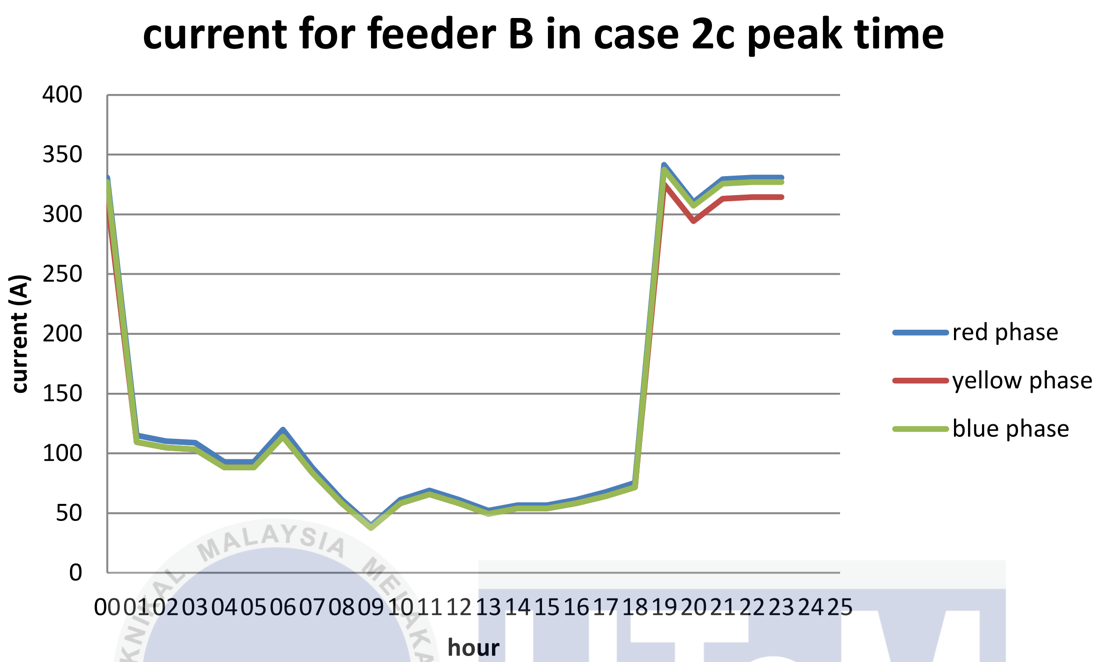


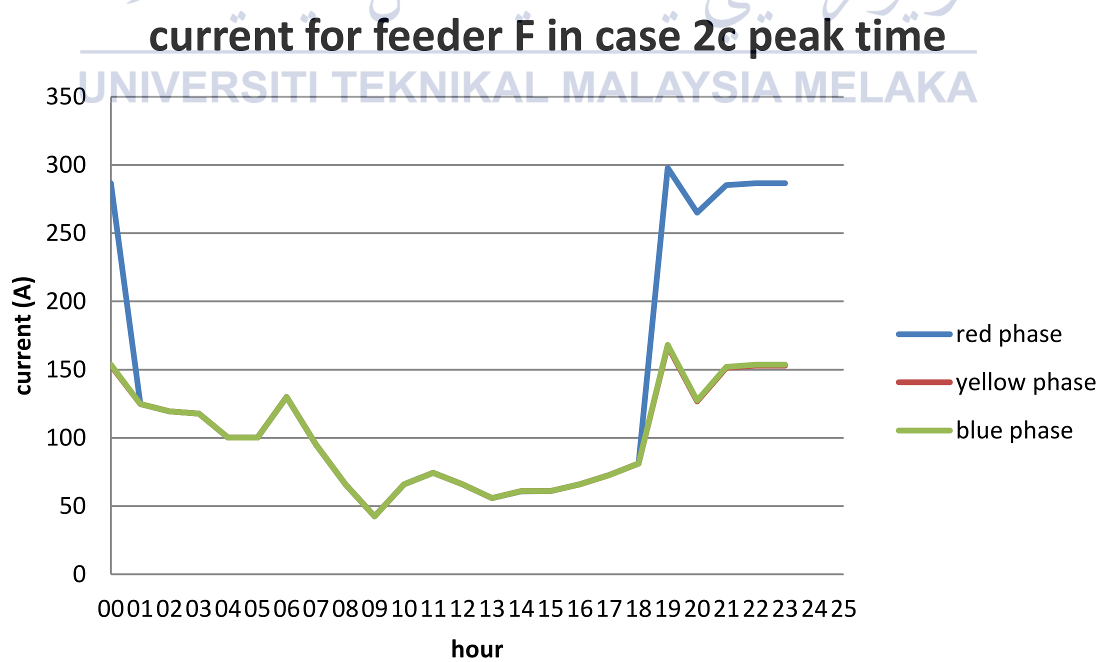

voltage for feeder E in case 5b
230
228
226
224
222
220
218
216
voltage (V)
00 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
hour
red phase
yellow phase
blue phase

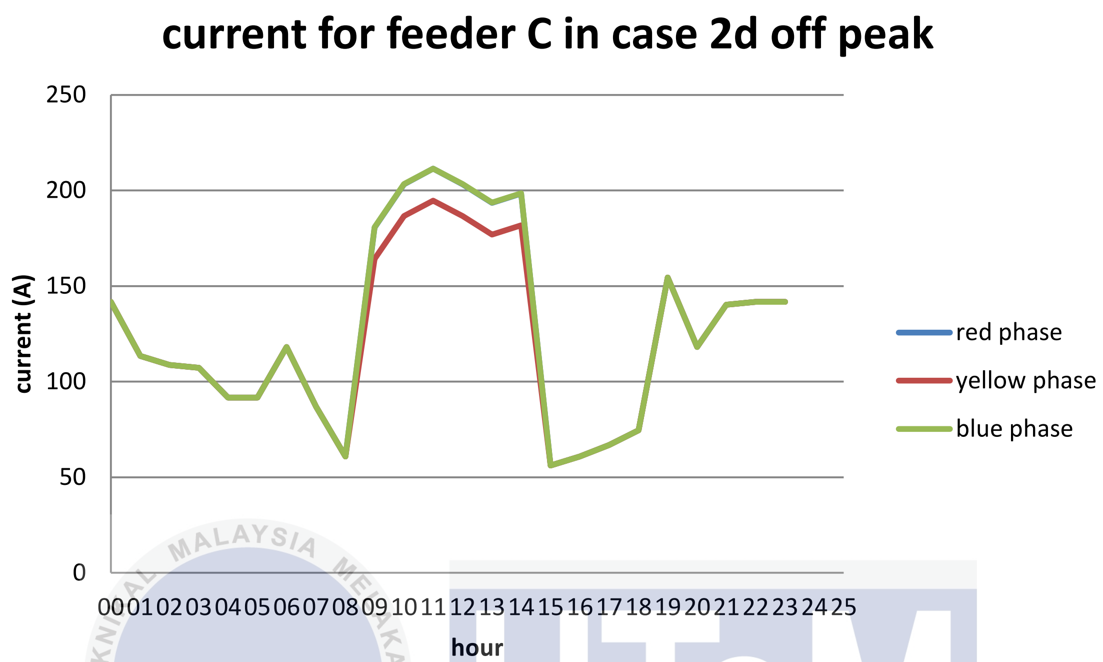

voltage for feeder F in case 5b
228
226
224
222
220
218
216
214
212
voltage (V)
00 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
hour
red phase
yellow phase
blue phase

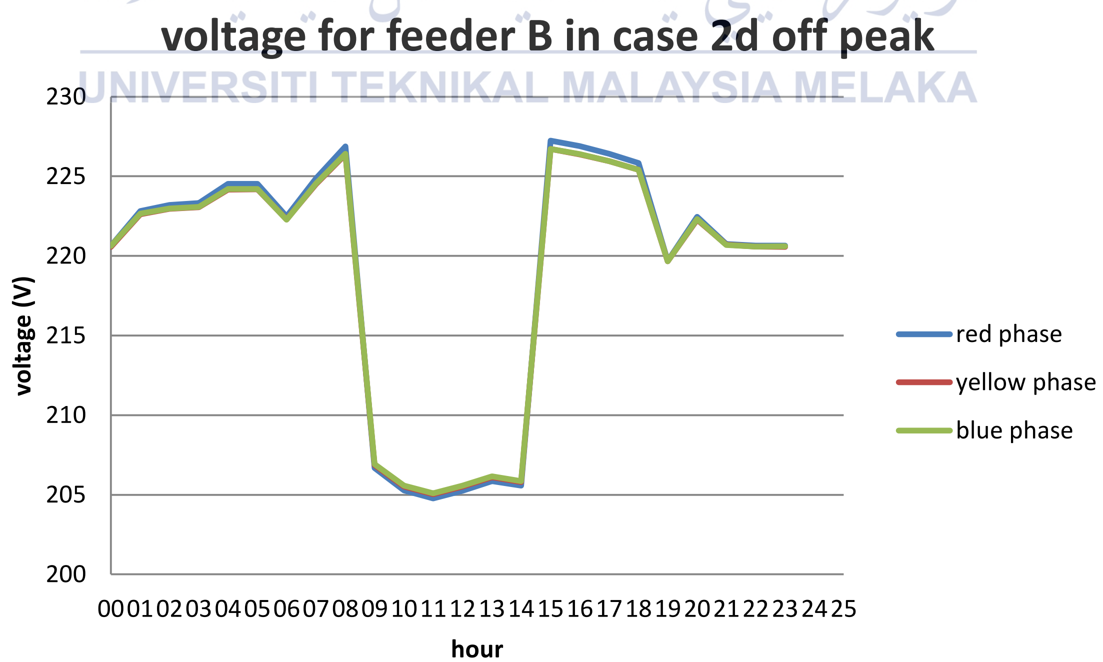

current for feeder E in case 4d
350
300
250
200
150
100
50
0
current (A)
00 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
hour
red phase
yellow phase
blue phase


current for feeder G in case 4d
300
250
200
150
100
50
0
current (A)
00 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
hour
red phase
yellow phase
blue phase


current for feeder B in case 2c peak time
400
350
300
250
200
150
100
50
0
current (A)
00 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
hour
red phase
yellow phase
blue phase


current for feeder F in case 2c peak time
350
300
250
200
150
100
50
0
current (A)
00 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
hour
red phase
yellow phase
blue phase


current for feeder C in case 2d off peak
250
200
150
100
50
0
current (A)
00 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
hour
red phase
yellow phase
blue phase


voltage for feeder B in case 2d off peak
230
225
220
215
210
205
200
voltage (V)
00 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
hour
red phase
yellow phase
blue phase

APPENDIX D

The table for EV amount for each case was attached for reference. For case 3 and case 5 which were controlled charging, there will be three periods for EV charging. For case 2 peak and case 4, same tables will be used and case 3 will used same tables with case 5. Case 2 off peak will use same table with case 2 peak and case 4. The only difference was case 2 peak and case 4 charge from 7pm until 1am while case 2 off peak charge from 9am until 2pm.

Case 2 peak and case 4- 7pm until 1am

Case 2 off peak- 9am until 3pm

100%

Type of houses	Single storey terrace house	Double storey terrace house	Semi detached house	Bungalow	Total houses per feeder
Feeder A	37	15	0	0	52
Feeder B	64	0	0	0	64
Feeder C	0	33	0	0	33
Feeder D	0	36	0	0	36
Feeder E	0	0	8	12	20
Feeder F	0	0	10	7	17
Feeder G	0	0	10	7	17
Total houses per type	101	84	28	26	**239**

80%

Type of houses	Single storey terrace house	Double storey terrace house	Semi detached house	Bungalow	Total houses per feeder

Feeder A	30	12	0	0	42
Feeder B	51	0	0	0	51
Feeder C	0	26	0	0	26
Feeder D	0	29	0	0	29
Feeder E	0	0	6	10	16
Feeder F	0	0	8	6	14
Feeder G	0	0	8	6	14
Total houses per type	81	67	22	22	**192**

60%

Type of houses	Single storey terrace house	Double storey terrace house	Semi detached house	Bungalow	Total houses per feeder
Feeder A	22	9	0	0	31
Feeder B	38	0	0	0	38
Feeder C	0	20	0	0	20
Feeder D	0	22	0	0	22
Feeder E	0	0	5	7	12
Feeder F	0	0	6	4	10
Feeder G	0	0	6	4	10
Total houses per type	60	51	17	15	**143**

40%

Type of houses	Single storey terrace house	Double storey terrace house	Semi detached house	Bungalow	Total houses per feeder
Feeder A	15	6	0	0	21
Feeder B	26	0	0	0	26
Feeder C	0	13	0	0	13

Feeder D	0	14	0	0	14
Feeder E	0	0	3	5	8
Feeder F	0	0	4	3	7
Feeder G	0	0	4	3	7
Total houses per type	41	33	11	11	**96**

20%

Type of houses	Single storey terrace house	Double storey terrace house	Semi detached house	Bungalow	Total houses per feeder
Feeder A	7	3	0	0	10
Feeder B	13	0	0	0	13
Feeder C	0	7	0	0	7
Feeder D	0	7	0	0	7
Feeder E	0	0	2	2	4
Feeder F	0	0	2	1	3
Feeder G	0	0	2	1	3
Total houses per type	20	17	6	4	**47**

a represent period 1 from 6pm until 12am

b represent period 2 from 10pm until 4am

c represent period 3 from 2am until 8am

<u>Case 3 and case 5</u>

100%

Type of houses	Single storey terrace house			Double storey terrace house			Semi detached house			Bungalow			Total houses per feeder
	a	**b**	**c**	**a**	**b**	**c**	**a**	**b**	**c**	**a**	**b**	**c**	
Feeder A	13	12	12	5	5	5	0			0			52
Feeder B	21	22	21	0	0	0	0			0			64
Feeder C	0	0	0	11	11	11	0			0			33
Feeder D	0	0	0	12	12	12	0			0			36
Feeder E	0			0			3	3	2	4	4	4	20
Feeder F	0			0			4	3	3	2	3	2	17
Feeder G	0			0			3	3	4	2	2	3	17
Total houses per type	34	34	33	28	28	28	10	9	9	8	9	9	**239**

80%

Type of houses	Single storey terrace house			Double storey terrace house			Semi detached house			Bungalow			Total houses per feeder
	a	**b**	**c**	**a**	**b**	**c**	**a**	**b**	**c**	**a**	**b**	**c**	
Feeder A	10	10	10	4	4	4	0			0			42
Feeder B	17	17	17	0	0	0	0			0			51
Feeder C	0	0	0	9	9	8	0			0			26
Feeder D	0	0	0	10	9	10	0			0			29
Feeder E	0			0			2	2	2	4	3	3	16
Feeder F	0			0			3	3	2	2	2	2	14
Feeder G	0			0			2	3	3	2	2	2	14
Total houses per type	27	27	27	23	22	22	7	8	7	8	7	7	**192**

60%

Type of houses	Single storey terrace house			Double storey terrace house			Semi detached house			Bungalow			Total houses per feeder
	a	**b**	**c**	**a**	**b**	**c**	**a**	**b**	**c**	**a**	**b**	**c**	
Feeder A	8	7	7	3	3	3	0			0			31
Feeder B	12	13	13	0	0	0	0			0			38
Feeder C	0	0	0	7	7	6	0			0			20
Feeder D	0	0	0	7	7	8	0			0			22
Feeder E	0			0			2	2	1	2	2	3	12
Feeder F	0			0			2	2	2	1	2	1	10
Feeder G	0			0			2	2	2	2	1	1	10
Total houses per type	20	20	20	17	17	17	6	6	5	5	5	5	**143**

40%

Type of houses	Single storey terrace house			Double storey terrace house			Semi detached house			Bungalow			Total houses per feeder
	a	**b**	**c**	**a**	**b**	**c**	**a**	**b**	**c**	**a**	**b**	**c**	
Feeder A	5	5	5	2	2	2	0			0			21
Feeder B	9	9	8	0	0	0	0			0			26
Feeder C	0	0	0	4	4	5	0			0			13
Feeder D	0	0	0	5	5	4	0			0			14
Feeder E	0			0			1	1	1	2	1	2	8
Feeder F	0			0			1	2	1	1	1	1	7
Feeder G	0			0			2	1	1	1	1	1	7
Total houses per type	14	14	13	11	11	11	4	4	3	4	3	4	**96**

20%

Type of houses	Single storey terrace house			Double storey terrace house			Semi detached house			Bungalow			Total houses per feeder
	a	**b**	**c**	**a**	**b**	**c**	**a**	**b**	**c**	**a**	**b**	**c**	
Feeder A	3	2	2	1	1	1	0			0			10
Feeder B	4	4	5	0	0	0	0			0			13
Feeder C	0	0	0	3	2	2	0			0			7
Feeder D	0	0	0	2	3	2	0			0			7
Feeder E	0			0			1	1	0	1	0	1	4
Feeder F	0			0			0	1	1	0	0	1	3
Feeder G	0			0			1	0	1	0	1	0	3
Total houses per type	7	6	7	6	6	5	2	2	2	1	1	2	**47**