COMMUNITY ENERGY STORAGE DISPATCH STRATEGY FOR MAXIMIZING THE TECHNO-ECONOMIC BENEFITS

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DECLARATION

I declare that this thesis entitled "COMMUNITY ENERGY STORAGE DISPATCH STRATEGY FOR MAXIMIZING THE TECHNO-ECONOMIC BENEFITS" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :

Name :

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APPROVAL

I hereby declare that I have checked this report entitled "Community Energy Storage Dispatch Strategy For Maximizing The Techno-Economic Benefits" and in my opinion, this thesis it complies the partial fulfillment for awarding the award of the degree of Bachelor of Electrical Engineering with Honours

Signature : ....

Supervisor Name : ....

Date : ....

DEDICATIONS

To my beloved mother and father

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ABSTRACT

Energy storage is a type of support devices at the power system. Energy storage consists of many applications that depends on the location it is implemented. One of the applications of energy storage is Community Energy Storage (CES) that is installed at the distribution system purposely to boost feeder level benefits. The implementation of CES is crucial to prevent technical problems that usually occurred at the distribution system with renewable energy generation such as reverse power flow, uneven voltage profile, fluctuation of frequency and power losses. Besides, the alternative for economic problems faced by the customers which is high electricity prices during peak demand can also be recognized. These problems can be solved if the CES is properly managed in terms location and power capacity deployment. The main purpose of this report is to develop an optimal dispatch strategy of CES in terms of techno-economic benefits by using optimal power flow (OPF) method. The OPF method is solved in MATLAB by using Genetic Algorithm (GA) Tool. The techno-economic benefits are determined by the cost of electricity and the technical performance of the distribution system such as voltage distribution and peak demand. The OPF analysis is computed by using forward-backward sweep method. The developed dispatch strategy of CES in tested on the 15-bus radial distribution system since the test system located in residential area. Numerical results obtained show that the developed dispatch strategy of CES may reduce the electricity cost and peak demand while improves the voltage profile of the system.

ABSTRAK

Penyimpan tenaga adalah sejenis alat pembantu dalam sistem kuasa. Penyimpan tenaga mempunyai banyak aplikasi bergantung kepada lokasi penyimpan tenaga tersebut digunakan. Salah satu daripada aplikasi penyimpan tenaga telah digunakan adalah penyimpan tenaga komuniti yang digunakan di sistem pengagihan untuk kawasan perumahanyang bertujuan untuk menggalakkan kebaikan pada aras penerima. Penggunaan penyimpan tenaga komuniti sangat penting bagi menyelesaikan masalah-masalah teknikal yang dihadapi pada sistem pengagihan seperti pengaliran kuasa terbalik, ketidakseragaman voltan, gangguan frekuensi dan kehilangan kuasa. Selain itu, aternatif kepada masalah ekonomi yang dihadapi oleh pelanggan iaitu kos bil elektrik yang tinggi yang tinggi ketika permintaan kemuncak juga dapat dikenalpasti. Masalah-masalah ini boleh diatasi jika penyimpan kuasa diuruskan dengan baik dari segi penempatan lokasi dan kapasiti kuasa . Tujuan utama laporan ini adalah untuk memaksimumkan kebaikan tekno-ekonomi menggunakan kaedah pengaliran kuasa optimum (OPF). Kaedah OPF berkenaan diselesaikan dalam MATLAB menggunakan alat Algoritma Genetik (GA). Kebaikan tekno-ekonomi dapat ditentukan dengan mengetahui harga bil elektrik dan keberkesanan aliran kuasa dalam sistem pengagihan seperti taburan nilai voltage dan permintaan kemuncak.. OPF ditentukan dengan cara pengiraan sapuan ke hadapan dan ke belakang. Strategi yang diusahakan telah diuji ke atas sistem pengagihan radial dengan 15-bas berikutan sistem yang diuji terletak di Kawasan perumahan. Hasil berangka yang diperolehi menunjukkan strategi yang diusahakan menggunakan CES dapat mengurangkan kos bil elektrik dan permintaan pada waktu puncak, sekaligus memperbaiki profil voltan pada sistem pengagihan.

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LIST OF SYMBOLS AND ABBREVIATIONS

CES	-	Community Energy Storage
GA	-	Genetic Algorithm
RE	-	Renewables Energy
NRE	-	Non-renewables Energy
PV	-	Photovoltaic
IFOM	-	In Front of Meter
TES	-	Thermal Energy Storage
BTM	-	Building Thermal Mass
PCM	-	Phase Change Material
PCC	-	Point of Common Coupling
OPF	-	Optimal Power Flow
TNB	-	Tenaga Nasional Berhad
MATLAB	-	Matrix Laboratory
ESS	-	Energy Storage System
BES	-	Battery Energy Storage
MCB	-	Miniature Circuit Breaker
PU	-	Per Unit
Eprice	-	Electricity Prices
P_{CES}	-	Power of Community Energy Storage
P_d	-	Power Demand
t	-	Time / Hour
F	-	Objective Function
O&M	-	Operational and Maintenance
C_{batt}	-	Capacity of Battery
x	-	Level of Peak Shaving
L	-	Load
LF	-	Load Factor
$P(t)$	-	Active Power for Every Hour
$Q(t)$	-	Reactive Power for Every Hour

$P_{bus}(i)$	-	Active Power at each 15-bus Data
$Q_{bus}(i)$	-	Reactive Power at each 15-bus Data
E_{load}	-	Energy at load
E_{PV}	-	Energy generated from PV
i	-	Number of bus
PV_p	-	PV data gain from Solar Energy
P_L	-	Active Power of Load Demand
Q_L	-	Reactive Power of Load Demand
P_G	-	Active Power generated
Q_G	-	Reactive Power generated
Y	-	Line Admittance
∂	-	Phase angle of voltage
θ	-	Phase angle of line admittance
P_{PVR}	-	PV generation profile

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CHAPTER 1

INTRODUCTION

1.1 Background

In recent decades, energy storage (ES) has been widely used in the endeavor for better flow and technical performance of the power distribution system. ES is initially a battery that is used for large scale application especially in the distribution system because its implementation can overcome many problems occurred at the distribution side of the system. The fundamental of ES is to store and accumulated the energy until it reaches certain capacity to be used later. This fundamental is developed because the energy that have been generated cannot be created or destroyed, but it can be transfer from one object to another object through conversion [1].

Based on these concepts, the implementation of ES is applied practicably into the distribution systems. However, to make sure the usage of ES is worth the investments towards it, proper strategies of energy management are crucial to ensure maximum benefits can be obtained by strategic ES deployment. This is because even the ES deployed at the right place, the benefits of ES in terms of technical performance of distribution system and economic profits will not fully utilized.

There are many types of ES according to its deployment. For example, home ES system is the implementation of ES for the single home usage where the capacity of storage is 3.8kWh which is a small value [2]. The substation ES that implemented at the substation for receiving energy from grid and assisting in distribution network would be with capacity of more than 1 MWh. The usage of the energy storage is based on the where it has been deployed. The capacity of energy storage is higher when the location is at the higher energy transfer region. The newest technology provide from the application of ES is Community Energy Storage (CES) that applied at distribution system near residential area.

1.2 Problem Statement

The generation of power have been massively evolved by the development of renewable energy (RE) generation to supply energy in distribution system network. This development occurred as the community have the awareness about the harm cause by non-renewable energy (NRE) generation that will be used up before long. The NRE generation also lead to the environment effect such as air pollution and global warming that resulted from the burning of coal at coal energy power plant. Besides, there are about 175 countries that already sign the global agreement for reducing the emission of carbon [3]. Thus, the generation of RE such as solar, wind and biomass are utilized to reduce the unfriendly NRE generation.

Most RE used recently is Photovoltaic (PV) system that implemented on the rooftop of the residential estate. There are many houses that were provided with PV system that used to generate electricity through solar energy. These PV systems are very useful to help generating the energy so that the customers can use the energy generated themselves and minimize the energy from the supplier. However, the increasing usage of PV systems in a community will cause another problem to be occurred. The increasing numbers of small-scale PV installation cause many impacts towards power distribution system such as voltage fluctuation and maximum voltage limitation. In this case, the high amount of energy generated from the PV system especially during peak solar energy generation at noon is not utilized because the residential dwellers are mostly not around at home cause energy generated by the PV system accumulated.

If the limit of the reversed power flow has reached the limits, the power will be discarded [4]. When this problem occurred, it shows the power generated from the PV system is not efficiently managed. The power generated discarded is futile because the customers still needs to buy energy from the power utility without using the power that generated itself. The purpose of implementation of PV system to reduce the power usage from the grid is not successfully achieved. Thus, by utilizing Community Energy Storage (CES), the reverse power flow phenomenon can be avoided and will reducing the electricity cost for the customers.

1.3 Objectives

In this project, there are a few objectives that need to be fulfilled. The objectives are as follows:

i) To identify the benefits and costs of energy storage deployment at residential distribution system.

ii) To develop an optimal dispatch strategy of community energy storage for maximizing the techno-economic benefits.

iii) To evaluate the performance of the dispatched strategy on radial distribution system in terms of electricity cost, load demand and voltage profile.

1.4 Project scope

There are a few scopes that have been decided to accomplish this research. These scopes need to be followed to make sure this research achieved the research objectives. These scopes have been decided based on the researches of information obtained from the literature review.

i) The study is conducted at radial residential distribution network system as this type of network is widely used at the residential state.

ii) The CES is installed in front of meter (IFOM) because it used to serve the local customers.

iii) This research uses Genetic Algorithm in MATLAB software to obtain the optimum timing and value of charge and discharge power of CES for minimizing the electricity cost.

iv) The dispatched strategy to improve the CES is only focus on active power where the power factor is unity.

1.5 Motivation

Based on the problem faced by community, ES is very crucial to be installed within the community especially at the residential area. This is following to the impact cause by high implementation of PV in the distribution network. The uses of ES give great benefits as it can manage the RE generation that is not stable with proper way. The energy storage development tends to focus on large scale region such as substation.

Recent years, the deployment of ES have been spread to the smaller scale of electrical system which is Community Energy Storage (CES) that served customer at the residential region. The motivation of this step has been made due to the enhancement of PV system usage that deployed on every rooftop of each community region that will disturb the flow of energy at the distribution system which is reverse power flow. The reverse power flow phenomenon occurred when the energy generated by PV system on the rooftop of residential area is not used especially during peak hours of solar energy which is during noon. When this problem occurs, the energy will reverse back to the substation from the residential area of distribution system. This will cause the disturbance of energy in the system.

The deployment of energy storage that introduced can gives a lot of benefits to the distribution and can act as ways of solutions for various problems of it is appropriately managed and controlled. Fitting the name Community Energy Storage as in Figure 1.1, it served the community where it connected to the secondary transformer because it only serves some residential area. The placement CES is much more reliable for the residential area distributed system because the scope covered the energy from the substation until the distribution feeder located near residential region. By following this scope, the benefits obtained from this placement is much wider than any other location of ES.

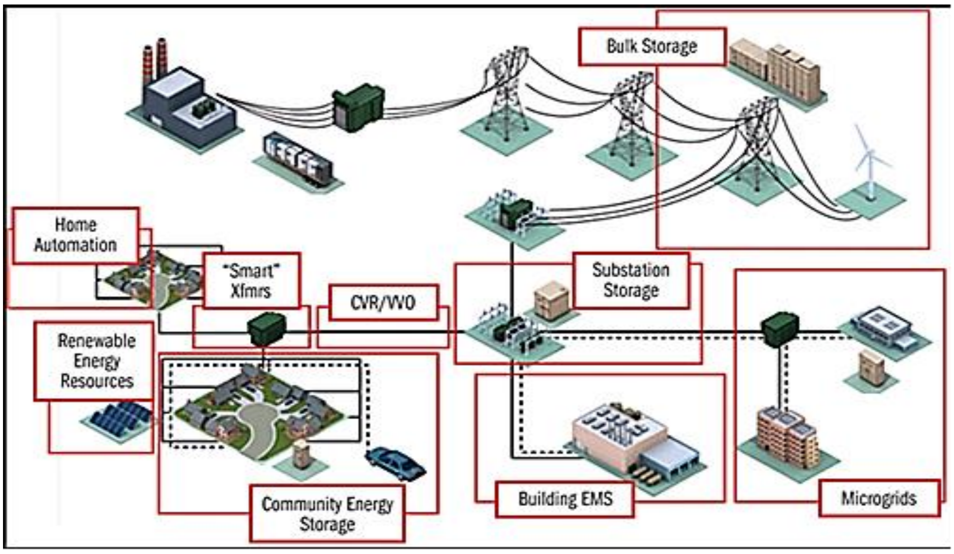

Figure 1.1: Potential location and application of Energy Storage in Power System [5]

CHAPTER 2

LITERATURE REVIEW

2.1 Energy Storage

The Energy Storage is very important to ensure a constant supply of power unlike wind and solar generation which particularly non dispatchable even though it have been advanced to a greater level. The benefits Energy Storage of includes three aspects which are technical, economy and environment. The uses of CES that connected at the utility distribution grid at distribution feeder is giving many benefits to the community.

2.2 Types of Energy Storage

The energy storages consist of many types that can be used for different application in the power system. The energy storage option that can be used like batteries, thermal and mechanical type. Each of the type have different ways to be used depend on the application of each types. There are various types of energy storage that have been revealed by many researchers and it already can be used as a safe accommodate component for the power system.

Figure 2.1 below shows the graph of currently most used types of energy storage in practical application. As shown in the figure below, pumped hydro energy storage have the highest rated power compared to other energy storages types and the most commonly used types of energy storage. For thermal storage, the Molten Salt Thermal Storage have the most installation which is 75% installation. For Electrochemical Energy Storage, the lithium ion batteries have the most installation with 59% and for Electrochemical, the most used is flywheel type that consist of 59% installation.

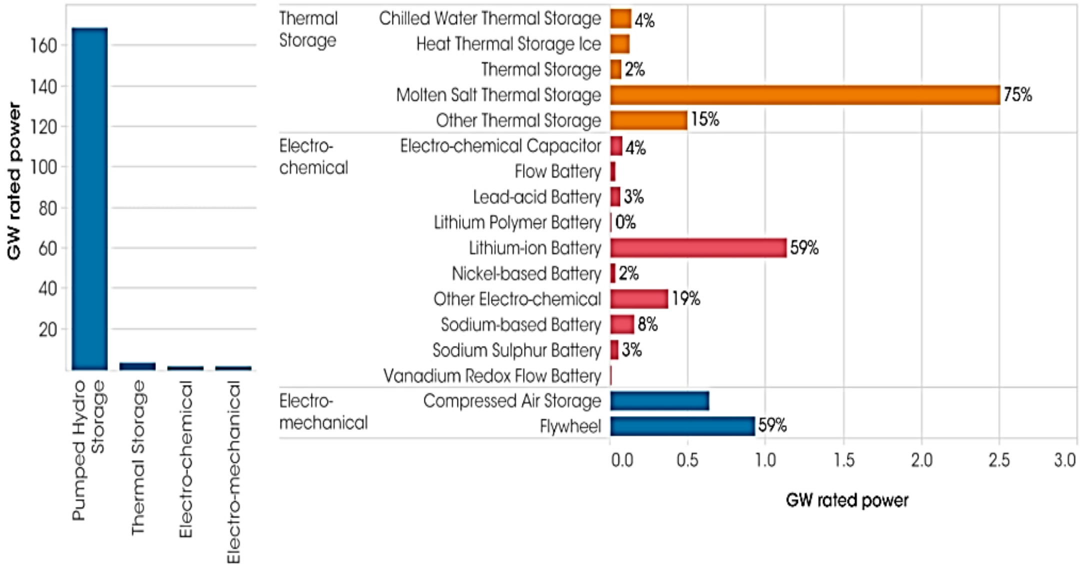

Figure 2.1: The current distribution of ESS by the most commonly used types by mid-2017 and the distribution of installed capacity among thermal, electrochemical and electromechanical systems for energy storage[6]

2.2.1 Battery

There are many types of battery that have been used recently such as lithium-ion, flow, lead acid, sodium, and others designed to meet specific power and duration requirements [7]. However, between these batteries, battery type that have been used the most is Li-ion type. As shown in Table 2.1, the properties of Li-ion type proved it as the preferred types of energy storage. Li-ion batteries presently have become large range and become the spearhead of the battery types which include smaller residential systems and larger systems that can store multiple megawatt hours and can be used to support the electric grid. These systems typically house many batteries together on a rack, combined with monitoring and management units. Lithium ion batteries have received a lot of press for their declining costs, due to the growing popularity of electric vehicles. Separately, flow batteries are electrochemical, energy is provided by two chemicals that are dissolved in liquids and stored in tanks. They are well suited for four or more hours of energy storage.

Table 2.1: Common Lithium Ion chemistry and properties [8]

Chemistry	**Thermal Stability**	**Energy Density**	**Power Density**	**Max C-Rate**
Lithium. Iron Phosphate	Very good	Low 50-130 Wh/kg	High > 1000 W/kg	>20
Lithium Manganese Oxide	Good	Moderate 100-180 Wh/kg	Moderate 160-720 W/kg	8
Lithium. Nickel Cobalt Manganese	Good	Moderate 130-170 Wh/kg	Good 400-800 W/kg	10
Lithium. Cobalt Oxide	Moderate	Moderate 40-200 Wh/kg	Moderate 130-380 W/kg	4
Lithium Titanite	Very good	Low 40-90 Wh/kg	High 700-1300 W/kg	10
Ultracapacitors	Good	Very Low ~1-10 Wh/kg	Very High ~10,000 W/kg	100

2.2.2 Thermal System

Thermal systems are another type of energy storage that widely used for conserving the energy and maintaining clean environment at the surrounding. This energy storage as it named, use heating and cooling methods to store and release energy to be used later. The uses of thermal energy storage are to balance the night and day energy demand. Besides, this energy storage can also store heat during summer to be used during for heater during winter. It is certainly a great contribution for minimizing the electrical bill prices as heater is one of the appliances that provides high wattage. In all conditions, it is required to charge the energy storage either by heating or freezing and then release it to be used later[9]. Figure 2.2 shows how thermal energy storage works in daily application.

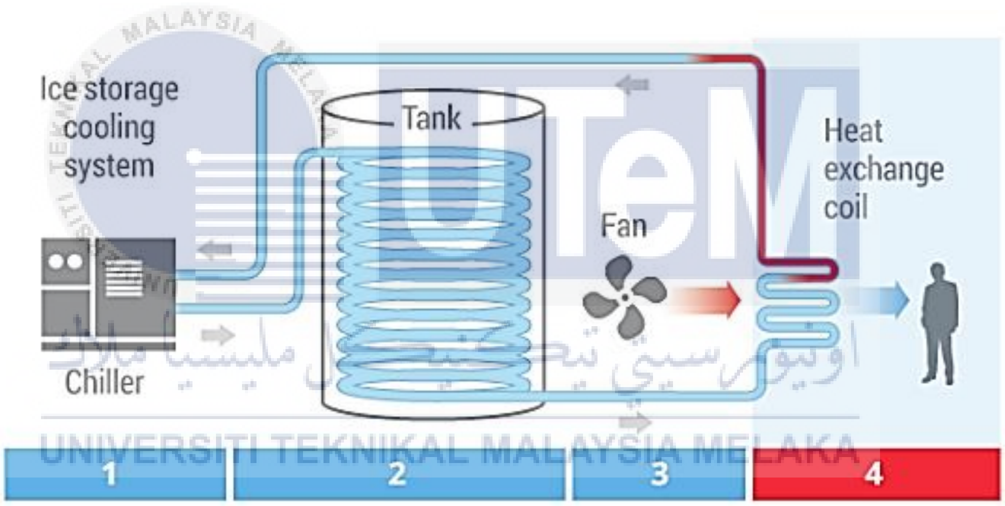

Figure 2.2: Principle thermal energy storage [9]

2.2.3 Flywheel Mechanical System

Flywheels energy storage working. principle is by increasing the speed of flywheel or rotor. The rotational speed is kinetic energy that will reject when the energy is taking out as the result of energy conservation. This flywheel will revolve the rotor by absorb and release energy in short periods of time which is in 15 minutes or less. The rotor is made of high strength material which is carbon-fibre to withstand high speed of rotation. The utilization of this type of energy storages is to balance the fluctuations in electricity supply and demand. In this case, the control signal that is adjusted every few seconds will be responded to the energy storage. The application of energy storage flywheel system based on the Figure 2.3 is built in a formula 1 racing car. This system is used in such high-speed car because to reuse and recover the kinetic energy during braking to obtain high speed [10].

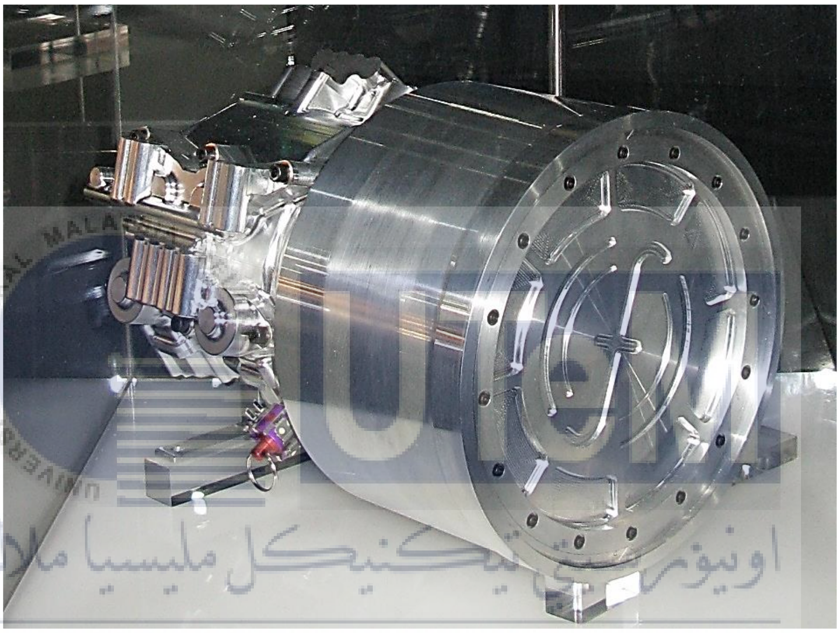

Figure 2.3: Example of Energy System flywheel[10]

2.2.4 Hydro Power System

Hydro Power Energy Storages are one of the mostly used energy storage within the grid which is 97% storage is used nowadays. The usage of this energy storage is located near the hydroelectric power generation region because of condition needed to utilize this energy storage. This type of energy storage is used during low demand of electricity. Figure 2.4 shows the application of Hydropower pumped storage. This condition occurs when the over enough of electricity is used to inject water from low source location to higher reservoir. During peak demand of electricity, the reservoir tunnels for the way will be unlocked in order to allow the stored water in the reservoir to flow right into the turbine, then resulting the production of electricity by this application. However, even this system is widely used nowadays, the construction of this type of energy storage is difficult to build because the levelling for the flows of water and long ways for the water to flow for continuously generation of electricity during peak demand. Other than that, the space needed to build this energy storage is very large and will needed high cost for the early construction.

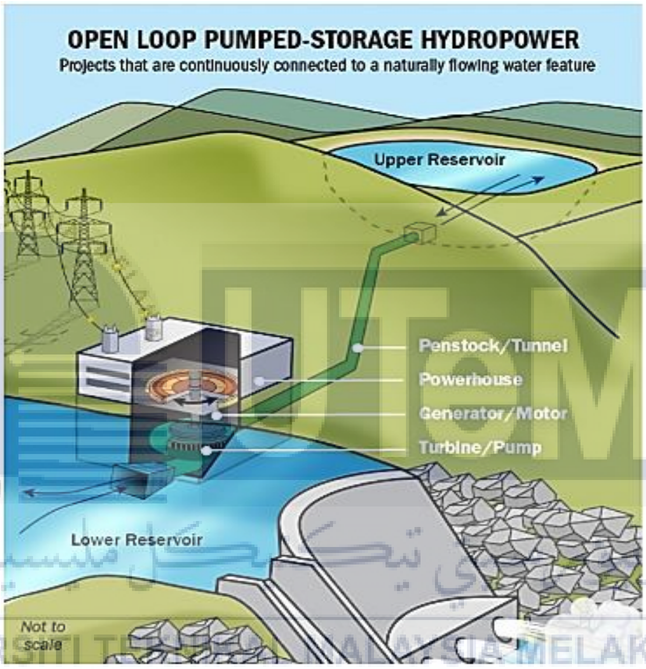

Figure 2.4: Hydropower pump storage[11]

2.3 Overview of Community Energy Storage (CES)

In recent years, the development of the distribution in system network of electricity have been increasing worldwide whether in Europe, Asia, Australia and America. The developments that have been massively achieved is the generation of renewable energy that are very significant source for the distribution power. The generation that have been developed are wind energy, solar energy, hydro energy and wave energy. The uses of these types of generation are very crucial to maintain the clean and healthy environment without the usage of non-renewables energy that will used up before long.

Other than that, this type of generation can also reduce the usage of unhealthy power generation that will cause harm towards environment such as emission of carbon, air pollution and thinning of ozone layer. Around the world, there are huge increasing of installed PV systems mostly at residential region. The massive development in the PV system have made the generation of solar energy become more stable and efficient. Moreover, the investment that have been made for the installation of PV system in the residential region have reach trillion dollars in the future as many investors see the potential of this investment will give high profits and benefits.

However, due to high usage of PV system that generated by solar panel cause some effects gives disadvantages to the distribution systems which is reverse power flow, unstable voltage profile and inefficient quality of power. Due to overcome these issues, the installation of energy storage is a vital solution as it can solve most of problem mentioned above. Table 2.2 is showing the difference installation of energy storage in different region which is single home, community and distributed region. The table shown the difference that is very conspicuous is the capacity scale of energy storage where it is built based on the condition will be served.

Table 2.2: Comparison between Single Home, Community and Distributed Energy Storage[12]

	Single Home	**Community**	**Distributed**
Scale	Up until 20kWh	< 1 MWh	> 1 MWh
Location	Single Home	Communities Distributed Feeder	Substations or along Distribution Feeder
Application	For the End-User	For the End-User and Distribution	Distribution

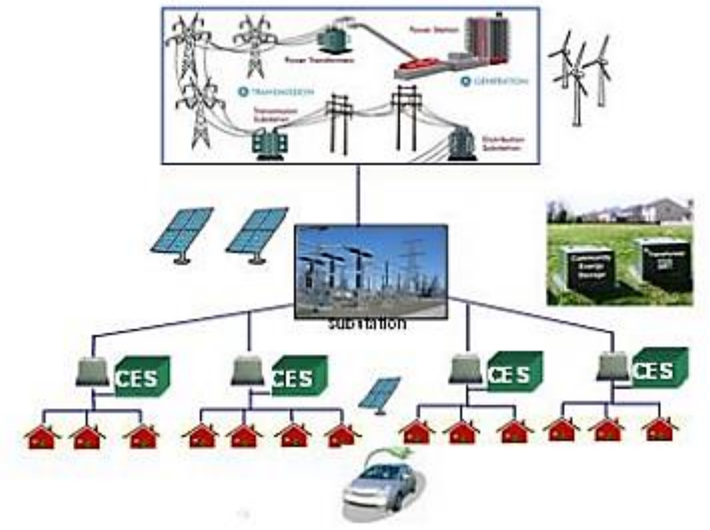

Figure 2.5: Deployment of CES at Distribution Network

2.3.1 Benefits of Energy Storage

There are many benefits of Energy Storage. In this section, there are six main benefits that presented in this section such as peak shaving, load shifting, voltage regulation, prevent reverse power flow and become renewable energy.

2.3.1.1 Peak Shaving

The electrical energy uses by the customer have irregular load level during the day. The load level fluctuates according to the customers demand resulting peak demand. The cost of electrical energy lingered with the peak demand resulting the spike in electrical bills [13]. So, peak shaving application as in Figure 2.6 is proposed. During that time, the uses of CES is required to supply the energy for the customers to reduce the electrical cost. This CES is charged during low demand as the cost of the electrical energy is not as high as during peak demand. Thus, the electrical bills that charged by the suppliers to the customers will be reduced. This is because the customers are not using all the electrical energy supplied from the grid but also uses the electrical energy from CES that have been charged earlier.

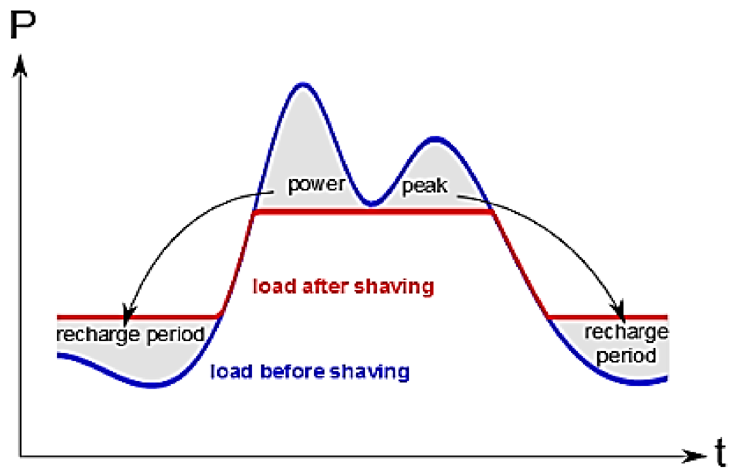

Figure 2.6: The principle of peak shaving[13]

However, there are several challenges in peak shaving which is to create and propose a control system that can detect the time where peak demand occur and how to make use of the energy storage efficiently. Regularly, the load peak is hard to predict and mostly the battery discharge has good chances to slip from catch the peak demand. Other than that, misfires may occur when the load is unknown or different from the expected load. The energy storage charged has lower electrical energy than the load resulting the objective of energy storage to support supplying the electrical energy to the customer during peak demand cannot be achieved. The formula for peak shaving objective function is as below:

$$f(x) = |C_{batt} - (max \int_{t_0}^{t} (L(t) - x)dt - min \int_{t_0}^{t} (L(t) - x)dt)| \tag{2.1}$$

Where, C_{batt} is capacity of battery, x is the shave level of peak shaving and L is load. By using this formulation, the objective function of the peak shaving can be determined.

2.3.1.2 Load Shifting

Load shifting is the transfer of energy utilization during the day at certain times known as peak load. To satisfy the requirement of electricity supply during the peak demand, high power must be generated from the system grid to the distribution feeder. However, during these peak hours, the cost of electricity from the supplier is very expensive compared to off-peak demand. Thus, the generation of variable power supply such as solar generation and wind generation are crucial for the satisfaction of the customer demands.

The implementation of load shifting is essential when the store of electricity supply is made during off-peak period and being used peak demand as in Figure 2.6. The thermal energy storage has (TES) been introduced by researchers for storing energy (whether cold or heat) during low demand period and be used during peak load demand period [14]. In this case, the relating device that can use this type of storage are air-conditioner, refrigerator, freezers and hot water cylinder as these types of appliances required stable and need high supply of electricity. The load shifting can diminish both peak demand cost and energy cost during peak demand. In this case, various efforts have been made to implement the load shifting control into the power system using energy storage. There are four types of groups that being used as facilities such as building thermal mass (BTM), thermal energy storage (TES), using combination of BTM and TES and phase change material (PCM).

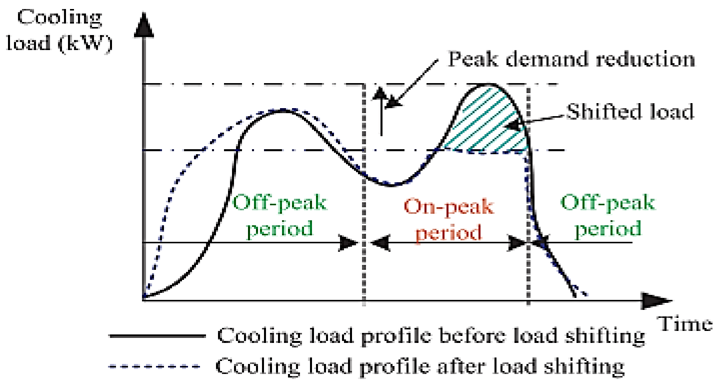

Figure 2.7: Schematic diagram of typical load shifting[15]

2.3.1.3 Voltage Regulation

The infiltration of Photovoltaic (PVs) into the power system is crucial to enumerate the existing power that generated by non-renewable resources. However, the interference of the renewable energy within the power system in high level cause a challenge where the disparity of the supply may lead to the irregular voltage level that usually will interrupt the distribution side which such as household. PVs that can only generate uncontrollable supply can give a huge impact to the distribution side of power system. Thus, CES is introduced to overcome this problem as it can act as voltage regulator.

The impedances of the distribution sides consist of mostly resistive as the R/X is significant against the medium voltage and transmission line [16]. The idea to regulate the voltage by utilizing reactive and active power and regulate the voltage by balancing these two parameters. The point of common coupling (PCC) abide the power injected by PV is contemplate as current source. As the medium distribution and transmission side voltage have low reactance, thus the reactive power is assumed constant. if the real power injected by PV is positive, the voltage also increases. While the real power injected by PV is negative, the voltage across the feeder also decreases. The voltage regulation principles are shown in Figure 2.8. The limit of the voltage may be permitted to be utilize until up to critical level, but it cannot surpass the minimum and maximum critical voltage that have been set up within IEEE standard 1547 which is 0.88 p.u. and 1.1 p.u. respectively. In this case, the CES is crucial to PVs where its unbalanced output can be controlled. By doing this, the battery of energy storage can be charge during peak generation and discharge during peak load conditions. The differences between the generation of PV and load demand could eliminate the irregular voltage level.

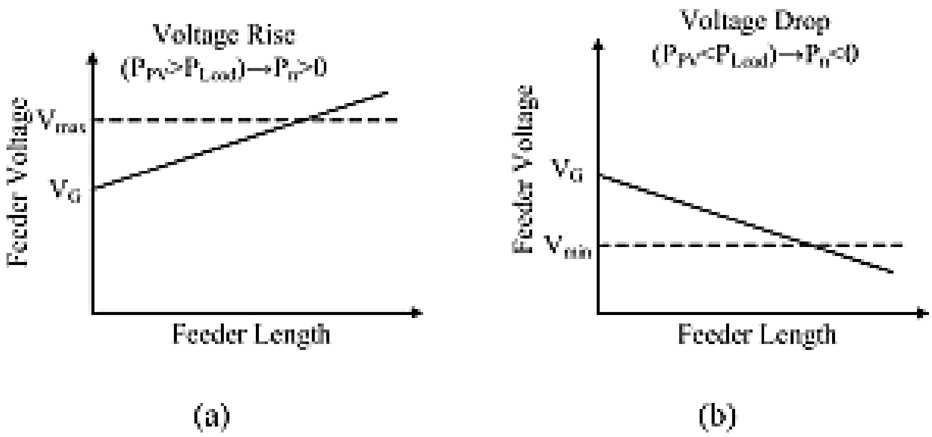

Figure 2.8: The voltage rise (a) and drop (b) across the distribution feeder[17]

2.3.1.4 Prevent Reverse Power Flow

The distribution network of electricity has been developed widely recent years. The purpose of developed network is to make sure the future of the power system will have high efficiency and low rate of losses presented. The renewables energy generation have been one of the steps towards these objectives. The maturity of renewables generations such as photovoltaic and wind turbine energy are very useful and crucial to serve as back up for the non-renewables generation that will probably uses up someday [18].The latest research regarding solar energy is to develop the uses of solar panel and energy at the residential estate. Thus, the uses of energy storage are beneficial for this case. This is because the energy generated at the residential side by the solar panel is not use during the day as most of the community were not at home. So, the energy is accumulated at the residential side as the peak hours of the day, the sun is at the highest where solar energy gained is at maximum.

The energy accumulated is very high and exceed the load demand. Thus, the flow of power is reversed back towards the substation [19]. At a certain amount of reverse power flow, it will affect the voltage controlling devices to be crashed or break down. Other than that, it will cause the voltage at the distribution feeder to exceed its limit [20]. In this case, the uses of energy storage are crucial to prevent this phenomenon. The energy storage installed between the distribution feeder of the residential region and the substation will store the energy the flow reversely and can be used during peak load demand. Figure 2.9 shows the utilization of CES to prevent reverse power flow problem. As in Figure 2.9, the demand of the system with battery is reduced during peak hour, while during off-peak, the demand is rise slightly. The increase in demand during off-peak show the utilization of excessive power from rooftop PV to prevent the power from dissipated.

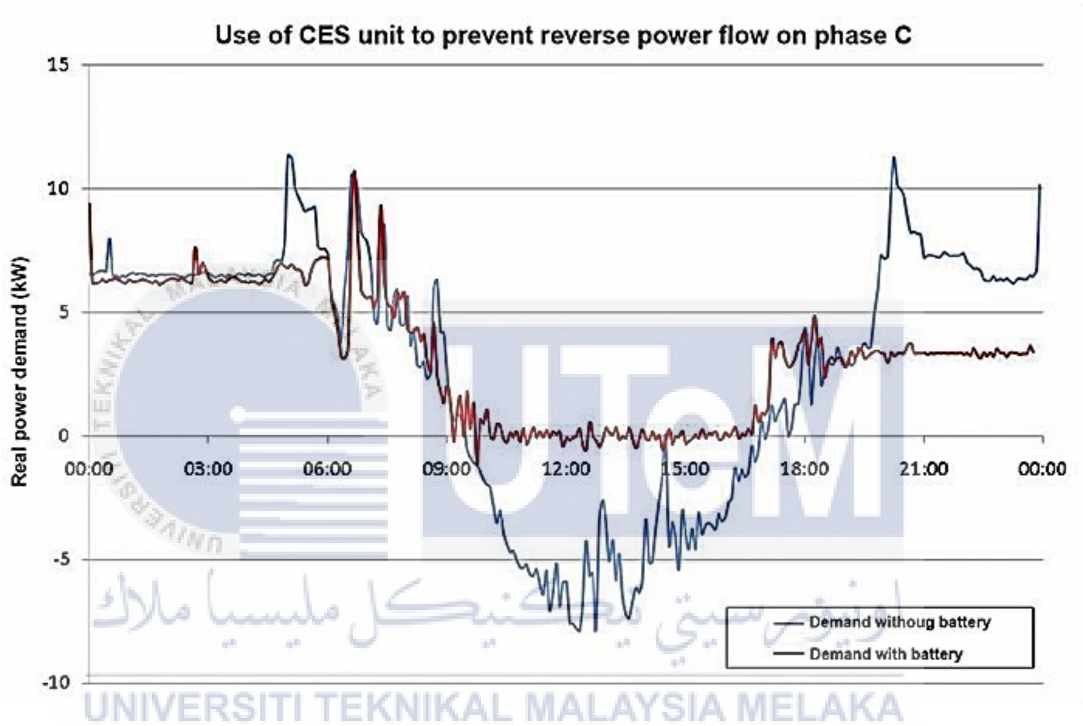

Figure 2.9: The Comparison of demand with CES and without CES[21]

2.3.1.5 Maximize the Utilization of Renewables Energy

CES is very useful for the system with renewable energy (RE) generation system. This is because the uses of CES can hit a significant part in RE generation into the grid. The types of RE that widely used for generation are wind generation and solar generation. CES addresses two notables RE generation integration challenges. First, CES can be charged with wind generation output, much of which occurs at night when the energy is not very valuable. In some circumstances, demand for energy is less than the amount being generated, so wind generation is “curtailed” (turned off) or the system operator must pay someone to take the energy.

By charging at night, CES takes advantage of the time when transmission systems are less congested and more efficient. Second, CES can be used to manage localized power quality related challenges posed by high penetrations of photovoltaics systems, especially in residential areas. Of note are undesirable voltage fluctuations that occur such as those associated with rapid variations of output due to passing clouds[22].

2.3.2 High Cost of CES

CES is a new type of technology that was found to improve the technical performance of power system. However, the high cost of CES cause the implementation worldwide is still low. The costs include the installation costs, battery lifecycle costs and maintenance costs. This problem become one of the challenges for the countries worldwide to implement the CES in the power system of the country. Table 2.3 shows the estimation cost to deploy CES for two type of CES that mostly used in practical application. The estimation costs include energy, power, Fixed operational and maintenance (O&M) and variable O&M costs.

Table 2.3: Estimation Cost of CES[12]

Type	Energy Cost ($/kWh)	Power Cost ($/kW)	Fixed O&M cost ($/kW-year)	Variable O&M Cost ($/MWh)
Li-Ion	443-562	514-1410	10	3.1
Advance Lead-Acid	750-1000	514-1410	5	0.5

2.4 Optimal Power Flow

In this subtopic, the information regarding optimal power flow will be explained. The topic that will be discussed are the concept, types of optimal power flow method, the uses of optimal power flow in distribution system and Genetic Algorithm.

2.4.1 Concept Optimal Power Flow

The Optimal Power Flow (OPF) research is said a very reliable optimization tools to a problem that have been well-defined since early 1960[23]. The OPF optimizes a power system operating objective function while satisfying a set of system operating constraints, including constraints dictated by the electric network. These methods have been used widely in power system analysis for planning and operation [24]. The usage of optimal power flow in the system is either to manage the energy and optimize the network within the system.

The purpose of management of energy in the system categorized into two which is islanded, and grid connected. The purpose of energy management in an island is to preserve and maintain the system's frequency and voltage. As for island is small power system, uneven load which is isolated will leave great impact to such small power system especially in term of network frequency. As for the grid-connected, the purpose is to reduce the cost of electricity during peak demand. Other than that, the management is to improve power factor of the system and regulate the voltage profile in the microgrid. These problems happened may due to unstable generation of RE from PV system on the rooftop of houses.

The optimal power flow solution method categorized into two which are traditional method and artificial intelligence method. The traditional method may become wider day by day. However, it suffered some disadvantages such as the uses may consequences stuck at local optimum, it weak at handling qualitative constraint and become so slow when variables become so large. So that, the uses of artificial intelligence methods as in Figure 2.10 were introduced because it is more advantages such as it can handle various qualitative constraint, can find multiple optimal solution in a single simulation run and can find global optimum solution.

Traditional Methods

- Linear programming
- Newton Raphson
- Quadratic Programming
- Non-linear Programming
- Interior Point
- Gradients methods

Artificial Intelligence Methods

- Genetic Algorithm
- Particle Swarm
- Artificial Neural Network
- Bee Colony optimization
- Differential evolution
- Grey wolf optimizer
- shuffled frog-leaping

Figure 2.10: Optimal Power Flow Solution Methods[25]

2.4.2 Optimal Power Flow in Distribution System

The usage of optimal power flow in distribution system is to minimize the cost of the electricity prices that customer need to pay monthly to the energy supplier such as Tenaga Nasional Berhad (TNB) in Malaysia. The minimization is made by yielding in optimal voltage set-points of each buses that have in the distribution system and power set-points of distributed energy generation that will result in yielding minimum value of power losses, energy cost generated from the supply and demand load that need to be served in the distribution grid [26]. The placement of energy storage will certainly affect the set-point of voltages and power from the base test system. So that, in order to configure the efficiency of energy storage installation in the distribution system will give many advantages rather than disadvantages will be determine on OPF method used.

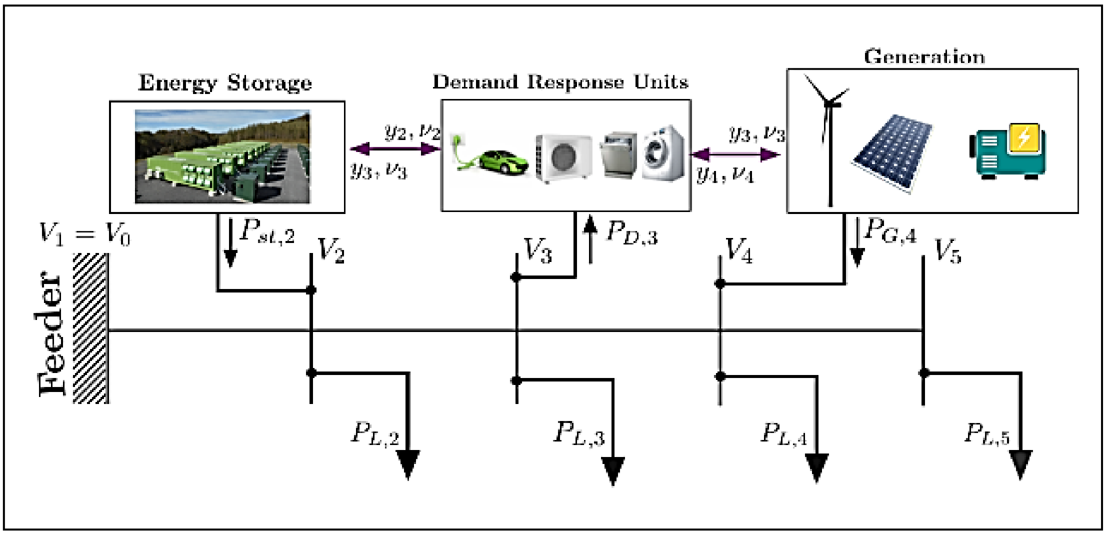

Figure 2.11: Optimal power flow set-point in distribution system [26]

2.4.3 Genetic Algorithm

Genetic algorithm is a method in MATLAB that can be used to solve the optimization base problems that content constrained and unconstrained naturally. The concept of this method is to repeat the optimization solution to find the best value for the result. The fundamental of this method is to choose aimlessly the population to become the parents. These parents will be used to choose its children for the next generation of population. From the children produced by the parent, it will iterate every child to find the best value which is the optimal solution. The child with replaced with new iterated child if the value of new one is more optimal than the old one.

In GA, it uses three main rules to guarantee the optimization of the population of children. The rules use is selection, crossover and mutation. First step to use genetic algorithm based on Figure 2.12 is initialization where in this first step, the initial value of the population is assign based on the project data or variable. Next step is selection where in this step the parent is chose in order to select the incoming generation that will produced based on them. After that, the crossover step. In this step, the combination of the parents is made to produced children or value for incoming iteration. The last step is mutation. In this step, the parent will be undergoing changes to generate their children or the incoming best solution for the iteration [27].

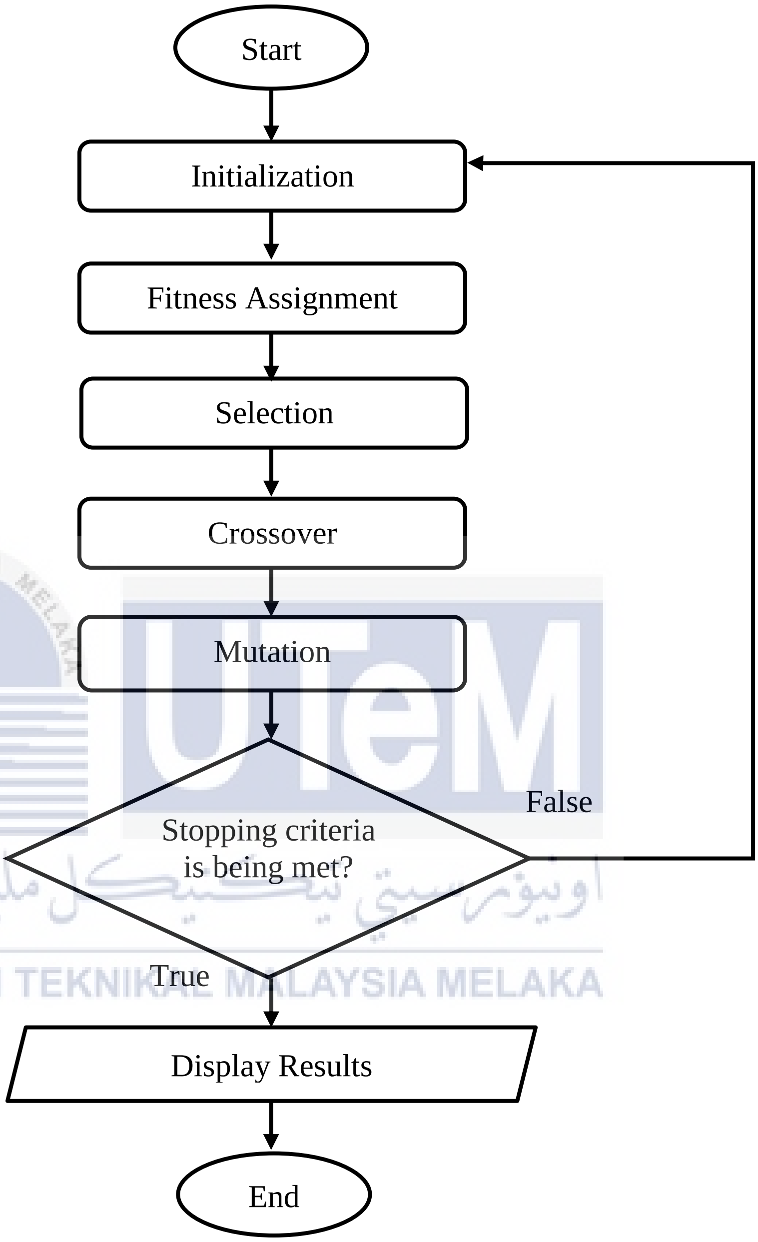

Figure 2.12: Basic working principle of Genetic Algorithm [28]

2.5 Electricity Prices at Utility

Electricity prices are different based on the component and type of customer. The electricity prices usually highest at residential and commercial consumers. The price is higher because it takes cost for distributing it, while for industrial consumers, they can get with wholesale price as they use more electricity and supply to these customers is more efficient and cheaper[29]. However, the utility needs to pay to the generation suppliers' different price of electricity. The cost for supplying electricity varies with times where it changes minute by minute. This changing happened because of variation in electricity demand, generation cost, fuel cost and power plant reliability. The price in summer is the highest because the usage generation source that expensive is higher to meet increased demand. The electricity demand usually increases during afternoon and early evening which is the peak hours. So, the price of electricity is usually high during these parts of the day. However, these prices only enshrined for the distributor while the consumers pay prices based on the tariff decided by the utility at the grid who manage the transmission of electricity of the area.

Table 2.4: Summary of previous research

Authors/Years	Field of study	Contribution	Weakness
G. Karmiris, T. Tengner[13].(2013)	Peak Shaving Control Method for Energy Storage.	Lower maximum peak load as low as possible but at the same time ensure that the ESS is not discharged too quickly	The paper only makes computer simulation without hardware experiment to prove the result.
J. A. Michline Rupa, S. Ganesh[30]. (2013)	Power Flow Analysis for Radial Distribution System Using Backward/Forward Sweep Method	Forward propagation calculated voltage nodes; backward propagation calculated power branches. Proposed for fast convergence characteristics and radial structure.	This paper did not consider CES in the power flow analysis of the system.
H. Nazaripouya, Y. Wang, P. Chu, H. R. Gadh[31][17][16]. (2015)	Sizing and Placement of Battery Energy Storage in Distribution System Based on Solar Size for Voltage Regulation	It allows calculating the optimal size and place of energy storage based on the size of integrated solar in distribution system with the goal of voltage regulation.	Did not include economic profits in the study.
Zeraati, Mehdi, Mohamad Esmail[17]. (2016)	Energy Storage Systems for Voltage Regulation in Distribution Networks with High PV Penetration	Developed coordinated control scheme to regulate the system voltage and efficiently utilize the storage capacity of Battery Energy Storage (BES) during daily operation	Did not include economic profits in the study.

2.6 Summary

In a nutshell, there are many types of energy storages that is utilized in the power system. The usage of energy storage increases gradually within time as the benefits have been exploited widely by many countries. In this chapter, the type of chemical that is commonly used for the energy storage is also known as Lithium ion. Next, in power distribution system, the implementation of CES is very important. This is because CES provides a lot of benefits such as peak shaving, load shifting, prevent reverse power flow, frequency regulation, voltage regulation and serves as renewables energy. Besides, the efforts towards dispatch strategy for maximizing the techno-economic benefits mentioned earlier can be done by using optimal power flow using GA. The optimal power flow will determine the optimum dispatched power of CES to maximize the techno-economic benefits. The implementation of the method to maximize the benefits will be explained further in the next chapter.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter explains the methods needed to accomplish this project. All methods used in this project will be mentioned and explained on how it will be carried out to obtain the desire result. This project is conducted using simulation of MATLAB by using optimal power flow method and Genetic Algorithm as tools. This method can be used to determine the optimal dispatch strategy for charging and discharging the CES every hour. This project only considered real power for the system, where the power factor without reactive power is unity.

The types of distribution system for this project is radial distribution system because it is widely used in the residential system. This system is made from one power source of supply. This system is also widely used in the residential distributed system because it is cheaper than mesh type distribution system and network type distribution system [27]. However, power failure and short circuit can affect the whole distributed system of connected line. It can only be restored once it has been fixed. During fault occurred, the miniature circuit breaker (MCB) will trip in order to prevent the electrical flow through the system from continuing in that state. This project will also incorporate the installation of rooftop PV that can reduce electricity cost. All the scope used in this project need to be well-adapted with the residential distribution system to acquire accurate result.

3.2 Project Flowchart

Figure 3.1 illustrates the flowchart of the overall project. This flowchart summarized the methodology conducted for this project. The overall purpose of this project is to determine the optimal dispatch power of CES for achieving maximized techno-economic benefits which in term of technical and economy. As explained in the literature review, the optimization method needs to be carried out by using Genetic Algorithm (GA) in MATLAB.

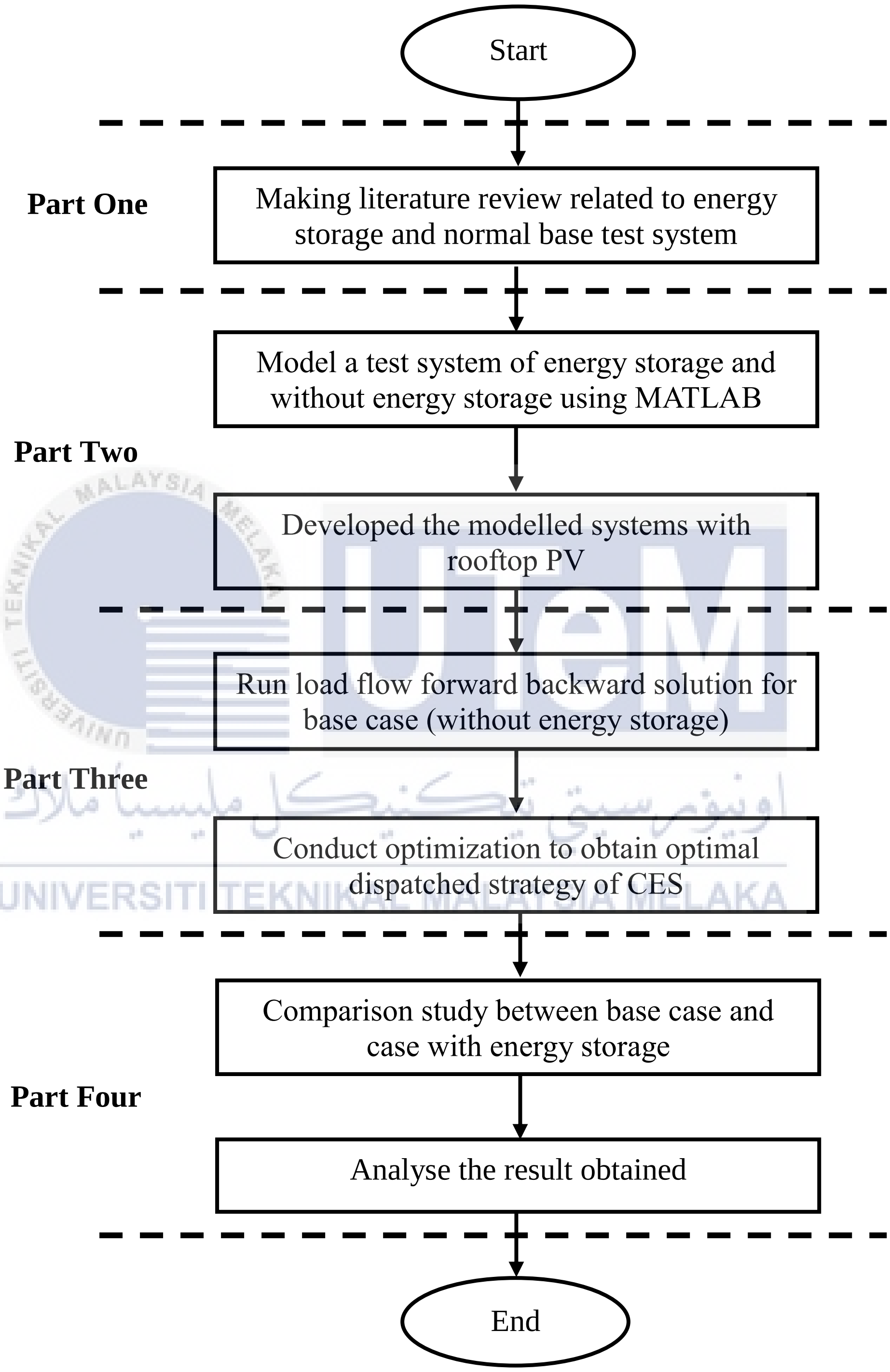

Figure 3.1: Flowchart of overall project

3.2.1 Part One: Research and Studies

In this part, the initial step is making literature review related to energy storage and normal base test system. Generally, the purpose is for collecting information and gaining knowledge about energy storage and how it operates. Figure 3.2 shows the information of energy storage and method to use in this project that have been find out in literature review. The literature review also needs to be done to find out the benefits of energy storage in terms of technical and economic. Besides, the electricity price for the distribution system also needs to be known in this project as reducing the electricity cost is crucial to show the benefits of using CES in term of economic.

Next, the benefits of energy storage in both technical and economic terms need to be find out to achieve the objectives of project. Then, the methods need to be used in this project such as optimal power flow and genetic algorithm also been find out to know the principles and correct procedures for completing this project. The whole elements stated in literature review is very crucial to be known to proceed for the next steps of methodology.

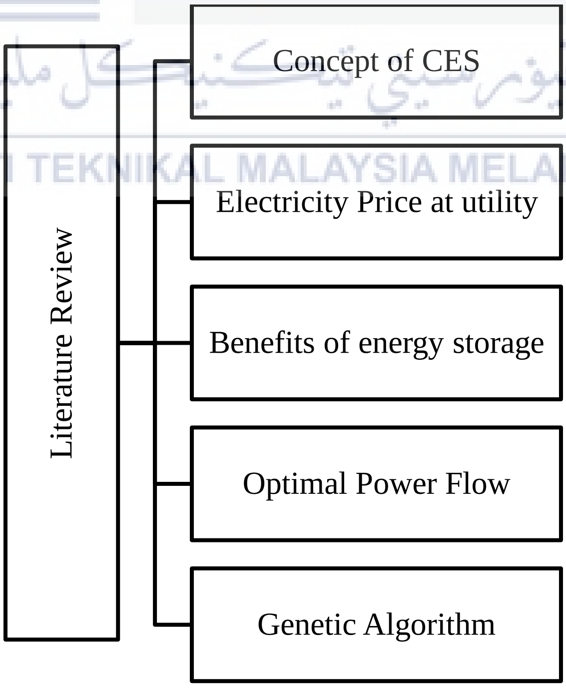

Figure 3.2: Literature Review of the project

3.2.2 Part Two: Modelling Test Systems

For this part, the steps are relating to modelling and simulating the test systems. The systems modelled must be relating to distribution system at residential area. Figure 3.3 below shows the single line diagram of base test system at residential area with 15 bus. The electricity prices, demand at buses, branches, load level for every hour and capacity of PV system for every hour were included in Appendix A, B, C, D, and E. These data are needed to model the test system for simulating the OPF using GA tools.

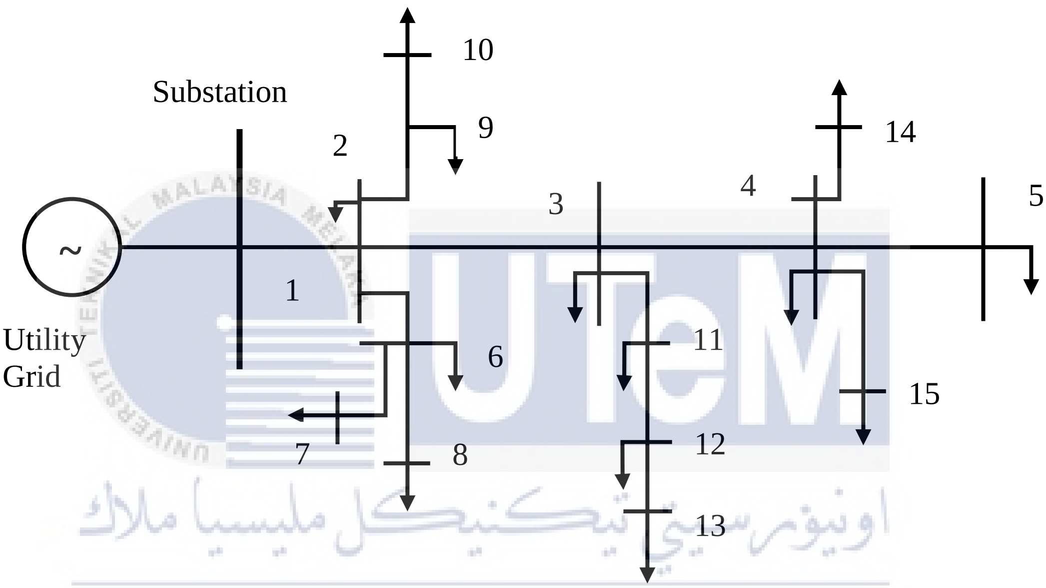

Figure 3.3: Base Test System with 15 Bus[32]

There are two types of test systems that need to be modelled. The applicable test systems that modelled are base test system and CES test system. There is only slightly difference between both cases. The base test system is the distribution system without the deployment of CES. This test system is modelled to figure out the power flow of the base test system in order to compare with the deployed CES test system. For the CES test system, the system is included with CES in one of the bus in the system. In this project, the bus selected to deploy CES is bus 7. Both systems are supplied with energy from the utility grid. The installation of CES at one of the buses in the system purposely for making improvement at the test system that can be determined in term of power demand, electricity cost and voltage profile.

Next, the further step is modelling the Rooftop PV system for additional supply at the residential area. By the implementation of PV system at the residential area, less energy required to be generated from utility grid to feed the demand of the system. The demand will be fed by the additional supply from PV system.

3.2.3 Part Three: Run Simulation of OPF

For the part three of methodology, power flow needs to be run at the base test system. The purpose of the optimal power flow is to determine the voltage, power demand and electricity cost for base test system. The project will be using specified method which is forward-backward sweep method that is very suitable for radial distribution network. These values are required for comparison of the base test system with CES test system. From the comparison it can be known whether the CES installed at the test system is well-functioned or not.

Then, the optimization to obtain optimal dispatched strategy of CES is conducted. Mainly, the dispatched strategy is to identify the most suitable time for charging and discharging of CES that will be decided by GA in MATLAB. The time of charging and discharging of CES is decided based on the electricity prices data for a day where the electricity prices changes within hours.

3.2.3.1 Optimization of CES using Genetic Algorithm (GA)

Genetic Algorithm is a package which is included in MATLAB software to simulate and compute the optimization on CES to maximize the techno-economic benefits. The benefits of CES will be optimize by gaining the highest profits for the customer. In this case, the profits referred to the electricity prices. Where the lower electricity prices gain by the customers, the higher the profits. Thus, in this case the optimization is to find the lowest value of electricity bills will obtained by the customers. Besides, the profits will also be determined by managing the energy storage capacity. By following this matter, the time of charging or discharging of energy storage is also determined through GA.

3.2.3.2 Process Flowchart Optimization with Genetic Algorithm (GA)

The initial step for this simulation to work is the generation of initial population. In this project, the initial population generated by GA is the time of charging and discharging of CES hourly in a day. GA provided the optimization by showing a graph on what hour the CES need to be charged and what hour the CES need to be discharged to supply the residential area. Next, the power of energy storage that will be used to supply the load is determined. This power will be decided based on the load at the residential area. After that, the optimization of the power flow will be conducted on the test system with energy storage implementation.

Then, next flow of the simulation is evaluating the population and the objective function. The population in the project is the rate of charging and discharging of CES. The evaluation is crucial to determine whether the CES charging and discharging rate hourly is well-managed after undergo optimization using GA. The objective function is the case that determined the maximized or minimized values. For the objective function in this scope of project is the best value of electricity prices. The electricity prices with the lowest and ideal value will be chosen by the GA to maximize the dispatch strategy for optimum techno-economic benefits.

Lastly, the stopping criteria for the simulation. Stopping criteria is an important thing that needed in computation of iteration method. The function is to make sure the iteration will be stopped once it meets the required condition decided by the programmer. Otherwise, if the iteration did not involve stopping criteria, the iteration will not stop and will continually its iteration for infinite times. Thus, in this project, the stopping criteria is very essential for the program to stop after its already find the best value for the electricity prices for the system. This stopping criterion will decide the continuity of the programmed. Once, the stopping criterion meet its condition, the programmed will ended while displaying the value obtained from the iteration made previously. Otherwise, if the stopping criterion still does not meet the conditions, the program will return to the initial step which developed a new population and repeat the whole process.

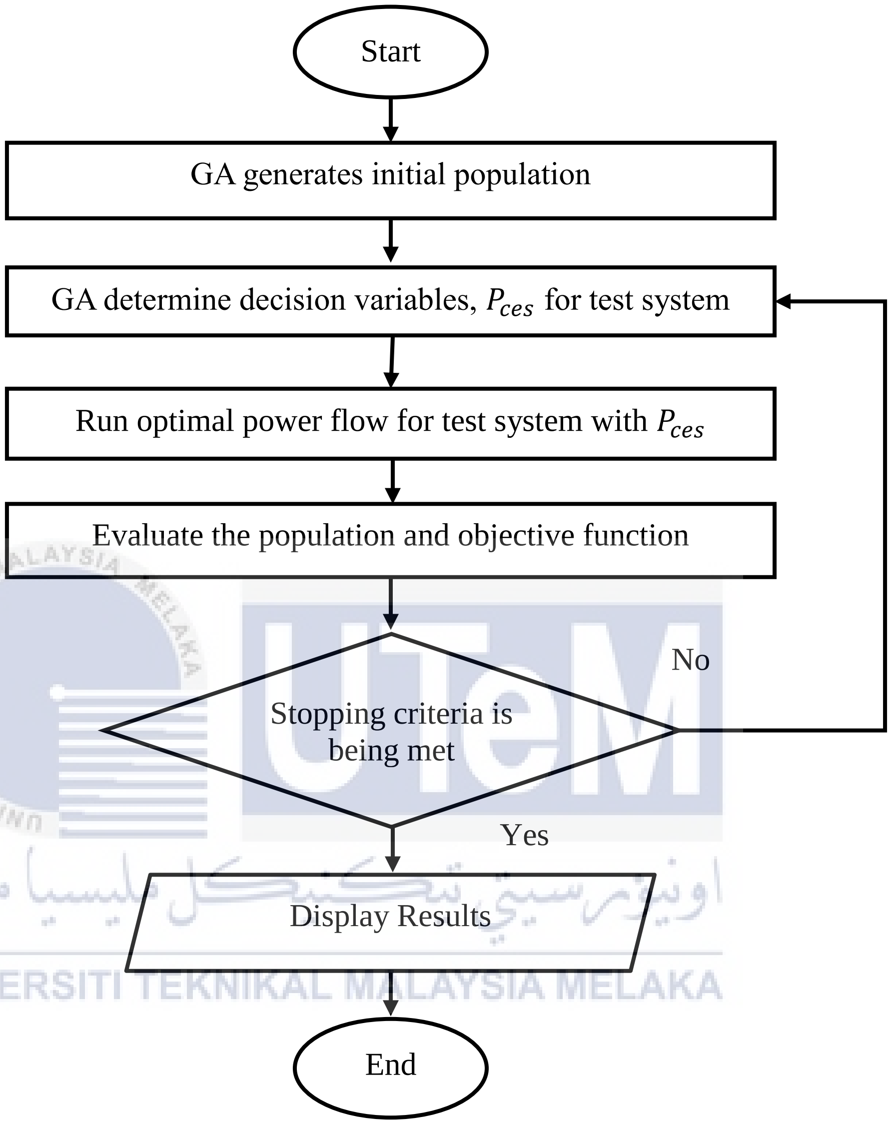

Figure 3.4: Flowchart for OPF Method

3.2.3.3 Problem Formulation

In this project, the objective function needs to be determined to achieve the desired result. Since the purpose of this project is to maximize the techno-economic benefits of CES which is in term of economic profits, the objective function set is electricity cost. This OPF purposely to determine the cheapest electricity cost with the implementation of CES. There are a few decisive variables that related to decide the Power of CES, P_{CES}. The decisive variables that crucial to determine P_{CES} is objective function, constraints and power balance. The formulation to determine objective function is as follows:

$$F = \sum_{t=1}^{24} \left(P_d(t) \times Eprice(t) \right) \tag{3.1}$$

Meanwhile, t is the number of hours for a day, P_d is power demand, Eprice is electricity prices within hours. There are several constraints that varies according to the P_{ces} where in this project the constraint is dispatched power of CES. Lastly, the decisive variables to determine P_{ces} is power balance that consist of active power and reactive power. The power balance of both active power and reactive power is in formulations as follows:

$$P_{Gi,t} + P_{ces} \times P_{PVRi} - P_{Li,t} = \sum_{j=1}^{N} V_{i,s,t} \times V_{j,s,t} \times Y_{i,j} \times \cos\left(\theta_{i,j} - \delta_{i,s,t} + \delta_{j,s,t}\right) \forall i, s, t \tag{3.2}$$

$$Q_{Gi,s,t} - Q_{Li,t} = \sum_{j=1}^{N} V_{i,s,t} \times V_{j,s,t} \times Y_{i,j} \times \sin\left(\theta_{i,j} - \delta_{i,s,t} + \delta_{j,s,t}\right) \forall i, s, t \tag{3.3}$$

Where P_G and Q_G are the active and reactive power generated; P_L and Q_L are the active power and reactive power of load demand; P_{PVR} is the PV generation profile; Y is the admittance at line; δ and θ are the voltage and line admittance phase angle, respectively. Meanwhile, with the installation of rooftop PV system at residential area resulting the existence of PV energy that can determine the PV penetration of the system. The formulation for percentage of PV penetration is as follows:

$$E_{load}(i,t) = LF(t) \times P_{bus}(i) \tag{3.4}$$

While,

$$E_{PV}(i,t) = PV_p(i) \times P_{PVR}(t) \tag{3.5}$$

Thus,

$$PV\ Penetration\ Percentage = \frac{E_{PV}}{E_{load}} \times 100\% \tag{3.6}$$

From above formulation, E_{load} is energy at load, i is bus number, E_{PV} is the total energy produced by PV units, PV_p is the maximum power of PV installed at every bus and P_{PVR} is PV profile in per unit. From this formulation, the percentage of PV percentage for the system can be determined.

3.2.4 Part Four: Results Comparison and Analysis

For this part, the steps of procedure that need to be conducted are about the analysis and synthesis of results. Firstly, comparison study made between base test system and CES test system. The purpose of this step is to verify whether the system that installed with CES is developed correctly or not. This is because from the literature review, it is proved that with implementation of CES installation in distribution system, the improvement in electricity cost, voltage profile and power demand will be achieved. So, the system that have been modelled in this project need to follow these criteria to verify that the system is successfully modelled.

Next, analysis for the results obtained from the simulations were made. The analysis that need to be implemented must be dependent on the criteria that have been mentioned above which is electricity cost, power demand and voltage profile. By analyzing the result, the reason on how the result obtained in such ways need to be justify based on benefits of energy storage that have been studied thoroughly in literature review.

3.3 Summary

In a nutshell, there are steps that required to be obeyed to obtain the desired result for maximizing the techno-economic benefits. The techno-economic benefits that meant is the rate of charging and discharging of CES hourly in a day. Other than that, techno-economic benefits meant by the best value of electricity prices by the rate of charging and discharging of CES proposed by the GA. However, in order to undergo these steps, the most important things are the literature review of the benefits of energy storage, optimal power flow, Genetic Algorithm and Forward-Backward Sweep Method. All these parts need to be researched to know how the method and project works based on other researches. Thus, in order to know the best method to use in a project, an efficient plan need to be done for the future works. The knowledge regarding the project also need to be understood very well to implement the method.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter discusses the result obtained from this project. The result of this project is divided into two parts. For both parts, there are several cases that have been made to prove the benefits of CES in terms of techno economic. The first part is the scenario where base test system with the installation of CES with different dispatched power. The second part addresses scenario where CES is installed in the test system with rooftop PV units.

4.2 Base Test System with CES Deployment

For the first part, where the installation of CES is deployed without the existence of PV at the test system. In this part, there are several cases that have been created to show on how the CES benefits the distribution system in terms of technical and economic. The cases that have been developed is shown in Table 4.2 which categorized into four different cases. Firstly, Case 1 which is the test system without the deployment of CES. This case is shown to find out the power flow of distribution system under normal circumstances. Secondly, Case 2 with the installation of CES with power of 500 kW. In this case, there should be slightly difference from base case in terms of power demand, voltage profile and electricity cost. Meanwhile, for Case 3 and Case 4, there will be higher difference from base case in all terms mentioned before.

Table 4.1: Description of simulated cases

Type of case	Maximum Power Capacity of CES (MW)
Case 1 (Base Case)	0
Case 2	0.5
Case 3	1.0
Case 4	1.5

4.2.1 Optimal CES Dispatched Power

In terms of CES dispatched power, approximately from the graph shown in Figure 4.1, Case 2, 3 and 4 provides a fine trend of optimal dispatched power of CES. Based on the graph, from 3^{rd} until 5^{th} hour, the power of CES is rise reaching its respective maximum power according to the power capacity. The risen of CES powers are because on that range, the electricity price is at its lowest price. Thus, it is very suitable for charging the CES at that time by using energy supplied from utility grid. The electricity cost for Case 2, Case 3 and Case 4 will be higher at that time compare to Case 1 because of the installation of CES as energy needed from utility grid increases to feed the power demand and charging the CES.

Meanwhile, at 17^{th} and 18^{th} hour, the power of CES descend until negative part of the graph which mean the CES is discharging during that time. This scenario happened because the electricity price during that time is at the highest where in those hours, peak demand occurred at the system. The peak demand causes the electricity price increases abruptly as more energy need to generate from power plant in short amount of time. Thus, during these hours, the uses of CES that have been fully charged is very crucial to supply the energy to feed the peak demand rather than only use energy from utility grid. By discharging the CES during these hours, the electricity cost at peak demand will be decreased.

As for the different power of CES, 1.5 MW CES provides better charging and discharging time. Based on the graph, the 1.5 MW CES will charged only when the electricity prices drop below than 40 USD/kWh. Whenever the electricity prices are above 40 USD/kWh, dispatched strategy will discharge the power of CES to assist supplying the load demand.

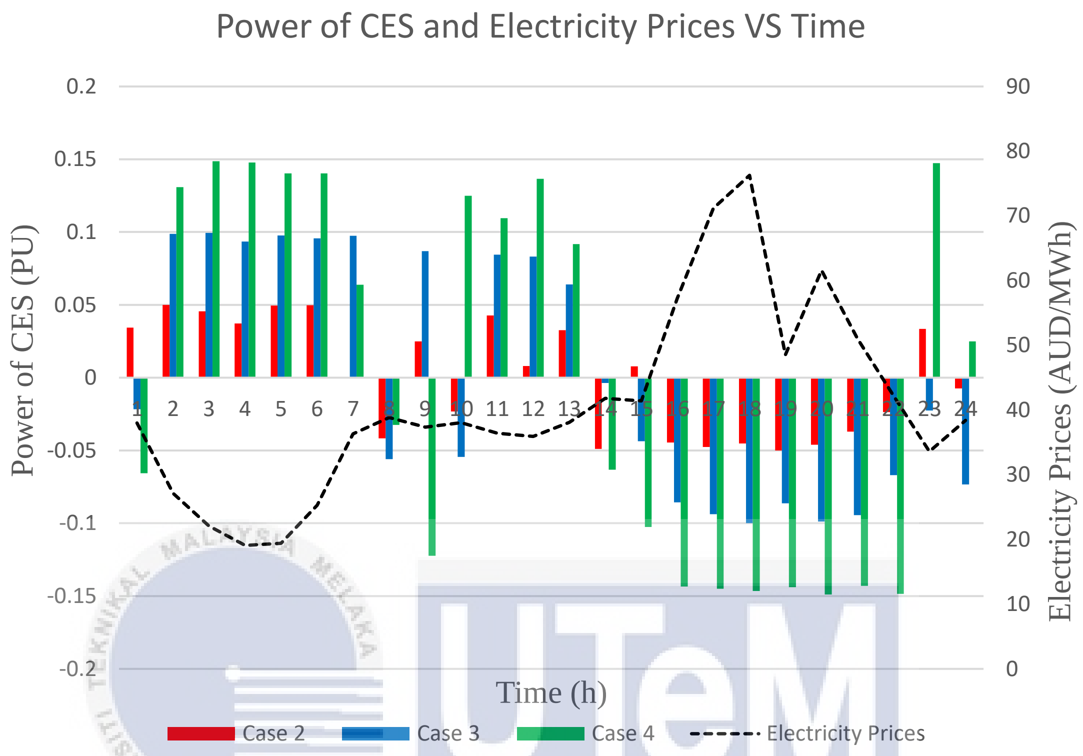

Figure 4.1: Trend of Charge and Discharge power of CES Based on Electricity Prices

4.2.2 Electricity Cost of System with Dispatched CES

The benefits of CES in term of economic can be determined based on its contributions towards reducing the electricity cost of the test system. Figure 4.2 shows the trends of electricity cost for all cases tested which is Case 1, Case 2, Case3 and Case 4. In graph below, the difference between all cases are the values of electricity cost for hours.

In 4^{th} to 5^{th} hour, the highest electricity cost obtained from the simulations is Case 4 with CES power of 1.5 MW followed with 1 MW, 0.5 MW and lastly Case 1 which is without CES deployment. The reason for Case 4 becomes the highest electricity cost is because it has CES deployment with highest power where it needs to charge for being used later. GA will pick the cheapest hour of electricity prices such as 4th and 5th hours to charge the CES since more energy needed from utility grid for the case. The Base case have the lowest electricity cost for these hours because in this case, it only needs to feed the load demand of the system since there is no deployment of CES to be charged.

During electricity prices are high, the sequence of highest electricity cost to the lowest is reversed. At 20th hour where the electricity price is quite high, the base case takes the lead with the highest electricity cost compared to other cases with installation of CES. This is because during this hour, base case needs to obtain the energy fully from utility grid while the other cases can depend to CES to discharge its power for assisting supply energy to load demand. As for Case 4 that obtained lowest electricity cost among all cases because it has highest CES power to give supply to the system while cases with lower CES power can only depend on CES with respective power with shorter amount of time. Then, those cases need to use supply from utility grid when CES power fully discharged.

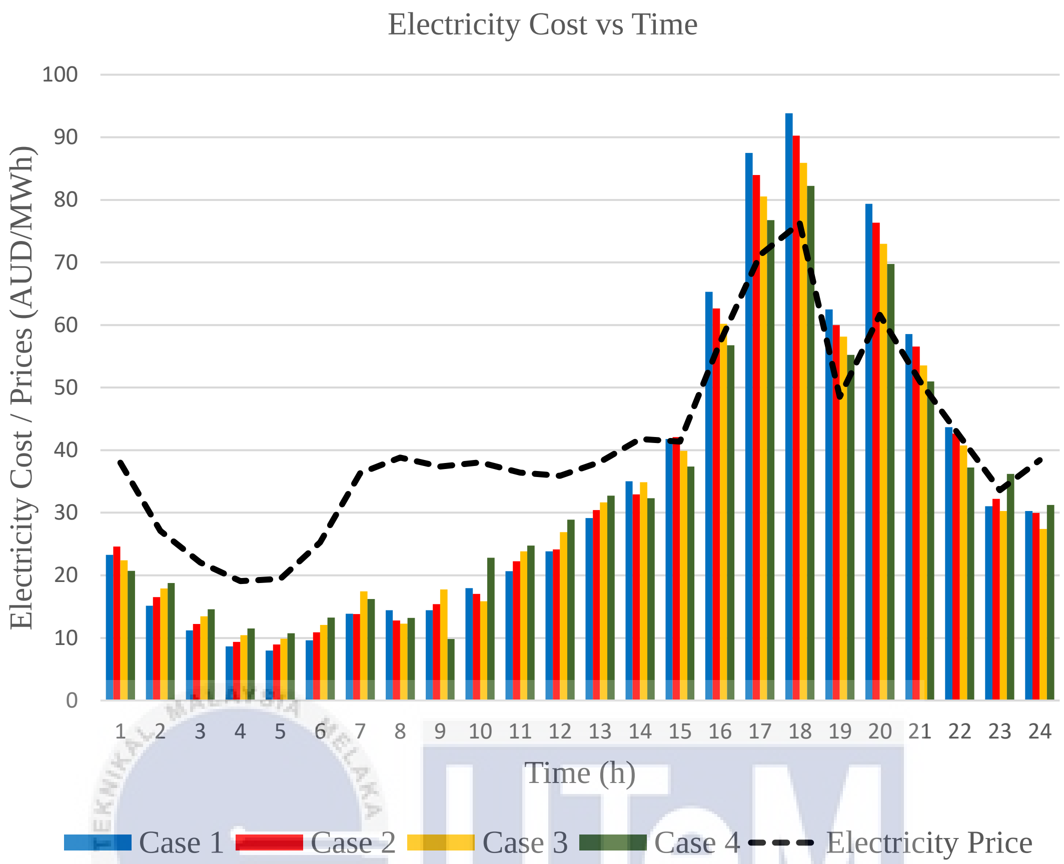

Figure 4.2: Trends of Electricity Cost in a day for different cases

Based on difference of electricity cost for each case, total electricity cost for a day is sum up in graph shown in Figure 4.3. From graph below, total electricity cost for Case 4 with 1.5 MW power of CES is the lowest which is 804.19 $ while Base case, without the deployment of CES obtained the highest total electricity cost which is 839.12 $. The difference of total electricity cost is because the uses of CES. By referring to electricity price that varies hourly, GA dispatch strategy by charging the CES during off-peak hour where electricity prices are low. Then, GA also calculated for the best hour for the CES to be discharge which is during electricity price is high. For Case 2 and Case 3 where there is deployment of CES, the electricity cost lower than Case 1. However, the CES power is not enough to discharge during peak hour as good as Case 4.

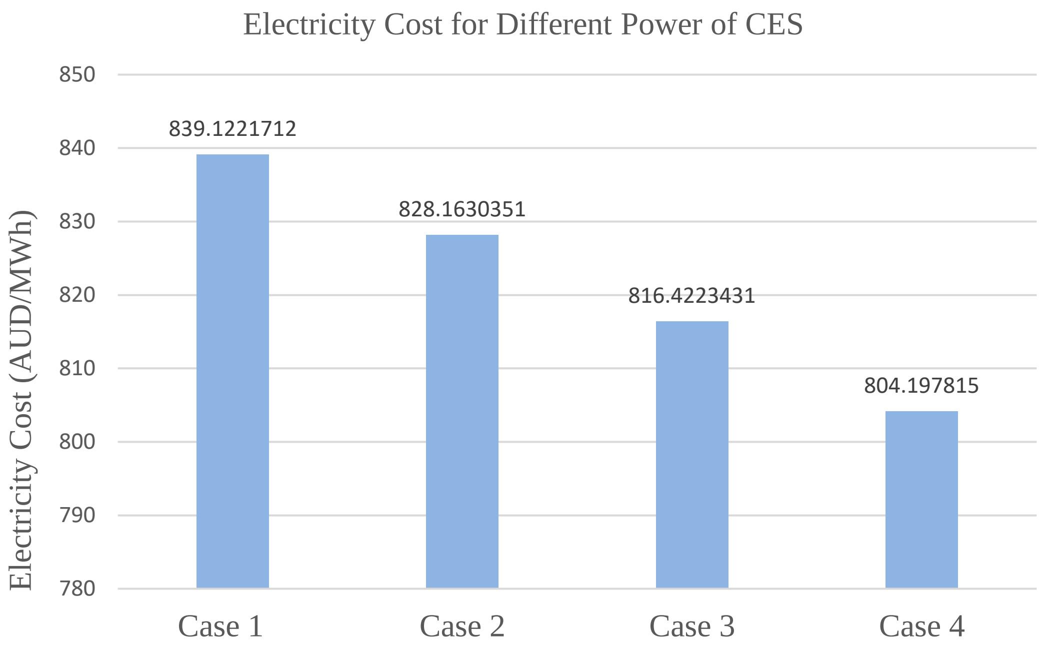

Figure 4.3: Total Electricity Cost for Different Cases

4.2.3 Demand Power of System with Dispatched CES

Figure 4.4 illustrates the demand profile measured at the substation for all the simulated cases. Every case formed different trend of power demand since all cases were built with different type of condition. During 18th hour, which is peak hour, electricity price is the highest. At this time, power demands of the cases are different. The highest peak demand during this time is Base case system while the lowest peak demand is Case 4 with CES power of 1.5 MW. The reduction of peak demand for this system is because the discharging of CES power to feed the load demand as the electricity price is high. The energy supplied from utility grid will be reduced by taking energy from CES.

The CES that have been used fully need to be charged. Thus, for reducing the electricity cost, the CES is charged during the electricity prices at the lowest. Based on graph, the lowest electricity prices can be seen during 4th hour where the power demand of Case 4 is higher compare to other cases. This situation occurred because of charging of CES that cause the CES to become another load demand of the system. Case 2 with CES power of 0.5 MW also charging the CES during this hour. However, the power of CES in Case 2 that lower than Case 4, resulting the load demand for this case is lower than Case 4 during 4th hour.

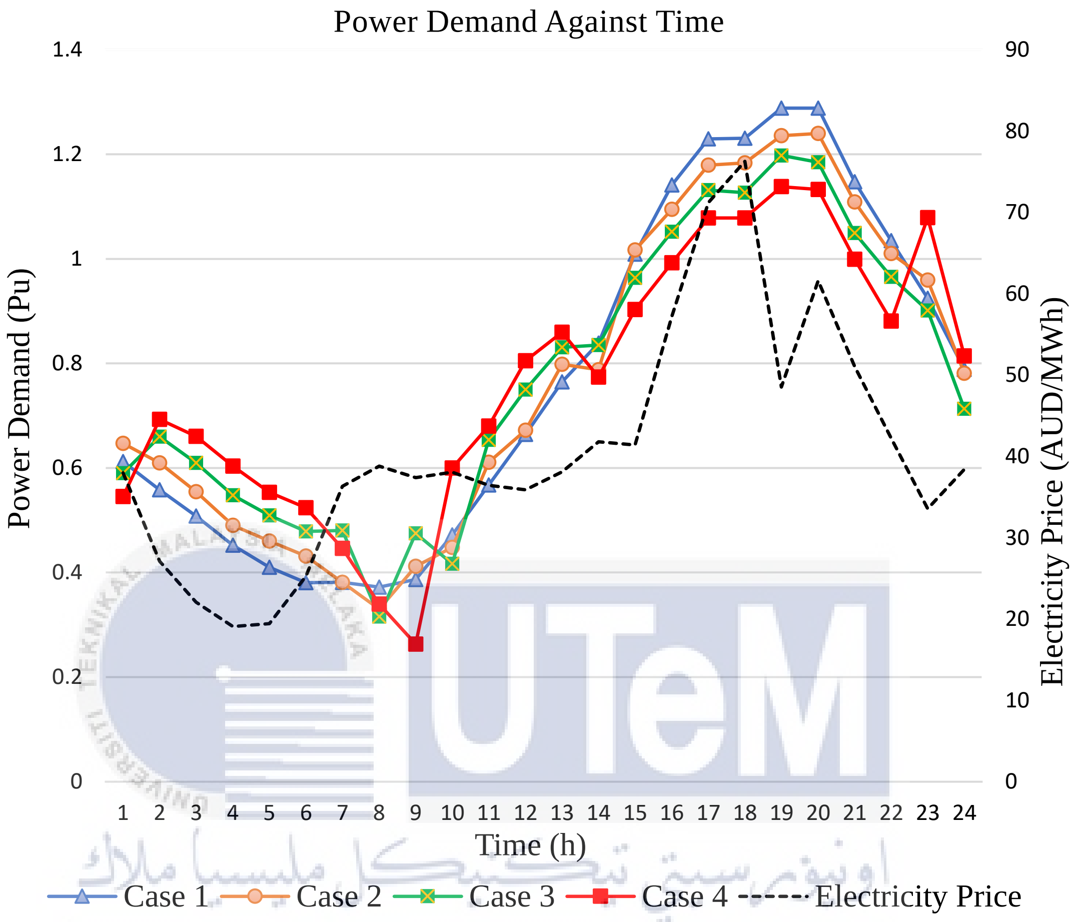

Figure 4.4: Graph of Demand Power and Electricity Price within Time

4.2.4 Voltage Distribution of System with Dispatched CES

In Figure 4.5, the graph comparison of voltage distribution between cases is shown. Based on the graph, it can be proved that the dispatched strategy of CES able to improve the voltage profile of the system. From the graph, voltage distribution of Case 3 and Case 4 are lower than Case 1 and Case 2 at voltage value below 0.95 pu. The dispatched power of CES which at optimal power factor, the test system should be maintained its voltage distribution within permissible limits set up in the simulation which is 0.95 pu to 1.05 pu. Apparently, the operating voltage for the

Case 1, 2, 3 and 4 exceed its lower limit of operating voltage. However, the differences between these cases is the number of occurrences that exceed 0.95 pu is lowest for Case 1 followed by Case 2, Case 3 and lastly Case 4. This shows that the higher dispatched power of CES, the lower number of occurrences for voltage exceed permissible limits set up for the test systems.

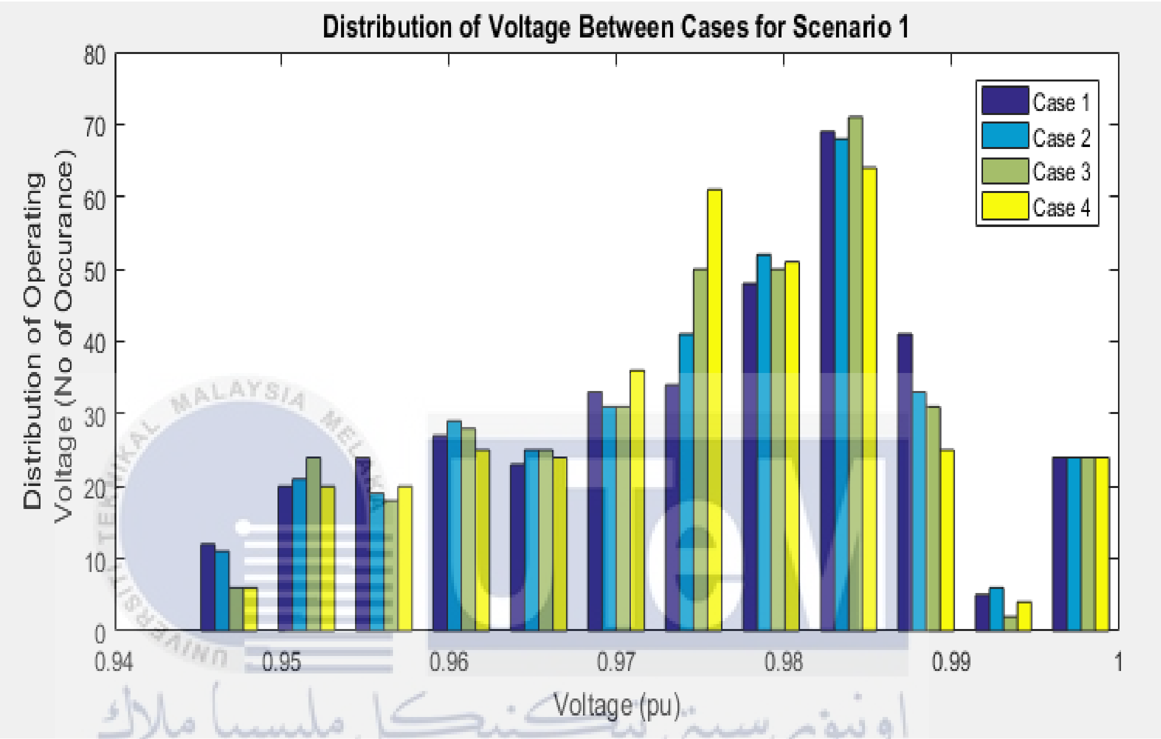

Figure 4.5: Comparison of Voltage Distribution between Cases

4.3 Base Test system with CES Deployment and Rooftop PV System

For the second part of the project, the scenario takes place where there are two cases that will be conducted. These cases are described in Table 4.2: Case of test system with PV system. Both cases are in 15 bus system and installed with PV system with same bus data and electricity prices data. The difference between both cases is the deployment of CES power. For Case 1, the system is modelled without CES, but it is provided with Rooftop PV units. For Case 2, the system is modelled with both deployment of CES and Rooftop PV units. The CES power installed in Case 2 is 1 MW. This scenario is conducted to study the effect of electricity cost, power demand and voltage distribution when Rooftop PV system is implemented with CES deployment.

Table 4.2: Case of test system with PV system

Type of Case	**Description**
Case 1	Base test system with PV only
Case 2	Base test system with CES and PV

4.3.1 Optimal CES Dispatch Power with PV System

In term of CES dispatched power that have been determined by GA, the trend for this graph is well-managed based on electricity prices that varies within hours. The charging and discharging of CES powers are distributed well for maximizing the uses of CES in the system corresponding to the electricity prices that varies based on peak hour and off-peak.

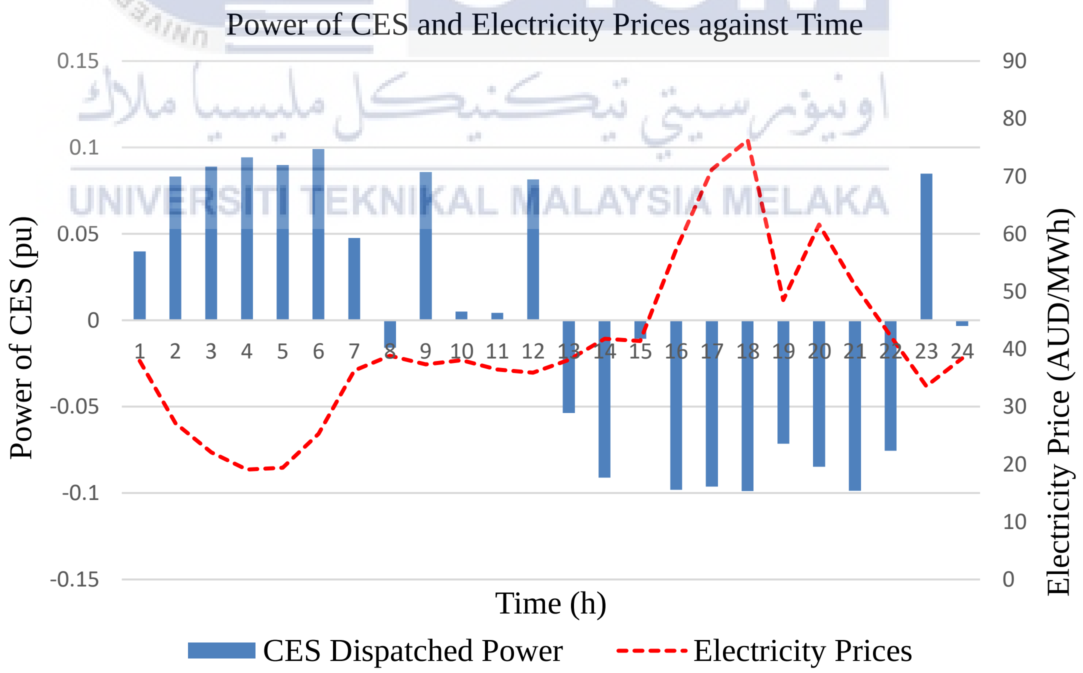

Figure 4.6: CES power deployment for every hours

4.3.2 Electricity Cost for Dispatched CES with Rooftop PV System

Based on Figure 4.7 below, it shows the trends of electricity cost for Case 1 and Case 2. There are some differences in graphs between these cases. The graphs differ during peak hour and off peak. Generally, the electricity cost is high due to high cost of generation during peak hour and low during off-peak hour. The example of off-peak hour from the graph is in 4th hour. At this hour, the electricity price is at the lowest. It can be seen at this hour; the electricity cost of Case 2 is higher than Case 1. However, the electricity cost difference is not that broad. The reason of high electricity cost for Case 2 is because the deployment of CES with 1 MW power. GA manipulate the off-peak hour to charge the CES to be during peak hour.

Based on Figure 4.7, 18th hour can be representative as peak hour where electricity cost is high. In the graph, electricity cost of Case 1 is higher than Case 2 at this hour. The difference of cost is quite tremendous compared to the electricity cost difference during off-peak hour. The reason electricity cost for Case 2 is lower compared to Case 1 is because the discharging of deployed CES. When GA generates population and make selection, it chose the most suitable time for the CES to be discharged. In this case, the most suitable time is peak hour where the load demand is high. Therefore, for supplying the electricity to customer, more energy needs to be generated resulting higher cost of electricity.

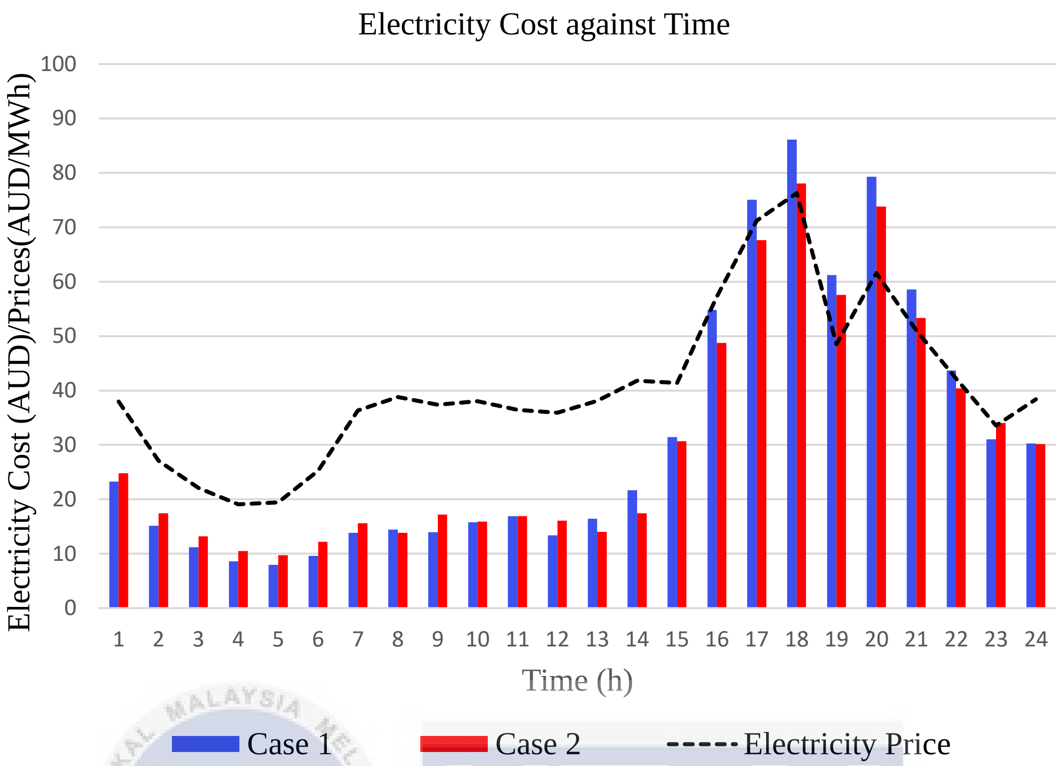

Figure 4.7: Electricity cost for every hour for both cases

Figure 4.8 shows the total electricity cost comparison between Case 1 and Case 2. Based on graph in Figure 4.8 the total electricity cost for Case 2 is lower than Case 1. The variation of electricity cost for every hour of the cases resulting this difference of total electricity cost. Even though, Case 1 obtained lower electricity cost during off-peak hour compared to Case 2, but the difference is not that tremendous. The differences of electricity cost during peak hour is much tremendous. The electricity cost for Case 2 is much lower than Case 1, resulting the significant differences of total electricity cost between both cases.

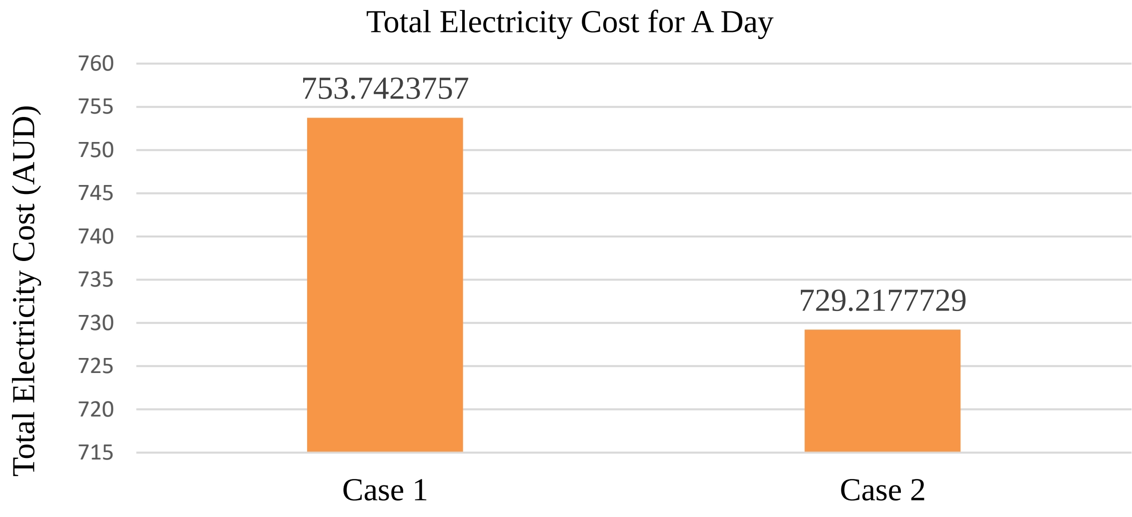

Figure 4.8: Total of Electricity Cost for Case 1 and Case 2

4.3.3 Power Demand of System with CES Deployment and Rooftop PV

In term of power demand, there are slightly difference in trend between both cases. The graph of power demand for both cases is shown in Figure 4.9. The different in trend of the cases is affected by electricity prices that varies within hour. From the graph in Figure 4.9, sighted the power demand for Case 1 is lower than Case 2 at the early hour which is the beginning of the day. At this hour, most of the occupants of the residences are resting from their daily live. Thus, the load demands at these hours are minimized due to low consumption of energy. Case 1 load demand is higher than Case 2 because the deployment of CES that will be charged during off-peak hour. The charging of CES make it become addition load to the system. However, the charging still required low energy power as the power from the PV system may run backwards and stored into the CES. This factor resulting Case 2 load demand become higher than Case 1.

During peak hour, from 16th hour to 20th hour, the power demand for both cases are obviously high. However, there are some gap appeared between both cases during these hours. These gaps are the load demand of Case 2 that become lower compared to Case 1. These scenarios are reversed from the previous scenario where load demand of Case 1 is lower than Case 2. The gaps between Case 1 and Case 2 arise because the CES deployment in Case 2 is discharged during these hours resulting the load demand for Case 2 become much lower than Case 1. The deployment of CES and PV system at Case 2 cause the power demand of the system reduced.

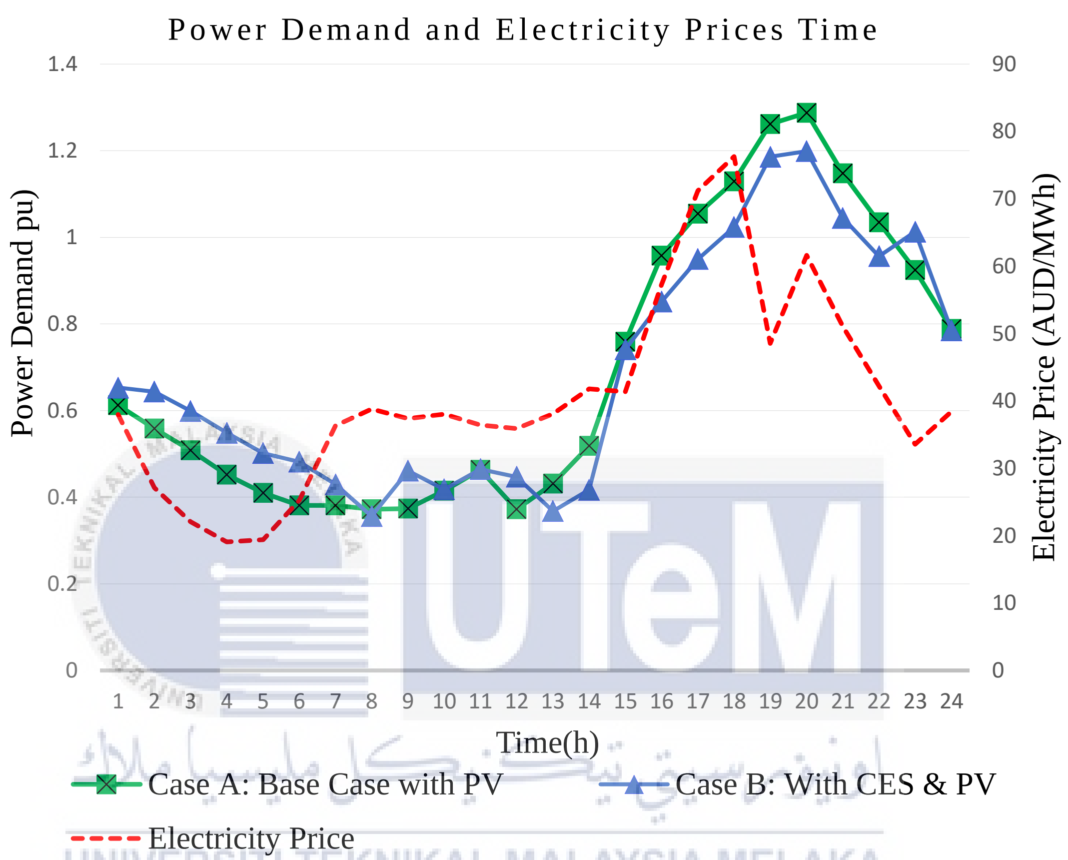

Figure 4.9: Power Demand for Case A and Case B

4.3.4 Voltage Distribution of System with CES Deployment and PV System

Figure 4.10 shows the voltage distribution for scenario 2 that included Case 1 and Case 2 data. The voltage distribution in the figure, shown the various trends of graph, where at voltage of 0.95 pu and below there are slightly higher number of occurrences for the distribution of operating voltage of Case 1 compared to Case 2. While, at voltage of around 0.98 pu, the number of occurrences for distribution of operating voltage of Case 2 are higher than Case 1. The voltage profile for the system should be maintained the permissible voltage limits which is around 0.95 pu to 1.05 pu. Even though both cases exceed the permissible limits of set up voltage, but Case 1 has higher number of occurrences for operating voltage lower than 0.95 pu. Thus, from this result, it shows that deployment of CES in PV system will lower down the number of voltage occurrence below the permissible limits.

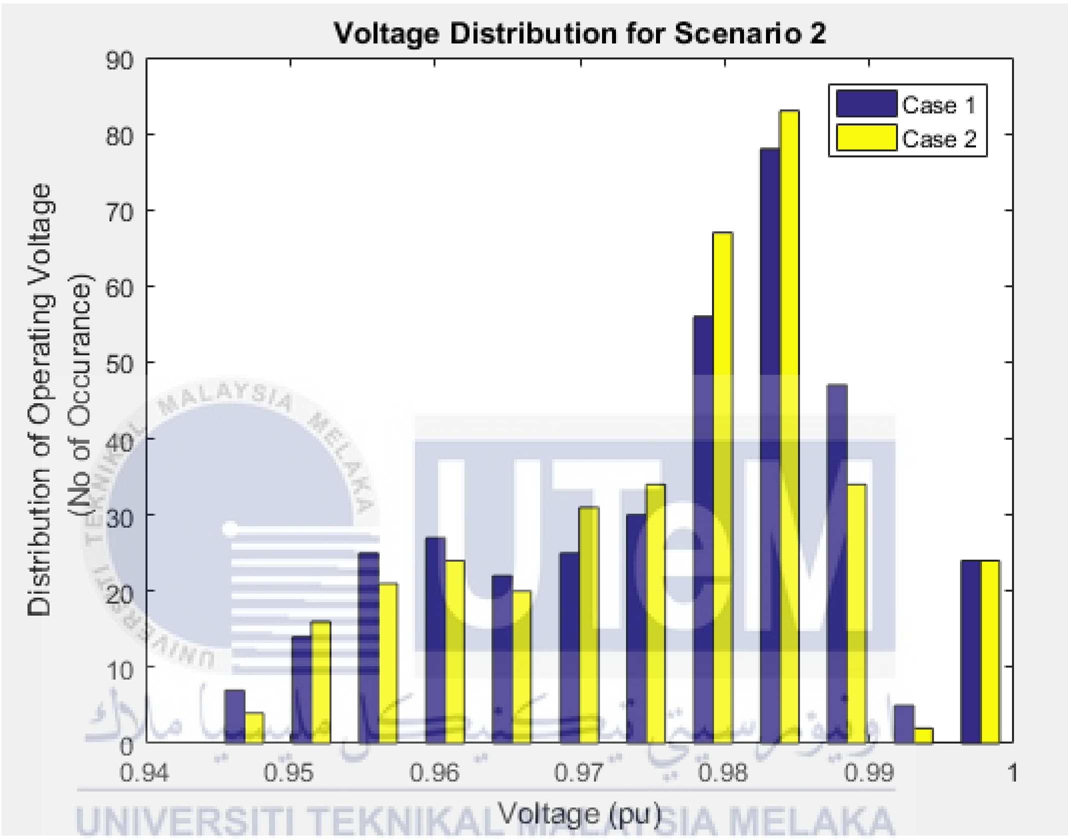

Figure 4.10: Comparison of Voltage Distribution for Scenario 2

4.4 Summary

In summary, this chapter presents the result obtained in this project. There are two part of scenario that have been constructed to be analyzed and discussed. The first part is the condition of a distribution system without PV system and the second part is condition with PV system. For the first part, there are four cases that have been conducted that consists of base case test system, Test system 0.5 MW, 1 MW and 1.5 MW CES power. These cases will be analyzed and synthesized based on

CES dispatched power, power demand, electricity cost for a day hourly and voltage profile. In this part, it is proved that the deployment of CES will improve power demand, reduce electricity cost and improve voltage profile. Plus, the higher CES power will provide better performance and benefits. As for the second part, the condition is to compare base test system with PV and CES test system with PV. The comparisons are also constructed in terms of CES dispatched power, power demand, electricity cost for a day hourly and voltage profile. The comparison undoubtedly shows the test system with CES and PV give more benefits for the terms mentioned before. This is because the CES test system give better voltage profile, cheaper electricity cost and lower load demand during peak hour. Finally, it is proven that deployment of CES will improve the techno-economic of distribution system.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Community Energy Storage (CES) is very important for the power distribution system at the residential region. The implementation of CES is crucial to solve the problem regarding reverse power flow cause by massive penetration of PV system on the rooftop of residential area which is at user-end of the customer. CES will store the energy accumulated at residential area that generated by PV system. This is very important in order to prevent the energy generated by PV system being wasted and discarded.

Besides, CES also have various benefits that will lead to improvement of voltage profile of the distribution network. Furthermore, CES can also implementing peak shaving of the system to minimize the electricity price during peak demand in a day. CES can maximize the utilization of RE because it will lower down the uses of NRE generated that will expose the environment with various impacts. CES can do load shifting by storing the energy generated during low demand period and use the energy stored during high demand period. This situation will also reduce the electricity price.

This project is conducted using OPF method with GA in MATLAB as tools to obtain the dispatch power of CES and better electricity cost. The optimal power flow is used to find the power flow in the base test system and test system with CES. It is also used in the scenario where the test system with installation of PV. The study for obtaining optimal dispatch power of CES and electricity cost is conducted in coding in the MATLAB. Based on this calculation, GA will create a population and decided the best electricity cost and dispatched power when the stopping criteria is being met according to objective function and constraints of the project. Based on the result obtained from the simulation, comparison study is made to verify the benefits of CES.

Even though the result in this project meets the project objectives and past research study from the literature review, however, there are some weakness in this project. One of the weakness is the project only conducted in the simulation and not conducted in hardware experimentation. Hardware experimentation of CES research is not implemented due to the high cost of CES since it needs to be conducted at large scope of experimentation which is distribution system at residential area. Next, the project only provides the power capacity of CES without the energy capacity of CES. So, whenever the energy is discharged, the remaining energy left in the CES is unknown. However, in real application, the CES is rated with power and energy. Thus, the energy capacity that can be stored in CES and maximum power that can be supplied from CES to the distribution system network will be known.

Last but not least, the utilization of CES should be implemented in Malaysia since it not yet available. Malaysia still not implement CES in the power system because of overpriced installation and O&M. Even though the installation of CES is very costly, the profits earned from the dispatched power of CES is also high which means the utilization of CES is a long-term investment. Since CES can reduced electricity cost and power demand during peak hour. The installation and replacement cost of CES is obviously high however, low maintenance cost is needed to keep the CES well-managed and in good performance. However, the prices of CES are going down currently as many competitors among CES developers. Other than that, it is also to encourage the deployment of CES in every country in the world as more benefits will be obtained.

5.2 Future Works

For future improvements of the project, the accuracy of CES dispatched power should be improved. The time for charging the CES after it fully utilized and discharged need to be specified to make it easier to use in practical application. Next, the dispatched energy of CES after it being used need to be included at the simulation interface to show the remaining energy of CES that still can be used for discharging later. Next, for the improvement of CES in practical application, it should be implemented by every country in the world as it can acts as tools or medium to improve the utilization of RE while reduce the consumption of NRE that will provide harm and pollution to the environment. Besides, more researches and studies relating to CES deployment need to be conducted especially in Malaysia since this country still not implement the deployment of CES in the distribution system. By implementing CES, the country indirectly will obtain economical profits other than improve the technical benefits of the distribution system.

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APPENDICES

APPENDIX A ELECTRICITY PRICE AT UTILITY

Hour	Electricity Prices (AUD/MWh)
1	37.98
2	27.11
3	22.07
4	19.08
5	19.42
6	25.28
7	36.31
8	38.82
9	37.37
10	38.04
11	36.43
12	35.9
13	38.1
14	41.8
15	41.39
16	57.23
17	71.2
18	76.27
19	48.53
20	61.6
21	51.04
22	42.22
23	33.58
24	38.4

APPENDIX B LOAD DEMAND AT 15 BUS SYSTEM

Number of Bus	Active Power (MW)	Reactive Power(MVar)	Maximum Voltage(pu)	Minimum Voltage(pu)
1	0.0000	0.0000	1.05	0.95
2	0.0441	0.0449	1.05	0.95
3	0.0700	0.0714	1.05	0.95
4	0.1400	0.1428	1.05	0.95
5	0.0441	0.0449	1.05	0.95
6	0.1400	0.1482	1.05	0.95
7	0.1400	0.1482	1.05	0.95
8	0.0700	0.0714	1.05	0.95
9	0.0700	0.0714	1.05	0.95
10	0.0441	0.0449	1.05	0.95
11	0.1400	0.1428	1.05	0.95
12	0.0700	0.0714	1.05	0.95
13	0.0441	0.0449	1.05	0.95
14	0.0700	0.0714	1.05	0.95
15	0.1400	0.1428	1.05	0.95

APPENDIX C LOAD LEVEL OF THE SYSTEM FOR 24 HOURS

Hour	Load Level (pu)
1	0.48774042
2	0.445925708
3	0.406283952
4	0.362472471
5	0.329173396
6	0.306239906
7	0.306445456
8	0.29930994
9	0.31067391
10	0.378006166
11	0.452855675
12	0.528292468
13	0.605872853
14	0.66239906
15	0.791924827
16	0.890823668
17	0.956423433
18	0.957480546
19	1
20	1

Hour	Load Level (pu)
21	0.895551314
22	0.811129056
23	0.727998825
24	0.624196153

APPENDIX D BRANCHES DATA OF THE SYSTEM

Number of Bus	Resistance (pu)	Angle
2	0.11182562	0
3	0.09671405	0
4	0.069513223	0
5	0.125907438	0
6	0.211344628	0
7	0.089933884	0
8	0.103423967	0
9	0.166377686	0
10	0.139397521	0
11	0.148390909	0
12	0.20235124	0
13	0.166377686	0
14	0.184364463	0
15	0.098927273	0

APPENDIX E PV SYSTEM CAPACITY FOR 15-BUS

Number of Bus	PV System Capacity (MW)
1	0.00000
2	0.02205
3	0.03500
4	0.07000
5	0.02205
6	0.0700
7	0.0700
8	0.03500
9	0.03500
10	0.02205
11	0.07000
12	0.03500
13	0.02205
14	0.03500
15	0.07000

APPENDIX F GANTT CHART OF OVERALL PROJECT

	Final Year Project 1															Semester Break					Final Year Project 2												
Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	1	2	3	4	5	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Title Registration																																	
Making literature review and find sources about test system and electricity prices																																	
Model a test system with CES and without CES																																	
Developed PV system in both systems																																	
Run load flow forward backward solution for base case (without energy storage)																																	

	Final Year Project 1															Semester Break					Final Year Project 2												
Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	1	2	3	4	5	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Conduct optimization to obtain optimal dispatched strategy of CES																																	
Result analysis of Base case and with CES test system																																	
Final Year Project Presentation																																	
Fulfil the report of Final Year Project																																	
Submission report of Final Year Project																																	

APPENDIX G PROJECT CODE IN MATLAB

Editor - C:\Users\fairu\Desktop\psm matlab\Case1.m

Case1.m | Case1ga.m | Electricprice.m | input15.m | solarpv.m | voltage.m

```matlab

function [ F1 ] = Case1( x  )
%x=[-0.0330512082967838,0.0711045611691823,0.0870318723548194,0.08720546533
%x=zeros(24);
input15;
Electricprice;
solarpv;
for t=1:24   % j=11 means LF = 1
    bustype=bus(:,2);
    LF=loadlevel(:,2);
    P=LF(t)*bus(:,3)/baseMVA;
    Q=LF(t)*bus(:,4)/baseMVA;
    Psolar=Ppv1(t)*Pvp(:,2)/baseMVA;
    FN = branch(:,1);
    TN = branch(:,2);
    R = branch(:,3);
```


Editor - C:\Users\fairu\Desktop\psm matlab\Case1.m

Case1.m | Case1ga.m | Electricprice.m | input15.m | solarpv.m | voltage.m

```matlab
    Qg=zeros(N,1);
    Pes=zeros(N,1);
    Pes=x;
    Pes1=Pes/baseMVA;
    ESdata=zeros(N,1);
    ESdata(7,1)=1;

 %%%%%%%% start LF%%%%%%%%%%%%%%%%%%

N=length(bustype);                                  % N is the number of nodes
n=N-1;                                              % n is the number of sections

j=sqrt(-1);
V=ones(N,1)+j*zeros(N,1);                           % flat start

for i= 1:N
```

Editor - C:\Users\fairu\Desktop\psm matlab\Case1.m

Case1.m | Case1ga.m | Electricprice.m | input15.m | solarpv.m | voltage.m

```
%Calculating Nodal Current

for i=1:N;

    Pi(i)=(P(i)+Pesl(t)*ESdata(i,1)-Pg(i)-Psolar(i));
    Qi(i)=(Q(i)-Qg(i));
    In(i,:)= (Pi(i)-j*Qi(i))/(conj(V(i)));          %In is the load cur

end
for i=2:N;
    I(i-1)= In(i);
end

%BACKWARD SWEEP

```

Editor - C:\Users\fairu\Desktop\psm matlab\Case1.m

Case1.m | Case1ga.m | Electricprice.m | input15.m | solarpv.m | voltage.m

```

%BACKWARD SWEEP

Vk = V;
for i=1:n
    a=N-i;
    for b=1:n;
        if FN(b)==a+1
            c=TN(b);
            I(a)=I(a)+I(c-1)+j*B(c-1)*V(a+1);
        end
    end
    I(a)=I(a)+j*V(a+1)*B(a)/2;                          % I is the branch
end

% FORWARD SWEEP
```

Editor - C:\Users\fairu\Desktop\psm matlab\Case1.m

Case1.m | Case1ga.m | Electricprice.m | input15.m | solarpv.m | voltage.m

```matlab

for f=1:14

    Pl(f,1)=(Ibri(1,f))^2*R(f,1);
    Ql(f,1)=X(f,1)*(Ibri(1,f)^2);
    PL(1,1)=PL(1,1)+Pl(f,1);
    QL(1,1)=QL(1,1)+Ql(f,1);

end
Ploss(t)=(PL)*baseMVA;
Pd(t)=sum(Pi)*baseMVA;
Pdit(t)=Pd(t)+Ploss(t);
V2(t,:)=abs(V);
end

for t=1:24
```

Editor - C:\Users\fairu\Desktop\psm matlab\Case1.m

Case1.m | Case1ga.m | Electricprice.m | input15.m | solarpv.m | voltage.m

```matlab
for t=1:24
F(t)=Pdit(t)*Eprice(t);
end
Pdi=0;
Pci=0;
for t=1:24
if x(t)<0
    Pdi=Pdi+abs(x(t));
else
    Pci=Pci+abs(x(t));
end
end
if Pci>=Pdi
    c=0;
else
    c=1000000000000000000000000000000000000;
```

Editor - C:\Users\fairu\Desktop\psm matlab\Case1ga.m

Case1.m | Case1ga.m | Electricprice.m | input15.m | solarpv.m | voltage.m

```
clear

lb=ones(1,24)*-0.10;
ub=ones(1,24)*0.10;


opts=gaoptimset('Display','iter', 'PlotFcns',{@gaplotbestf,@gaplotbestindiv,@gaplotstopping}, 'TolFun',0.001);
opts = gaoptimset(opts,'UseParallel',true,'TolFun',0.0001,'Generation', 500, 'populationsize', 300);
tic
[x,f,eflag,outpt]= ga(@Case1,24,[],[],[],[],lb,ub,[],[],opts);
toc
```

Case1.m | Electricprice.m | input15.m | Case1ga.m | solarpv.m

```
%$/MWh
Eprice=[37.98
27.11
22.07
19.08
19.42
25.28
36.31
38.82
37.37
38.04
36.43
35.9
38.1
41.8
41.39
57.23
```

Case1.m | Electricprice.m | input15.m | Case1ga.m | solarpv.m

```
    35.9
    38.1
    41.8
    41.39
    57.23
    71.2
    76.27
    48.53
    61.6
    51.04
    42.22
    33.58
    38.4];
```

Case1.m | Electricprice.m | input15.m | Case1ga.m | solarpv.m

```
%%-----  Power Flow Data  -----%%
%% system MVA base
baseMVA = 10;


%% bus data
%bus_i type Pd (MW)     Qd (MW)     Gs  Bs  area Vm  Va baseKV zone Vmax Vmi
bus  = [
1   3   0   0   0   1   1   0   11  1   1.05    0.95;
2   1   0.0441  0.044990999 0   1   1   0   11  1   1.05    0.95;
3   1   0.07    0.071414284 0   1   1   0   11  1   1.05    0.95;
4   1   0.14    0.142828569 0   1   1   0   11  1   1.05    0.95;
5   1   0.0441  0.044990999 0   1   1   0   11  1   1.05    0.95;
6   1   0.14    0.142828569 0   1   1   0   11  1   1.05    0.95;
7   1   0.14    0.142828569 0   1   1   0   11  1   1.05    0.95;
8   1   0.07    0.071414284 0   1   1   0   11  1   1.05    0.95;
9   1   0.07    0.071414284 0   1   1   0   11  1   1.05    0.95;
```

Case1.m × Electricprice.m × input15.m × Case1ga.m × solarpv.m × +

```
    5   1   0.0441   0.044990999 0   1   1   0   11  1   1.05    0.95;
    6   1   0.14     0.142828569 0   1   1   0   11  1   1.05    0.95;
    7   1   0.14     0.142828569 0   1   1   0   11  1   1.05    0.95;
    8   1   0.07     0.071414284 0   1   1   0   11  1   1.05    0.95;
    9   1   0.07     0.071414284 0   1   1   0   11  1   1.05    0.95;
    10  1   0.0441   0.044990999 0   1   1   0   11  1   1.05    0.95;
    11  1   0.14     0.142828569 0   1   1   0   11  1   1.05    0.95;
    12  1   0.07     0.071414284 0   1   1   0   11  1   1.05    0.95;
    13  1   0.0441   0.044990999 0   1   1   0   11  1   1.05    0.95;
    14  1   0.07     0.071414284 0   1   1   0   11  1   1.05    0.95;
    15  1   0.14     0.142828569 0   1   1   0   11  1   1.05    0.95;



    ];


```

Case1.m × Electricprice.m × input15.m × Case1ga.m × solarpv.m × +

```
    %% branch data
    % fbus  tbus r  (p.u)          x(p.u)      b  rateA rateB rateC ratio angle
    branch = [
    1   2   0.11182562  0.109379339 0   1
    2   3   0.09671405  0.094598347 0   1
    3   4   0.069513223 0.067992562 0   1
    4   5   0.125907438 0.08492562  0   1
    2   6   0.211344628 0.142553719 0   1
    6   7   0.089933884 0.060661157 0   1
    6   8   0.103423967 0.069760331 0   1
    2   9   0.166377686 0.11222314  0   1
    9   10  0.139397521 0.094024793 0   1
    3   11  0.148390909 0.100090909 0   1
    11  12  0.20235124  0.136487603 0   1
    12  13  0.166377686 0.11222314  0   1
    4   14  0.184364463 0.124355372 0   1
    4   15  0.098927273 0.066727273 0   1
```

Case1.m | Electricprice.m | input15.m | Case1ga.m | solarpv.m

```
%hour LF      PDG      QDG
loadlevel = [
1    0.48774042
2    0.445925708
3    0.406283952
4    0.362472471
5    0.329173396
6    0.306239906
7    0.306445456
8    0.29930994
9    0.31067391
10   0.378006166
11   0.452855675
12   0.528292468
13   0.605872853
14   0.66239906
15   0.791924827
```

Case1.m | Electricprice.m | input15.m | Case1ga.m | solarpv.m

```
12   0.528292468
13   0.605872853
14   0.66239906
15   0.791924827
16   0.890823668
17   0.956423433
18   0.957480546
19   1
20   1
21   0.895551314
22   0.811129056
23   0.727998825
24   0.624196153

];
```

Case1.m | Electricprice.m | input15.m | Case1ga.m | solarpv.m

```
Ppv = [ 0
0
0
0
0
0
0
0
0.018424167
0.082960167
0.150521833
0.423243667
0.481126333
0.460379167
0.356737167
0.259430833
0.246673667
```

Case1.m | Electricprice.m | input15.m | Case1ga.m | solarpv.m

```
0.246673667
0.14269
0.037372333
0.000830333
0
0
0
0

];
Ppv1 = Ppv*0.73;%10%pv penetration

Pvp = [ 1 0
        2 0.02205
        3 0.035
        4 0.07
        5 0.02205
```

```
Ppv1 = Ppv*0.73;%10%pv penetration

Pvp = [ 1 0
        2 0.02205
        3 0.035
        4 0.07
        5 0.02205
        6 0.07
        7 0.07
        8 0.035
        9 0.035
        10 0.02205
        11 0.07
        12 0.035
        13 0.02205
        14 0.35
        15 0.07];
```

APPENDIX H INTERFACE OF GA RUN THE SIMULATION