ASSESSMENT OF UTILIZATION FACTOR IN NETWORK OVER THE GROWTH OF PHOTOVOTLAIC SYSTEM

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A project report submitted in partial fulfilment of the requirements for the award of Master of Engineering (Electrical)

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DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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APPROVAL FOR SUBMISSION

I certify that this project report entitled **"ASSESSMENT OF UTILIZATION FACTOR IN NETWORK OVER THE GROWTH OF PHOTOVOLTAIC SYSTEM"** was prepared by **LOO PIN LIKH** has met the required standard for submission in partial fulfilment of the requirements for the award of Master of Engineering (Electrical) at Universiti Tunku Abdul Rahman.

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ABSTRACT

There are several potential benefits of the installation of distributed generation unit such as photovoltaic system. In order to acquire full advantage of photovoltaic system, it has to integrate optimally sized of renewable energy generation at appropriate locations. With a joint of lowering the greenhouse gas emissions and dependency of fossil fuels, the global now urges to shift toward low-carbon economies. The potential of distributed generation could lead many opportunities in term of economies, environment, technologies, and the future research purpose. In addition, this paper analyses the growth of photovoltaic system that may attract to the conflict of interests, economies, and technique issues on penetration of photovoltaic system to the network. By increasing the photovoltaic system in network over the years, the installation could provoke the power quality and operation issues. Therefore, optimization tools are applied for optimizing the distributed generation in the network. Finally, it concludes that optimization power flow and analytical approach is used for analyzing the growth of photovoltaic system to the network. The proposed approach is implemented to simulate the assumption data and the simulation results are carried out.

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LIST OF SYMBOLS / ABBREVIATIONS

PV	Photovoltaic System
DG	Distributed Generation
LV	Low Voltage
MV	Medium Voltage
HV	High Voltage
PV	Power Voltage Control
PQ	Real and Reactive Power
RE	Renewable Energy
SVC	Static Volt-Ampere Reactive Compensator
STATCOM	Static Synchronous Compensator
FACTS	Flexible AC Transmission System

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CHAPTER 1

INTRODUCTION

1.1 The New Trend of Power System

Traditionally, the energy is dependent on fossil fuels. 80% of the energy produced from nonrenewable energy source. Theoretically, the fossil fuels are converted into electricity and as more as heat and greenhouse gasses and pollution. Recently, this is noticeable that global warming at atmosphere is alerting in our world to reduce centralized power generation and this may relegate the animal extinction. Technologies that the renewable energy resource such photovoltaic system is encouraged to promote for long-term diversification due to the environmental conservation and sustainable energy development. (Abdmouleh, Z. et al. (2017). Solar energy is a feasible solution as this renewable energy is clean, emission free sources of energy that this can use to generate electricity and protect environment for future.
In recent decade, it is huge potential that photovoltaic system can fulfil electricity needs of mankind. The amount of installed of photovoltaic system has rapidly increased. Therefore, it can be seen that a series of addressed issues with integrating solar energy into power network has begun to encounter new non-traditional technical problems due to discontinuous nature of solar energy. (Nuri, M. et al. (2012). An increased penetration of photovoltaic system presents many challenges in the network integration. Historically, the centralized power system is designed in one direction from upstream generation to end-use customer. With the electricity load increased in the different timeframe, the amount of power is forced to transfer over long distance of transmission line to distribution network. However, the utilisation in transmission and distribution system is generally employed but the efficiency of the power is low due to power losses and injection of reactive power over a long distance in transmission line. (Lopes, J. A. P. et al. (2007).

It is necessary to plan and build power plant at the nearer of load centers by reducing the transfer of large power transmission to distribution. Beside this, this is advantage to support local power grid system and enhance the stability of power system. Therefore, distributed generation such as solar photovoltaic is highly introduced to be developed. (Conti, S. and Rizzo, S. A. (2015) With inappropriate planning in the network, that is significant that the photovoltaic system penetrated into power network may operate bidirectional power flow. Additionally, this could appear voltage rise and fault level which may affect the existing protection equipment and increase probability of interruption of distribution circuits. (Yang, X. et al. (2018) Moreover, this method is evaluating the problem of location and the size of solar photovoltaic system The discussed methods will be provided to solve the most predominated technique to evaluate the circumstance.

1.2 Problem Statement

For a wider concept, a large number of solar photovoltaic connected to power network system will inevitably have an impact on power system stability. It is seriously affect the distribution design, supervisory, operation and protection. The uncertainties of photovoltaic system are mainly constrained two aspect of control and power regulation. Power quality is the major impact of high solar photovoltaics penetration level to the distribution network. That will appear a moment that net production is more than net demand especially at the noon time. Thus, the direction of the power flow will be changed from medium voltage side to the high voltage side. The over generation and reverse of power flow may results voltage swell and excessive power losses.

- What is the allowable size of photovoltaic system?
- How voltage profile will be improved if photovoltaic system is installed?

Beside this, the power transformer is required a fast convergence due to adverse effects in on-load tap changers. After the high irradiation of solar photovoltaic generating, centralized power generation or non-renewable source must rapidly increase the output the time at sunset. This is key element for future study. (Hung, D. Q., Mithulananthan, N. and Bansal, R. C. (2013). The review shows that the photovoltaic system generates real power with unity during day time and plays a compensator of reactive power during night. The scenarios reflected that the factor of long distance and thermal resistive will increase the reactive power by transmitting same amount of real power through the network. Thus, the efficiency of centralized power generation is low and utilization factor is high. By increasing the efficiency of centralized power generation, photovoltaic system may provide feasible solution for the above problems. (Borges, C. L. T., Falcão, D. M. and Member, S. (2015)

1.3 Aims and Objectives

The main of the purpose for this thesis work is to model grid-network with solar photovoltaic system. The modern of renewable generation such as photovoltaic system is encouraged that more of the deployment of photovoltaic system and to reduce the cost of large scale investments. In fact, the liberalized electricity market, this is opportunities for the investor to put effort in the photovoltaic system. With an alert of global warming, many countries have urged to uptake of renewable energy and reducing the dependency of fossil oil based power generation. However, small or large scale photovoltaic system could raise the capital costs due to the complicated in term of monitoring and simulating the network, on the other hand, the facilities might perform the expected efficient in term of power system and secure electricity network. In contrasts, with the impractical of penetration, the capacity utilization factor in network may appear scenario of overload and voltage rise. (Nuri, M. *et al.* (2012), (Griffin, T. *et al.* (2000), (Lopes J. A. P. *et al.* (2007)

Investment in fossil-oil based power generation has become ineffective due to environmental affect and large dimension. In addition, photovoltaic system will highly shorten the installation time to achieve low emission of CO_2 for the next decade. The penetration of photovoltaic system in the power network system may provoke saturation.

The main objectives will be carried out for designing the photovoltaic system at optimal location and size

- To identify locations that can maximize the reliability in the power network system
- To optimize power flow schedule with integrated approach
- To model the allowable size of photovoltaic system
- To improve contingency technique by using AC optimal power flow

The limitation in this paper is the limited technologies advancement and geographic of Malaysia. Wind turbine, biomass and nuclear are not feasible solution of distributed generation due to low wind speed forecast, emission of CO_2, barrier of technologies, geographic location and economic factor. Thus, photovoltaic system is the choice for distributed generation.

A hypothesis is the dispersion mode of mirco-grid power network system and liberalized electricity market. The purpose is to create a constitution with competitive electricity market and flexible "stock market" of buying and selling electricity in different timeframe. Thus, the capacity of utilization factor in power network system is ease to manage by different competitors. However, this is difficult to achieve mirco-grid power network system due to incomprehensive of distributed generations and unified power grid.

1.4 Outline of the Report

The outline of thesis that shows the presentation of the work is as shown at below table.

Chapter No.	**Title**	**Content**
1	Introduction	Background of the photovoltaic system study, explained the future trend of power system
2	Literature Review	Review of photovoltaic system, impact of power quality, utilization factor of photovoltaic system in network and method of conventional scheduling
3	Objectives of Project	Discuss and identify the objectives of the project
4	Research Methodology	Discuss the details for each of the working model by using Optimal power flow and analytical approach to derive the photovoltaic system in network
5	Result and Discussion	Discuss in details on the outcome of working model and analyse the simulation result with objective of thesis
6	Conclusion and Future Enhancement	A conclusion of thesis by commenting the overall outcome of thesis work, future enhancement and research purpose

CHAPTER 2

LITERATURE REVIEW

2.1 Photovoltaic System

A recent study has shown photovoltaic system from renewable energy source can deliver power production and reliability. Utilizing the photovoltaic system to generate electricity provides a feasible solution as the same time to protect environment for future generation.

Generally, Photovoltaic system is well known as solar PV system, it is designed to transform luminous energy into electrical energy by using application of semiconductor interface. The photovoltaic system in the network is volatile to integrate with distribution system with policy of “plug and play”. One of potential benefit by using photovoltaic energy is free source and clean source that could ever use. Hence, solar energy paves the way for saving money and supports the environment where the solar panel system in turned on. However, (Yang et al., 2018) elaborated that the output power of photovoltaic is nonlinearity and it is susceptible to environmental factors. In the engineering application, photovoltaic generator is fundamentally obtained the light intensity and temperature at each of time point. However, the photovoltaic system that it can provide the needs of renewable energy which the solar resource is the most predictable and inexhaustible.

It should be noted that solar source (figure 1) is also important a measure of clock time which to be determined the location of the sun in the sky at different time of day-time at any location on the planet. Under such circumstances, it is easy to determine the production of real power during daytime but the entire asset remains idle at night (Varma et al., 2011). Thus, the photovoltaic system must be able to track the sun every day to optimal enhancing energy collection.

Irradiance is the measure of power density of sunlight and the unit is in W/m2. Thus, it is instantaneous quantity and identified as the intensity of sunlight. (Hossein safamehr, 2015) displayed the operation of PV panel depends on the solar irradiance, cell surface, temperature, and the optical air mass of operating environment. Under different irradiances, Maximum power point tracking (MPPT) is used for obtaining incremental conductance and maximizing power extraction under all conditions.(Ravi

Dharavath, 2018)

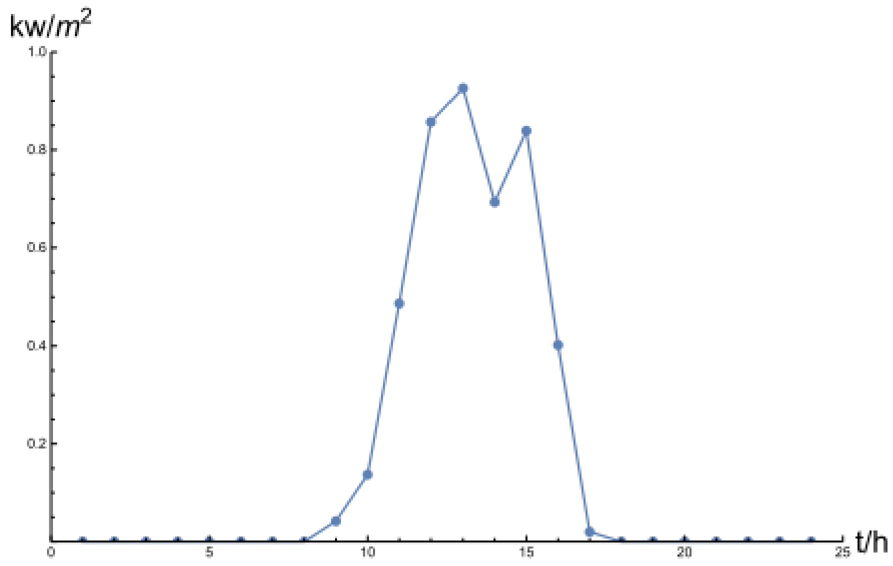


Figure 1: 24-Hour ahead Solar Irradiation Forecast

However, photovoltaic system creates new challenges. On the other hand, it has been introduced that a new innovation of photovoltaic system will bring benefit in term of technical and economic factors.

2.2 Growth of Photovoltaic System

Malaysia’s electricity demand is forecasted to reach 19,000MW in 2020 and 23,100MW in 2030 reflecting an increase of almost 36% from the 14,007MW in 2008. (Almaktar, Abdul and Yusri, 2015) and table 1 show that the interest in solar photovoltaic energy is growing rapidly, with annual growth rate 25-35% over last ten years . (El-saadany, 2011) proved that different photovoltaic system incentive programs is introduced in various countries to encourage residential and commercial use of PV systems (Rajiv. K. Varma, 2011). Additionally, (Almaktar, Abdul and Yusri, 2015) reported that the annual solar irradiation in Malaysia is 1643 kwh/m^2. Thus, the photovoltaic system is expected to increase at least 1000% of PV uptake by 2050.

Energy potential of solar and some other RE sources in Malaysia.

Year	Cumulative RE installed capacity in MW			
	Solar	Solid waste	Biomass	Biogas
2011	9	20	110	20
2013	33	90	200	50
2015	65	200	330	100
2020	190	360	800	240
2025	455	380	1190	350
2030	1370	390	1340	410
2050	18700	480	1340	410

Figure 2: Potential of Solar Energy

This paper will discuss the present and future development of Photovoltaic system in Malaysia to promote renewable energy source, for example solar energy in the future.

2.3 Utilization Factor of Photovoltaic System in Network

An electric grid is an interconnecting network for delivering electricity from generation to consumer. Traditionally, transmission power system is only designed to meet bulk consumers from the large scale power generation and transporting power to consumer by using passive network distribution of unidirectional electricity transportation (Conti, S. and Rizzo, S. A. (2015). Inversely, the investment of transmission system doesn't adequate account for long term diversification due to environmental consciousness and long scale of demand and supply. Figure 3 shows that pattern of daily curves of residential, commercial and industrial user. (Griffin, T. *et al.* (2000). The deterministirc solar irradtion forecast of photovotlaic system shall resolve to contribute load shaving to commerial and industrial user by not transmitting large power from transmision system. Thus, power losses may increase.

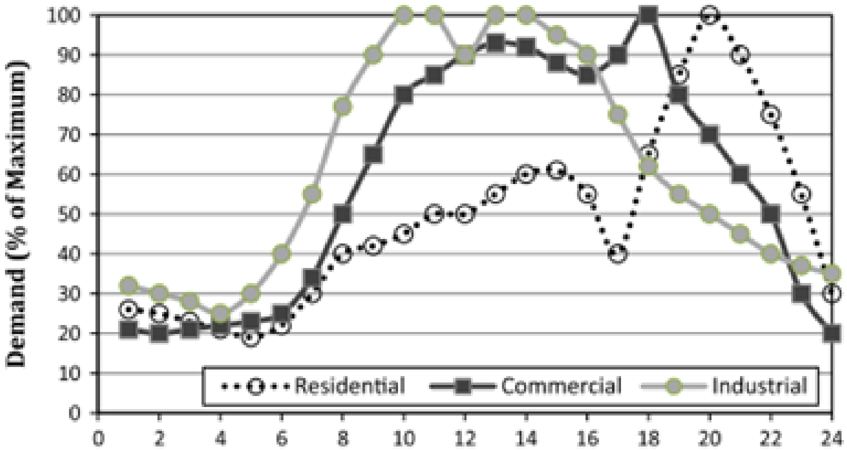


Figure 3: Daily Load Curve for Three Load Type

As the distribution penetration of photovoltaic system increases, it will provide the best interest for players involved to allocate photovoltaic system in an optimal way such as to reduce system losses and improve voltage profile. (Acharya, Mahat and Mithulananthan, 2006). The distribution substation connects from main transmission to the sub-transmission network and converts HV to MV for primary distribution feeder, the distribution transformers is to perform a transformation from MV to LV for residential and commercial users. With the increase in photovoltaic system penetration nowadays, electric grid plays the major transition from passive distribution networks with unidirectional electricity transportation to active distribution network with bidirectional electricity transportation. The new feature of bidirectional power flows in network shall be prevailed by the penetration of photovoltaic system. (Galagedara, 2015).

The behind of increasing penetration of Photovoltaic system may appear challenges in the integration of photovoltaic system into electric power system. In particular, distributed generators tend to be smaller size and quick installation. Geographical and flexibility made it possible to set up distributed generators during the congested areas or use during consumption peaks. (Lopes et al, 2007). Obviously, the growth of photovoltaic system in the network is volatile due to penetration in Congestion is defined as the situation of overloading of transmission lines. (Ochoa, L. F., Dent, C. J. and Harrison, G. P. (2010) stated that the fastest way to relieve congestion is removing congested lines leading to emergence of seondary market where it should be supported for tranmisssion right. This is also to ensure the generators dispatching with transmission constraints at least system cost. Without a proper planning in penetration, the utilisation factor of power network system is questionable that the limiting capacity utilisation factor in network might appear non-linear power flow and increase the power losses. Centralized power generation may increase the cost in power generating, while long distance transmitting, it happens low return due to increase of reactive power. The capacity of utilisation is occupied with low efficiency of power factor.

Utilisation of photovoltaic system in power network system is very important to insight that renewable generation such as photovoltaic system could raise the cost due to complicated of supervisory, but it would enhance the network to be more relibity and electricity network of security (Abdmouleh et al, 2017)(Lopez et al 2017). (Wang et al, 2017) proposed a stochastic energy management system is a tool to handle energy demand and supply in uncertainties in power network operation. In this context of uncertainy in electricity demand, many research studies have proved that the power will enhance power system from, centrelized and conventional to small scale of power generation systems, decentralized, by reducing power losses and increasing reliabity of power system.

2.3.1 Environmental Factor

That is no doubt that the climate change rose last decade, which is to enforce at promotion renewable energy and reducing CO_2 emission development distributed generation. Figure 4 shows that development of renewable energy may avoid emission of CO2.The study and Figure 4 show that the implementation clean sources such as renewable energy sources may generally curtail the time year-by-year to achieve the objectives of reduction CO_2 emissions and dependency on fossil fuels. (Almaktar, Abdul and Yusri, 2015). With this deterministic solution, photovoltaic systems were perceived to acquire the demands when this is to optimize the energy consumption by consumer due to conventional power load. (Abdmouleh, Z. *et al.*, 2017) (Yang et al, 2018). With an agreement for decreasing greenhouse gas emissnions, this is an important signal for citizen to be cautious that determination toward low-carbon.

Year	Annual RE electricity (GWh)	Annual CO_2 avoided (tons/year)
2015	5,374	3,707,825
2020	11,227	7,746,837
2025	14,662	10,117,015
2030	16,512	11,393,197
2050	25,579	17,649,620

Figure 4: RE Electricity and CO_2 avoided

2.3.2 Economic Factor

One can prove that the photovoltiac system shall install close to the load center with having quality of power system in case of interuptions. This will help to avoid unexpected event and economic losses. Historically, the cost of tranissmion and distribution system was increased from 25% to 150% which can be considered impratical and enviromental concern by using large scale area (Griffin et.al, 2000). Figure 5 shows that the rates for Photovltaic system in Malaysia. It presents the rate is dropped from the year 2012 to 2014 due to competitive advanatges. In order to facilite competitive market on electricity, the price of photovotltaic must provide beneficial incentive to compete with large scale power generation.

	FiT rate (RM)		
Basic rates according to installed capacity	2012	2013	2014
Installed capacity up to and including 4 kWp	1.23	1.1316	1.0411
Installed capacity above 4 kWp and up to and including 24 kWp	1.20	1.1040	1.0157
Installed capacity above 24 kWp and up to and including 72 kWp	1.18	1.0856	0.9988
Installed capacity above 72 kWp and up to and including 1 MWp	1.14	1.0488	0.9649
Installed capacity above 1 MWp and up to and including 10 MWp	0.95	0.8740	0.8041
Installed capacity above 10 MWp and up to and including 30 MWp	0.85	0.7820	0.7194
Bonus FiT rates according to the following criteria (one or more)	2012	2013	2014
Use as installation in buildings or building structures	+0.2600	+0.2392	+0.2201
Use as building materials	+0.2500	+0.2300	+0.2116
Use of locally manufactured or assembled solar PV modules	+0.0300	+0.0276	+0.0254
Use of locally manufactured or assembled solar PV inverters	+0.0100	+0.0092	+0.0085

Figure 5: Fit rates for Solar (21 years from Fit commencement date)

Additionally, the photovoltaic system show the attractive incentives to compete with the centrelized power genartion. The installation on photovoltaic system may dramatically increase. the traditional power generation has become degradration. (Nuri et al, 2012) As the time goes on, large power generation and existing of high voltage transmission line will be slowly eliminated due to the increase of photovoltaic system and other renewable generation. (Huang, Yao and Wu, 2016). On the other hand, the monopolized power generation and utility company will be carried a reformation to multiple power generation and utility companies. The intention is to introduce a positive competition, lower costs of power production, and power supply. (Huang, W., Yao, K. and Wu, C. (2016)

In order to achieve two-win situation between distributed generation and traditional power generation, utility companies must coordinate positive competiveness by not degrading the usage of traditional power generation. It is simple to describe that traditional power generation is main input while photovoltaics system is used for temporary load shaving or contigency. For photovoltaics system, it can assume that the paid of tariff in the noon time should be higher than the rest of the time due to focus at peak load demand. However, the government should promote the persperctive of buying and selling electricity marketer in different due to different timeframe.

2.3.3 Power Quality Factor

Photovoltaic systems are expected the most rapid growing in next decades. By increasing of photovoltaic system penetration to utility, power quality is the one factor with injection from the growth of photovoltaic system to the distribution system(Huang, Yao and Wu, 2016) Reverse power flow may have the effect of the moments net production. This phenomenon is expressed at the noon time, this results the distribution is overloading and excessive power losses. (Dharavath, R.,Raglend,I. J. and Ganest, C.H.V (2018)). Futuremore, the most of photovoltaic system is in single-phase basic. The unbalance phase should be taken the place of moving neutral voltage to safe value (Borges, C. L. T., Falcão, D. M. and Member, S. (2015). Hence, the protection system for phototvoltaic system shall take into consideration with the problem of forward reverse power flow and power current by reducing the conflict in the feeder distribution.

Power inverts from DC to AC injecting power to distribution system causes voltage rise at the noon time and harmonic distortion at the point of commom coupling.Thus, the appearance of voltage and current harmonics shall be filtered high pulse order in the network, this may occur at resonance in the system with high frequency and reduce the photovoltaic system life time(Conti, S. and Rizzo, S. A. (2015). However, the research is clearly required to address this problem by limiting total harmonic distortion below than 5% with an enhanced power quality output.

Also, photovoltaic system shall play a different role during day and night time. It generates real power with unity at the day time and it compensates the reactive power at the night time although it is idle operation.

2.3.4 Optimal Utilization in Power Network System

Microgrid is an optimization tool for power network system. The operation of demand side management system is important for local control and to achieve energy efficient level. (Mazidi et al, 2014). However, a number of regulatory issues need to be addressed carefully especially high installation cost for mircogrid. This is a technical difficulties of taking long period meeting up the enviroment consciousness and optimal communication infrastructure implementation in rural areas.

Many researchers presented several algorithms must ensure that short computing time and fast convergence of the circuit circumstances. In fact, the several algorithms shall be applied to increase reliabity and reduce losses in the system. The application is referred on the analytical approach of the continuous power flow calculation and the most susceptible of voltage drop. This purpose is to improve power transfer capacity (Abdmouleh, Z. *et al.*, 2017) (Yang et al, 2018).

Genetic algorithm is wisely used as optimization tool at solving the optimal photovoltaic system capacity and location. (Huang, Yao and Wu, 2016) In the power system, genetic algorithm was applied to reduce expansion cost of power system and increase the system reliability. (Mithulanantha, Oo and Phu, 2004) stated that analytical appraoch consists 5 functions which are selection, crossover, mutation, evaluation and terminaion. The valuation is the driving force and to determine the fitness of each solution string generated during the search. Crossover takes two individuals and produces two individuals while mutation alters one individual to produce one new solution. Selection is to determines the survival of individual and continue to next generation, termination function determine to stop evolution and return to the beginning. This provides a high degree of modularity and extensibility. (Nuri et al, 2012) extented that genetic algorithm is different from conventional optimization methods. It works with a set of encoded parameters from a parallel set of points instead one point and probability of reaching to the false point (Mithulananthan, N., Oo,T., & Phu, L. Van. (2004)).

From the above review, it can be seen that genetic algorithm is a function of feed-back loop with providing intelligent solution. It can be applied both discrete and contionous paramenter for evolving toward better side (Mithulanantha, Oo and Phu, 2004).. Thus, the result could be accurated and good solutions.

Moreover, the approach should achieve with providing the stable value and tend to a better optimal value with fewer iteration times, faster convergence speed, higher computational effiency and higher accuracy. Technology can make better combination between algorithm so-called hybrid technique. The aim of improving effiency and simplicity of implementation are to solve the optimal capacity and location of photovoltaic system.

2.4 Summary

In sum, the demand of electricity is due to the rise of industrialisation and population. On the source supply, there is also a continous of increase in the fossil based fuse supply. This associated to a global warning and source of depletion. This is the reason that the research and development on photovoltiac system has become urgent. Based on above review, it presented that photovoltaic systems have a huge potential to provide electricity due to continous source supply.

As a result, it can be seen that the growth of photovoltaic system can benefit to enviroment and economy, but it has still number negetive impact to the optimal location and size of photovoltaic system

Thus, the anticipated increase in photovoltaic system penetation to distribution network is required to address the impacts and to elongate the allowable limits for photovoltaic system. By concerning the interest of stakeholder, scheduling on power network system and favourable incentives shall take into consideration. Finally, this can be concluded that a quality power network combined with photovoltaic system depends on the network characteristic including the measure of optimal location, geographocal photovoltaics arrays and allowable size of photovoltaic system.

CHAPTER 3

METHODOLOGY AND WORK PLAN

3.1 Methodology

Power optimization tools shall be approached to solve the problem of solar photovoltaic location and sizing. On the other hand, the approaches shall maximize the power flow equality, utilities profit, and minimize the power losses. Analytical approach and AC optimal power flow are used to determine the optimal sized and operating strategy of photovoltaic system. The formulation of multi optimal power flow includes the calculation active/reactive day-ahead of power dispatch, stationary of photovoltaic system charging and discharging, real time energy operation with transformer on load tap changers. (Acharya, N., Mahat, P. and Mithulananthan, N. (2006), Galagedara ,L. W (2015), (El-saadany, E. and Seethapathy, R. (2010)

3.1.1 Location to maximise reliability of power system

Optimal power flow approach is an optimization tool to produce a numerical equation. This tool is used because it offers the benefit of less computing time and simplicity in the application based on analytical, forecasting, theoretical, computering and mathematical analysis.to simplify the problems of continuous power flow calculations and identify the busses where it is susceptible of voltage fluctuation with integration of solar photovoltaic in the power system network. This approach shall evaluate the improvement of voltage constraints and reducing line losses while increasing the transfer capacity of the transmission line.

3.2 Optimization of power flow

AC optimal power flow (ACOPF) is a method to fully optimize and schedule efficiency and through out of economic operating cost while considering the impact of power network system. This approach is considered to maximize find available location in the system. The most commonly desire objectives are to minimize fuel cost, active and reactive power slack generation and maximize active power transfer of the capacity allocation problem

Step 1: Simulate the case study with optimal power flow.

Step 2: Execute one-line diagram by using optimal power flow.

Step 3: Evaluate the optimal capacity of the added photovoltaic system for PQ bus.

Step 4: Calculate total line losses for the each transmission line by estimating optimal size of photovoltaic system to PQ bus.

Step 5: Evaluate the PQ Bus it's reached to the lowest utilisation factor in network. After, adding photovoltaic system as optimal location.

Step 6: Find the voltage constraints limitations of the system ($0.95 < V < 1.05$ p.u).

Step 7: The acceptable range of PQ bus voltage limitation shall be worked under desired value. The photovoltaic system shall be omitted from the PQ bus and return to Step 4 and choose the next bus priority list.

Step 8: Schedule the photovoltaic system to bus within the acceptable power penetration.

3.3 Model allowable size of photovoltaic system

AC optimal power flow are used to solve continuous, discrete variables and objective functions and constraints. In this context, the optimal size of solar photovoltaic in the power system shall be determined economically and operationally. Beside, this method is also to improve the reactive power demand on the system voltage while increasing the growth of solar photovoltaic to the network.

Step1: Simulate AC optimal power flow calculations to decide initial conditions when the power system is allocated in peak load

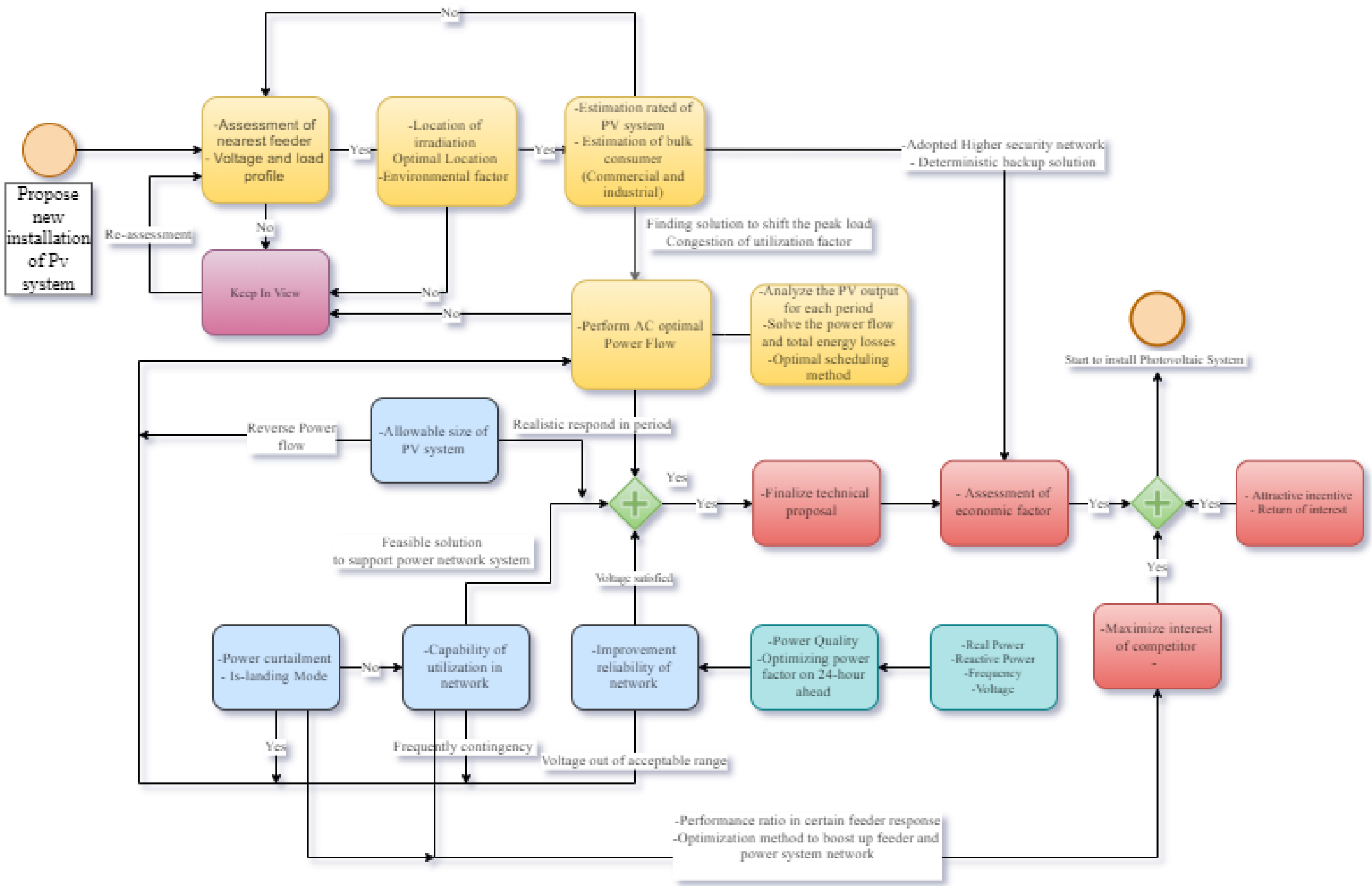
Step 2: Evaluate the most possible locations of that reach the larger line losses

Step 3: Selected location of photovoltaic, analyse and recalculate the system losses if estimated power such 50MW and 50MVAR of photovoltaic systems are added.

Step 4: Analyse the system losses based the photovoltaic system location, to be decided the total amount capacity of desired new photovoltaic system shall be placed

Step 5: Assess for the noon periods for comparing with or without penetration of photovoltaic system. The peak load normally appeared in the noon time.

3.4 Flow chart



CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter is to present the result where the results is obtained from the test cases by using the research methodologies in the previous chapter. This chapter directly linked with the previous chapter. The results were derived by using POWERWORLD and discussion of the obtained results were made under the test case title for ease of reference.

4.2 Case Information

The test case consists of 5 generators, 7 buses, and 11 lines which are named accordingly. The buses are interconnected with top area, left area and right area.

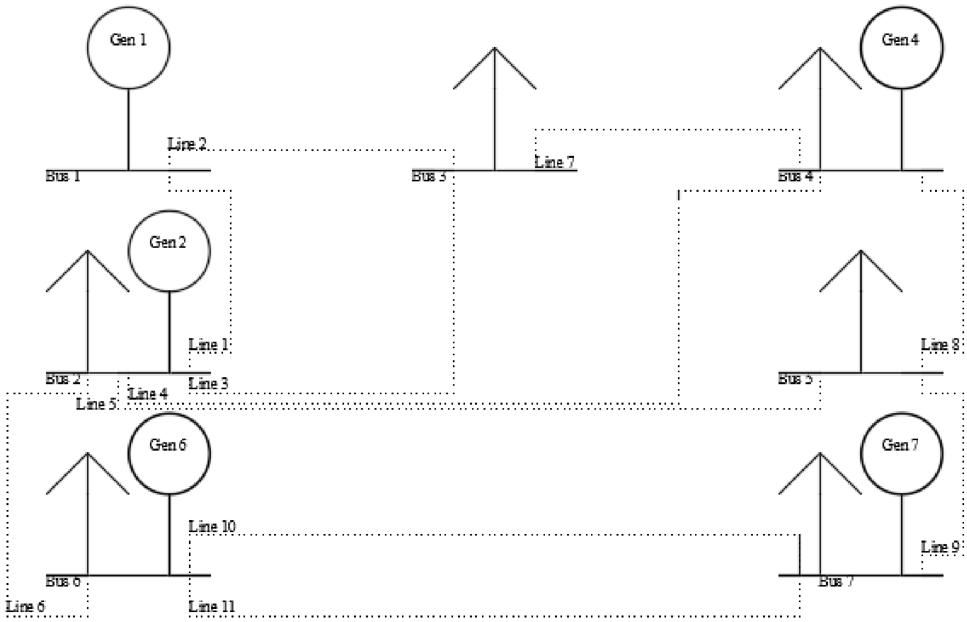


Figure 6: One-line diagram – interconnection between generators, busses and lines

The loads are connected with conventional generators which has shown at above. Below shows the information about generators, line and load profile.

Bus. No	Type	Min. Output	Max. Output	Initial Generation		Initial Load		Initial Voltage	
				P.MW	Q.MVAR	P.MW	Q.MVAR	Magnitude	Angle
1	PV	100	400	100	19.8	-	-	1.05	5.18
2	PV	150	500	150	191.5	150	150	1.04	2.978
3	PQ	-	-	-	-	50	50	0.9975	1.794
4	PV	50	200	52	23.8	50	50	1	1.878
5	PQ	-	-	-	-	50	50	1.01	0.317
6	PV	150	500	150	84.9	100	100	1.04	3.07
7	SLACK	10	600	0	93.1	50	50	1.04	0
			Total	452	413.1	450	450		

Figure 7: Buses and generators data

				Series Impedence, Z (p.u)		Series Impedence, Y (p.u)		Total Charging		Line Limit (MVA)		
Line No	Line	to	Line	R	X	G	B	MVAR		Limit A	Limit B	Limit C
1	1	-	2	0.01	0.06	0	0.06			150	100	100
2	1	-	3	0.04	0.24	0	0.05			65	80	80
3	2	-	3	0.03	0.18	0	0.04			90	80	80
4	2	-	4	0.03	0.18	0	0.04			100	100	100
5	2	-	5	0.02	0.12	0	0.03			100	100	100
6	2	-	6	0.01	0.06	0	0.05			200	200	200
7	3	-	4	0.005	0.03	0	0.02			100	100	100
8	4	-	5	0.04	0.24	0	0.05			60	100	100
9	7	-	5	0.01	0.06	0	0.04			200	200	200
10	6	-	7	0.04	0.24	0	0.05			200	200	200
11	6	-	7	0.04	0.24	0	0.05			200	200	200

Figure 8: Lines data

4.2.1 Network equations and variables

Below describes four variables at each bus in a power system;

i. P_i – active power of bus i

ii. Q_i – active power of bus i

iii. V_i – Voltage magnitude of bus i

iv. θ_i – active power of bus i

Among of the variables, always there are only two variables are specified and known before the study whereas the remaining two variables are obtained at the end of the study.

The formulation of single-phase power-flow analysis is done by considering an electrical network as a linear lumped series of balanced three-phase system at rated frequency. The positive sequence models are used for the constructing the system admittance matrix. The nodal voltage equation, using matrix notation, is given by:

$$\mathbf{I} = \mathbf{Y}\mathbf{V} \tag{1}$$

Where symbol **I** represents the equivalent nodal injected currents vector, **Y** is the admittance matrix, and **V** is the bus voltage vector. The current injected to a certain bus *i*, is calculated by:

$$\overline{I}_i = \frac{\overline{S}_i^*}{\overline{V}_i^*} \tag{2}$$

The net injected power on bus *i* is:

$$\overline{S}_i^* = \left(P_{g\,i} - P_{d\,i}\right) - j\left(Q_{g\,i} - Q_{d\,i}\right) = P_i - jQ_i \tag{3}$$

Where $\overline{S}_i$ refers to the net generation at busbar *i*, *g* and *d* refer to the generated and demand values respectively.

The injected current at certain bus *i* can be calculated by extracting (1) as follows:

$$\overline{I}_i = \overline{Y}_{ii}\overline{V}_i + \sum_{j\in k}\overline{Y}_{ij}\overline{V}_j \tag{4}$$

Where *k* refers to a set of busbars connected to bus *i*, the summation refers to the total power injected currents to the busbars *i*.

Substituting $\overline{I}_i$ into (2), the following relation is obtained in complex form:

$$\overline{S}_i^* = \overline{V}_i^*\overline{Y}_{ii}\overline{V}_i + \overline{V}_i^*\sum_{j\in k}\overline{Y}_{ij}\overline{V}_j \tag{5}$$

The problem (5) can be also stated in polar form as:

$$\overline{S}_i^* = \left(V_i\ \angle -\theta_i\right)\overline{Y}_{ii}\left(V_i\ \angle\theta_i\right) + \left(V_i\ \angle -\theta_i\right)\sum_{j\in k}\overline{Y}_{ij}\left(V_j\ \angle\theta_j\right) \tag{6}$$

Equating for both the real and imaginary parts of (6); the following equations can be evaluated:

$$P_i = V_i^2 G_{ii} + V_i \sum_{j \in k} \left(G_{ij} \cos\theta_{ij} + B_{ij} \sin\theta_{ij} \right) V_j \qquad (7)$$

$$Q_i = -V_i^2 B_{ii} + V_i \sum_{j \in k} \left(G_{ij} \sin\theta_{ij} - B_{ij} \cos\theta_{ij} \right) V_j \qquad (8)$$

Where:

$$\overline{Y}_{ij} = G_{ij} + jB_{ij}, \qquad \theta_{ij} = \theta_i - \theta_j \qquad (9)$$

4.2.2 Bus specification

Based on the state variables specification, busses are usually categorized into three types.

Node	Specified Values	Unknown Values
PQ	P_i^{sp}, Q_i^{sp}	V_i , θ_i
PV	P_i^{sp}, V_i^{sp}	Q_i , θ_i
Slack	V_i^{sp}, $\theta_i^{sp} = 0$	P_i , Q_i

Voltage-controlled bus (PV bus):- The specification of total penetrated active power P_i and voltage magnitude V_i are the fixed value. The buses are generally corresponded to either a generators where P_i is fixed by turbine governor setting and V_i is fixed by automatic voltage regulators acting on the machine excitation, or as a bus where the voltage is fixed by supplying reactive power from static capacitors or rotating synchronous compensators, e.g. at substation.

Non-voltage-controlled bus (PQ bus):- The definition of PQ bus is specified which the real and reactive power P_i+jQ_i required from the bus. The characteristic of the PQ bus are known as the commercial, industrial or residential where consumer is demanding the power for consumption. Both P_i and Q_i will vary the voltage constraints.

Slack bus (Swing bus):- The bus is acting as a reference bus in the power system network, where its voltage angle serves as reference (voltage angle of zero) for other angles at buses. A slack bus is an infinite bus with constant voltage and unlimited real and reactive power capability. Both the voltage magnitude and angle are specified at this bus. Therefore, this bus is chosen from voltage-controlled buses.

4.2.3 Optimization tool – AC optimal power flow

The optimal power flow contains of economic dispatch which held the total generation to equal to the losses plus the total load. Optimal power flow is to solve and minimize generation cost and required that the optimization calculation to balance the entire power flow at the same time. That is noteworthy that the objective function can take the different forms other than minimizing the generation cost. It can express that the optimal power flow as a minimization of the electrical losses in transmission system and minimization shift of generation and an optimum of operation.

$$\boldsymbol{P}_{\mathrm{Load}} + \boldsymbol{P}_{\mathrm{Losses}} - \Sigma\, \boldsymbol{P}_{\mathrm{i}} = 0$$

The entire system of power flow are solved simultaneously. It is to achieve the minimization of generation cost. Further, the objective function that could simultaneously minimize the loss and maximize the power flow in transmission. Moreover, the optimal power flow included the contingency outage. The objective function of defensive manner is to dispatch the as so called security constraints in the resulting voltage and flows within the limitation.

This paper only reviews part of the adjustable variables that be specified. The partial list of the variable included:

- Bus Real and reactive power balance
- Generator voltage set points
- Area MW interchange
- Transmission line/transformer/interface flow limits
- Generator MW limits
- Generator reactive power capability curves
- Generator MW outputs
- Load MW demands

The applications of optimal power flow is considered in this paper including:

1) The analytical calculation of the optimum generation is to achieve the minimum cost of generation with meeting the transmission system limitations.

2) By implementing the above load curve to the simulation, optimal power flow is in cooperated with the security constraints.
3) The optimal power flow provided a function to find optimum value for generation voltages, bus voltage, and reactive power value.
4) The output cost model of optimal power flow included unit fuel cost (RM/MBTU), Fuel cost dependent value (RM/hr), and piece-wise linear cost curve. The cost function is increased strictly due to the multiply fuel input by fuel cost, No-load cost, minimum and maximum generation. The incremental cost curve is linearly increased by measuring the derivatives of cost curve.

The optimal power flow is a very difficult to solve the mathematical power system problem. There are several algorithm to be used to solve the mathematical power system problem such as Gauss-Seidel method, Newton-Raphason (N-R) method and Fast Decoupled (FDC) method and DC load flow analysis. In this paper, Newton-Rahpason is chosen for the studies.

The reason to choice Newton-Raphason (N-R) algorithm is because the merit of operation is very fast convergence as long as initial prediction is very close to the solution. In addition, it can cover large scale convergence of the region. This is common algorithm in power flow analysis.

The next is to plug the fuel price into simulator. This paper only reviews for natural gas. That is because this can independently make the comparison between natural resource and renewable resource. The latest of natural gas price is according to the gas Malaysia tariff and rates. The following tariff rats were approved by government in accordance with the section 13 of Gas supply Act 1993.

TARIFF CATEGORY	APPLICABILITY RANGE (MMBtu/year)	TARIFF AFTER SURCHARGE (RM/MMBtu) (15 July 2019 until 31 Dec 2019) (with GCPT surcharge of RM1.92/MMBtu)
A	Residential	25.44
B	0-600	32.32
C	601 – 5,000	32.48
D	5,001 – 50,000	32.78
E	50,001 – 200,000	34.12
F	200,001 – 750,000	34.12
L	Above 750,000	35.20

Figure 9: Natural gas tariff rate category

Category of tariff rate "L" is chosen that is because the estimated amount of generation per day is about 28,865 MWh/day. By considering the safety factor 15% of fuel cost, the first year estimated of fuel cost is about 12,116,083.75 MWh/yr. The rate of conversion between MMBtu to MWh is rated as 0.293071 by multiplying the energy measurement. The unit of gas tariff is converted from RM/MMBtu to RM/MWh. The rate is about RM 120.20/MWh or RM 0.1202 /KWh. Therefore, the rate RM120.20/MWh is implemented for base value.

In order to apply the method of optimal power flow, piece-wise linear cost curve required that cost function must be strictly increasing. The new fuel cost is set according to the current gas tariff which is rated as RM 120.20/MWh. The original of incremental gap remained same and piece-wise linear cost curve is based on RM 120.20/MWh according to the different generators. The schedule cost is shown at below.

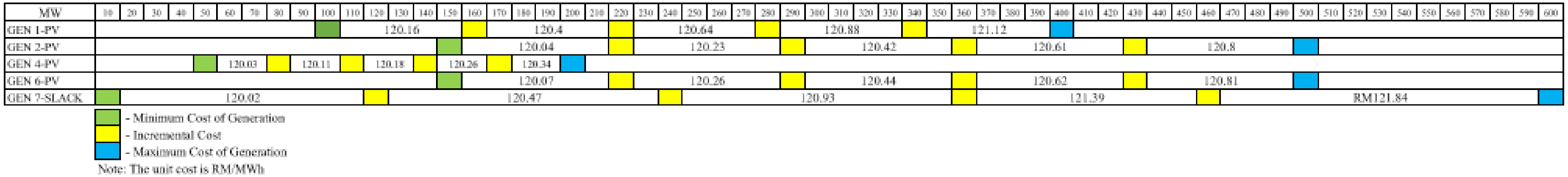


Figure 10: Fuel cost piece-wise linear cost curve for generators

Gen 1, 2, 4, and 6 are incorporated as PV bus which is voltage controlled bus. Gen 7 is incorporated as slack bus which voltage angel served as reference. The base value of minimum output for each generator is referred to figure 7. The function of optimal power flow is to choice the lower rate based on the demand. Gen 1, 2, 4, and 6 are priority to supply the minimum output 450MW to network. Then, Gen 7 as known as a slack bus, which started off to supply electricity when the demand is above 450MW. The electricity of output below 450MW the gen 7 will absorb the electricity from generator turning to motor behaviour (Hong, T., & Burke, J. J. (2010)).

The design must set as minimum as 450MW and so do maximum output to the network is set 2200MW, than the load curve is scheduled as per required minimum and maximum output. Refer to one-line diagram, the diagram consists of top area cost, left area cost, and right area cost. The sum of area cost is named case hourly cost. The function of piece-wise linear cost curve determined the cost, for example, Gen 1-PV, minimum output as100MW, the cost is about RM120.16/MWh. The next of cost is about RM120.4 when the output is above 160MW, the sum of total generation cost is about RM 19,240/h which 100MW times RM120.16/MWh and 60MW times RM120.4/MWh.

4.3 Simulation on 7 buses without photovoltaic system

The network is simulated as referring to the assumed load curve. The load curve is cooperated with the conventional generator. The generators are proportionally increased or decreased based on the loads. The load curve for the variant time loads is simulated by following varied characteristic of load (Mithulananthan, N., Oo,T., & Phu, L. Van. (2004)). Furthermore, the load curve is developed based on the 24-hour timeline. The illustrated 24-hour load profile in MW and MVAR for the system is implemented without distributed generation unit. The load curve of MW and MVAR are assumed as power factor of 0.707 (θ=45^{o}).

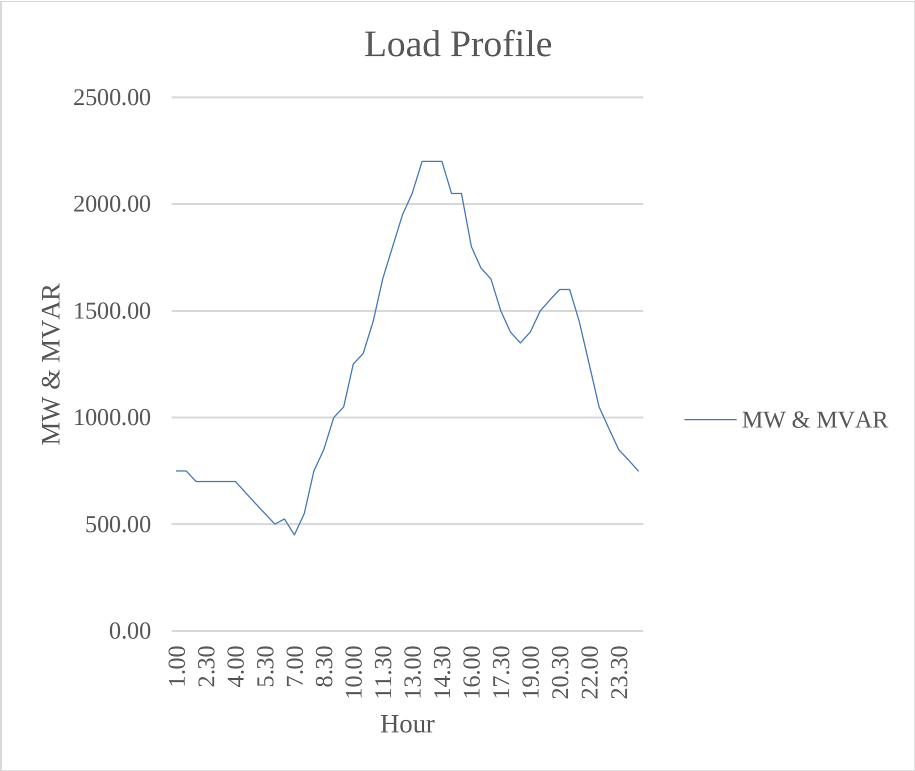


Figure 11: Assumed 24-hour load curve – MW and MVAR

POWERWORLD is simulated with using the schedule as shown at figure 11 assumed 24-hour load curve. Furthermore, the list of pre-set cost and value is applied to POWERWORLD.

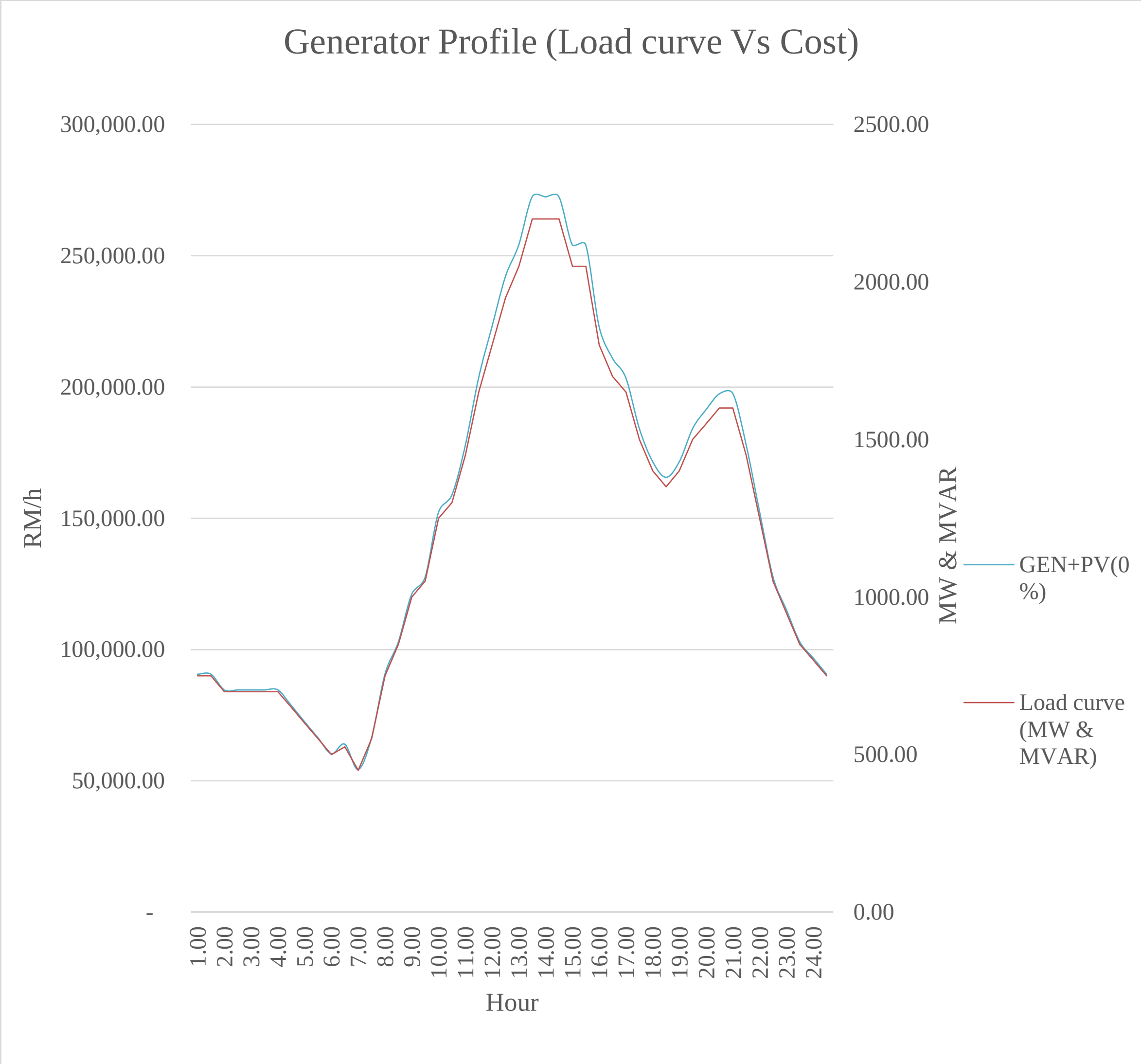


Figure 12: Generator profile (Load curve Vs Generation Cost)

Figure 12 shows the load curve with generation cost by the 7 units of generators. The timeline of load curve and generation cost is attached in between 21:00PM to 9:00AM. The detached timeline from 10:00AM to 20:00PM shows that the incremental cost in piece wise linear cost curve. The result also presents that the maximum demand of the load required the multiply fuel input of incremental cost and maximum generation output of generator to sustain the network. On the other hand, the line losses and voltage drop has to be taken as a consideration. The line losses is dependable to the load demand. As the load demand is increased, the line losses will increase accordingly.

In this case, the reactive power line losses is negligible. The reactive power line losses is dependent to the transmission capacity. The line losses is increased when the increment of load demand is increased. This is a significant amount of cost when the load demand reaches the highest peak. That is only method to reduce the losses which is to build a new transmission line. This violated the environmental factor and capital investment of transmission line. The limitation of line responds the maximum capacity amount that can contain in term of MVA. The function of optimal power flow can re-schedule the line flow while one of the line limitation is reached. That is because the optimal power flow can minimize the losses. The below figure shows the losses in the different of time (Hong, T., & Burke, J. J. (2010)).

4.3.1 Line losses

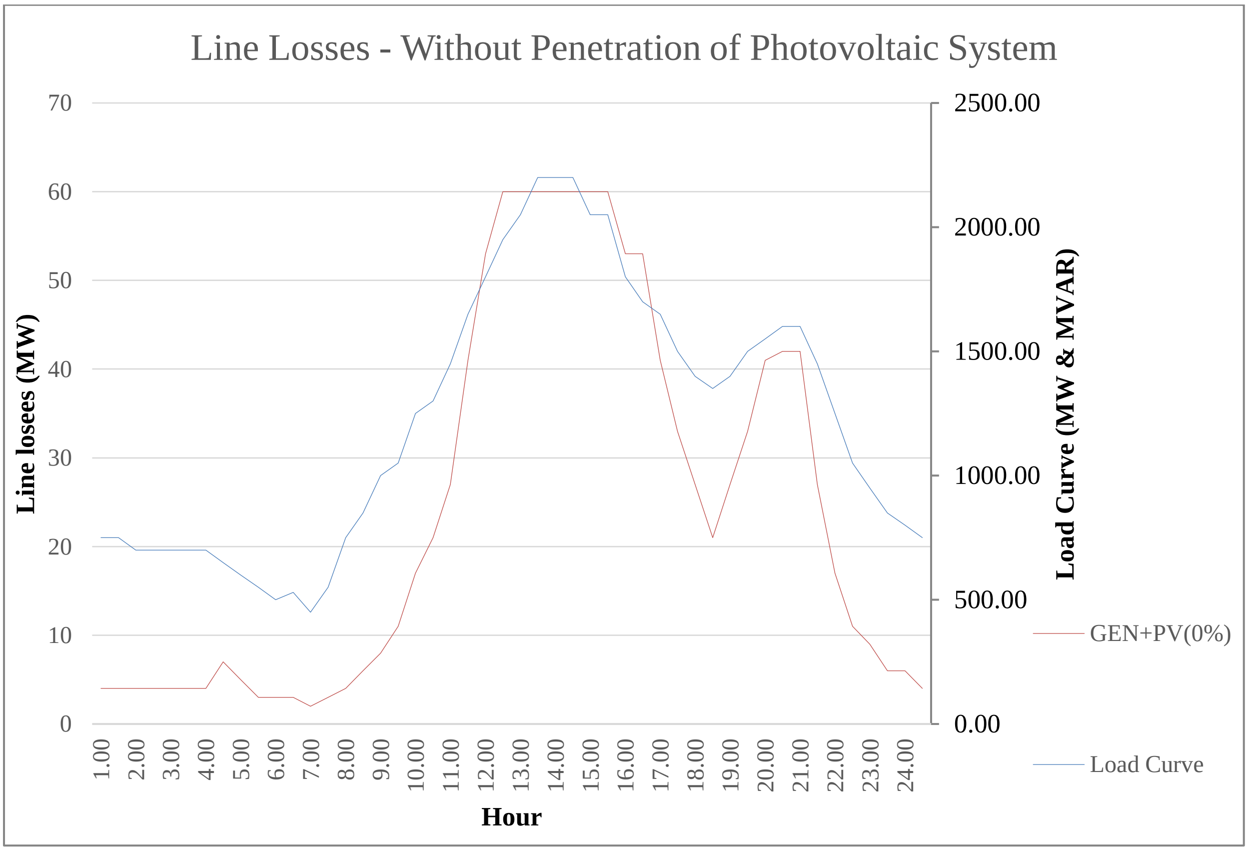


Figure 13: Line losses – GEN+PV(0%) vs Load Curve

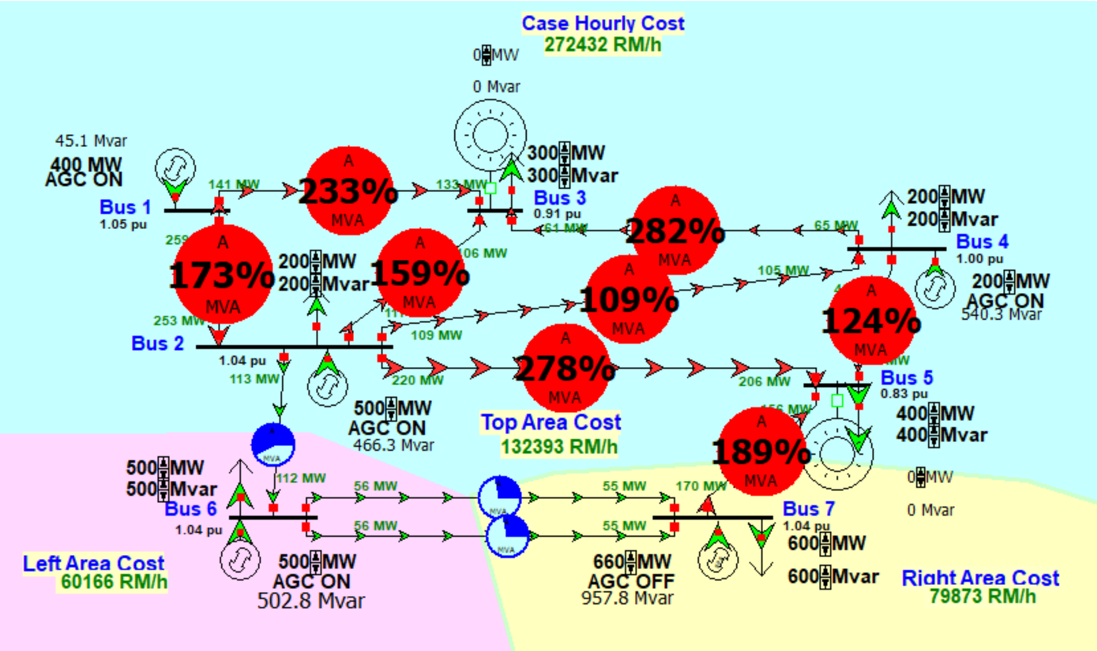


Figure 14: Line congested when the demand of load is 2200MW and 2200MVAR

The figure 13 shows line losses over the time. The pattern of line losses is similar like load curve. Next, the limitation of line reached to the peak except two of line 6-7 and the line appeared congestion when the demand of load reached 2200MW and 2200MVAR. As well, utilization factor of the network shall remain the space and safety mode for contingency manner in case either of the line is open. In this case, N-1 manner of transmission line is violated because the environmental factor is not a better solution for this. An expected solution to solve this congestion is to place the distributed generation close to the load at PQ bus 3 and 5 (Hong, T., & Burke, J. J. (2010)).

Moreover, The losses under the area is about 346.5MWh/day or 126,472.50MWh/yr which means the total amount of losses is about RM 41,649.3/day RM 15,201,994.50/yr by multiplying the base fuel cost RM 120.20/MWh. The losses is about 2% sum of generation per day. The voltage drop is also a significant technique problem. The below figure shows the voltage drop at bus 3 and bus 5.

4.3.2 Voltage Constraints

Figure 15: Voltage profile in bus 3 and bus 5

This can easily observe that the real and reactive power could induce the voltage drop. The figure show three items such as MW, MVAR and MW&MVAR. The MW&MVAR result the significant voltage drop than MVAR and MW. That is because the generator shall supply the reactive capacitive power from a long distance transmission line. In order to improve the voltage profile, this can be solved by using many methods such as integration of SVC, STATCOM and distributed generation.

4.3.3 Levelized Cost of Electricity – Generators

This section will discuss the LCOE. The main three character is considered such as generators, utility, and customers. The buying and selling cost is levelized based on the factor that indicated in the list. The limitation on this section is the capital cost due to uncertain data from reference. Therefore, all the data in this section is designed and assumed. As well, the formulation is to present the average selling cost to customer. This is so called the tariff rate (Kuang, H., Li, S., & Wu, Z. (2011)).

The regulation of base tariff is according to the Incentive based regulation (IBR) which is published by Energy Commissioner. Incentive based regulation consists of three main mechanism such as generation, transmission and distribution & retail. In the generation mechanism, TNB generation and independent power plants (IPPs) are the main characters which is to generate the electricity and transform to the high voltage 138KV for this case study. The next mechanism is transmission. This mechanism is to manage the single buyer generation tariff, single buyer operation tariff, grid system operators and transmission in the power network. Lastly, distribution & retail plays an important role for interfacing to distribution system. This consists of customer services and distribution network. All of the each item is regulated and priced according to IBR. The below table shows the LCOE by simulating the above test network (Wang, R., Wang, P., & Xiao, G. (2015)).

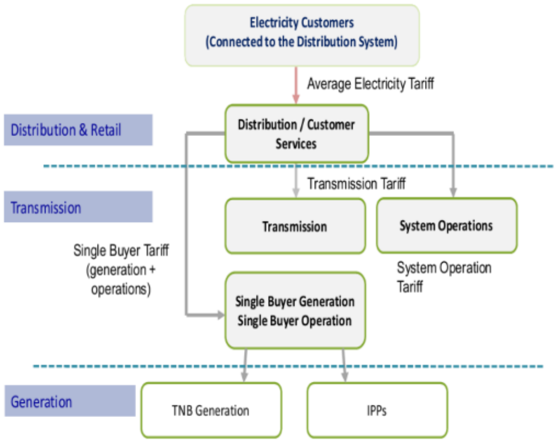


Figure 16: Incentive Based Regulation (IBR) mechanism

Capital Cost of Generators									
			GEN						
Total Cost generation (RM/day)			2,163,010.20	RM/day					
Total generator generation (KWh/day)			17,632,500	KWh/day					
Total PV generation (KWh/day)			-	KWh/day					
Average cost rate per KWh			0.1227	RM/KWh					
Fuel Cost Saving (RM/day)								Total Cost Saving/year	
Fuel Cost Saving (RM/year)								-	RM/year
					Gen 1	Gen 2	Gen 4	Gen 6	Gen 7
Basic parameters		Capacity(MW)			400	500	200	500	600
		Capital Cost(RM/KW)			1800	1600	2000	1600	1400
		Equity % of Capital			25%	25%	25%	25%	25%
		Annual return of equity%			15%	15%	15%	15%	15%
		Loan interest			7%	7%	7%	7%	7%
		Loan term years			25	25	25	25	25
		O&M Capital			3%	3%	3%	3%	3%
Capital Investment of Generators		Capacity(KW)			400,000	500,000	200,000	500,000	600,000
		Project Cost			720,000,000	800,000,000	400,000,000	800,000,000	840,000,000
		Annual Factor			0.085810517	0.085810517	0.085810517	0.085810517	0.085810517
		Annual Payment (RM/Yr)			61,783,572	68,648,414	34,324,207	68,648,414	72,080,834
		O&M (RM/Yr)			21,600,000	24,000,000	12,000,000	24,000,000	25,200,000
		Return of equity			27,000,000	30,000,000	15,000,000	30,000,000	31,500,000
		Annual Cost/Yr			110,383,572	122,648,414	61,324,207	122,648,414	128,780,834
Fuel Cost(Natural gas)		Estimated Generation per day			17,632,500	KWh/day			
		Safety Factor (15%)			20,277,375	KWh/day			
		Estimated fuel purchase per year			7,401,241,875	KWh/yr	1 MMBtu = 0.293071 MWH		
		Gas Tariff(RM35.20/MMBtu = RM0.1202/KWh)			889,629,273.38	RM/yr	Note: Average. cost rate per day RM0.1236/KWH		
GENERATION	Levelized Cost of Electricity	Total Capital levelized cost			545,785,441	RM/yr			
		Total Capital+Fuel			1,435,414,715	RM/yr			
		Total Estimated Generation per year			6,435,862,500	KWh/yr			
		LCOE			0.2230	RM/KWh			
		Profit Margin of LCOE(20%)			0.2676	RM/KWh			
TRANSMISSION	1) Single Buyer Generation Tariff				0.2676	RM/KWh			
	2) Single Buyer Operation Tariff				0.0019	RM/KWh			
	3) Grid System Operator				0.0006	RM/KWh			
	4) Transmission				0.0403	RM/KWh			
DISTRIBUTION & RETAIL	5) Distribution Network				0.0715	RM/KWh			
	6) Customer Service				0.0096	RM/KWh			
	7) Average tariff rate Selling to Customer				0.3915	RM/KWh			

Figure 17: Capital cost of generators

The above figure 17 shows the capital cost of generators. The basic parameters contains the capacity, capital cost, equity of capital, annual return of equity, loan interest, loan term years, and O&M capital. The figure of percentage are assumed. Capital investment of generators results that the figure of annual cost to be returned. Capacity of generators is based the maximum output MW from figure 7. Each of the generator capital cost is assumed. The maximum capacity of generators has the lowest capital cost and the minimum capacity has inversely the highest capital cost due to competitive advantage.

Natural gas is only considered in this case study. The estimated generation or fuel consumption is found the area under the curve in figure 12. That is about 17,632.500 KWh/day. Fitting the safety factor of 30% into fuel consumption, that is about 20,277,375 KWh/day. The estimated annual fuel consumption is about 7,401,241,875 KWh/yr. by using the tariff rate from Gas Malaysia category “L”, the conversion of tariff rate is about RM 0.1202/KWh. Therefore, the estimated capital fuel cost per year is about RM 889,629,273.38/yr. The sum of the annual fuel cost and annual cost of generator is about RM 2,069,595,336/yr. Basic of LCOE is rated RM 0.2230/KWh. By marking up a profit of 20%, the actual selling from generator to utility rate is about RM 0.2676/KWh.

The items such as single buyer operation tariff, grid system operator, transmission, distribution network, and customer service remain same as following the average tariff by IBR entities RP2 (2018 – 2020). Refer to figure 17 and objective, the actual average tariff rate selling to customer is about RM 0.3915/KWh. In this paper, the tariff is only focusing at commercial due to load curve. The average tariff rate selling to customer is set for base rate for comparing with the penetration of photovoltaic system (Takahashi, I., Sakurai, T., & Andoh, I. (n.d.)).

In sum, the natural gas generation is type of conventional or traditional pattern to transmit power to meet bulk customer. On the other hand, the emission of CO_2 will be increasing if the demand of load is increasing. Therefore, this method of using generators can't achieve the green energy by referring to the objectives. The below is the summary by using the natural gas generators generating electricity.

- Emission of CO_2 is increasing by foresing and increasing the demand of load.
- The voltage drop is significant if the demand of load is increased especially the reactive inductive power.
- The peak of load resulted excessive of line limitation and network appeared insecure of contingency manner
- The accumulative of line losses is about 346.5MWh/day or 126,472.50MWh/yr
- The expansion of transmission line is no longer a good option for new route due to environmental factor.

4.4 Simulation on 7 busses with penetration of photovoltaic system

Refer to the previous topic, that is questionable that the expansion of generators. These reasons can't achieve the objectives that it is mentioned at chapter 3.A detail of technique to solve the above problem, distributed generation such as photovoltaic system is used for this case study. That is arguable that the allowable size and location of photovoltaic system is to be installed. The excessive size of photovoltaic system may cause the unwanted result as mentioned at problem statement.

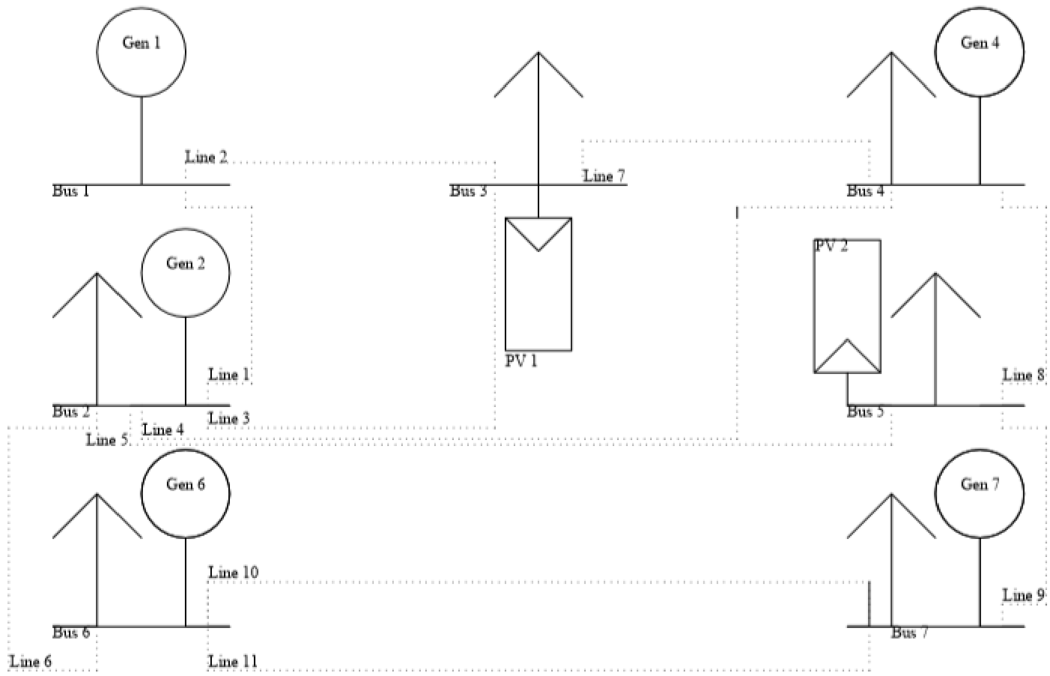


Figure 18: One-line diagram-Photovoltaic system integrated at Bus 3 and Bus 5

In order to achieve the objectives, the allowable photovoltaic system size and location will be determined according to the voltage constraint in the PQ bus 3 and 5. Although photovoltaic system can periodically generate the electricity from sun, it only appears from morning to evening. The figure 1-24-hour ahead irradiation forecast shows the assumption of irradiation of the day. The maximum of irradiation could reach about 1000 W/m^2 at sun hour 12:30 PM. Therefore, the first step to design the capacity of photovoltaic system is that PQ bus 3 and bus 5 could reach desired voltage level 1 P.U at the sun hour 12:30PM. The second step is to reduce a 10% of capacity back-to-back per half an hour. At last, it will form hierarchy timeline that the pattern is similar like figure 1 24-hour ahead irradiation forecast.

By implementing the rule of thumbs, the distributed generation of photovoltaic system shall install close to the load centre in order to improve the voltage constraint and decreasing the probability to build a new transmission line. Furthermore, that is also capable to increase the secure of contingency manner and reduce the line limitation for transmitting the power from the distance (Takahashi, I., Sakurai, T., & Andoh, I. (n.d.)).

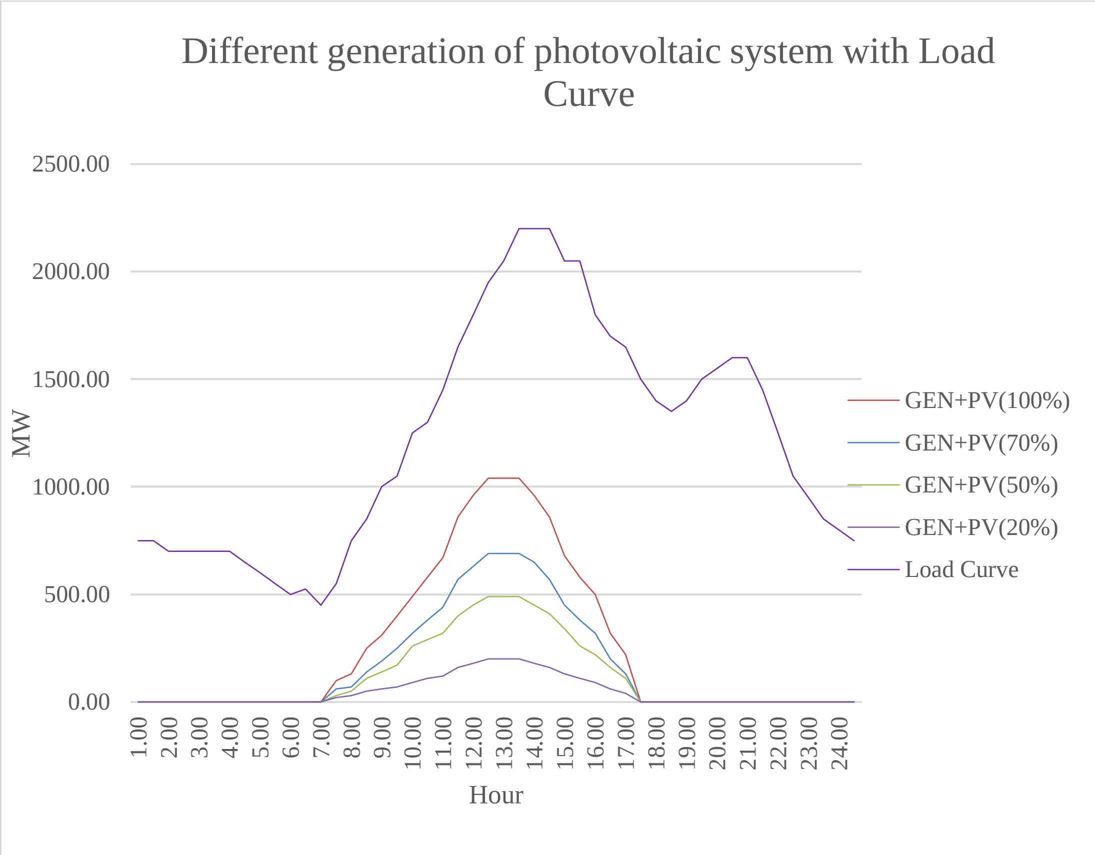


Figure 19: The total estimated generation of PV 1 and PV 2

The figure 19 show the total estimated generation of photovoltaic system PV 1 and PV 2. The different capacity of photovoltaic system presented different accumulation of generation to the network. The peak generation of photovoltaic system and load curve coincidently meet interception point during 12.30PM. The individual estimated generation of photovoltaic system PV 1 at PQ bus 3 and PV 2 at PQ bus 5. Refer to the item PV (100%), the maximum load is about 2200MW and 2200MVAR during 13.30PM to 14.30PM. Furthermore, the demand of load at PQ bus 3 and bus 5 required 300MW - 300MVAR and 400MW – 400MVAR. This caused the voltage drop as per shown at figure 15. In order to improve the voltage profile, the maximum capacity of photovoltaic system in PQ bus 3 and bus 5 is 470MW and

570MW. The contribution of reactive power is the key to determine the voltage level. Eventually, the photovoltaic system power factor is adjusted to 0.9 leading or lagging which it may supply or absorb the reactive power. In this case, the photovoltaic system PV 1 and PV 2 are supplying the reactive capacitive power to the bus which to boost up the voltage profile. Therefore, the maximum capacity of PV 1 and PV 2 is designed based on the voltage profile that it is already reached at 1 P.U (Kuang, H., Li, S., & Wu, Z. (2011)).

PV (70%), PV (50%) and PV (20%) is the linear decrement capacity of photovoltaic system. This is where to compare the efficiency and cost saving between 20%, 50%, 70% and100%. The purpose for this section is also to compare the LCOE between 20%, 50%, 70% and100%. The competitive advantage of economic factors bring the most expensive cost of installation with the less capacity penetration to network while the most cheapest cost of installation with the most capacity penetration to network. That is going to find out the absolute LCOE to meet the objectives. Some more, it can also evaluate that the photovoltaic system can increase the security to the network (Wang, R., Wang, P., & Xiao, G. (2015)).

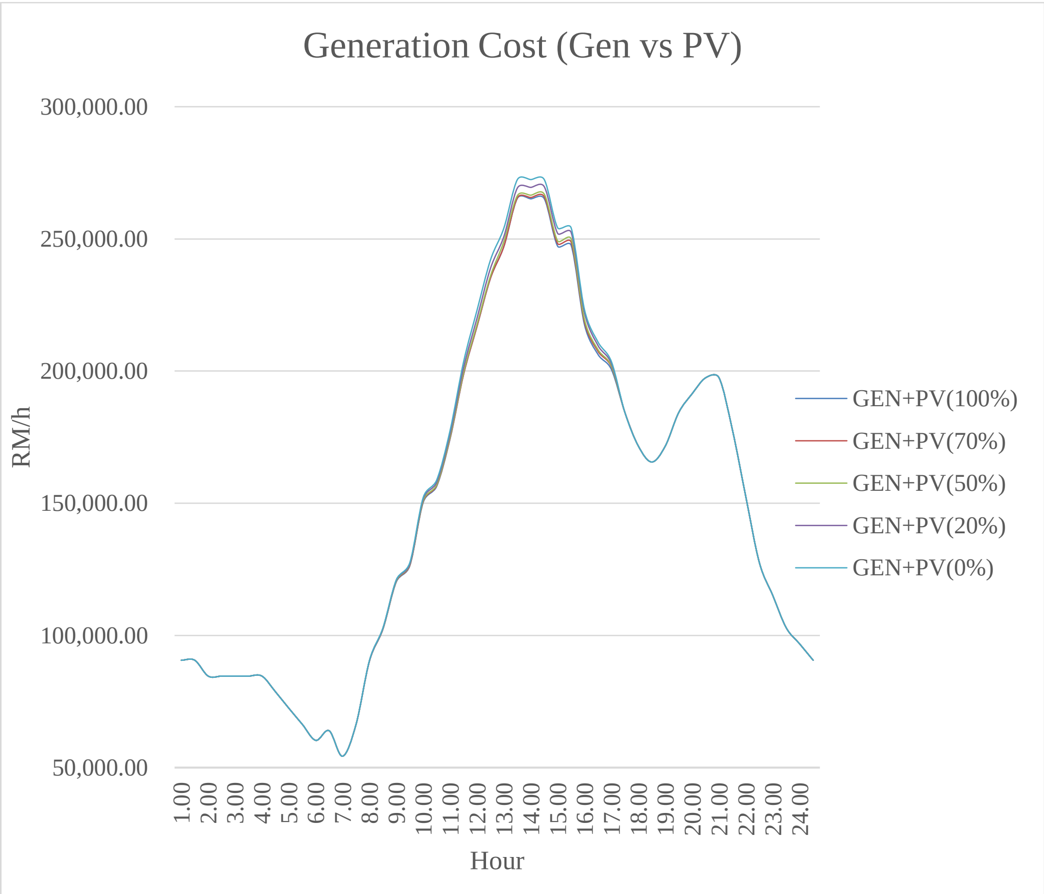


Figure 20: Generation cost with different size of photovoltaic system

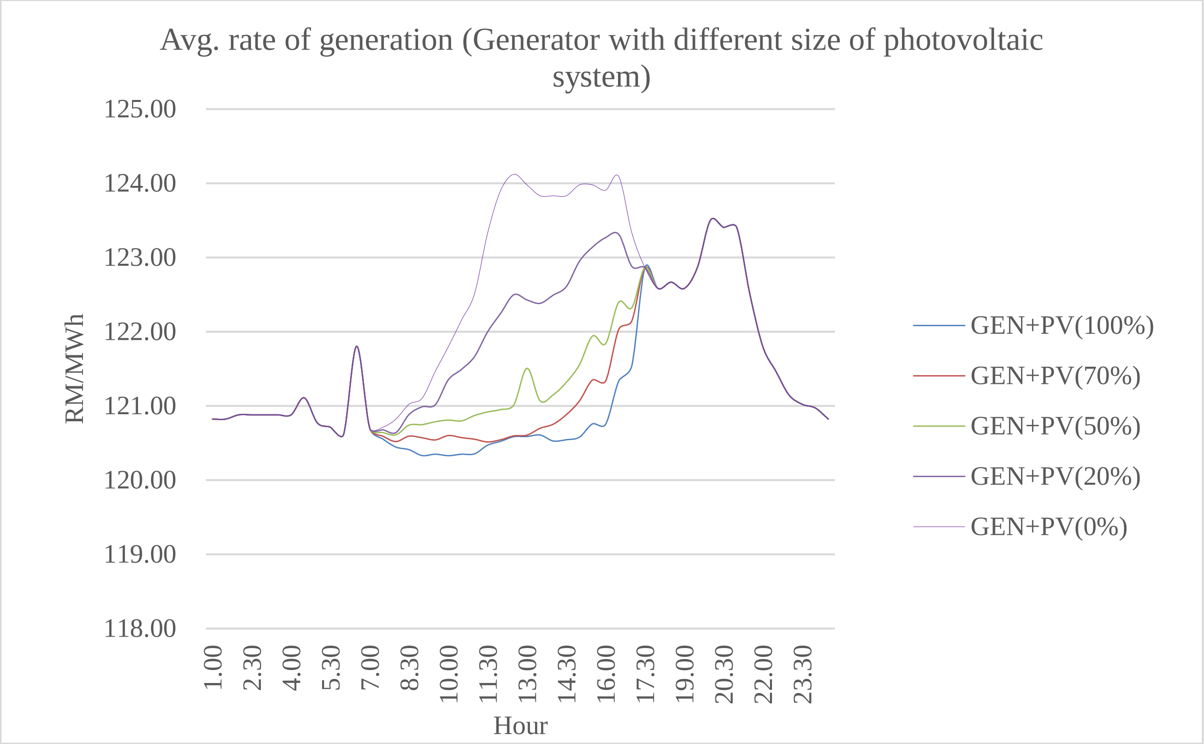


Figure 21: Average rate of generation with different size of photovoltaic system

It is obviously to observe that the incremental capacity of photovoltaic system penetration to network may reduce the case hourly cost, as so called generation cost. The GEN+PV(100%) reached the optimum average rate of generation at about 8.30AM. Meanwhile, GEN+PV(0%) has the peak rate during 11.30AM. The next figure will show the total generation cost with different capacity of photovoltaic system. This is to identify that the generation cost will be reduced when the photovoltaic system is penetrated to network.

4.4.1 Line losses with penetration of photovoltaic system

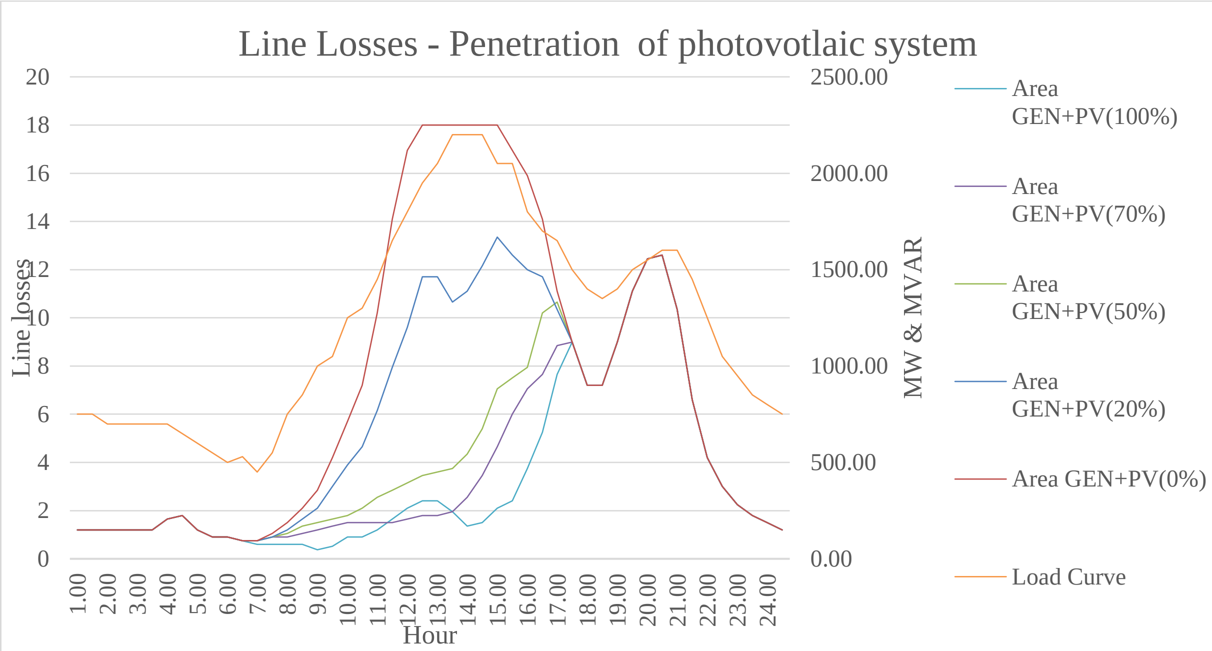
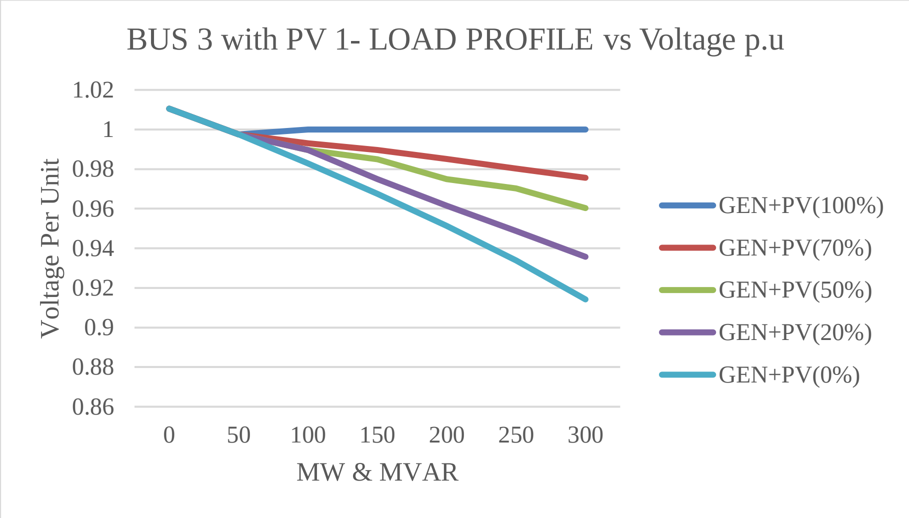


Figure 22: Profile of line losses with the different capacity of photovoltaic system

The increased capacity of photovoltaic system is obviously decreasing the line losses. The line losses under the area are where GEN+PV(100%) – 154.7MWh/day, GEN+PV(70%)- 173.4MWh/day, GEN+PV(50%)- 194.7MWh/day, GEN+PV(50%)- 273MWh/day and GEN+PV(0%)-346.5MWh/day. Furthermore, the loss of generation is where GEN+PV(100%) – RM 18,594.94/day, GEN+PV(70%)-RM 20,842.68/day, GEN+PV(50%)-RM 23,727.48/day, GEN+PV(50%)- RM 32,814.60/day and GEN+PV(0%)-RM 41,649.30/day. The result shows that GEN+PV(100%) is the lowest losses among the capacity of photovoltaic system (Hong, T., & Burke, J. J. (2010)).

4.4.2 Enhancement of voltage constraints



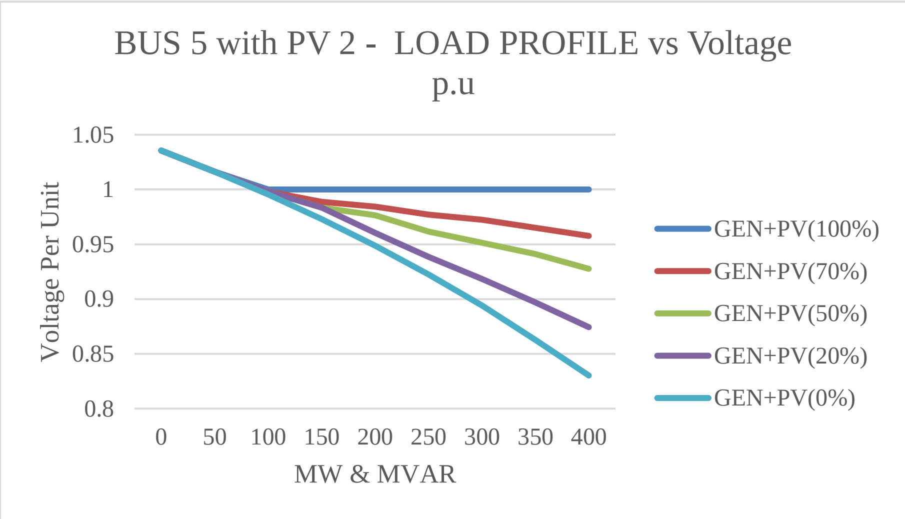


Figure 23: Voltage improvement with PV 1 and PV 2 at PQ bus 3 and bus 5

The figure 23 shows the voltage improvement by integrating with the photovoltaic system into PQ bus. Comparing to the figure 15, the GEN+PV(100%) show the maximum capacity of photovoltaic system. Therefore, the voltage per unit reached 1 per unit. The reduction of photovoltaic system capacity will proportionally decrease the enhancement of voltage profile. Although the on-load tap changer and compensator such as SVC and STATCOM is not considered, the photovoltaic system presented the advantage than the compensator and on-load tap changer. This constraint of this advantage only performed in short period which enhancing during the peak sun hour. The acceptable range of the voltage limitation from the above figure is 690MW,GEN+PV(70%) and 1040MW,GEN+PV(100%) because the voltage variation is between 0.95<V<1.05 P.U as mentioned at research methodology.

4.4.3 Levelized Cost of Electricity – Photovoltaic System

Capital Cost of Generator + Photovoltaic system with size 20%, 50%, 70% and 100%								
		GEN	GEN+PV 1	GEN+PV 2	GEN+PV 3	GEN+PV 4	Total PV generated capacity	
	Total Cost generation (RM/day)	2,163,010.20	2,153,735.40	2,144,337.00	2,140,612.20	2,138,021.40		
	Total generator generation (KWh/day)	17,632,500	16,954,500	15,940,500	15,286,500	14,035,500		
	Total PV generation (KWh/day)	-	678,000	1,014,000	654,000	1,251,000	3,597,000	KWh/day
	Average cost rate per KWh	0.1227	0.1221	0.1216	0.1214	0.1213		
	Fuel Cost Saving (RM/day)		9,274.80	9,398.40	3,724.80	2,590.80	Total Cost Saving/year	
	Fuel Cost Saving (RM/year)		3,385,302.00	3,430,416.00	1,359,552.00	945,642.00	9,120,912.00	RM/year
			PV 20% Size - 1	PV 30% Size - 2	PV 20% Size - 3	PV 30% Size - 4	Cumulative of PV(MW)	
Basic paramenters	Capacity(MW)		200	290	200	350	1040	MW
	Capital Cost(RM/W)		10	8	6	4		
	Equity % of Capital		25%	25%	25%	25%		
	Annual return of equity%		15%	15%	15%	15%		
	Loan interest		7%	7%	7%	7%		
	Loan term years		25	25	25	25		
	O&M Capital		3%	3%	3%	3%		
Capital Investment of levelized Cost	Capacity(W)		200,000,000	290,000,000	200,000,000	350,000,000		
	Project Cost		2,000,000,000	2,320,000,000	1,200,000,000	1,400,000,000		
	Annual Factor		0.0858	0.0858	0.0858	0.0858		
	Annual Payment (RM/Yr)		171,621,034	199,080,400	102,972,621	120,134,724		
	O&M (RM/Yr)		60,000,000	69,600,000	36,000,000	42,000,000		
	Return of equity		75,000,000	87,000,000	45,000,000	52,500,000		
	Annual Cost/Yr		306,621,034	355,680,400	183,972,621	214,634,724		
Fuel Cost(Natural gas)	Estimated Generation per day		-	-	-	-	KWh/day	
	Safety Factor (15%)		-	-	-	-	KWh/day	
	Estimated fuel purchase per year		-	-	-	-	KWh/yr	
	Gas Tariff		-	-	-	-	RM/yr	
Levelized Cost of Electricity	Total Capital levelized cost		306,621,034	355,680,400	183,972,621	214,634,724	RM/yr	
	Total Capital+Fuel		306,621,034	355,680,400	183,972,621	214,634,724	RM/yr	
	Total Estimated Generation per year		247,470,000	370,110,000	238,710,000	456,615,000	KWh/yr	
	LCOE		1.2390	0.9610	0.7707	0.4701	RM/KWh	
	Profit Margin of LCOE(20%)		1.4868	1.1532	0.9248	0.5641	RM/KWh	
1) Renewable Energy Generation Tariff			1.4868	1.1532	0.9248	0.5641	RM/KWh	
2) Estimated Subsidied rate (Singer Buyer Generation tariff = RM 0.2676/KWh)			1.219	0.886	0.657	0.296	RM/KWh	
	Total PV generation (KWh/day)		678,000	1,014,000	654,000	1,251,000	KWh/day	
	Estimated Subsidied fund (RM/day)		826,636.35	898,013.82	429,831.09	370,880.81	RM/day	
	Total Subsidied fund (RM/day)		2,525,362.07				RM/day	
3) Renewable Energy Fund (1.6%)								
	Total Customer Consumption (KWh/day)		17,632,500				KWh/day	
	Average Tariff Rate (RM/KWh)		0.3915				RM/KWh	
	Total Generation Income (RM/day)		6,903,123.75				RM/day	
	Renewable Energy Fund (1.6%)		110,449.98				RM/day	
4) Net of Energy Fund			- 2,414,912.09				RM/day	

Figure 24: Capital cost of generator with different capacity of photovoltaic system

The figure shows the levelized cost of electricity calculation. The parameters are based on previous figure and simulated by POWERWORLD. The total cost of generation, generator generation and PV generation is derived base on curve under the area. The result shows that the increased capacity of photovoltaic system in network will increase total cost saving and saved CO_2 emission (Mithulananthan, N., Oo,T., & Phu, L. Van. (2004)).

The average cost rate per KWh is reduced while the capacity of photovoltaic system is increased. The function of optimal power flow choices the lower price of fuel cost especially photovoltaic system cost priority. Therefore, the average cost rate is going to be reduce when the capacity of photovoltaic system reached 1040MW. On the other hand, the fuel cost in this section is idle because the fuel is free source by absorbing the energy from the sunlight. The below figure presented the fuel cost saving with the penetration of photovoltaic system to network.

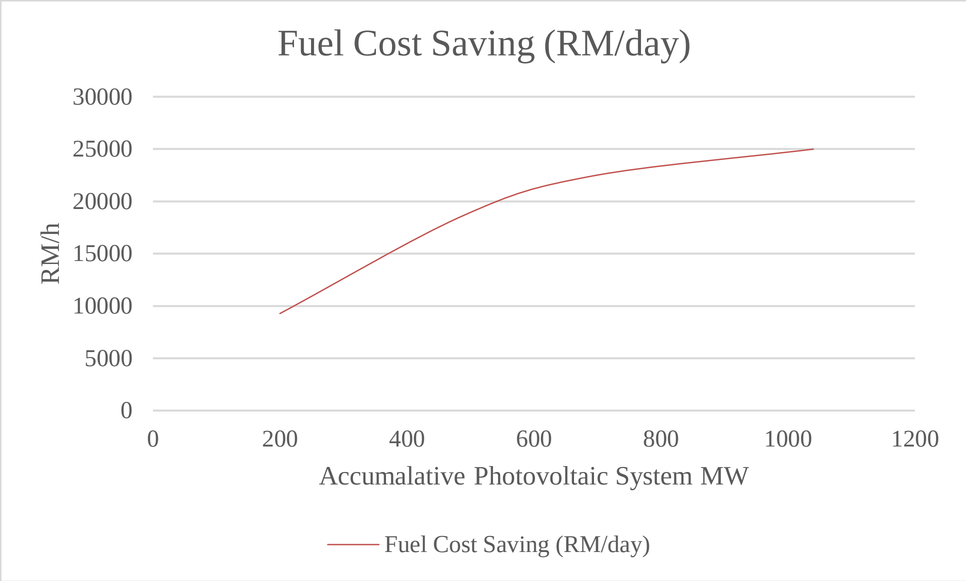


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Figure 25: Penetration of photovoltaic system – Fuel Cost Saving

The figure can be identified that the increased capacity of photovoltaic system will logistically grow the fuel cost saving per day. Furthermore, the amount of cost saving per year can reach up to RM 9,120,920.00/yr. By using the gas tariff RM 120.20/MWh, the amount of 75,881.20MWh/yr or 258,917.46MMBtu/yr can be saved and the probability of fuel depletion can be also reduced.

The basic parameter of LCOE is assumed as well as capital cost (RM/W) of photovoltaic system. The capital cost rate is referred to Source Breyer et al. (2010): Research and development investments in PV – A limiting factor for a fast PV diffusion. The figure of source presented a linear drop of the price and increase of cumulative PV in MW. The LCOE result shows that a linear drop of photovoltaic system capital cost will also decrease rate of LCOE

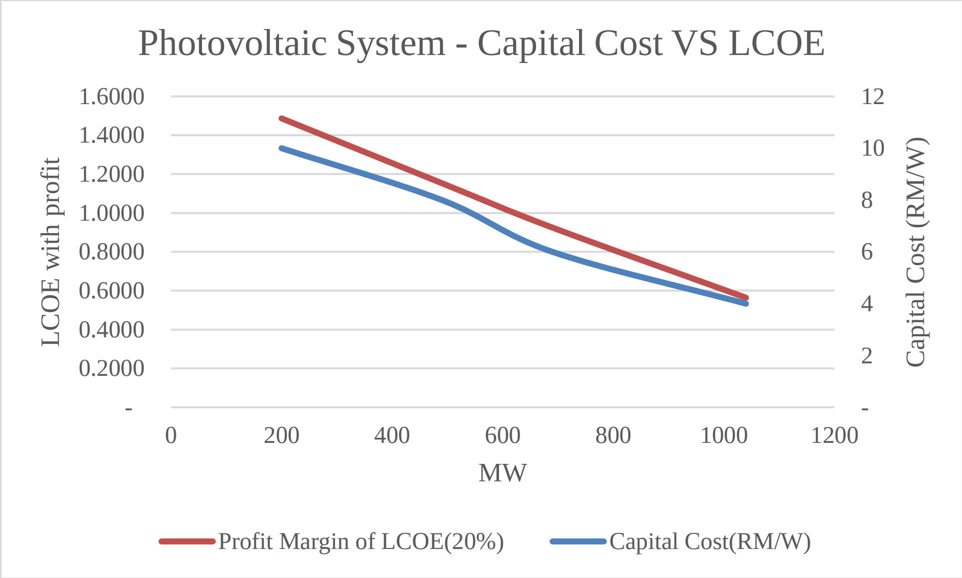

Figure 26: Photovoltaic system – Capital Cost vs LCOE

Eventually, the comparison of singer buyer generation tariff and renewable energy generation tariff show the significant gap. The utility company is not able to buy the energy from the renewable energy due to expensive rate. The government has promote a new term of renewable energy fund which is rate 1.6%. The fund is collected by the government thru the customer's electricity consumption. This fund is to promote the renewable generation from renewable energy resources. The figure 24 shows the price rate between renewable energy generation tariffs, estimated subsidised rate, and renewable energy fund 1.6%. The result shows that the figure on net of energy fund. In contrast, the net of energy fund is controversial because the amount is in negative value. That is the limitation about the net of energy fund. That may be neither bear by government or customers. By right, the renewable energy fund has the purpose to promote the renewable energy. Therefore, the utility company will pay only RM 0.2676/KWh to the renewable generation accordingly. The energy policy is regulated by energy commissioner. This is to keep the interest among of players. Furthermore, the percentage between renewable energy and conventional generation is formulated:

$$Percentage\ \% = \frac{\Sigma\ \text{Generation of Photovoltaic System under area per day}}{\Sigma\ \text{Generation of Generator with PV under area per day}}$$

$$= \frac{3{,}597{,}000\ \text{KWh/day}}{14{,}035{,}500\ \text{KWh/day}}$$

$$= 25\%$$

The figure shows that the penetration of photovoltaic system has been achieved 25% when the capacity of photovoltaic system is sized as 1040MW, GEN+PV(100%).

4.5 Carbon Balance

Item	Sum Capacity of Photovoltaic System	Sum Capacity of Generators	MW		System Lifetime	Year		Life Cycle Emission grid	gCO2/KWh		Carbon Balance	
GEN+PV(100%)	1040	0	MW	x	25	Year	x	660	gCO2/KWh	=	17160	t CO2
GEN+PV(70%)	690	0	MW	x	25	Year	x	660	gCO2/KWh	=	11385	t CO1
GEN+PV(50%)	490	0	MW	x	25	Year	x	660	gCO2/KWh	=	8085	t CO0
GEN+PV(20%)	200	0	MW	x	25	Year	x	660	gCO2/KWh	=	3300	t CO1
GEN+PV(0%)	0	2200	MW	x	25	Year	x	660	gCO2/KWh	=	36300	t CO2

Emission CO2 to Air
Saved CO2 to Air

Figure 27: Carbon Balance – Generator vs Photovotlaic system.

The figure 27 shows the carbon balance between generators and photovotlaic system to the earth. Without the integrating the photovoltaic system, the generators may release 36,300 t CO_2 to the earth within 25 years. This will result the global warming as mentioned at introduction. Once of the purpose to promote the renewable energy such as photovoltaic system is decreased dependency on the natural gas. Meanwhile, it can use photovoltaic system to reduce the CO_2 to the earth.

The GEN+PV(100%) shows that the reduction releasing CO_2 to earth is about 17,160 t CO_2. The figure presented a significant amount that it could achieve the milestone of greenhouse by using the promotion of using renewable energy. Eventhought, the power system still rely on the natural resources generator. It could be new technologies to be invented by using without the conventional generator.

4.6 Contingency manner – Enhancement of congestion

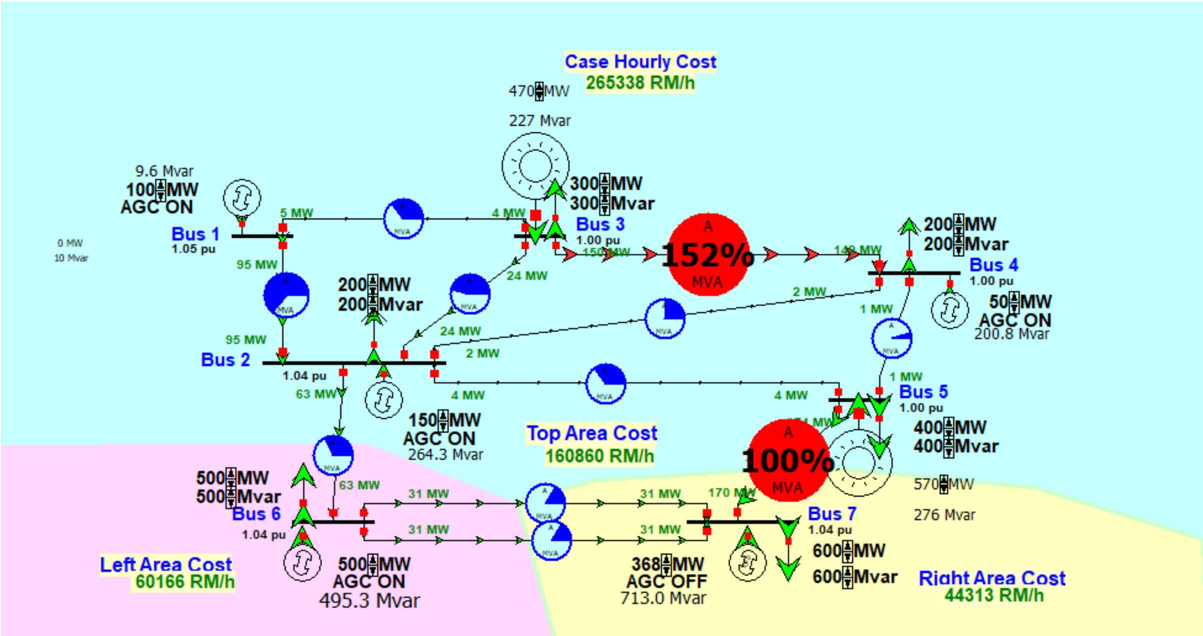

Figure 28: Contigency manner with penetration of photovoltaic system

Comparing the figure 17, the reached of the load 2200MW and 2200MVAR shows the congested line limation while the PQ bus 3 and bus 5 without photovotlaic system. Frankly, the PQ bus 3 and bus 5 integrated with the maximum capacity of 470MW and 570MW relieved the congestion in network. It presented that is the advantage by using the photovoltaic system where it allowed the system to execute contigency manner in temporary switch-off (Safamehr, H., & Rahimi-kian, A. (2015)).

Furthermore, that is also an advanatage for expansion and future planning. The the rapid economic growth is also advanced by the availability and security for the cheap electricity. On the other hand, the availability and security of energy is to ensure the national energy policy to be providing adequate, secure and cost effective to the customers due to rapild growth of electricity. The development of transmission line can be negligible that is because the penetration of photovoltaic system can relief the space of convergence.

4.7 Assessment of utilization factor in network

The above results presented the advantage of photovotlaic system have brought to the power network. It can be seen that the integration of photovoltaic system to network may relax the line transmission rather than without photovoltaic system penetration to network. The above shows the result about contigency manner and line losses. Furthermor, the expansion for power network planning is the key for the future development. The parameters is where these shall be considered in order to achieve the security of network.

- Photovotlaic system can play as back-up grid in peak sun hour period
- Periodical generation to save at the peak period and reduce the cost of generation
- Excessive of generation back to network for surplus power
- Improving the voltage quality and reliability
- Meet to the new trend of green power.
- Development of transmission line is no longer a solution

The points reviewed that penetration of photovotlaic system offered the list of benefits which can bring the advanges for covering saving world fuel, development of transmission line, and reducing the wholesale electricity price as shown as the simulation. This is noteworthy to promote that the photovotlaic system place power availability in case of contigency manner. To review the above point, the large scale of power plant such as coal, natural gas, and hydro can be considered idle comparing to the distributed generation (Safamehr, H., & Rahimi-kian, A. (2015)).

One of the key is distance solution and long scale of transmission line. The fast convergence of using conventional generators could lead the low efficiency rather using distributed generators. That is because conventional generators responds from far distance than distributed generators. That is the reason distributed generators must install close to the load especially the PQ bus. Therefore, the photovotlaic system contributes to increase reliabity in power network. Optimal power flow may easily manage the power network during the peak period. Eventhough, photovotlaic system is just performing the generation during the sun hour. As long as this solution can be also reduce the congestion and emission CO_2 (Galagedara ,L. W (2015)).

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The paper explains the technique of utilisation factor in power system network while the growth of penetration photovoltaic system. The result and discussions achieved the objectives which is photovoltaic system's location, contigency manner of line, and allowable size of photovoltaic system. The above review offers the approach and application to decide optimal capacity of size and placement of photovoltaic problem in power network system. The distributed generators of photovotlaics system enjoys a numbers of potential characteristics to optimize ths system performance.

The results showed the application of photovoltaic system in the distribution system enhanced the benefits as the reliability of network system, reduction of line losses, improvement of power quality and reduction of generation cost. The result reviewed the size of photovotlaic system shall be implemented to the PQ bus by accouting the voltage contraints. Therefore, the minimum and maximum size of the photovoltaic system is between 690MW(70%) to 1040MW(100%) and this cause the voltage result is in between acceptable range, $0.95<V<1.05$ P.U.

Overall, the penetration percentage of photovoltaic system achieved to 25% while the maximum size 1040MW is used. For further development, total harmonic distortion, transformer overloading, fault current level, and power quality can be featured in this paper. The cost and budget limit is more toward to the economic factor. On the other hands, the data is base on the assumption.

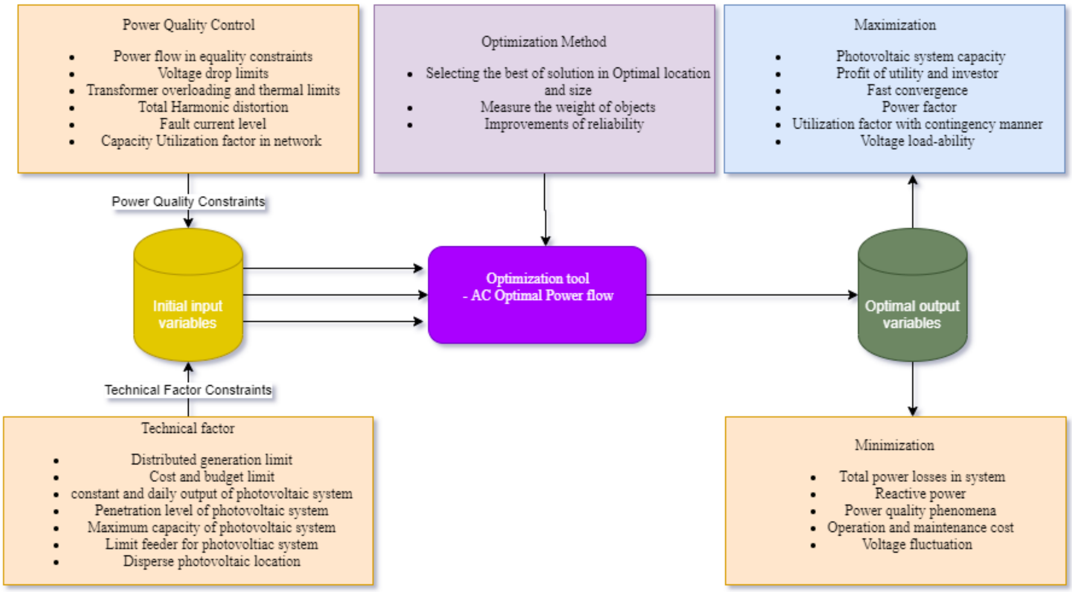

Figure 29: Component of optimization model to location and size of photovoltaic system

However, the cost of natural gas and capital cost of generators and photovoltaic system is the limitation due to currency fluctuations and lack of interest of installation capital. The value is based on the assumption that in order to fit to the competitive market price. The modelling of allowable photovoltaic system size and capacity is the key to contribute the advantages for the above simulation. The limitation of this simulation is the data of load curve, price of natural gas, simulation without using mix of energy, and photovotlaic system data. All of the limitation data is assumed.

5.2 Recommendations for future work

This conclusion summarized the above discussed element forming a general approach to solve the utilisation factor problem. All the possibility types of the constraints and objectives are related to the location and size of photovoltaic.

- Appropriate guideline and regulations: the establishment of photovoltaic system need to solve penetration in power system. The constitution shall be approached for the technical standards and load forecast. In addition, the parties interest is considered to be formulated the relevant regulation for future investment purpose.

- Technologies research: The modern of power system has been introduced that a nontraditional of power flow may change power flow. The research and development of modern power network system shall pay attention of corresponding requirements such as protection, control and instrumentation system. The future of research and development shall be established:
    - Advancement of mirco-grid power and intelligent of islanding mode o
    - Power quality and reliability of power network system
    - Improve power factor and maintain utilization factor in safe zone in case of contingency
    - Advancement to accommodate the uncertainty of net load and net ramping load. Example: A high capacity of DC battery.

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APPENDICES

APPENDIX A: Table of Generators and Photovoltaic System Profile

GEN+PV(0%)

Item	Real Power	MW	Reactive Power	MVAR	PV 1 MW	PV 1 MVAR	PV 2 MW	PV 2 MVAR	BUS 1 Generation MW	BUS 1 MVAR	BUS 1 Voltage p.u
1	450	MW	450	MVAR	0	0	0	0	100	9.9	1.05
2	500	MW	500	MVAR	0	0	0	0	100	19.9	1.05
3	530	MW	530	MVAR	0	0	0	0	100	23.5	1.05
4	550	MW	550	MVAR	0	0	0	0	100	26.2	1.05
5	600	MW	600	MVAR	0	0	0	0	123	23.6	1.05
6	650	MW	650	MVAR	0	0	0	0	160	19.7	1.05
7	700	MW	700	MVAR	0	0	0	0	160	19.6	1.05
8	750	MW	750	MVAR	0	0	0	0	160	19.6	1.05
9	800	MW	800	MVAR	0	0	0	0	160	26.4	1.05
10	850	MW	850	MVAR	0	0	0	0	160	27	1.05
11	950	MW	950	MVAR	0	0	0	0	168	25.8	1.05
12	1000	MW	1000	MVAR	0	0	0	0	168	25.8	1.05
13	1050	MW	1050	MVAR	0	0	0	0	220	29	1.05
14	1250	MW	1250	MVAR	0	0	0	0	220	30.5	1.05
15	1300	MW	1300	MVAR	0	0	0	0	240	37.8	1.05
16	1400	MW	1400	MVAR	0	0	0	0	280	36.1	1.05
17	1450	MW	1450	MVAR	0	0	0	0	280	36.1	1.05
18	1500	MW	1500	MVAR	0	0	0	0	280	45.7	1.05
19	1550	MW	1550	MVAR	0	0	0	0	338	44.4	1.05
20	1600	MW	1600	MVAR	0	0	0	0	339	44.6	1.05
21	1650	MW	1650	MVAR	0	0	0	0	338	44.4	1.05
22	1700	MW	1700	MVAR	0	0	0	0	399	44.8	1.05
23	1800	MW	1800	MVAR	0	0	0	0	399	44.8	1.05
24	1950	MW	1950	MVAR	0	0	0	0	400	45.1	1.05
25	2050	MW	2050	MVAR	0	0	0	0	400	45.1	1.05
26	2200	MW	2200	MVAR	0	0	0	0	400	45.1	1.05

Item	BUS 2 Generation MW	BUS 2 MVAR	BUS 2 Load MW	BUS 2 Load MVAR	BUS 2 Voltage p.u	BUS 3 Load MW	BUS 3 Load MVAR	BUS 3 Voltage p.u	BUS 4 Generation MW	BUS 4 MVAR	BUS 4 Load MW	BUS 4 Load MVAR	BUS 4 Voltage p.u
1	150	191.6	150	150	1.04	50	50	0.9975	50	24.1	50	50	1
2	172	246	200	200	1.04	50	50	0.9974	80	39	50	50	1
3	202	245.9	200	200	1.04	80	80	0.9888	80	47.2	50	50	1
4	220	246.5	200	200	1.04	100	100	0.9829	82	66.1	50	50	1
5	220	247.8	200	200	1.04	100	100	0.9827	110	120.5	100	100	1
6	220	269.1	200	200	1.04	100	100	0.9828	125	127.4	100	100	1
7	220	268	200	200	1.04	100	100	0.9828	124	126.9	100	100	1
8	220	268	200	200	1.04	100	100	0.9828	124	126.9	100	100	1
9	256	271.4	200	200	1.04	150	150	0.9679	140	174.2	100	100	1
10	290	287.3	200	200	1.04	150	150	0.9675	150	231.4	150	150	1
11	290	287.7	200	200	1.04	150	150	0.9675	200	232.4	150	150	1
12	290	287.7	200	200	1.04	150	150	0.9675	200	232.4	150	150	1
13	290	301.5	200	200	1.04	200	200	0.9519	200	288	150	150	1
14	396	312.9	200	200	1.04	200	200	0.9513	200	359.1	200	200	1
15	450	329.7	200	200	1.04	250	250	0.9544	200	417.7	200	200	1
16	445	350.9	200	200	1.04	250	250	0.9339	200	430.7	200	200	1
17	445	350.9	200	200	1.04	250	250	0.9339	200	430.7	200	200	1
18	500	358.2	200	200	1.04	300	300	0.9153	200	493.4	200	200	1
19	500	394.7	200	200	1.04	300	300	0.9153	200	588.1	200	200	1
20	500	394.7	200	200	1.04	300	300	0.9153	200	588.1	200	200	1
21	500	394.7	200	200	1.04	300	300	0.9153	200	588	200	200	1
22	500	436	200	200	1.04	300	300	0.9144	200	525.4	200	200	1
23	500	436	200	200	1.04	300	300	0.9144	200	525.4	200	200	1
24	500	466.3	200	200	1.04	300	300	0.9142	200	540.3	200	200	1
25	500	466.3	200	200	1.04	300	300	0.9142	200	540.3	200	200	1
26	500	466.3	200	200	1.04	300	300	0.9142	200	540.3	200	200	1

Item	BUS 5 Load MW	BUS 5 Load MVAR	BUS 5 Voltage p.u	BUS 6 Generation MW	BUS 6 MVAR	BUS 6 Load MW	BUS 6 Load MVAR	BUS 6 Voltage p.u	BUS 7 Generation MW	BUS 7 MVAR	BUS 7 Load MW	BUS 7 Load MVAR	BUS 7 Voltage p.u	Line Losses MW	Line Losses MVAR
1	50	50	1.0163	150	84.9	100	100	1.04	2	92.7	50	50	1.04	2.00	-47
2	50	50	1.0163	150	84.8	100	100	1.04	1	93	50	50	1.04	3.00	-37
3	50	50	1.0163	150	84.9	100	100	1.04	1	93.1	50	50	1.04	3.00	-35
4	50	50	1.0163	150	85	100	100	1.04	1	93.2	50	50	1.04	3.00	-33
5	50	50	1.0162	150	85.1	100	100	1.04	2	93.5	50	50	1.04	5.00	-29
6	100	100	0.995	150	85.8	100	100	1.04	2	130.7	50	50	1.04	7.00	-17
7	100	100	0.9954	150	142.9	150	150	1.04	50	120.5	50	50	1.04	4.00	-22
8	100	100	0.9954	150	142.7	150	150	1.04	100	170.1	100	100	1.04	4.00	-23
9	100	100	0.9954	150	143	150	150	1.04	100	170.3	100	100	1.04	6.00	-15
10	100	100	0.9955	150	142.9	150	150	1.04	100	170.8	100	100	1.04	6.00	-11
11	150	150	0.973	200	193.9	200	200	1.04	101	209.8	100	100	1.04	9.00	0
12	150	150	0.973	200	193.9	200	200	1.04	150	259.8	150	150	1.04	8.00	0
13	150	150	0.9729	200	193.8	200	200	1.04	151	259.9	150	150	1.04	11.00	28
14	200	200	0.9489	250	245.6	250	250	1.04	201	353.5	200	200	1.04	17.00	52
15	200	200	0.9486	250	245.9	250	250	1.04	201	353.6	200	200	1.04	21.00	85
16	250	250	0.9227	301	298.1	300	300	1.04	201	400.3	200	200	1.04	27.00	116
17	250	250	0.9227	301	298.1	300	300	1.04	251	450.3	250	250	1.04	27.00	116
18	250	250	0.9224	301	298.5	300	300	1.04	252	451.6	250	250	1.04	33.00	147
19	300	300	0.8941	301	301.2	300	300	1.04	252	502.7	250	250	1.04	41.00	201
20	300	300	0.8941	351	351.2	350	350	1.04	252	502.7	250	250	1.04	42.00	201
21	300	300	0.8941	351	351.2	350	350	1.04	302	552	300	300	1.04	41.00	200
22	350	350	0.8629	351	351.6	350	350	1.04	303	609.5	300	300	1.04	53.00	267
23	350	350	0.8629	401	404.6	400	400	1.04	353	659.5	350	350	1.04	55.00	270
24	400	400	0.8302	451	452.8	450	450	1.04	459	758.1	400	400	1.04	60.00	313
25	400	400	0.8302	500	502.8	500	500	1.04	510	807.8	450	450	1.04	60.00	312
26	400	400	0.8302	500	502.8	500	500	1.04	660	957.8	600	600	1.04	60.00	312

GEN+PV(100%)

Item	Real Power	MW	Reactive Power	MVAR	PV 1 MW	PV 1 MVAR	PV 2 MW	PV 2 MVAR	BUS 1 Generation MW	BUS 1 MVAR	BUS 1 Voltage p.u
1	550	MW	550	MVAR	100	48	0	0	100	19	1.05
2	750	MW	750	MVAR	110	51	20	9	100	15.1	1.05
3	850	MW	850	MVAR	200	95	20	9	100	14.6	1.05
4	1000	MW	1000	MVAR	200	95	110	51	100	16.5	1.05
5	1050	MW	1050	MVAR	290	139	110	51	100	18.5	1.05
6	1250	MW	1250	MVAR	290	139	200	94	100	17.9	1.05
7	1300	MW	1300	MVAR	380	183	200	94	100	18.8	1.05
8	1450	MW	1450	MVAR	380	183	290	140	100	18.8	1.05
9	1650	MW	1650	MVAR	470	227	390	183	100	19.1	1.05
10	1650	MW	1650	MVAR	60	29	160	77	220	38.9	1.05
11	1700	MW	1700	MVAR	120	58	200	97	220	33.6	1.05
12	1800	MW	1800	MVAR	470	227	480	229	100	19.1	1.05
13	1800	MW	1800	MVAR	210	102	290	140	160	29.3	1.05
14	1950	MW	1950	MVAR	470	227	570	276	100	19.1	1.05
15	2050	MW	2050	MVAR	470	227	570	276	100	19.1	1.05
16	2050	MW	2050	MVAR	300	145	380	184	100	25.1	1.05
17	2050	MW	2050	MVAR	250	121	330	160	160	26.5	1.05
18	2200	MW	2200	MVAR	470	227	570	276	100	19.1	1.05
19	2200	MW	2200	MVAR	430	208	530	257	100	21.4	1.05
20	2200	MW	2200	MVAR	380	183	480	232	100	24.5	1.05

Item	BUS 2 Generation MW	BUS 2 MVAR	BUS 2 Load MW	BUS 2 Load MVAR	BUS 2 Voltage p.u	BUS 3 Load MW	BUS 3 Load MVAR	BUS 3 Voltage p.u	BUS 4 Generation MW	BUS 4 MVAR	BUS 4 Load MW	BUS 4 Load MVAR	BUS 4 Voltage p.u
1	150	248.9	200	200	1.04	100	100	1	50	18.6	50	50	1
2	192	255.7	200	200	1.04	100	100	1	80	76.1	100	100	1
3	202	256.6	200	200	1.04	150	150	1	80	135	150	150	1
4	162	260.1	200	200	1.04	150	150	1	80	134.7	150	150	1
5	150	262.4	200	200	1.04	200	200	1	50	140.5	150	150	1
6	150	262	200	200	1.04	200	200	1	63	197.4	200	200	1
7	150	262.4	200	200	1.04	250	250	1	50	200.2	200	200	1
8	150	262.4	200	200	1.04	250	250	1	50	200.2	200	200	1
9	150	263.8	200	200	1.04	300	300	1	50	201	200	200	1
10	378	329	200	200	1.04	300	300	0.9298	200	432.9	200	200	1
11	326	338.5	200	200	1.04	300	300	0.9415	200	396.5	200	200	1
12	150	264	200	200	1.04	300	300	1	50	200.9	200	200	1
13	258	309.6	200	200	1.04	300	300	0.958	140	340.4	200	200	1
14	150	264.3	200	200	1.04	300	300	1	50	200.8	200	200	1
15	150	264.4	200	200	1.04	300	300	1	50	200.8	200	200	1
16	220	302.4	200	200	1.04	300	300	0.9733	106	294.3	200	200	1
17	228	320.8	200	200	1.04	300	300	0.965	140	321.7	200	200	1
18	150	264.3	200	200	1.04	300	300	1	50	200.8	200	200	1
19	150	272.7	200	200	1.04	300	300	0.9942	50	222.9	200	200	1
20	150	285.8	200	200	1.04	300	300	0.9865	50	252.9	200	200	1

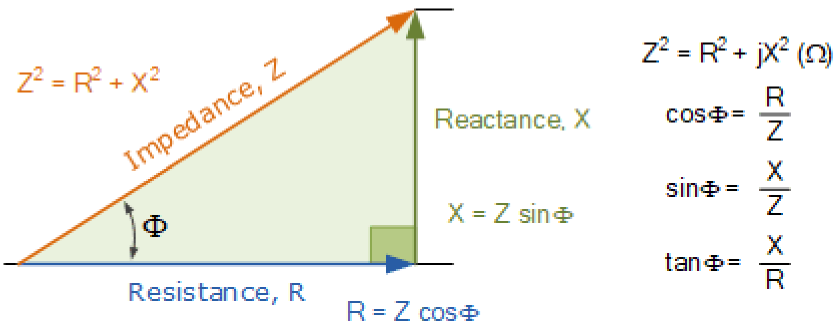
Item	BUS 5 Load MW	BUS 5 Load MVAR	BUS 5 Voltage p.u	BUS 6 Generation MW	BUS 6 MVAR	BUS 6 Load MW	BUS 6 Load MVAR	BUS 6 Voltage p.u	BUS 7 Generation MW	BUS 7 MVAR	BUS 7 Load MW	BUS 7 Load MVAR	BUS 7 Voltage p.u	Line Losses MW	Line Losses MVAR
1	50	50	1.0163	150	84.7	100	100	1.04	2	92.7	50	50	1.04	2.00	-38
2	100	100	1	150	142.4	150	150	1.04	100	162.1	100	100	1.04	2.00	-39
3	100	100	1	150	142.4	150	150	1.04	100	162.1	100	100	1.04	2.00	-35
4	150	150	1	200	192.1	200	200	1.04	150	211.9	150	150	1.04	2.00	-38
5	150	150	1	200	192	200	200	1.04	150	211.8	150	150	1.04	-	-35
6	200	200	1	250	241.9	250	250	1.04	200	261.6	200	200	1.04	3.00	-36
7	200	200	1	250	242.1	250	250	1.04	175	266.6	200	200	1.04	3.00	-33
8	250	250	1	300	292.3	300	300	1.04	183	324.1	250	250	1.04	3.00	-29
9	300	300	1	350	343.9	350	350	1.04	145	393.2	300	300	1.04	5.00	-19
10	300	300	0.9453	350	344.2	350	350	1.04	300	458.1	300	300	1.04	18.00	59
11	350	350	0.9322	350	344.4	350	350	1.04	301	481	300	300	1.04	17.00	49
12	350	350	1	400	394.6	400	400	1.04	156	452.8	350	350	1.04	6.00	-13
13	350	350	0.9571	400	392.5	400	400	1.04	350	486.5	350	350	1.04	8.00	0
14	400	400	1	450	445.3	450	450	1.04	368	513	400	400	1.04	8.00	-5
15	400	400	1	500	495.5	500	500	1.04	218	563	450	450	1.04	8.00	-4
16	400	400	0.9574	500	492.1	500	500	1.04	450	585.4	450	450	1.04	6.00	-22
17	400	400	0.9448	500	492.6	500	500	1.04	450	608.6	450	450	1.04	8.00	1
18	400	400	1	500	495.3	500	500	1.04	368	713	600	600	1.04	8.00	-5
19	400	400	0.9925	500	495.3	500	500	1.04	445	706.7	600	600	1.04	5.00	-16
20	400	400	0.9817	500	492	500	500	1.04	544	704	600	600	1.04	4.00	-28

Item	Real Power	MW	Reactive Power	MVAR	PV 1		PV 2		BUS 1			BUS 2					BUS 3			BUS 4					BUS 5			BUS 6					BUS 7					Line Losses	
									Generation		Voltage	Generation		Load		Voltage	Load		Voltage	Generation		Load		Voltage	Load		Voltage	Generation		Load		Voltage	Generation		Load		Voltage		
					MW	MVAR	MW	MVAR	MW	MVAR	p.u	MW	MVAR	MW	MVAR	p.u	MW	MVAR	p.u	MW	MVAR	MW	MVAR	p.u	MW	MVAR	p.u	MW	MVAR	MW	MVAR	p.u	MW	MVAR	MW	MVAR	p.u	MW	MVAR
GEN +PV(70%)																																							
1	550	MW	550	MVAR	60	29	0	0	100	21.7	1.05	150	162	200	200	1.04	100	100	0.993	60	54.2	50	50	1	50	50	1.0165	110	84.7	100	100	1.04	2	93	50	50	1.04	- 8.00	-125
2	750	MW	750	MVAR	60	29	10	5	102	21.5	1.05	220	257.1	200	200	1.04	100	100	0.993	110	95.3	100	100	1	100	100	0.998	110	142.5	150	150	1.04	100	165.7	100	100	1.04	2.00	-34
3	850	MW	850	MVAR	110	63	10	5	133	19.6	1.05	220	260.5	200	200	1.04	150	110	0.9897	110	164.7	150	150	1	100	100	0.998	110	142.4	150	150	1.04	100	165.8	100	100	1.04	3.00	-29
4	1000	MW	1000	MVAR	110	63	60	29	134	19.3	1.05	220	268.6	200	200	1.04	150	110	0.9897	110	166.6	150	150	1	150	150	0.9887	200	192.5	200	200	1.04	150	231.9	150	150	1.04	4.00	-27
5	1050	MW	1050	MVAR	190	92	60	29	124	22.6	1.05	220	270.6	200	200	1.04	200	200	0.9853	110	183.9	150	150	1	150	150	0.9887	200	192.5	200	200	1.04	150	231.9	150	150	1.04	4.00	-28
6	1250	MW	1250	MVAR	190	92	130	63	155	19.6	1.05	220	276.5	200	200	1.04	200	200	0.9847	110	246.3	200	200	1	200	200	0.9842	210	242.4	250	250	1.04	200	289.8	200	200	1.04	5.00	-21
7	1300	MW	1300	MVAR	210	121	130	63	145	22.6	1.05	220	278.5	200	200	1.04	250	210	0.9869	110	261.7	200	200	1	200	200	0.9842	210	242.1	250	250	1.04	200	289.5	200	200	1.04	5.00	-22
8	1450	MW	1450	MVAR	210	121	190	92	135	22.6	1.05	220	283.8	200	200	1.04	250	210	0.9802	110	284.4	200	200	1	250	250	0.9771	300	292.3	300	300	1.04	250	351.7	250	250	1.04	5.00	-83
9	1650	MW	1650	MVAR	310	150	260	126	108	28.8	1.05	220	288.8	200	200	1.04	300	300	0.9756	110	281.7	200	200	1	300	300	0.9724	350	342.1	350	350	1.04	300	409.7	300	300	1.04	4.00	-23
10	1650	MW	1650	MVAR	30	17	100	48	265	41.9	1.05	410	350.7	200	200	1.04	300	300	0.9232	200	485.1	200	200	1	300	300	0.9275	310	346.2	350	350	1.04	301	480.8	300	300	1.04	26.00	100
11	1700	MW	1700	MVAR	70	34	130	63	244	38.4	1.05	410	357.7	200	200	1.04	300	300	0.9316	200	442.8	200	200	1	350	350	0.9304	310	346.9	350	350	1.04	301	520.7	300	300	1.04	25.00	104
12	1800	MW	1800	MVAR	310	150	220	115	100	29.4	1.05	220	294.9	200	200	1.04	300	300	0.9756	185	285.8	200	200	1	350	350	0.9651	400	392	400	400	1.04	350	472.4	350	350	1.04	5.00	-21
13	1800	MW	1800	MVAR	110	63	190	92	220	32.9	1.05	500	326	340.1	200	1.04	300	300	0.9637	200	291.2	200	200	1	350	350	0.9294	400	394.4	400	400	1.04	351	536	350	350	1.04	75.00	16
14	1950	MW	1950	MVAR	310	150	380	184	100	29.5	1.05	220	301.5	200	200	1.04	300	300	0.9733	96	291	200	200	1	400	400	0.9576	470	442	450	450	1.04	400	535.4	400	400	1.04	6.00	-17
15	2050	MW	2050	MVAR	310	150	380	184	100	29.5	1.05	220	301.5	200	200	1.04	300	300	0.9733	96	291	200	200	1	400	400	0.9576	500	492	500	500	1.04	450	585.4	450	450	1.04	6.00	-17
16	2050	MW	2050	MVAR	200	97	250	121	172	30	1.05	290	338.6	200	200	1.04	300	300	0.957	200	340.3	200	200	1	400	400	0.9217	500	493.5	500	500	1.04	451	648.8	450	450	1.04	13.00	28
17	2050	MW	2050	MVAR	160	77	220	107	220	30	1.05	317	353.1	200	200	1.04	300	300	0.9694	200	370.3	200	200	1	400	400	0.9324	500	495	500	500	1.04	451	665.6	450	450	1.04	18.00	37
18	2200	MW	2200	MVAR	310	150	380	184	100	29.5	1.05	220	402	200	200	1.04	300	300	0.9733	96	291	200	200	1	400	400	0.9576	500	492	500	500	1.04	600	735.4	600	600	1.04	6.00	176
19	2200	MW	2200	MVAR	290	140	360	174	127	27.8	1.05	220	309.1	200	200	1.04	300	300	0.9722	110	301.5	200	200	1	400	400	0.9525	500	492	500	500	1.04	600	744.3	600	600	1.04	7.00	-11
20	2200	MW	2200	MVAR	210	121	220	115	160	27.6	1.05	220	315.4	200	200	1.04	300	300	0.9655	140	323	200	200	1	400	400	0.9418	500	492.6	500	500	1.04	600	785.1	600	600	1.04	- 10.00	-5

Item	Real Power	MW	Reactive Power	MVAR	PV 1		PV 2		BUS 1			BUS 2					BUS 3			BUS 4					BUS 5			BUS 6					BUS 7					Line Losses	
									Generation		Voltage	Generation		Load		Voltage	Load		Voltage	Generation		Load		Voltage	Load		Voltage	Generation		Load		Voltage	Generation		Load		Voltage		
					MW	MVAR	MW	MVAR	MW	MVAR	p.u	MW	MVAR	MW	MVAR	p.u	MW	MVAR	p.u	MW	MVAR	MW	MVAR	p.u	MW	MVAR	p.u	MW	MVAR	MW	MVAR	p.u	MW	MVAR	MW	MVAR	p.u	MW	MVAR
GEN+PV([illegible])																																							
1	[illegible]	MW	[illegible]	MVAR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	MW	[illegible]	MVAR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	[illegible]	MW	[illegible]	MVAR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	[illegible]	MW	[illegible]	MVAR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	MW	[illegible]	MVAR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	[illegible]	MW	[illegible]	MVAR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	[illegible]	MW	[illegible]	MVAR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	[illegible]	MW	[illegible]	MVAR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	[illegible]	MW	[illegible]	MVAR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
10	[illegible]	MW	[illegible]	MVAR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
11	[illegible]	MW	[illegible]	MVAR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
12	[illegible]	MW	[illegible]	MVAR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
13	[illegible]	MW	[illegible]	MVAR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
14	[illegible]	MW	[illegible]	MVAR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
15	[illegible]	MW	[illegible]	MVAR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
16	[illegible]	MW	[illegible]	MVAR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
17	[illegible]	MW	[illegible]	MVAR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
18	[illegible]	MW	[illegible]	MVAR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
19	[illegible]	MW	[illegible]	MVAR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
20	[illegible]	MW	[illegible]	MVAR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Item	Real Power	MW	Reactive Power	MVAR	PV 1		PV 2		BUS 1			BUS 2					BUS 3			BUS 4					BUS 5			BUS 6					BUS 7					Line Losses	
									Generation		Voltage	Generation		Load		Voltage	Load		Voltage	Generation		Load		Voltage	Load		Voltage	Generation		Load		Voltage	Generation		Load		Voltage		
					MW	MVAR	MW	MVAR	MW	MVAR	p.u	MW	MVAR	MW	MVAR	p.u	MW	MVAR	p.u	MW	MVAR	MW	MVAR	p.u	MW	MVAR	p.u	MW	MVAR	MW	MVAR	p.u	MW	MVAR	MW	MVAR	p.u	MW	MVAR
GEN+PV([illegible])																																							
1	[illegible]	MW	[illegible]	MVAR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	MW	[illegible]	MVAR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	[illegible]	MW	[illegible]	MVAR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	[illegible]	MW	[illegible]	MVAR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	MW	[illegible]	MVAR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	[illegible]	MW	[illegible]	MVAR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	[illegible]	MW	[illegible]	MVAR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	[illegible]	MW	[illegible]	MVAR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	[illegible]	MW	[illegible]	MVAR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
10	[illegible]	MW	[illegible]	MVAR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
11	[illegible]	MW	[illegible]	MVAR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
12	[illegible]	MW	[illegible]	MVAR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
13	[illegible]	MW	[illegible]	MVAR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
14	[illegible]	MW	[illegible]	MVAR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
15	[illegible]	MW	[illegible]	MVAR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
16	[illegible]	MW	[illegible]	MVAR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
17	[illegible]	MW	[illegible]	MVAR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
18	[illegible]	MW	[illegible]	MVAR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
19	[illegible]	MW	[illegible]	MVAR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
20	[illegible]	MW	[illegible]	MVAR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

APPENDIX B: List of Equation



Real Power $P = I^2R$ Watts, (W)

Reactive Power $Q = I^2X$ Volt-amperes Reactive, (VAr)

Apparent Power $S = I^2Z$ Volt-amperes, (VA)

$P = V_{rms} \times I_{rms} \times \text{Cos}\ \Phi$

Power factor = Cos (Φ)

$Q = V_{rms} \times I_{rms} \times \text{Sin}\ \Phi$

Power factor = Cos (Φ)

$S^2 = P^2 + Q^2$

$S = V_{rms} \times I_{rms}$