"I hereby declare that I have read through this report entitle "Impact Of Grid-Connected To PV System" and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Electrical Engineering (Industrial Power)"

Signature : ………………………………….

Supervisor's Name : Prof. Madya. Dr. Gan Chin Kim

Date : ………………………………….

IMPACT OF GRID-CONNECTED TO PV SYSTEM

MUHAMMAD ZULHILMI BIN MOHD NOH

A thesis submitted in partial fulfillment of the requirement for the degree of Bachelor of Electrical Engineering (Industrial Power)

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

I declare that this report entitle "Impact Of Grid-Connected To PV System" is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : …………………………………….

Name : MUHAMMAD ZULHILMI BIN MOHD NOH

Date : …………………………………….

DEDICATION

To my beloved father, mother and whole family. And not to forget to beloved lecturer and friend.

ACKNOWLEDGEMENT

To complete this report and research i have go through many obstacle, so I have refer to many side such as researchers, academicians and practitioners. Those of them help me a lot of to understand and improve my knowledge. I wish to express my sincere appreciation to my main project supervisor, Prof.Madya Dr. Gan Chin Kim for guidance in order to compete my research. I was survive now because their continued support and interest to follow up my research.

And do not miss, for my fellow postgraduate student that also support me in term of physically and mentality. Without their support I may be not strong enough to fulfil my research.

And lastly, I am grateful to all may family member for their kindness and supportive. I was fortunate to be a part of this family.

ABSTRACT

The increasing of Distributed Generation (DG) in the electrical network may cause power quality problem such as fluctuation, voltage rise, unbalance voltage and other [1]. In this research, residential grid-connected solar system was considered as the DG in the low voltage network. This research starts to model the low voltage residential network at the selected location. In Malaysia solar system at residential was directly selling to TNB without connected to the load. Hence, the area of research randomly selected. Subsequently, it will continue to install the PV system at the network. Main of this research is to analyse the impact of grid-connected on the distribution network. This research utilises Digsilent software which is well known as simulation software in power system analysis. The results obtained can be divided by two parts which are the result before PV installation and after installation. Both of the result will be compared to analyse its impact to the network.

ABSTRAK

Peningkatan pengjanaan elektrik dikawasan pembahagian (DG) dalam rangkaian elektrik boleh memperngaruhi masalah didalam kualiti kuasa seperti turun naik voltan, kenaikan voltan, voltan tidak seimbang dan lain-lain [1]. Dalam kajian ini, kediaman sistem solar grid yang berkaitan adalah mempertimbangkan sebagai KP dalam rangkaian voltan rendah. Kajian ini bermula untuk model rangkaian kediaman voltan yang rendah pada lokasi yang dipilih. Di Malaysia sistem solar di kediaman telah terus menjual kepada TNB tanpa disambungkan ke beban. Oleh itu, bidang penyelidikan yang dipilih secara rawak. Selepas itu, ia akan terus memasang sistem PV di rangkaian. Utama kajian ini adalah untuk menganalisis kesan grid yang berkaitan pada rangkaian pengagihan. Kajian ini menggunakan perisian Digsilent yang terkenal sebagai perisian simulasi dalam analisis sistem kuasa. Keputusan yang diperolehi boleh dibahagikan kepada dua bahagian yang hasilnya sebelum pemasangan PV dan selepas pemasangan. Kedua-dua keputusan yang akan dibandingkan untuk menganalisis kesannya kepada rangkaian.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Malaysia is in the midst of an era of strong industrial growth due to strong domestic demand together with the development of science and technology is significant. To cope with the economic and industrial growth, energy demand is growing rapidly. So, government must take other alternative to accommodate the energy needed in this country. Renewable Energy (RE) was marked as the 'fifth fuel' that supplied the energy needs of the country. Thus, in 2011 parliament of Malaysia has given approval to the Renewable Energy (RE) in Malaysia. Hence, "Renewable Energy Act 2011" is introduced as law in RE by SEDA [2]. This act intend to establishment and implementation of tariff system. This important to encouraging Malaysia citizen for install renewable generation. In 2014, the total RE capacity approval is 396.61MW and it represents year by year growth of 466% [2]. It has been found that among all the renewable energy sources, solar energy is the most prospective one in Malaysia. Malaysia's strategic geographical location makes it an advantage because of its huge amount of the solar irradiance. The longitude of Malaysia is located at the equatorial region with an average solar radiation of 400–600 MJ/m2 per month [3]. That mean land of Malaysia achieves a higher exposure to the sun's rays throughout most day. As a result, The Small Renewable Energy Power Programme (SREP) was launched to allow independent producers of renewable power to connect to the distribution network and gain compensation for their energy generation [3]. And another programme, dubbed Malaysian Building Integrated Photovoltaic Technology Application Project (MBIPV) encouraged the public and commercial sectors to institute solar technology into their premises, providing energy for a portion of their electricity consumption [1]. On the governmental effort to explore renewable generation technologies and to reduce the carbon footprint, now there are many areas such as residential, premise or other type of building had ben install the solar photovoltaic system on their place.

1.2 Background research

Photovoltaic (PV) generation has now-a-days proved to be a cost-effective method for renewable power generation with minimum environmental impact. Due to environmental and economic benefits, PV is now being widely deployed as a distributed energy resources (DER) in distributed generation systems. Photovoltaic (PV) is the technology that converts energy from sunlight into electrical energy. Photovoltaic generation have two type which are solar photovoltaic (PV) connected to grid and stand-alone solar system. Nowadays, the number of installation PV system was increasing does not matter in individual, community or non-individual scope producing. Individual installation for the residential distribution while community include for school or other government building. And non-individual for reseller of electric company. In 2014, statistic show the number of approve by FiAH to generate electricity using PV system is 4065 for individual, 91 for community and 342 for non-individual [20]. Hence, mostly connected to distribution network system which means connected to the grid. The total estimation in (MW) of capacity for individual for 2014 installation is 4.32% from total RE in Malaysia and it not include the available PV system that already install. Due to increasing installation PV system to the distribution, it could have the impact to the network grid base on the reverse power flow.

1.3 Problem statement

Photovoltaic (PV) are suitable for the energy generation in Malaysia. However, when a certain time the penetration of PV is higher than total load used, meaning higher ratio of PV generate voltage will injected to the grid system , significant grid stability issues may arise. Grid voltage fluctuation is a notable concern [1]. The previous power flow designing system of the national producer only consider the one way direction of power flow without consideration a reverse power flow by the distribution generation. Since that situation, the reverse power flow may have impact on the national grid system. Moreover, the research have found about PV integration may bring the reverse power flow and cause voltage rise in the grid [5]. Hence, several serious technical issues relating to power quality, distribution system efficiency and else must be study .This analysis important to minimise the potential negative impact of the PV integration to national grid system.

1.4 Objective

The objective of this project is:

1. To model the power flow of the residential area.
2. To study impact of grid-connected solar system to residential low voltage network due to voltage profile and losses of the system.
3. To understand the use of Digsilent software.

1.5 Scope Of Research

The scope of research is

1. Select the low voltage residential area at Taman PD Impian Putra Port Dickson Negeri Sembilan.
2. Modelling the residential area using Digsilent software.
3. Compare voltage profile at each feeder.
4. Check the the statutory limit for voltage variation
5. Analyse the losses of the network when PV was install.

1.6 Contribution Of Research

This research will give benefit to the distribution low voltage system network if it was study deeply. Whether the impact distribution generation will give positive impact to voltage profile and losses or negative. This because if the PV have positive impact to the grid, the government have to concern the community to install the PV for every each residential home. So consumer will generate their own power supply thus minimise the energy consumption and monthly bill.

1.7 Report Outline

This research will cover five chapters. Chapter one will cover the introduction, project background, project objective, scope of project and problem statement. These to intend the motive of this project occur. Chapter two will elaborate about the theory and basic concept of the project and comparison between previous researches. And then chapter three explain the method used in this research. All the equipment and type of modelling will be introduces. Then in chapter 4, there are overall results for this research. And lastly, there are conclusion about the study impact of grid-connected solar system to residential low voltage network due to the voltage profile and losses that are study.

CHAPTER 2

LITERATURE REVIEW

2.1 Theory And Basic Principle

A grid connected photovoltaic power system is electricity generating at the distribution area which will transfer to the grid network. For a basic connection of photovoltaic connected to the grid usually have a few part that needed such as solar panel, inverter, power conditioning units and grid connection equipment.

2.2 System Of Solar

PV generation systems usually consist of series-parallel Combinations of PV cells in order to obtain the required voltage and current output. These combinations, known as PV panels and arrays, generate DC power that has to be converted to AC at standard power frequency in order to feed the loads [4]. Therefore system of photovoltaic has been available for inverter to ease conversation power from DC to AC supply. There are a few type of PV panel that famous used in the building such as monocrystalline, polycrystalline, thin-film types. Each of the PV panel has their own characteristic and behaviour.

2.3 Module technology

2.3.1 Monocrystalline

Monocrystalline are made off from single silicon seed crystal which is took to the crucible of molten silicon and then was pulled slowly while rotating, so the content of the monocrystalline cell can produce pure crystalline silicon ingot [10]. Between existing solar panel, monocrystalline are most efficient and expensive. Commercially available of solar cell have efficiencies of 22.5% [7].The typical monocrystalline solar cell usually is a dark black colour look alike figure 2.3.1 below.

Figure 2.3.1: Monocrystalline cell

2.3.2 Polycrystalline

Different with monocrsytalline, polycrystalline are not manufacture from single crystal ingots. It made off from block casting molten silicon [7]. Polycrystalline is less efficient than monocrystalline because it content from many small of crystals which the molecule are random orientations. However, it easier to install and less expensive. The laboratory research about efficiency of polycrystalline are recorded which is 17.84% [7]. In figure 2.3.2 is polycrystalline look alike.

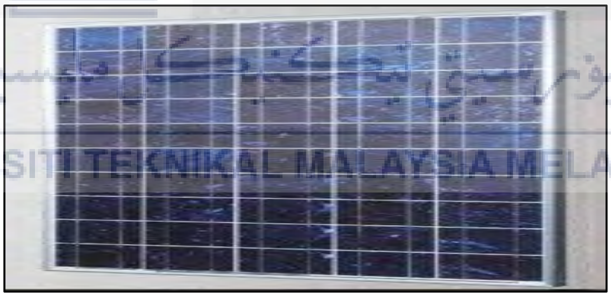


Figure 2.3.2 : Polycrystalline

2.3.3 Thin-film

There are three primary type of thin film which is amorphous silicon, cadmium telluride and copper indium [9]. Mostly all the thin film is expensive rather than other type of solar cell. Previous research has upgrade to increase the efficiencies of solar cell to 20.1% [7].

Figure 2.3.3 : Thin-film cell

2.4 Operation Of Solar Cell

When sunlight strikes the solar cell, electrons are knocked loose. They move toward the treated front surface. An electron imbalance is created between the front and back. When the two surfaces are joined by a connector, like a wire, a current of electricity occurs between the negative and positive sides [1].

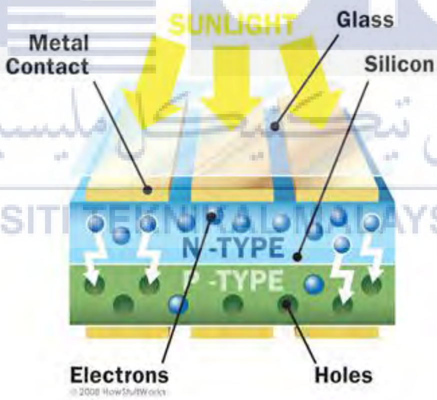


Figure 2.4.1: Structure of solar sell

2.5 Solar Radiation

The operation of PV system depends on radiation of sunlight. There are three type of solar radiation strike on PV panel which direct, diffusion and reflected radiation [18]. Direct radiation means there no shading between sunlight to the solar cell. The diffusion radiation is when sunlight is blocking by cloud or other component. And lastly reflected radiation is the part that reflected by surfaces in front of panel. If radiation of sunlight high toward to solar cell then the value generating current increase.

2.6 Technical impact of PV generation to distribution network

2.6.1 Voltage Fluctuation

From previous research, Installation of PV system to the grid may influence the voltage fluctuations [8]. Voltage fluctuation may occur when the weather is uncertain, sometime a formation of thick cloud or bright situation which no shading from obstacle. Hence, make the uneven power generation to the grid.

2.6.2 Harmonic

Harmonics distortion one of the effect toward installation of PV system to the grid [8]. The existing of harmonics because there are electronic devices used in the PV system such as inverter. Inverter is use to convert DC current to AC. Means, when the installation of PV system is increase so the use of electronic devices also increase. Thus, harmonics distortion may occur or maybe will exist in big amount.

2.6.3 Reverse Power Flow

PV is distribution generation for a small scale. For PV connected to grid, when extra power was produces, it will flow to the national grid. And when power generates by PV cannot support the maximum demand, the TNB power will supply. That makes the network flow two way condition.

2.7 Digsilent Software

Digsilent power factory is power system analysis software that currently used in electrical modelling, analysis and simulation for more than 2 decade [19]. It applicability to modelling of generation, transmission line, distribution and industrial network. Digsilent preparing the whole modelling features for studying all kind of phasing technologies, meshed or radial topologies. Hence to minimize network unbalance, improve quality of generation and optimize distribution network. Our grid system was design for one flow direction only, but existing of distribution generation will give reverse power flow. Digsilent software is suitable tool to analyse the impact of distributed generation on the network and in figure 2.7.1 is logo of Digsilent software. It includes calculating voltage drop, unbalancing network, load and generation model [19]. In Malaysia, digsilent is one of the software that has been use in modelling and analysis among other software by TNB. In this research, digsilent software was used to get the overall analysis.

Figure2.7.1: Logo of Dig silent

2.8 Load Profile And PV Generation

By referring typical aggregated Malaysia domestic load shape [12], 24 hour load shape was assigned to the each house of the residential network at figure 2.8.1 below. Base on the load shape, the lowest demand start in working hour period where starting 9.00 a.m. until 5.00 p.m. It can be assumed nobody have at the house in the range and only small of quantity power was consume for the appliance at the house. Hence, the demand was increase when time achieve at 5.00 p.m until night. The increase of power consume maybe all the major appliance was totally used such as air-Cond, washing machine, television and other that contribute of power consume.

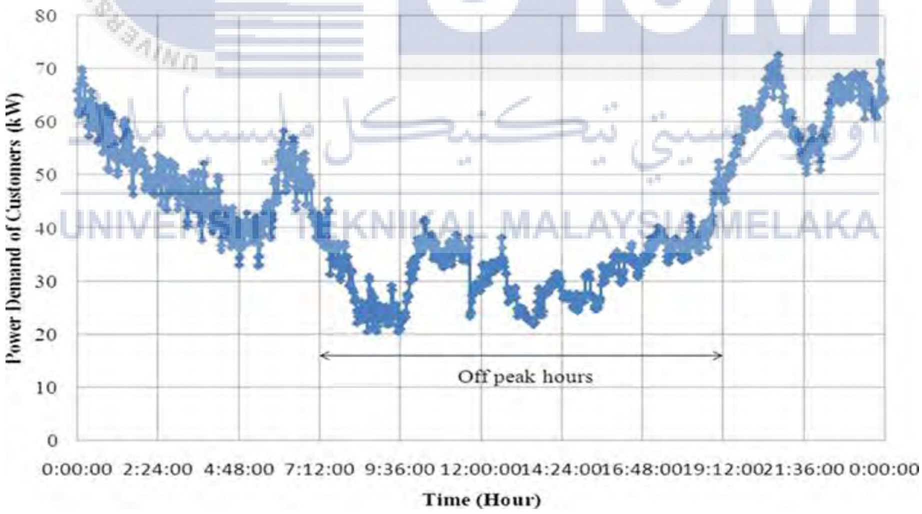


Figure2.8.1: Load demand

The other graph is the 24 hour power generation of PV system taken from [12] at figure 2.8.2 below. PV system generate the maximum power 11.00 am until 5.00 p.m. According the This time, the irradiation of solar was high to generate the electric. Hence when night and early morning, the PV no generate the electricity.

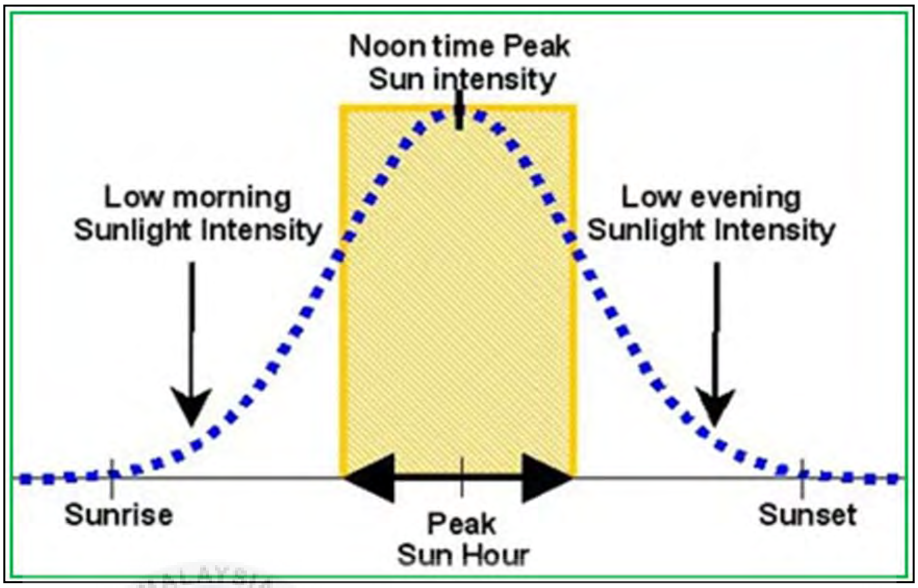


Figure2.8.2: Radiation of sunlight

However comparison between both of graph at figure 2.8.3, we know at the time PV generate maximum electricity the minimum load was use. So surplus of voltage will flow back to grid. It is important to investigate the impact of reverse power flow to the grid.

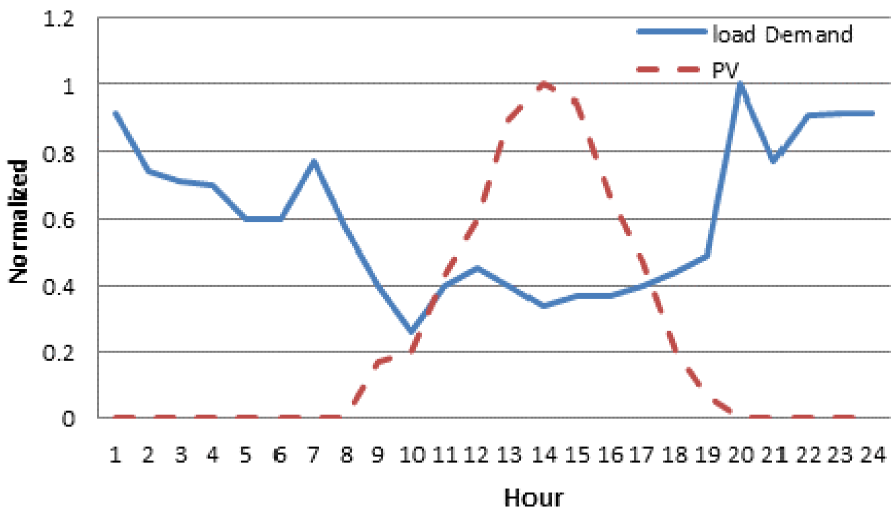


Figure 2.8.3: Load profile and PV generation profile

CHAPTER 3

METHODOLOGY

3.1 Introduction

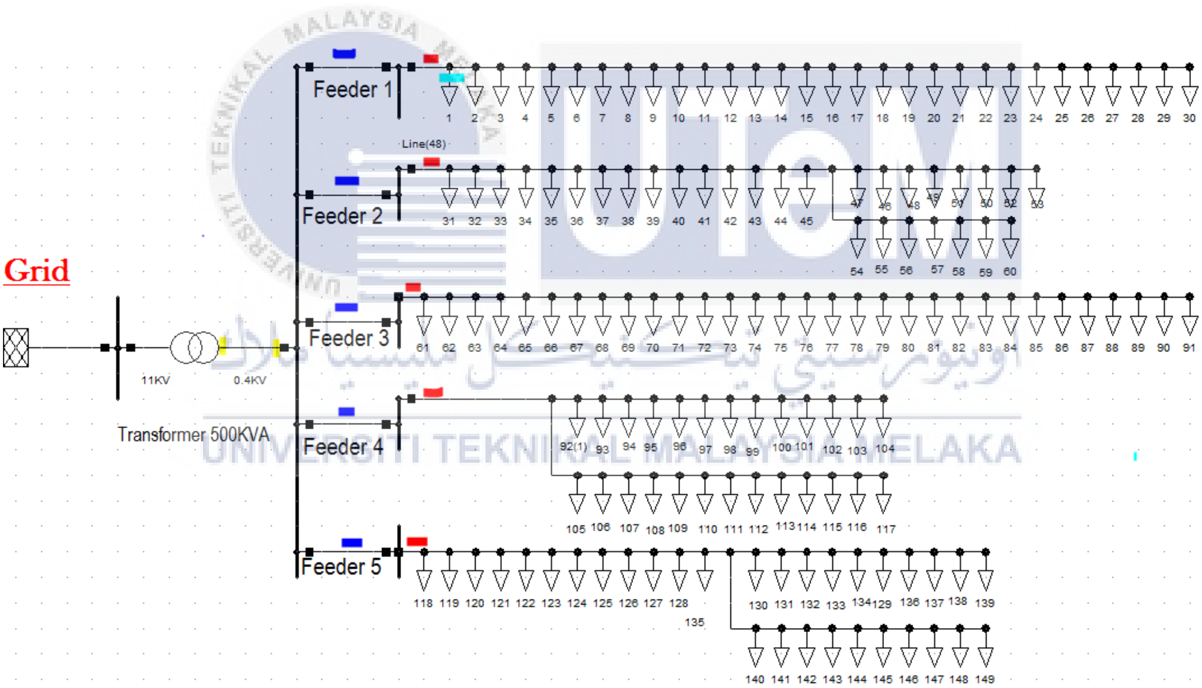
Based on the available network data at figure 3.1.2 and table 3.1.1 given from TNB, several approaches have been used to model the residential distribution network. Taman PD Impian Putra Port Dickson Negeri Sembilan was chosen as the location research. The available data are transformer rating, the number of feeder, cable rating and cable type. The residential low voltage network is supply 11KV incoming from TNB network. And then was step down by transformer to 415KV at rating transformer 500kva. The type of cable using to connect between the transformer and feeder pillar is 4x500 mm^2 PVC/PVC Aluminium (Al) which is along 10 metre. There are 5 feeders that connected to the bus bar at the feeder pillar. The type of cable using between feeder pillar and pole is 185 mm^2 4C Al. XLPE. The Aerial bundle cable (ABC) 3 x 185 mm^2 + 120 mm^2 was used for distribute the electric to the houses in that area.

The residential LV network is three-phase four wire radial system. For feeder 1 and 2 it serves a total of 30 houses, feeder 3 serves 31 houses. And then, feeder 4 is the shortest feeder measuring 186 metre which has 26 houses. Lastly, feeder 1 with longest length of 360 metre which serves 32 houses.

According the TNB, standard maximum demand for the terrace type of house will consume 2kw for each consumer [11]. All consumers are modelled for the same power load with power factor 0.95 for each house. And for the overall maximum demand for the total house will consume 298KW.

Table 3.1.1 :Characteristic of network

Characteristic	Quantity/Rating
Area (km^{2})	0.075
No. of houses	149
Total demand (kw)	298
Energy consumption (MW/year)	1572
Load density (MW/km^2)	4
Total network length (km)	1.5
Transformer rating (kVa)	500



(yellow)	**4 x 500 mm^2 PVC/PVC AL**
(blue)	**185 mm^2 4C XLPE AL**
(red)	**ABC 3 X 185 mm^2 + 120 mm^2**
(light blue)	**16 mm^2 PVC/PVC**

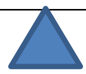
	**house**

Figure 3.1.1: Single line diagram for low voltage distribution network at Taman PD Impian Putra

The Dig Silent power factory 15.1 software has been used to modelling the low voltage residential area network and performs all the behaviour the power flow system before and after installation of the PV system. This software capable to simulate the steady state, dynamic and transient modelling of low voltage distribution network [14].

3.2 Network Loses

In power transmitting system there are no 100% efficiency, there are existing of power loses in the line whether come from cable or other factor. In the line of distribution network there are loses at the underground cable or overhead line based on the parameter per length of resistance [13]. There are equation for the power loses at (1) below.

$$P_{losess} = I^2R = \frac{(P_G - P_L)^2 + (Q_G - Q_L)^2}{V^2}R \quad (3.2.1)$$

P_G and Q_G are the real power (kw) and the reactive power (kVar) respectively for the PV system .While P_L and Q_L is real power (kw) and reactive power (KVar) for the loads. I is the line current for the network and then V is the line voltage. R is the cable resistance.

3.3 Voltage Unbalance

The three-phase voltage in the power system is in sinusoidal and balance in magnitude by each phase divided by 120°. By existing of distribution generation like solar may cause the voltage unbalance in the system. In Malaysia, the standard limit of voltage unbalance approval is 1.0% [16]. The major factor cause unbalance voltage is unequal voltage magnitude at the fundamental system frequency such as under voltage or overvoltage, fundamental phase angle deviation and unequal level of harmonic distortion between phases [17]. The impact of unbalance voltage will increase losses and heating effect. To calculate the degree unbalance of voltage use equation Voltage Unbalance Factor (VUF) [13].

$$VUF(\%) = \frac{V^-}{V^+} \times 100 \quad (2)$$

Where V^- and V^+ is negative and positive sequence of voltage respectively. The V^- and V^+ will get from resolving three phase unbalance line voltage V_{ab}, V_{bc}, and V_{ca} into symmetrical component which V^- and V^+.

3.4 Load Estimation

TNB have provided the scheme of load estimation for every design premise and location. All the values of estimation base on demand from customer and available data from TNB. Table 3.4.1 show the range of estimation [11]. For this analysis, type premise is single storey terrace and located at urban area. So, 2.0 Kw was used as reference demand.

Table 3.4.1: Table demand estimation for premise

No.	Type of premise	Rural (Kw)	Suburban (Kw)	Urban
1	Low cost flats, single storey terrace, studio apartment(<600 sq ft)	1.5	2.0	3.0
2	Double storey terrace or apartment	3.0	4.0	5.0
3	Single storey, semi detached	3.0	5.0	7.0
4	Double storey, semi detached	5.0	7.0	10.0
5	Single storey bungalow & three room condominium	5.0	7.0	10.0
6	Double storey bungalow & luxury condominium	8.0	12	15

3.5 Penetration Level Of PV

For this research, there are level penetrations of PV system are being use system to indicate for every changes behaviour of the area residential low voltage network. The starting penetration level of PV is 20% until 200%. Number of PV install can get from the equation (3.5.1). Where percentage of PV time with total number of load or houses which is 149. And then get the number of PV want install it. The PV was randomly installed to every feeder and capacity installation for every percentage at the table 3.5.1.Every single number of PV generates 2kw output of power. Figure of network after installation of PV was shown in appendices.

$$\frac{penetration\ of\ PV\ (\%)}{100\%} \times 149 \approx number\ of\ PV\ install \qquad (3.5.1)$$

Table 3.5.1: Number of PV install

Penetration level of PV(%)	Number of PV install	Capacity of PV install (kw)
20	30	60
40	60	120
60	90	180
80	120	240
100	149	298
120	180	360
140	210	420
160	240	480
180	270	540
200	298	596

3.6 Parameter Of Low Voltage Residential Area

3.6.1 Characteristic Of Transformer

For this low voltage residential area, it use step –down three phase transformer which have 0.5 MVA at nominal frequency 50Hz. For the low and high voltage side it's rated at 0.4 Kv and 11Kv respectively. This transformer using delta to start winding connection. On table 3.6.1 below there is nameplate of the transformer.

Table 3.6.1: Characteristic of Transformer

Characteristic	Rating
Rated power	0.5MVA
Nominal frequency	50HZ
Rated voltage - HV side/LV side	11/0.4kV
Vector group – HV side/LV side	Delta-Y connection

3.6.2 Characteristic Of Cable

1. 4x500 mm^2 PVC/PVC Aluminium (Al)

Between of transformer and main feeder, the cable use is 4x500 mm^2 PVC/PVC Aluminium. It is a three phase and neutral cable with rated current is 1Ka. For parameter per length 1, 2- sequence, it has AC-Resistance R' (20'C) at 0.11 ohm/km and Reactance X' is 0.14 ohm/km. Then for parameter per length zero sequence it has AC-Resistance R0' at 0.12 ohm/km and Reactance X0' 0.15 ohm/km. Rated voltage is 0.4Kv for cable. In figure 3.6.2 is a rating of cable.

Table 3.6.2: characteristic of cable

Characteristic	Rating
Rated current	1kA
Rated voltage	0.4kV
AC-Resistance R' (20'C)	0.11 ohm/km
Reactance X'	0.14 ohm/km
AC-Resistance R0'	0.12 ohm/km
Reactance X0'	0.15 ohm/km

2. 185 mm^2 4C Al. XLPE

Cable 185 mm2 4C Al. XLPE connection between main feeders to distributed feeder. It is a three phase and neutral cable with rated current is 1Ka.rated voltage of this cable is 0.4kV. For parameter per length 1, 2- sequence, it has AC-Resistance R' (20'C) at 0.165 ohm/km and Reactance X' at 0.076 ohm/km. In table 3.6.3 there is a rating of cable used.

Table 3.6.3 characteristic of cable

Characteristic	Rating
Rated current	1kA
Rated voltage	0.4kV
AC-Resistance R' (20'C)	0.165 ohm/km
Reactance X'	0.076 ohm/km
AC-Resistance R0'	0.12 ohm/km
Reactance X0'	0.15 ohm/km

3. (ABC) 3 x 185 mm^2 + 120 mm2

To distribute power supply from feeder to house, cable 3 (ABC) 3 x 185 mm2 + 120 mm^2 is used. In table 3.6.4 below there are rating of cable. It is a three phases and neutral cable with rated current is 1Ka and rated voltage of this cable is 0.4kV. For parameter per length 1, 2- sequence, it has AC-Resistance R' (20'C) at 0.165 ohm/km and Reactance X' at 0.076 ohm/km. Then for parameter per length zero sequence it has AC-Resistance R0' at 0.18 ohm/km and Reactance X0' 0.03 ohm/km.

Table 3.6.4: characteristic of cable

Characteristic	Rating
Rated current	1kA
Rated voltage	0.4kV
AC-Resistance R' (20'C)	0.165 ohm/km
Reactance X'	0.076 ohm/km
AC-Resistance R0'	0.18 ohm/km
Reactance X0'	0.03 ohm/km

3.6.3 Characteristic Of Load

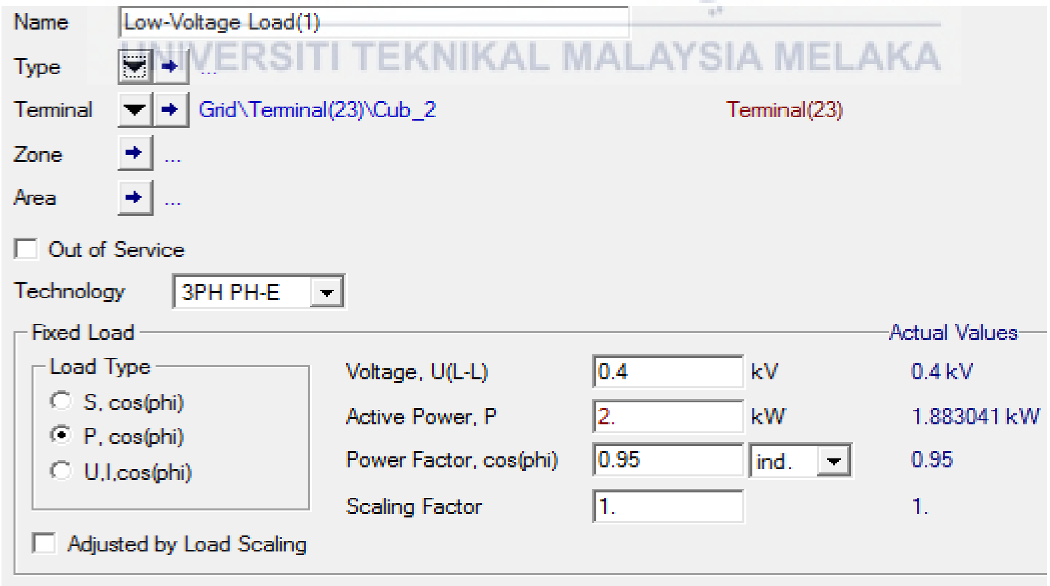


Figure 3.6.1: Characteristic Of Load

For the load, it used 2kw for each house at the area. This value was estimation from TNB data for single storey terrace at suburban area [11].Figure 3.6.1 show the characteristic of load.

3.6.4 Characteristic Of PV

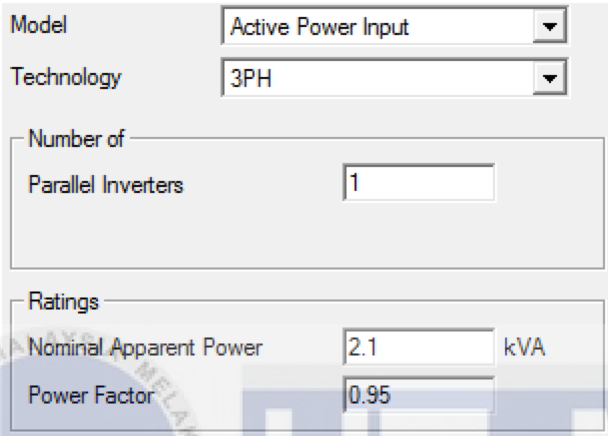


Figure 3.6.2: Characteristic Of PV Generation

On PV system, it generate 2kw each house which install it. It have 0.95 power factor and nominal apparent power is 2.1 Kva. Figure 3.6.2 show characteristic of PV in the Digsilent software.

3.6.5 Time Characteristic Of Load Demand

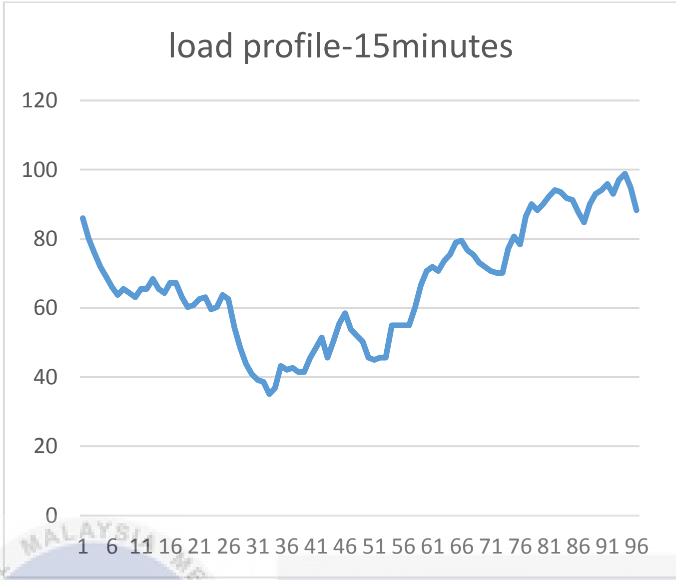


Figure3.6.3: Load Profile

At figure 3.6.3 above, there are time characteristic of load demand for each 15 minute and value of time characteristic load used in per cent for each 15 minute respectively that taken from [13]. Load used for each house is not same for every time. .In appendix shows the value of load demand for each 15 minute in per cent of the load use [13]. The load use not 24 hour are static, in every minute it will change depend on users. So for this research use gap for 15 minute changes of load use. It suitable time gap to use based changes using of load.

3.6.6 Time Characteristic PV Generation

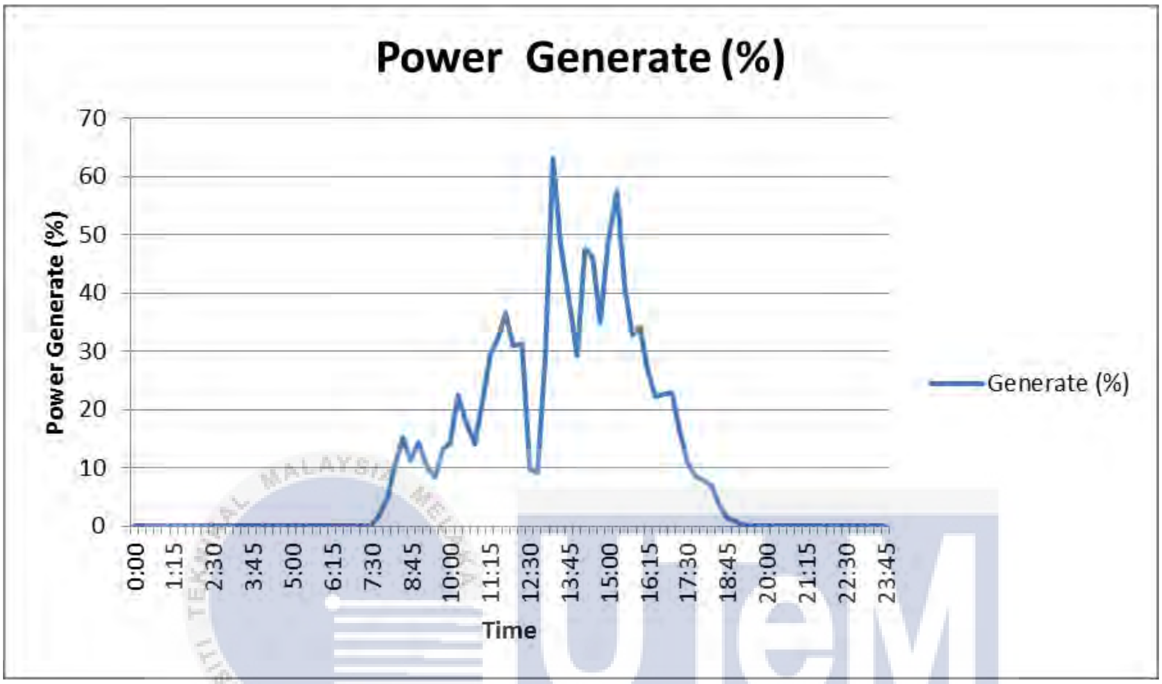


Figure 3.6.4: PV Generation Profile

In figure 3.6.4 show the time characteristic of PV generation for each 15 minute and value of PV generate power for each 15 minute in per cent respectively along a day [13]. The value of PV generation in 24 hour per day was taken from [13]. So the value in per cent in in appendix shows generating by PV from 2kw.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Impact Of PV On Voltage Profile At Each Feeder

There are 5 number of feeder in the low voltage residential area at Taman PD Impian Putra Port Dickson. Every each feeder was recorded their voltage profile at beginning and the end of the feeder. Mostly each feeder show the voltage profile starts to increase from 20% penetration of PV till 200%. The rise of voltage may relate because of increasing of generating of power supply from PV. The voltage rise across the line can be approximated by equation (4.1) below [22]. Where ΔV as voltage variation, P and Q represent are active and reactive power from PV. Then X and R reactance and resistance exist along the line to the load. And V represent as nominal voltage at the terminal.

$$\Delta V = \frac{PR+QX}{V} \qquad (4.1)$$

Feeder 1

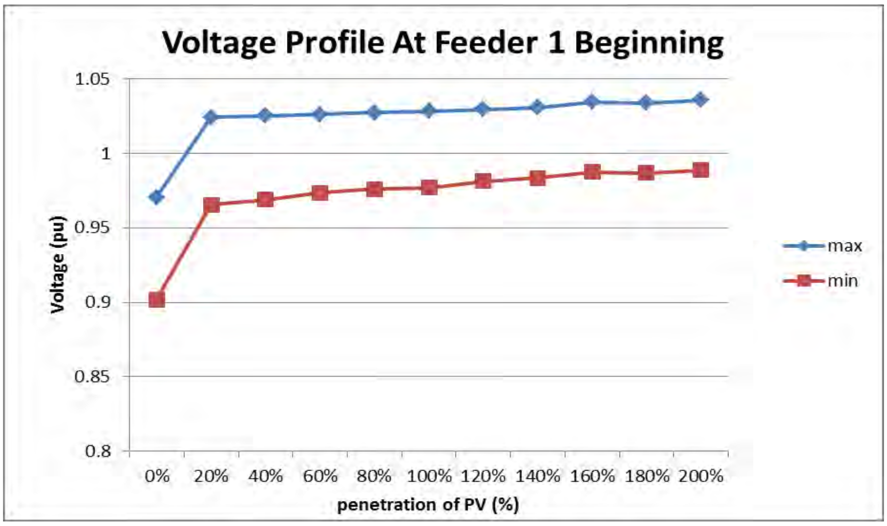


Figure 4.1.1: Voltage Profile At Feeder 1 Beginning

Based on figure 4.1.1, the feeder 1 beginning reading show initial voltage at 0% is 0.970625 pu and then increase to 1.035889 pu at 200% penetration. The variation of voltage before and after installation of PV until 200% penetration is Δ+0.03.

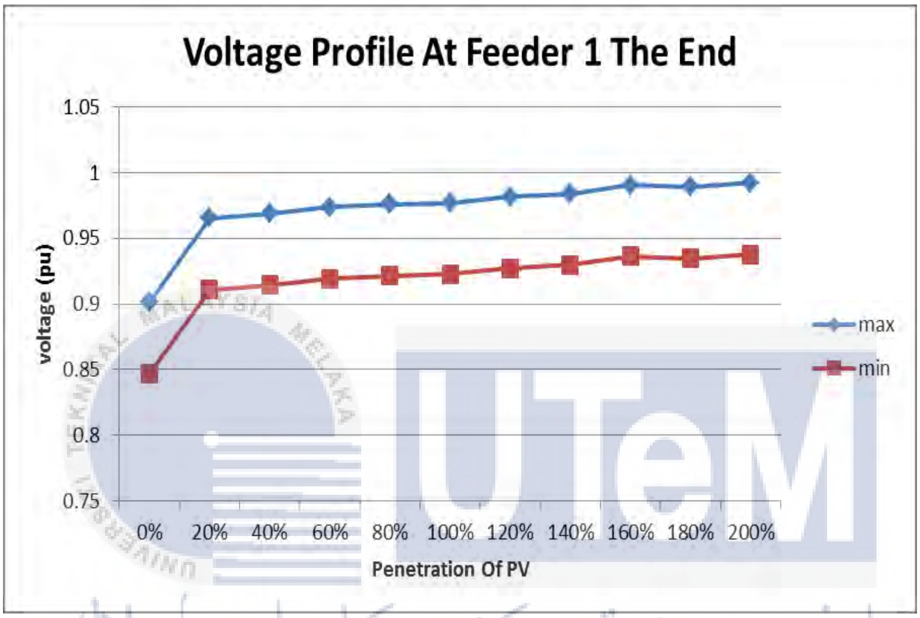


Figure 4.1.2: Voltage Profile At Feeder 1The End

On the measurement toward feeder 1 at the end on figure 4.1.2, it seen the value of voltage starting less than value at beginning. Feeder 1 beginning start with 0.970625 pu while 0.90165pu at feeder 1 back. The difference between both readings is Δ0.07 pu. This occurs because feeder 1 is the longest feeder with length 360m. So, there are voltage drop along the line cable due to resistance and reactance to transmit the power supply to all houses.

Feeder 2

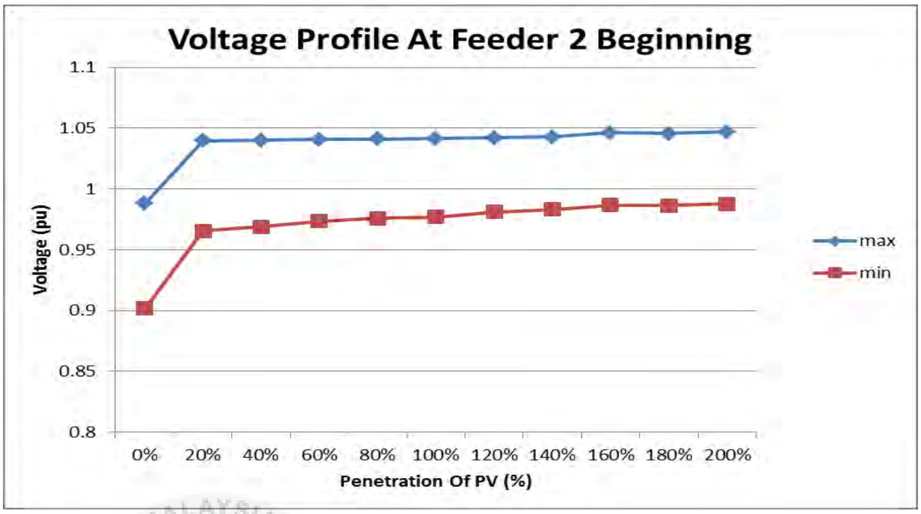


Figure 4.1.3: Voltage Profile At Feeder 2 Beginning

Based on figure 4.1.3 and 4.1.4 the variation of voltage from 0% to 200% penetration for both are Δ+0.05 pu at feeder 2 front side and Δ+0.06 for end side. While at feeder 2 at the end show the value of voltage starting less than feeder 2 beginning. The different of both voltage beginning and end at 0% is Δ 0.03 pu. This is because voltage drops along line due to impedance along line. At the end side will less than the beginning.

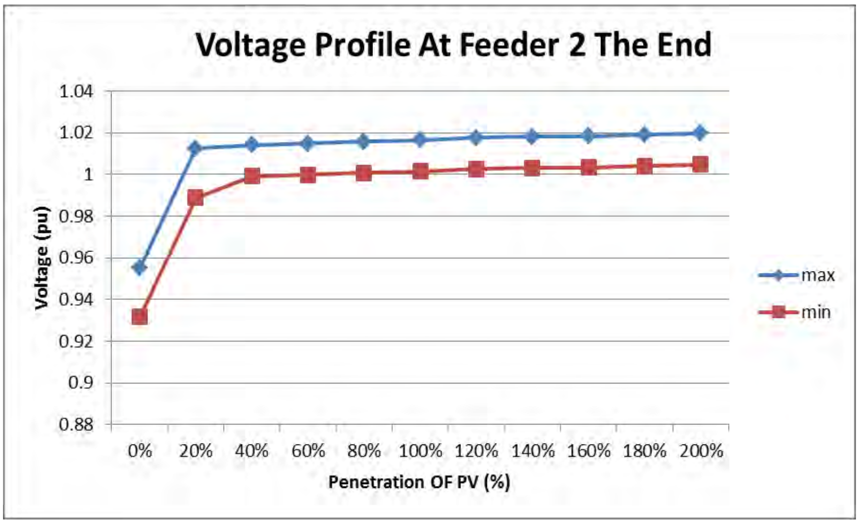


Figure 4.1.4 : Voltage Profile At Feeder 2 The End

Feeder 3

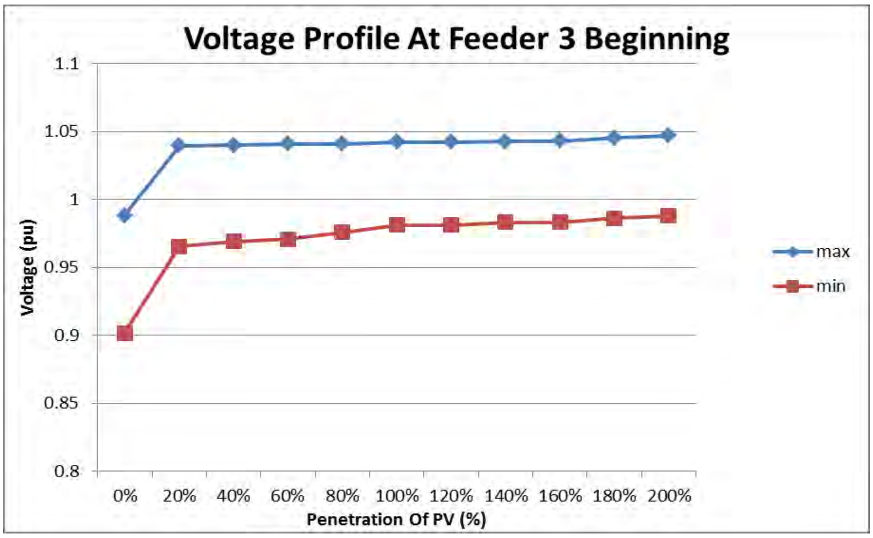


Figure 4.1.5: Voltage Profile At Feeder 3 Beginning

Base on figure 4.1.5 and 4.1.6 at feeder 3 , the variation of voltage from 0% to 200% penetration of PV for beginning and end side is Δ+0.05 pu and Δ+0.8 respectively. And different voltage at 0% for both reading is Δ0.06 pu. The values of different are higher because feeder 3 is 2nd longest with length 320m. So a lot of voltage drops along line due the impedance in cable.

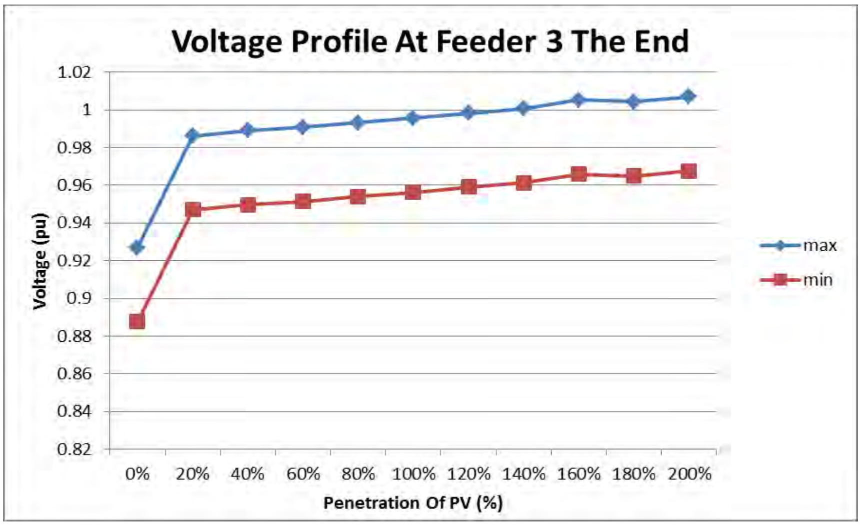


Figure 4.1.6: Voltage Profile at Feeder 3 the End

Feeder 4

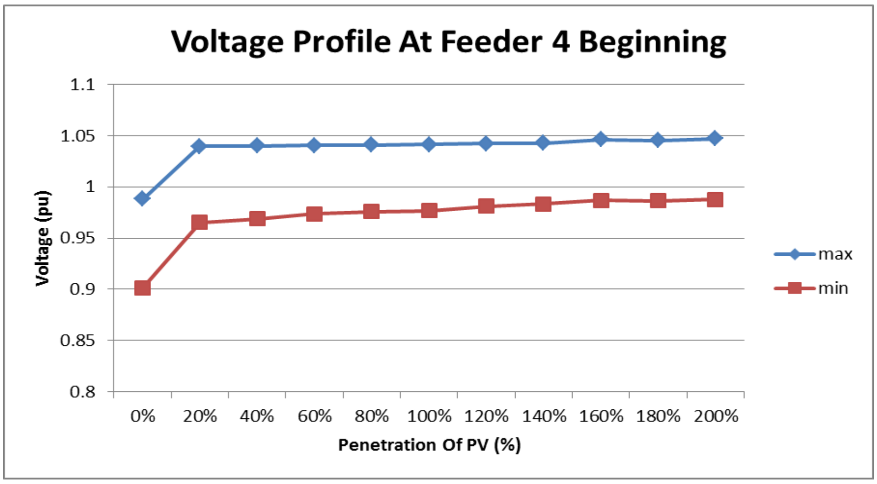


Figure 4.1.7: Voltage Profile At Feeder 4 Beginning

At figure 4.1.7 and 4.1.8 the variation of voltage for the beginning and end from 0% to 200% is Δ+0.05 pu and Δ+0.06 respectively. Different of voltage for both at 0% penetration reading is Δ0.01 pu. The value of changes is small because feeder 4 is the shortest line with length 186m. So voltage drop along line is small.

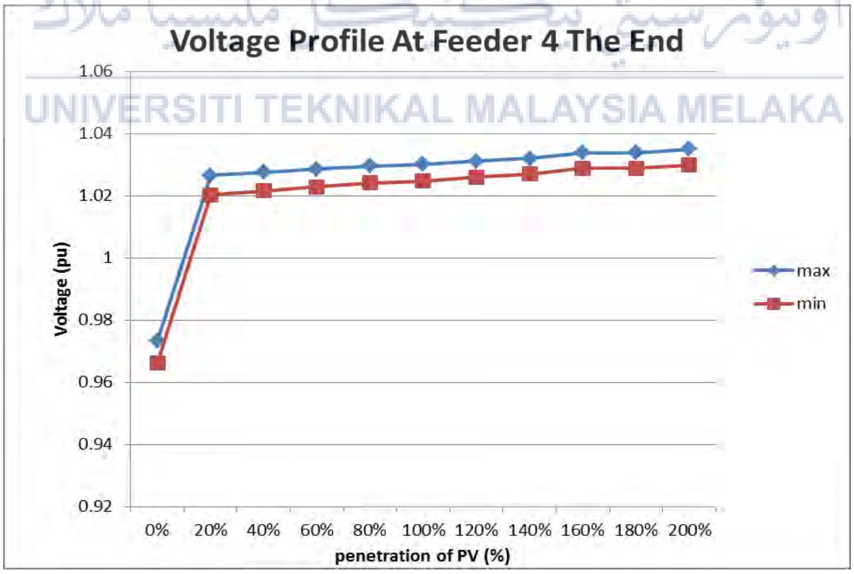


Figure 4.1.8: Voltage Profile at Feeder 4 the End

Feeder 5

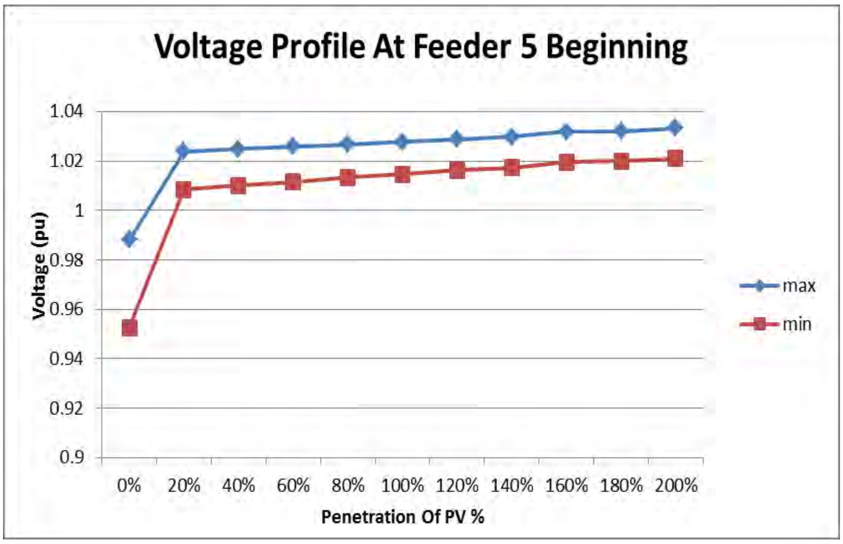


Figure 4.1.9: Voltage Profile At Feeder 5 Beginning

Base on figure 4.1.9 and 4.1.10 the variation of voltage for the beginning and end from 0% to 200% is Δ+0.06 pu and Δ+0.06 pu respectively. The different changes for the starting voltage at 0% for both reading is Δ0.01 pu.the differences of voltage not to large because feeder 5 line have closely length with feeder 4 length which is 280m.So voltage drop along the line is less.

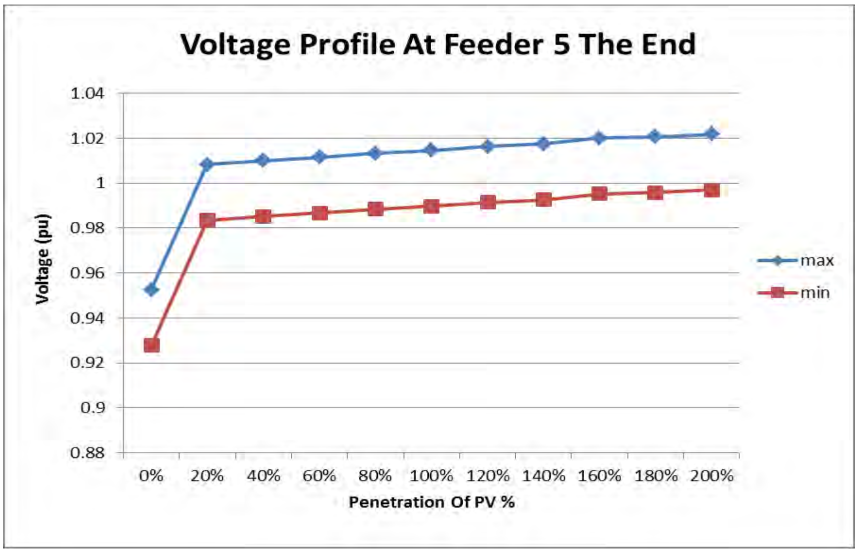


Figure 4.1.10: Voltage Profile At Feeder 5 the End

Main feeder

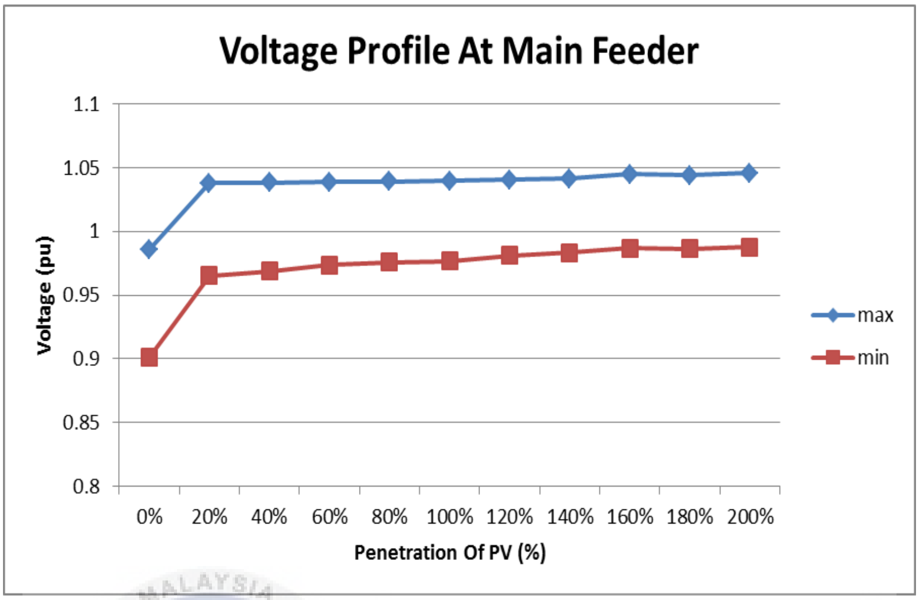


Figure 4.1.11: Voltage Profile At Main Feeder

Figure 4.1.11 show voltage at the main busbar feeder. It indicate the higher level penetration of PV, the higher voltage was recorded. The variation of voltage at main busbar isΔ +0.08 pu. The statutory limit for voltage variation for the system is between -6% to +10% of nominal voltage [11]. It means the voltage in pu is between 0.96 pu to 1.1 pu. So for this residential low voltage area is obeying the TNB standard even 200% penetration of PV.

Table 4.1.11: Comparison between Beginning and End Voltage of Different Feeder at 0% penetration of PV

Number Of Feeder	Length (m)	Voltage Max at 0% penetration of PV (pu)	
		Beginning	End
Feeder 1	360	0.970625	0.901652
Feeder 2	260	0.988148	0.955157
Feeder 3	320	0988148	0.92690
Feeder 4	186	0.988148	0.97329
Feeder 5	280	0.988148	0.952638

Based on table 4-1.11 above, there a comparison between beginning and end voltage at feeder with different length of feeder. The voltage recorded before installation of PV. For both reading of voltage not equally 1 pu which must same as nominal voltage that are inserted to the digsilent software while simulation Since the feeder 1 has longest line than other feeder, it has lowest reading at the receiving end of voltage. Overall for each feeder have lower voltage at the end rather than beginning.

Figure 4.1.12: Comparison between Beginning and End Voltage of Different Feeder at 200% penetration of PV

Number Of Feeder	Length (m)	Voltage Max at 200% penetration of PV (pu)	
		Beginning	End
Feeder 1	360	1.035889	0.9921395
Feeder 2	260	1.047138	1.019738
Feeder 3	320	1.047138	1.006944
Feeder 4	186	1.047138	1.034918
Feeder 5	280	1.033161	1.021848

Based on table 4.1.12 after 200% both reading at beginning and the end feeder achieve 1pu and more than. However it still under the statutory limit for voltage variation. This show after installation of PV, it just increase the voltage and indirectly correct the voltage profile at the feeder.

4.2 Impact Of PV On The Losses

For the initial condition at figure 4.2.1, the system have 3.862333% of losses which without installation of PV. Result show losses were decrease starting 20% penetration of PV until 160%. The generation of PV may influence the losses because it will support for the load demand for each houses. When PV was installing at the load, it will supply active power to load first than the TNB supply. Hence, current flow from TNB supply was reduces along the line to distribute each house. So losses due to heating or impedance at the line will reduce.

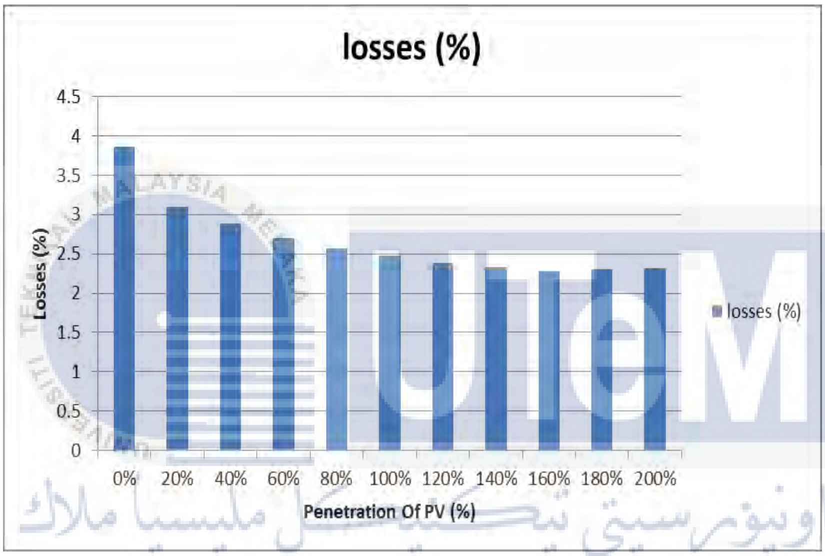


Figure 4.2.1: Losses In System

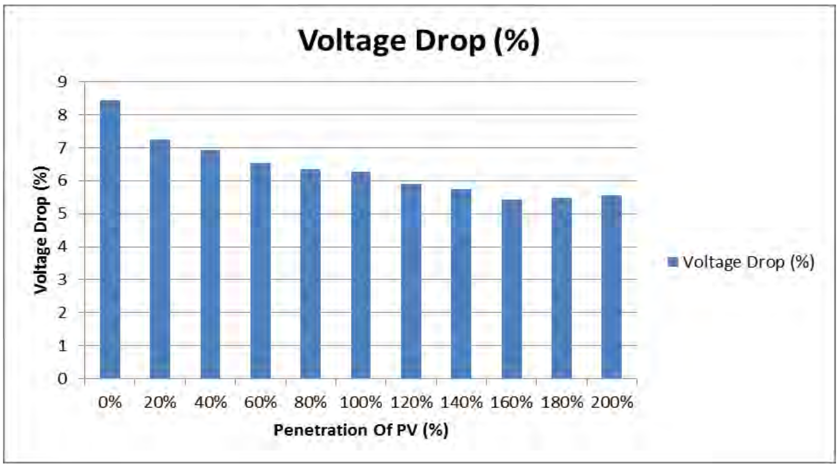


Figure 4.2.2: voltage drop

In additional the power was generate by PV system will backup for the voltage drop along the line. In figure 4.2.2 show voltage drop start to decrease starting 20% until 160% penetration of PV. So it will reduce the losses to transmit the power supply. So until 160% penetration current flow along the line decrease from the source utility and load use from the PV generation output.

However, losses may increase after 180% penetration of PV, it is because after load demand was backup by the generating of PV system until 160% penetration, and there are more power was injected to the system back. After each house was fill fully with power demand by PV, surplus of power produces was flow back to grid along the line cable. So it will be reverse power flow. Since occur the reverse power flow by PV, voltage drop gain to increase along the line each feeder on 180% according current flow to grid. Due to the impedance of cable it may be make the losses for the reverse power flow. Losses will come if power was supply was more than demand.

CHAPTER 5

CONCLUSION

The study on the impact of grid to PV system to the grid based on low voltage residential area was evaluated. There are two criteria that were study which is on voltage profile and losses of the system. Firstly, according the study it can be conclude that the higher the penetration level of PV generation will lead to the rise of voltage on the power system. And it will make voltage profile correction at the system. However, the voltage rise of PV is still within the statutory limit referring to standard from TNB. Secondly, impact on losses due to increasing of generation PV is show when the generation of PV increase; the losses will decrease. The losses may include of heating or copper losses during transmit the power. It is because PV generates active power and then direct supply to load. Thus power that supply from TNB do not fully use by load. Thus current not flow along line which make the losses. However until 180% penetration of PV, losses will increase back. This is due to overpower that was generating in the system. The surplus power produces by PV make reverse power flow turn back to the grid. As the power that is transmitted along the line increases, the current flow in .the line becomes larger. It may involve the losses due to copper losses at the cable while transmit the power.

As conclusion, PV system or else type distribution generation will give a good benefit to the power system if it was installing. However, the values of power generate must be under the limit that allowed. It should be not to overpower produces but only according the load demand respectively.

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APPENDICES

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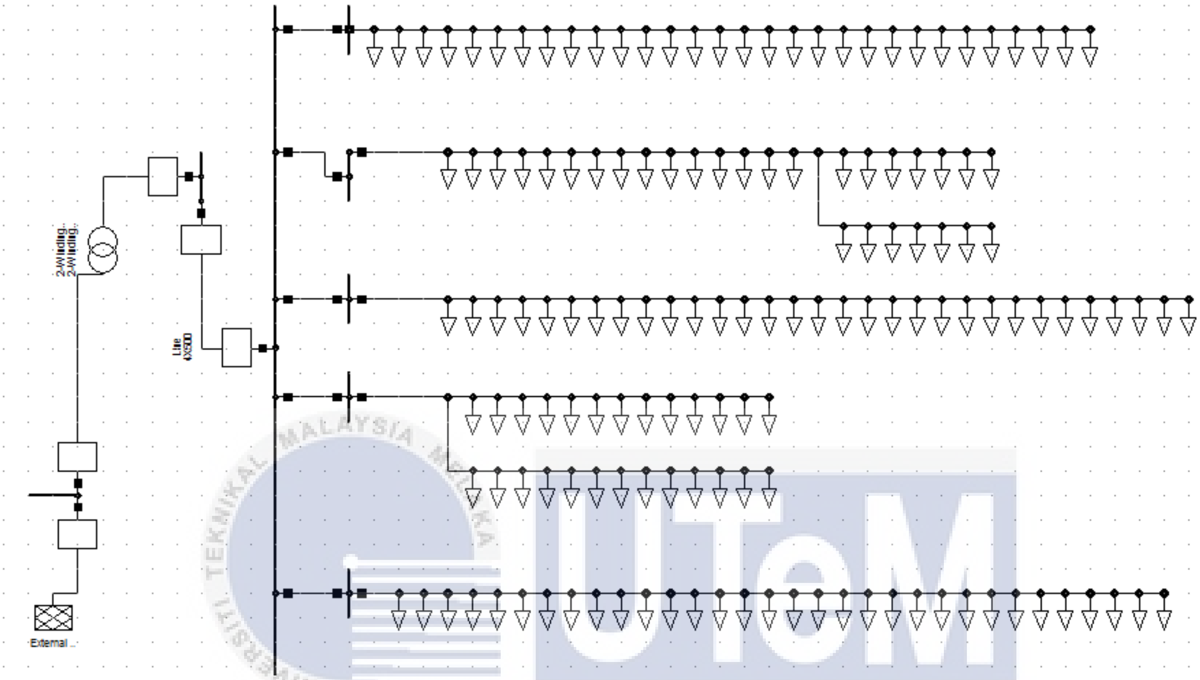

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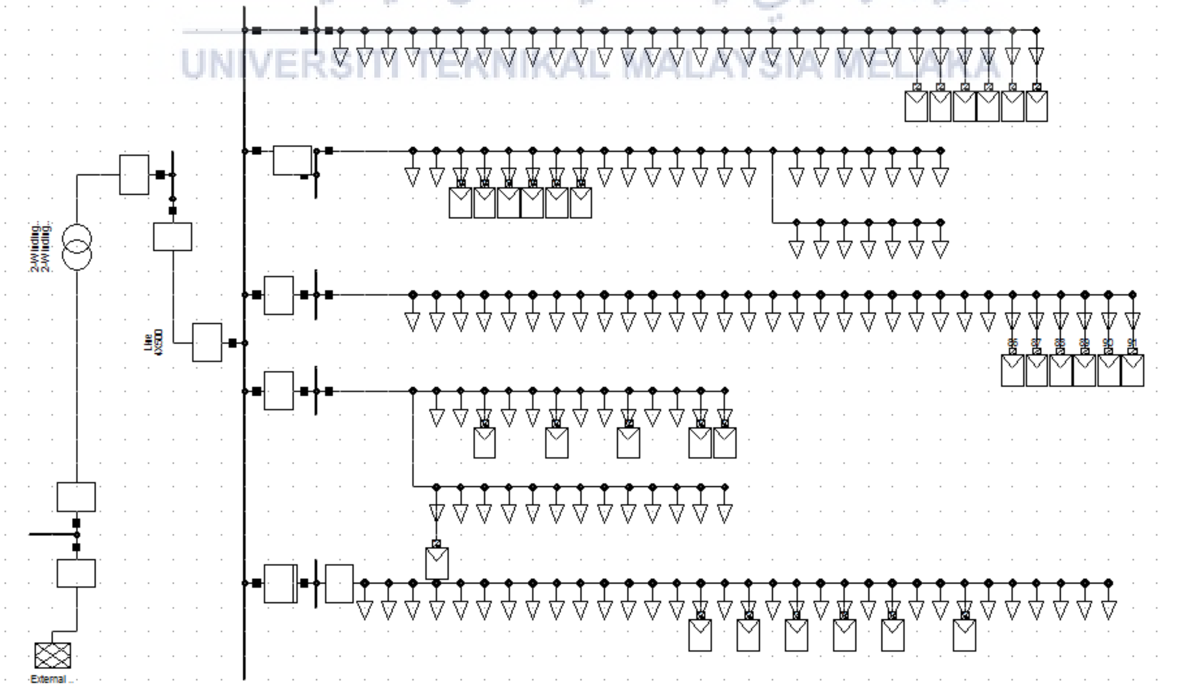

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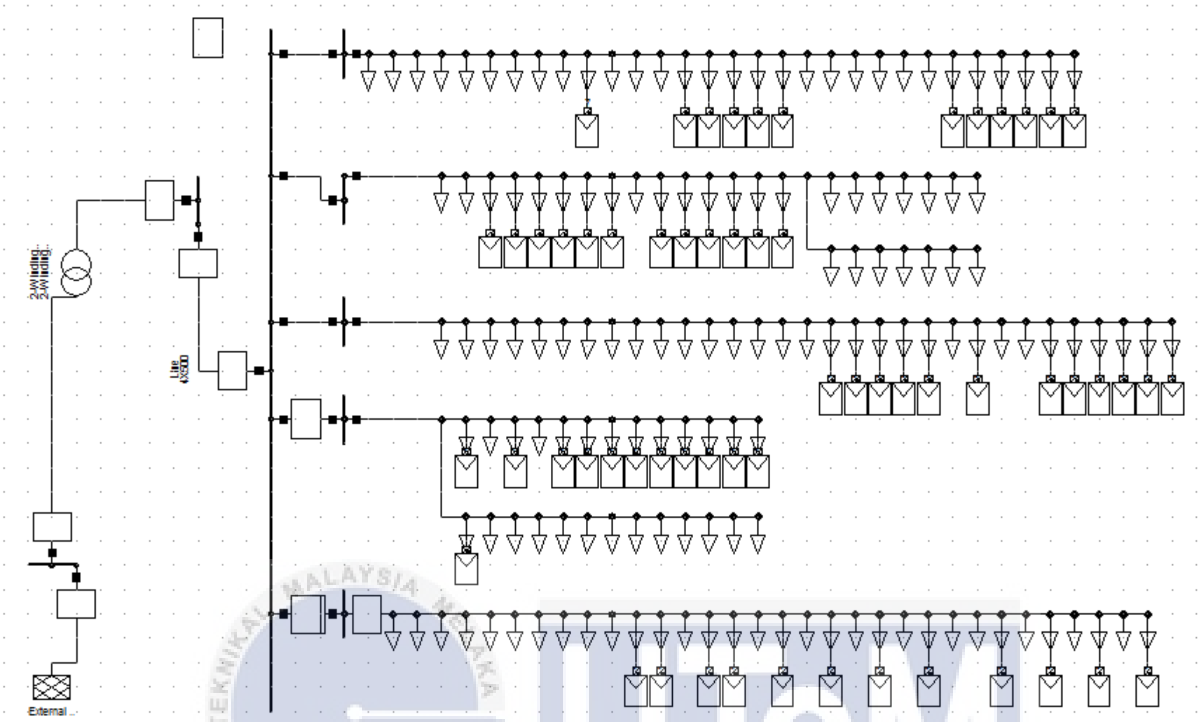

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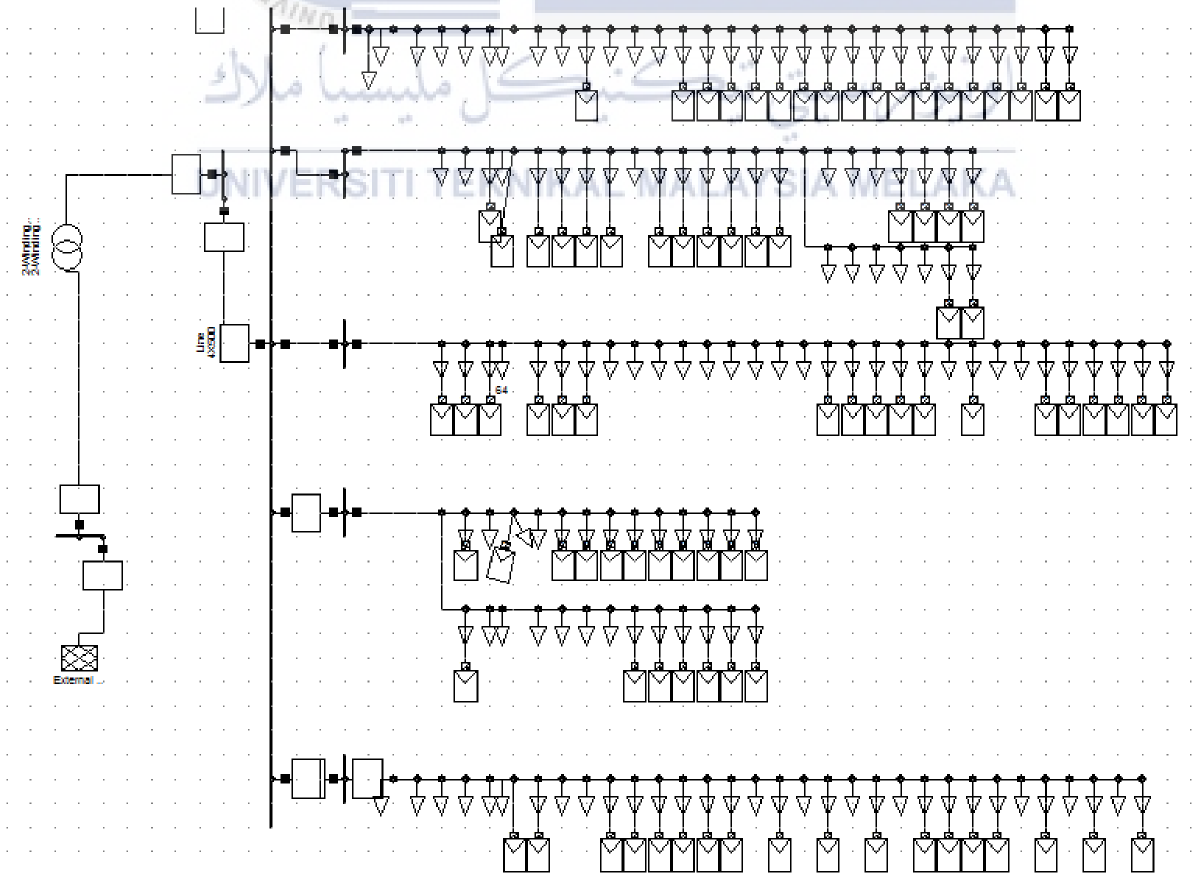

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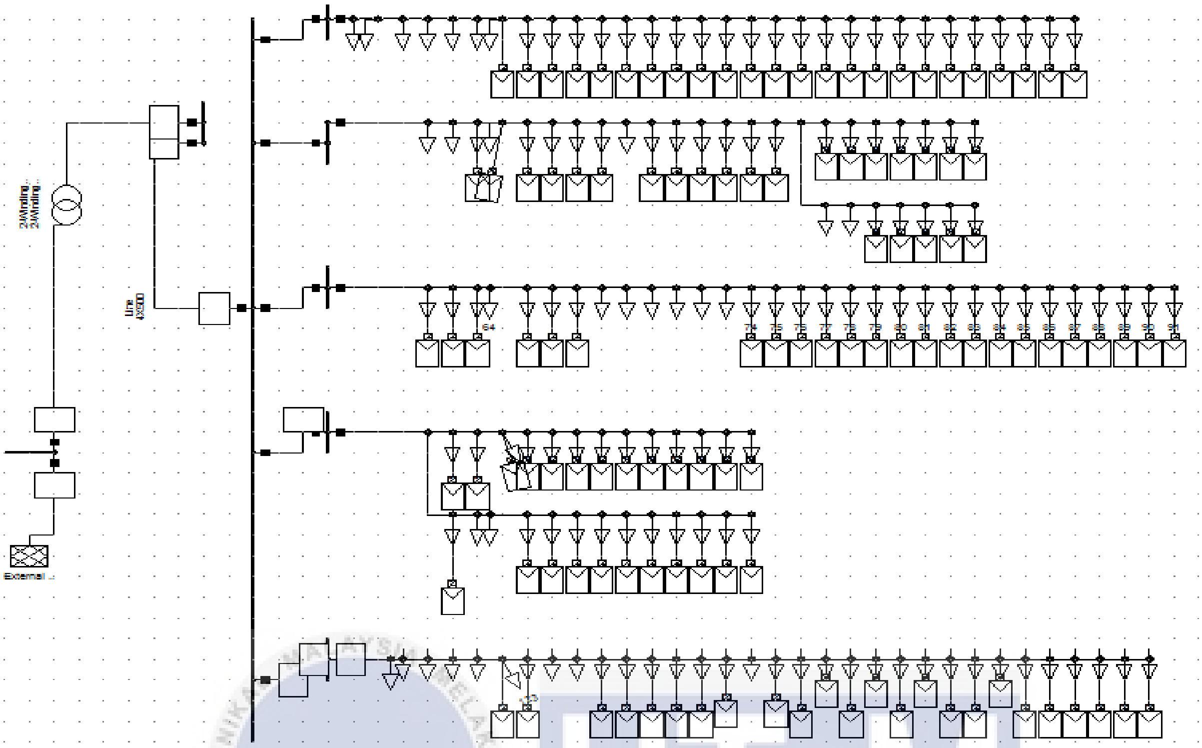

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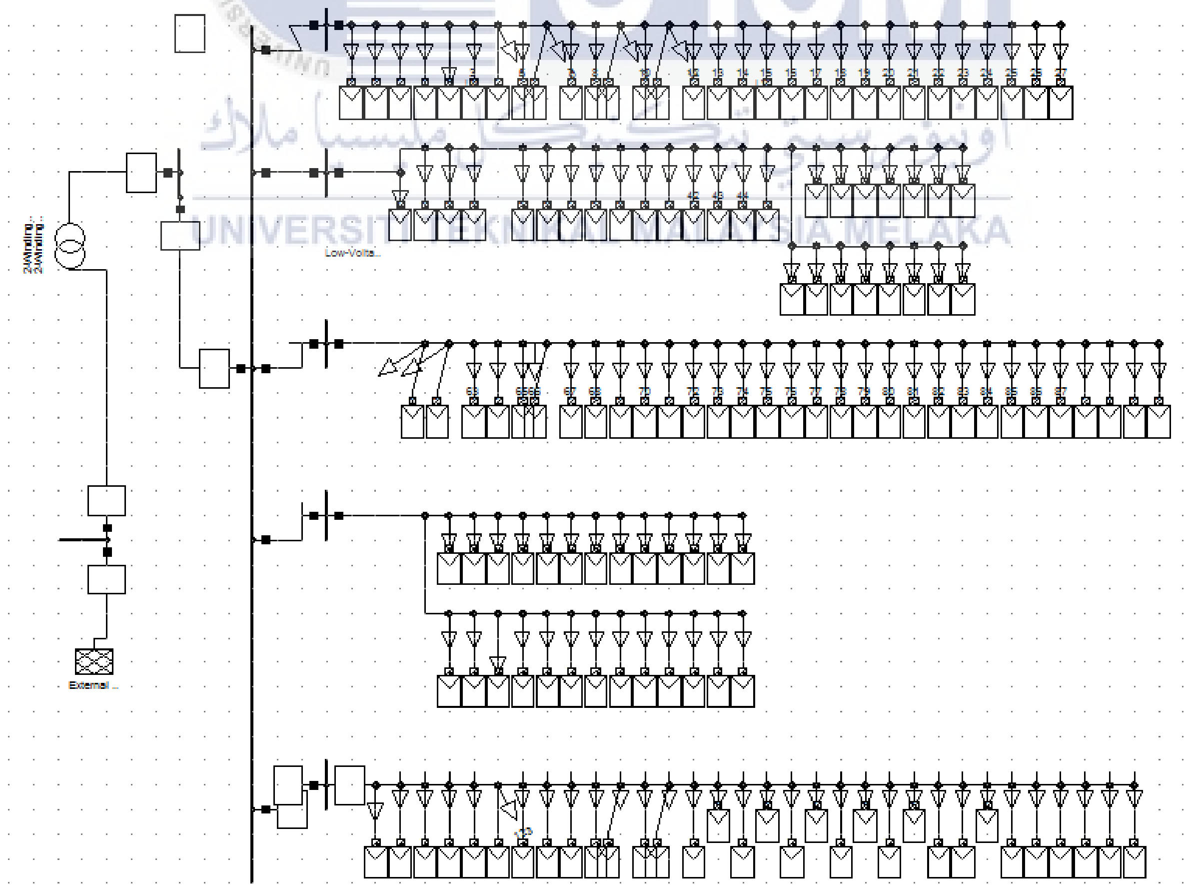

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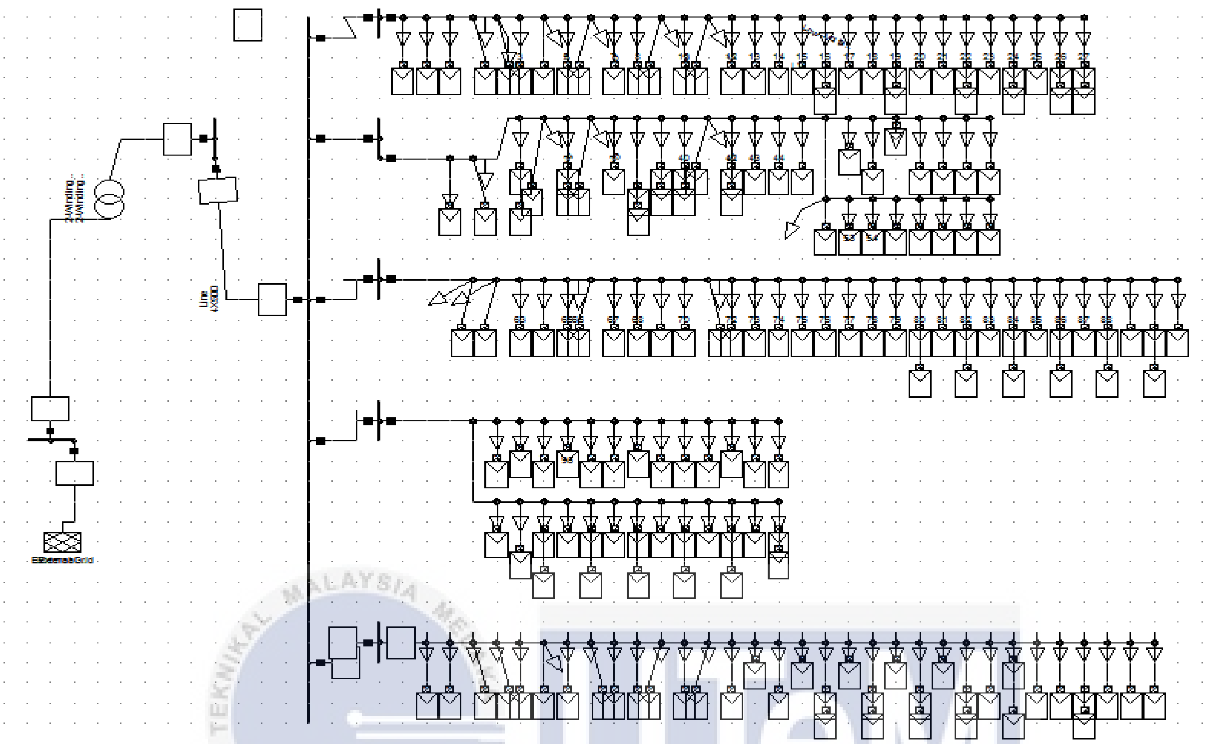

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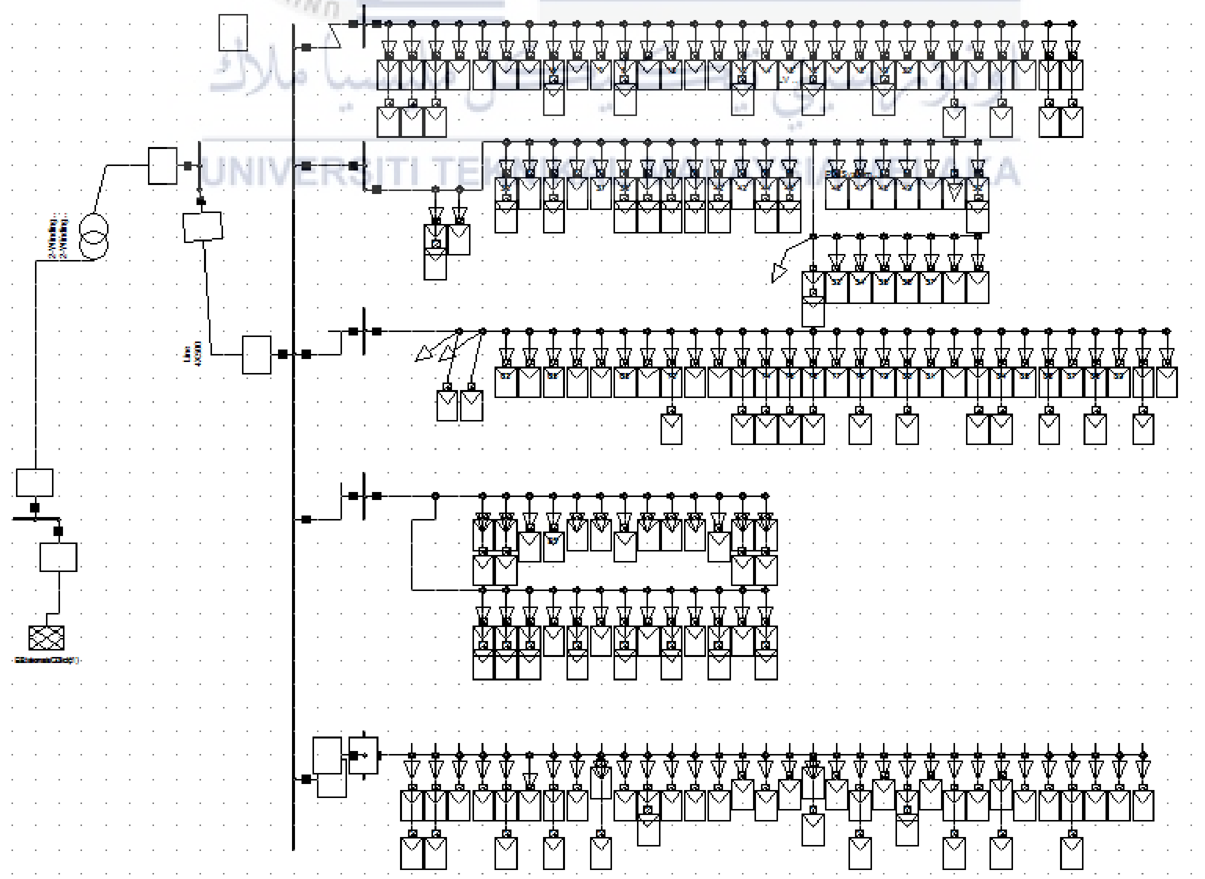

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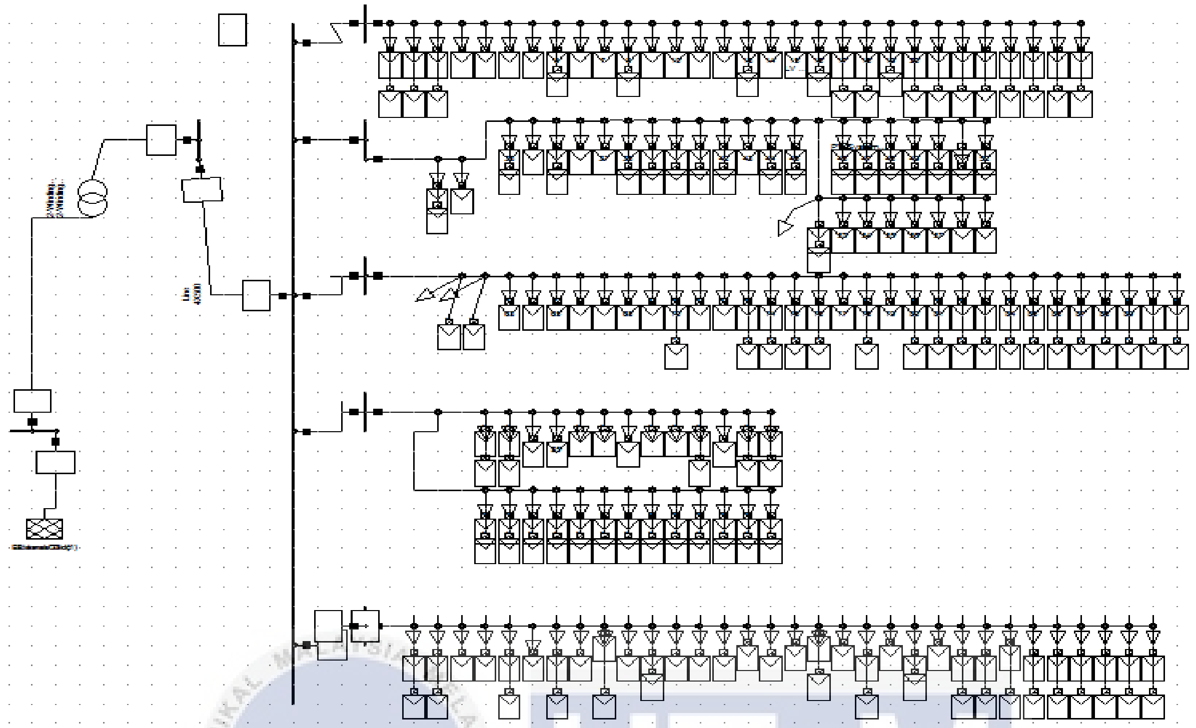

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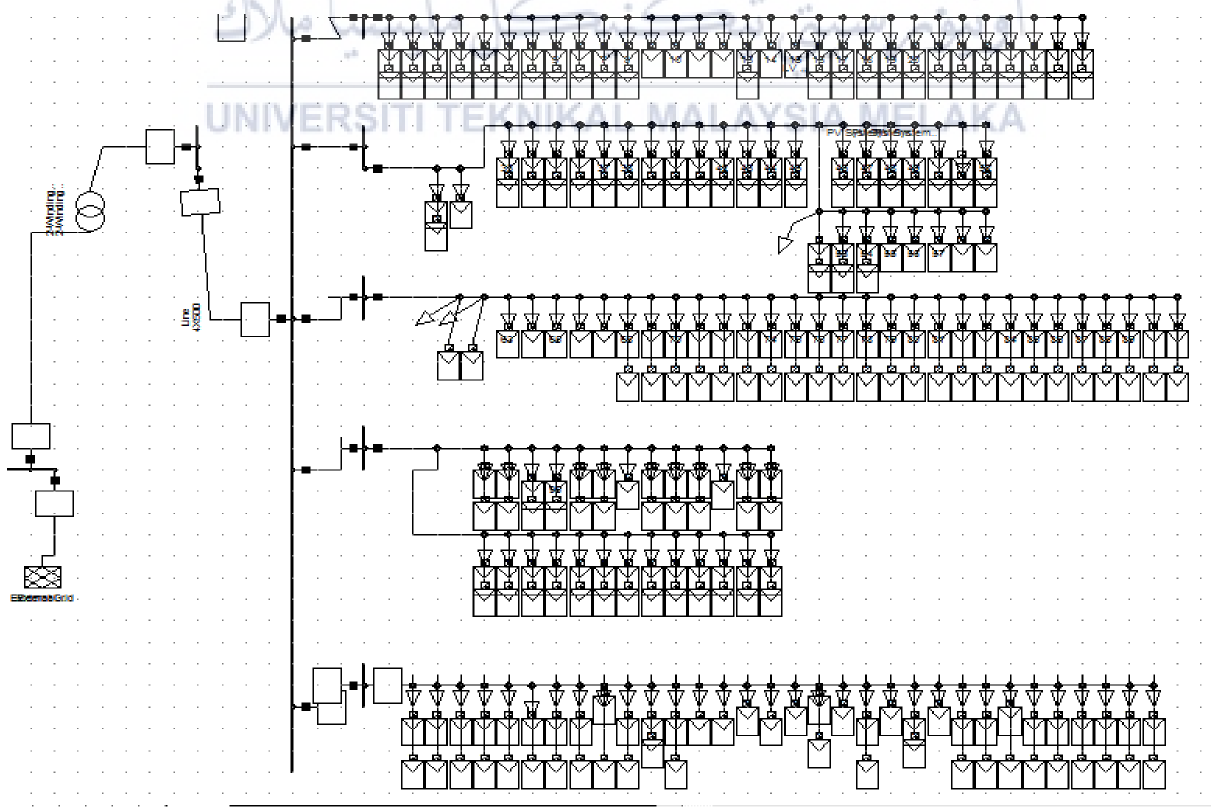

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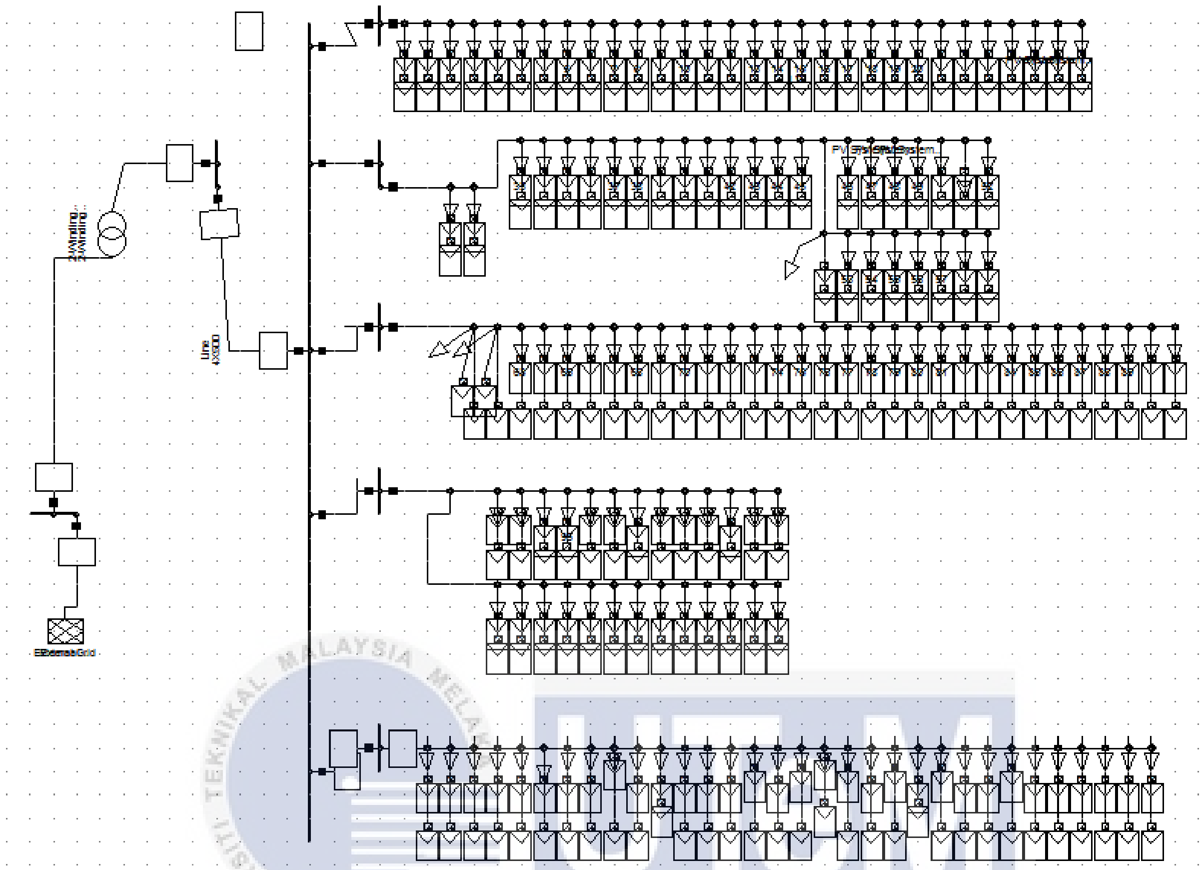

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1:00	0.6900585	69.00585
1:15	0.6608187	66.08187
1:30	0.6374269	63.74269
1:45	0.6549708	65.49708
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2:30	0.6549708	65.49708
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4:30	0.6023392	60.23392
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6:00	0.6374269	63.74269
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6:45	0.4853801	48.53801
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7:15	0.4093567	40.93567
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21:30	0.8479532	84.79532
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22:15	0.9415205	94.15205
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23:15	0.9883041	98.83041
23:30	0.9473684	94.73684
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14:15	0.475061	47.50609
14:30	0.461571	46.15705
14:45	0.350341	35.03413
15:00	0.485628	48.56282
15:15	0.57317	57.31699
15:30	0.411431	41.14311
15:45	0.327564	32.75641
16:00	0.341099	34.10994
16:15	0.266353	26.63526
16:30	0.221615	22.16154
16:45	0.227643	22.76426
17:00	0.228446	22.84455
17:15	0.162351	16.2351
17:30	0.111101	11.1101
17:45	0.085391	8.539103
18:00	0.079835	7.983494
18:15	0.068059	6.805929
18:30	0.035856	3.585577
18:45	0.014595	1.459455
19:00	0.009607	0.960737
19:15	0.002644	0.264423
19:30	0	0
19:45	0	0
20:00	0	0
20:15	0	0
20:30	0	0
20:45	0	0
21:00	0	0
21:15	0	0
21:30	0	0
21:45	0	0
22:00	0	0
22:15	0	0
22:30	0	0
22:45	0	0
23:00	0	0
23:15	0	0
23:30	0	0
23:45	0	0

Voltage profile at feeder 1 beginning and the end

Penetration PV (%)	Max (p.u)	Min (p.u)
0%	0.970625	0.901652
20%	1.024325	0.965506
40%	1.02535	0.969003
60%	1.026369	0.973667
80%	1.027423	0.975919
100%	1.028279	0.976971
120%	1.029656	0.981184
140%	1.03075	0.983411
160%	1.034687	0.987553
180%	1.033959	0.986864
200%	1.035889	0.988732

Penetration PV (%)	Max (pu)	Min (pu)
0%	0.901652	0.847222
20%	0.965521	0.911091
40%	0.969003	0.914573
60%	0.973706	0.919276
80%	0.975998	0.921568
100%	0.977061	0.922631
120%	0.98168	0.92725
140%	0.984063	0.929633
160%	0.990634	0.936204
180%	0.989246	0.934816
200%	0.99214	0.93771

Voltage profile at feeder 2 beginning and the end

Penetration PV (%)	Max(pu)	Min(pu)
0%	0.988148	0.901652
20%	1.039716	0.965506
40%	1.040134	0.969003
60%	1.040543	0.97346
80%	1.041012	0.975814
100%	1.041355	0.976948
120%	1.042178	0.981075
140%	1.04282	0.983246
160%	1.046128	0.986802
180%	1.045451	0.986205
200%	1.047138	0.987802

Penetration PV (%)	Max(pu)	Min(pu)
0%	0.955274	0.93176
20%	1.012425	0.988911
40%	1.014034	0.999052
60%	1.014807	0.999825
80%	1.015828	1.000846
100%	1.016444	1.001462
120%	1.017662	1.00268
140%	1.018209	1.003227
160%	1.01831	1.003328
180%	1.019054	1.004173
200%	1.019738	1.004857

Voltage profile at feeder 3 beginning and the end

Penetration PV (%)	Max(pu)	Min(pu)
0%	0.988148	0.901652
20%	1.039716	0.965506
40%	1.040134	0.969003
60%	1.040951	0.970622
80%	1.041012	0.975907
100%	1.042178	0.981095
120%	1.042178	0.981095
140%	1.04282	0.983246
160%	1.043142	0.983353
180%	1.045451	0.986205
200%	1.047138	0.987802

Penetration PV (%)	Max(pu)	Min(pu)
0%	0.926902	0.887577
20%	0.986244	0.946919
40%	0.988925	0.9496
60%	0.990623	0.951298
80%	0.993241	0.953916
100%	0.995538	0.956213
120%	0.998296	0.958971
140%	1.000642	0.961317
160%	1.005199	0.965874
180%	1.004204	0.964879
200%	1.006944	0.967619

Voltage profile at feeder 4 beginning and the end

Penetration PV (%)	Max(pu)	Min(pu)
0%	0.988148	0.901652
20%	1.039716	0.965506
40%	1.040134	0.969003
60%	1.040543	0.97346
80%	1.041012	0.975814
100%	1.041355	0.976948
120%	1.042178	0.981075
140%	1.04282	0.983246
160%	1.046128	0.986802
180%	1.045451	0.986205
200%	1.047138	0.987802

Penetration PV (%)	Max(pu)	Min(pu)
0%	0.97329	0.966143
20%	1.026622	1.020322
40%	1.027613	1.021582
60%	1.028591	1.022902
80%	1.029562	1.024106
100%	1.030059	1.02465
120%	1.031141	1.025995
140%	1.032021	1.026991
160%	1.033821	1.028846
180%	1.033854	1.02889
200%	1.034918	1.029909

Voltage profile at feeder 5 beginning and the end

Penetration PV (%)	Max (pu)	Min(pu)
0%	0.988148	0.952638
20%	1.023783	1.008342
40%	1.024783	1.01006
60%	1.025768	1.011525
80%	1.02675	1.013306
100%	1.027776	1.014574
120%	1.028813	1.016236
140%	1.029775	1.017321
160%	1.031723	1.019603
180%	1.032119	1.020001
200%	1.033161	1.02103

Penetration PV (%)	Max(pu)	Min(pu)
0%	0.952638	0.927752
20%	1.008355	0.983469
40%	1.01006	0.985174
60%	1.011525	0.986639
80%	1.013317	0.988431
100%	1.014597	0.989711
120%	1.01633	0.991444
140%	1.017449	0.992563
160%	1.020185	0.995299
180%	1.020689	0.995803
200%	1.021848	0.996962

Main feeder voltage profile

penetration of PV	max	min
0%	0.986091	0.901652
20%	1.037925	0.965521
40%	1.038401	0.969003
60%	1.03888	0.97346
80%	1.03942	0.975814
100%	1.039812	0.976951
120%	1.040702	0.981083
140%	1.041399	0.983266
160%	1.044741	0.986868
180%	1.044066	0.986274
200%	1.045785	0.987904

Losses of the system

penetration PV (%)	loses (%)
0%	3.862333
20%	3.092549
40%	2.880174
60%	2.706045
80%	2.565041
100%	2.482258
120%	2.37895
140%	2.324829
160%	2.28344
180%	2.3068
200%	2.311848

Voltage drop

Penetration PV (%)	Voltage Drop (%)
0%	8.443917
20%	7.240449
40%	6.939862
60%	6.541998
80%	6.353649
100%	6.275107
120%	5.909122
140%	5.734267
160%	5.427018
180%	5.491538
200%	5.570532