Department of Mechanical and Aerospace Engineering

Integration of Renewable Energy Resource for Electric Vehicles Charging Station in Thailand

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Abstract

Nowadays, Using electric vehicles are becoming popular transportation in many countries such as U.K., U.S.A. and Thailand etc. According to reduce of the environment impact and cost problem from conventional vehicles which consume energy base on oil and gas. Consequently, the requirement of electric vehicles in the future will significantly increase. However, the electric vehicles charging station which is important element of using electric vehicles seem to not sufficient for these demand in many areas. The problems of the growth electric vehicles charging station is not only increase electrical grid demand but also increase high level emission from petroleum-electrical generation instead of reducing.

Hence the aim of this feasible study is optimization the renewable energy system for electric vehicles charging station for example the percentage of energy matching power demand, power supply from renewable energy resource, capital cost of renewable energy system, amount of surplus energy and amount of deficit energy. These data is analysed to improve the performance of renewable energy system for electric vehicles charging station that can reduce electrical using from the grid and meet the charging demand of electric vehicles in the future.

The location will be focus on this project is Bangkok in Thailand which has high potential of solar energy. However, there will also be comparison with areas that complete for installation renewable energy system into electric vehicles charging station such as Glasgow in the U.K. and south western states in the U.S.A. From the literature review, simulation results and technical analysis, it has been found the solution to develop the performance of renewable energy resource for electric vehicles charging station in Thailand.

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Chapter 1: Introduction

1.1. Background

During the last few decades, the adoption of using Electric Vehicles is continuously increasing due to a number of reasons. Their performance is improving, they have smaller environmental impact with no greenhouse emissions while their efficiency begins to outperform traditional fossil fuel vehicles. Therefore, many governments and organizations in the world have launched the policy to support the electrical vehicles in their countries. However, electric vehicles charging stations which are important elements of electric vehicles are not as widespread yet. The main reason for this is that of electric vehicles charging stations not only increase the electrical grid demand but also increase high level of emission from petroleum-electrical generation also. Thus using only electricity from the grid is not best solution for charging vehicle station. For improving ability and performance of the electric vehicles charging station, of renewable energy resources should be integrated to their systems as well. This will also have the added benefit of making EV with greener credentials as their environmental impact depends on the primary source of energy.

The main focus of this feasible study is the optimization for renewable energy system for an EV charging station. We aim to investigate parameters such as the percentage of energy matching power demand, power supply from renewable energy resource, capital cost of renewable energy system, amount of surplus energy and amount of deficit energy. The feasible study is divided into two categories; individual renewable energy systems and integration of renewable energy systems into the existing power grid.

As a case study we chose the location to be is Bangkok, Thailand where solar energy is already widespread and still growing (The detail of solar energy in Thailand will mention in chapter 3.3). Thailand has begun in recent years to implement electric vehicles charging. We also aim to compare the project also compares the module in Thailand with the existing systems such as Glasgow, United Kingdom and California, U.S.A. which is established renewable charging systems already.

1.2. Aims and Objectives

The main purpose of this feasible study is the optimization for renewable energy system of EV charging station in Thailand such as the percentage of energy matching power demand, power supply from renewable energy resource, the ability of energy storage in charging station, capital cost of renewable energy system, amount of surplus energy and amount of deficit energy. This data is analyzed to improve the performance of renewable energy system for EV charging station in Thailand.

The project objectives are:

1. Design the scale of renewable energy system for sufficient supplying electricity to EV charging station demand.
2. Investigate various renewable energy technology and climate of EV charging station to improve their performance in Thailand.
3. Investigate how renewable energy EV charging station can achieve carbon savings in an intelligent and cost effective manner.

Finally, with the help of software programs we aim to design the renewable energy system of EV charging station in order to meet the following four criteria:

- Find the best match.
- Minimize capital cost for electric vehicles charging station.
- Response an increasing of energy demand from electric vehicles in the future.
- Minimize energy wastage.

1.3 Methodology

At the beginning of the process before achieving the main aims and objectives that mentioned before, the steps described in this section have been undertaken in this dissertation as follow.

1.3.1 Literature Review Part

- **The first step** has been to review general knowledge and working- principles of electric vehicles and charging station technology. The dissertation describes how important of electric vehicles charging station that has effect to electric vehicles. Two normal types of electric charging station, private and public points, have been showed its characteristics and differences. The factors of electric vehicles driving and charging such as time, cost, and range also compared by different types of vehicles. After that the battery, most important part of electric vehicles, batteries, were reviewed in more detailed of technology. From this first section, it is possible to achieve the general understanding of electric vehicle and charging station technology.

- **The second step** undertaken has been to review the existing electric vehicle charging stations around the world. Particular attention is drawn to charging stations which are powered by renewable energy. Three different locations were focused and analysed. Thailand is the main country that was chosen for this study. It was compared with U.S.A. and U.K. both well established in the renewable energy charging stations. From this section, it is possible to know the recent technology of global charging stations for improving to install electric vehicle charging systems in Thailand.
- **The third step** has been to review the potential of renewable energy technology which is able to be installed for electric vehicle charging station systems. The most popular technology to install for charging station is solar panels and wind turbine technology. Hence this section will first discuss about the solar photovoltaic and wind turbine technology. After that we focused on the potential to install the renewable energy resource into charging station in U.S.A., U.K. and Thailand. Then, technology of energy storage to keep energy from renewable energy resource is discussed. From this part, it is conceivable to get the information of technology that suitable to locate the renewable energy charging station in Thailand.
- **The fourth step** undertaken has been to review the program that suitable to simulate the demand and supply of renewable energy charging station systems in Thailand. The software for this simulation should support the basic and special required which is easy to input data and give the essential results as the user design. In this part, many software programs will mentioned such as Homer Software, RETScreen Software and Merit Program. After this step, one of these programs will be selected for running the data and get more result as can make the aim and objective of this project will be complete.

1.3.2 Modelling Analysis and Results Part

- **The fifth step** has been to simulate the program which as selected from the fourth step in order to complete the aim and objective of this project. The program inputs climate data of Bangkok with three different types of vehicles, seasons and multi-supply energy resource. From this task, it is possible to get result that can be a model of charging station which is suitable to locate in Thailand in term of energy and cost efficiency.

1.3.3 Modelling Discussion and Conclusion Part.

- **The sixth step** has been to discuss the result of simulation from the fifth step for find out the best model which has highest matching percentage of demand and supplied to install these systems in Thailand. Topics were discussed and analysed related with reliability of system, cost, surplus energy etc. From this task, it is possible to get the suitable model of renewable energy charging station for three different types of vehicles and seasons in Thailand.
- **The seventh step** has been to conclude the negative and positive of this project as discuss in the sixth step. Finally, we suggest future work to develop the electric vehicle charging station systems in Thailand.

1.4 chapter overview

The assumptions taken are based on a research and literature review explained in Chapters 2 to 6. Chapter 2 discusses the concept of electric vehicles which includes range and public charge points, charging time, cost and range affecting factors, size of battery and battery performance. In Chapter 3 the current electric vehicles charging system powered by renewable energy in many countries such as United Kingdom, United Stated, and Thailand are discussed. The renewable energy technology such as wind turbine and solar cell which are installed into the electrical charging station are discussed in Chapter 4. Chapter 5 is on electric vehicles batteries for solar and wind energy storage. Charter 6 is reviews the software used on this project. After this review the software are chosen and the methodology is set, Chapter 7. The results obtained for different renewable energy scenarios are shown and discussed in Chapter 8. Finally, the conclusions and future work are presented in Chapter 9.

Chapter 2: Electric Vehicles and Charging Stations

2.1 Overview

Nowadays, the pollution from global warming effects and cost of fuel are increasing significantly. Switching to use renewable energy and electric vehicles are some prospective ways that can solve these problems. The electric vehicles are becoming a popular choice to use instead of internal combustion vehicles especially in the last ten years (Speidel & Bräunl, 2014). Many leader vehicles manufactures in the world have high competition to produce and sell the electric vehicles under their brand to domestic and international market. Azadfar, Sreeram, and Harries (2015) write that the electric vehicles could be the important of transport sector in the future.

The exact number of electric vehicles in the future is difficult to estimate accurately. In the early state, many organizations have provided estimates on the amount of electric vehicles. For example the national grid (2014) predicts the amount of electric vehicles in UK by 2030 is going to be between 1 and 3.9 million. However these figures are not guaranteed since the industry as well as the consumer may change direction depending on future technologies in automotive industry.

The National Automobile Dealer Association (NADA) which is the non-profit organization for car users presents two of the most important factors to consider when purchasing a new car in 2014. These are the fuel economy and the cost of ownership as shown in Table 1. That means that electric vehicles will be more attractive in the mass market, whencan be driven forlong distances, while requiring less charging. The the price for each charging as well as the cost of these vehicles should also be reasonable when compared with the traditional vehicles.

Ranking of Factors Considered during New Car Purchase		
[illegible]	[illegible]	[illegible]
Fuel Economy	3.0	1
Cost of Ownership	3.8	2
Power & Performance	4.2	3
Advanced Safety Systems	4.8	4
Versatility & Utility	5.2	5
Build Quality & Reliability	5.8	6
Vehicle Design	6.1	7
Environmental Impact	6.6	8
Brand	7.4	9
Technology	8.2	10
*(1 - Most Important, 10 - Least Important)		

Table 1: Ranking of factors considered during new car purchase (NADA, 2014)

According to the survey above, the goal of electric car manufacturers should be to improve their efficiency and reduce their cost. Also the government can provide incentives to the people so that using electric vehicle in the future will successful adopted. An important aspect affecting the range and the economics of electric vehicles. Hence this report will focus on the impact of electrical vehicles charging that concerns the demand of electric vehicles, the power supply of renewable energy resource, the ability of battery storage in charging station, the capital cost of renewable energy system, amount of surplus energy and amount of deficit energy. Especially in Thailand where has the potential of renewable energy resource and initial to implement the electric vehicles project in recent years.

2.2. Distance for single charge of electric vehicles.

Research by Maloney (2015) found that the distance of electric vehicles which can drive for one charging is depend on many conditions such as the battery size of electric vehicles, the powering of electric vehicles, types of the road for driving and the style of driving speed.

Nowadays many car companies have created their own electric vehicles which have different ranges. The Nissan LEAF is an electric car which has the same size as a conventional family car. The manufacturer claims that the car can run for 160km for one full charge under normal speed conditions.. In contrast to the Leaf, there are also smaller electric vehicles, such as the G-Wiz and Renault Twizy which are not classified as the family cars because they have the smaller batteries size than the Nissan Leaf. Hence the distance of their driving is also less than as well. The basic distance of G-Wiz is around 77 kilometers while Renault Twizy is nearby 97 kilometers. However, there are totally different distances from Tesla which is a brand of sport pure electric car that can drive more than 430 kilometers for one charging (Convey, 2011). From the information above, the average distance for one charging is not the main problem for using electric vehicles.

2.3. Charging Points and Times for Charging.

The charging point is an important element of electric vehicles using because the pure electric car cannot run without charging. Hence, the user should ensure that they have available charging point in their own route before the power runs out. Normally the charging point can separate into 2 types: charging at private points and charging at public points.

2.3.1 Charging at private points

Basically every electric vehicle come with standard charging cable that can plug into the car and a normal household socket which is similar to the plug of electric device such as television, radio, phone charger etc. That means that the user can charge their vehicles at home or office garage which has the outdoor socket. However, the user should ensure that their socket and electric systems in their house can support electric vehicles charging device.

The time for charging in private points depend on the electric systems in each country. For example in United Kingdom, the time of one full charging for 160 kilometer is around 6 to 8 hours contrast with United State which spend 16 to 20 hours. Nevertheless the charging at private point is not convenient for everyone because the charging process takes a long time and some users do not have a private location that is available to charge their own electric cars.

2.3.2 Charging at public points

At present, people in the city tend to live in condominium or flats. Therefore charging at the private point is not suitable for them because they do not have a parking or garage that can support to charge electric vehicles. The public charging points are the best choice for solving this problem.

The public points are not only suitable for people who did not have own private charging points but some public charging points can charge the electric car more quickly than private point. The time for quick charge at the public points is approximately 45 minutes that make people more satisfy with a short time for charging. This year, there are 1,500 public electric vehicles charging points around United Kingdom. This number has grown significantly in recent years. Some reports say that the problem of electric vehicles charging is not the number of stations but their location, which may be too difficult to find due to not being updated on the GPS-map (TheChargingPoint.com, 2015).

However, 85% of people who use the electric vehicles prefer to charge their cars at home or office even though electric charging from public station is cheaper and quicker than charging from their house. Hence the public charge points may be not convenient for daily charging of electric car owner as the private charge points (Convey 2011).

2.4 Charging Costs and Range for single charging.

According to the individual report of Maloney (2015), University of Strathclyde that choose three example of electric vehicles: Renault Twizzy, Nissan Leaf and Tesla for comparison the charging times and costs in different car types. Renault Twizzy represents for a small commuter car was compared with Nissan Leaf which is compact family car and Tesla is a high end full-sized car.

The information of charging time and range for each electric vehicle that use in Maloney’s report were sourced from the manufacture’s website. The cost of charging for single time comes from a calculation which is based on the cost per unit of electricity in United Kingdom (14p/kWh) and the battery size of each car. The table below shows the charging time, ranges, and cost in 3 different electric vehicles the same driving condition for a single full charging.

Model	Time for full charging (hour)	Range (kilometer)	Calculate cost per charge	Cost per 100 kilometer
Twizzy	3.5	80	£0.85	£1.0626
Nissan Leaf	8	200	£3.36	£1.68
Tesla	14	480	£11.90	£2.47

Table 2: Charging time, range and cost for single full charging of 3 different model electric vehicles (Maloney, 2015)

2.5 Electric vehicles battery

2.5.1 Overview of development

Albright, Edie, and Al-hallaj (2012) wrote that the development of battery technology is very slow when compare with other elements of electronics because electrolyte and electrode material is difficult to improve. Moreover the expertise in battery technology is still hidden for each company, so the knowledge transferring of this technology is difficult to extend as well.

One battery technology improvement that was illustrated is lithium-ion batteries. Lithium-ion is a type of batteries that has better performance to save energy more than 5 times when compare with original lead acid batteries, which have existed for 100 years. The batteries also are seen as more expensive, heaver and with a larger environment impact when compared with other electronic elements of electric cars. Obviously, they are very important components of electric vehicles as well.

2.5.2 Size of Battery Capacity

As the individual report of Maloney (2015) they show that the performance of three different capacities of electric vehicles battery affects to the range for driving in term of kilometers as show the details in table 3 below.

Model	Battery Capacity (kWh)	Range (kilometers)	kWh/Kilometer
Renault Twizzy	6.1	80	0.07
Nissan Leaf	24	200	0.15
Tesla	85	480	0.18

Table 3: Battery capacity, range of different model electric vehicles (Maloney, 2015)

The three different size of battery capacity that show in table 3 also can help to explain why the Renault Twizzy car takes the shortest time for charging, more than 3.5 hours quicker when compare with other cars. While Tesla and Nissan leaf take longer times, 8 and 14 hours respectively. It can be summarized that the range and time for electric car charging depends on the size of capacity battery.

2.5.3 Sustainable Battery Production

Many types of battery that were used in manufacture, most of common type are lithium-ion which has potential to gain high specific energy and energy density. However Nickel battery is also popular to use in electric vehicles but it does not too general as lithium-ion battery. (Young et al, 2012)

To make electric vehicles more widespread in use, the battery needs to be improved. The good battery should be sustainable, low maintenance and high performance for obtain energy from specific source. The four key factors for confirming the battery to be a sustainable product include:

- Life cycle of battery
- Plenty of raw materials
- Recycling of electrode
- Safety of using battery product

Life cycle of battery is the number for charging and discharging before the battery decays to an unacceptable level. At present, the current generation of batteries is using lithium ions, which is a finite resource. Therefore new technologies should be sought which are based on sustainable materials (Battery University, 2013). An example of such battery technology is sodium-ion batteries.

Furthermore for making the battery production sustainable, the new electrodes of battery should be come from the recycle parts of old batteries. Another important factor to consider is of cause safety. The battery should not be dangerous to the user or to humans, and be fully environment-friendly. (MIT Electric Vehicle Team, 2008)

2.6 Performance Characteristics

In this report will focus on the existing battery, Lithium-ion, which use generally for electric vehicles in present. This battery type also has the benefit and negative effect to electric vehicles using that can be concluded as follows:

Advantages:

- High energy density.
- High charge currents which make shorten for charging.
- Long battery life.
- Low self-discharge when it does not using
- Low maintenance.

Disadvantages:

- Limited the voltage and current for protection circuit.
- Limited transportation by regulation when shipping in larger quantities.

The main performance of battery depends on the chemistry cathode which use in different raw material. Currently the two cathodes materials, Li-manganese and Nickel-manganese-cobalt (NMC), both are commonly used for electric vehicles were summarized in the table 4 below.

Battery Type	Voltage (V)	Float Voltage (V)	Cycle Life	Specific Energy	Loading (C-rated)
Li-manganese	3.8	4.2	500-1000	100-135	10C, 40C Pulse
NMC	3.6/3.7	4.2	1000-2000	140-180	40C

Table 4: The battery performance characteristic of two cathode materials,Li-manganese and Nickel-manganese-cobalt (Maloney, 2015)

The performance characteristics of both materials in table 4 show that the Nickel-manganese-cobalt battery has higher cycle life and specific energy than Li-manganese battery. While the voltage, float voltage and loading are similar, the technology of Li-manganese is cheaper than the Nickel-manganese-cobalt (Battery University, 2013).

However the performance characteristics of a battery can be improved by any three methods includes:

- Making the two electrodes has the high chemical potential difference.
- Making the electron exchange as least as possible at the reactants.
- Making sure that the chemical substance of battery was not consumed by electrolyte (Maloney, 2015).

2.7 Range Effecting Factors

As said by Convey (2011), the range of an electric vehicle is not only affected by the size of the battery but also by the other conditions such as weather, driving style.

2.7.1 Weather.

The weather is too hot or too cold will reduce the efficiency of electric car's battery that mean the distance for their running will be decrease also. Normally the best temperature of battery that can work is between 20 to 40 degrees. If some country that have condition of temperature below or higher than normal case, the driving distance of electric vehicles will reduce from the standard rate as well.

Using extremely air condition or heating system in the car also can be huge drain of battery that makes the distance of electric vehicles running will decrease. The one third of the range will drop rapidly when heater or air conditioner is turned on full blast. Noticeably, other elements in the car such as headlight and widescreen wiper also drain the battery but they do not have as a significant effect asa heating system. Similarly, very cold or hot weather and using the air condition system will be negative effect to the distance of electric vehicles as same.

An example of such an adverse effect of battery life is Norway where the average temperature is around 7C. This means the range of electric vehicle is shorter because of the cool temperature, while at the same time means the passenger will also require heating which will also have detrimental effect on the range of the vehicle.

2.7.2 Driving Style.

One significant effect to the range of electric vehicles running is the driving style. The more aggressive breaking and accelerating is worse for range, the best stopping or approaching should gradually slow than without suddenly speed up or breaking. The electric car will recapture energy lost when user can drive a car smoothly that mean gentle driving can helps to improve the range for driving of electric vehicles.

2.7.3 Types of Road.

An electric vehicles feasibility by Boxwell (2011) that choose three different types of road such as motorway, rural, inner city for testing the effect of road under the same condition of electric cars brand (Mitsubishi i-Mev) which was claimed range of running approximately 150 kilometers for one full charging. This investigated get some real-situation as table below:

Type of Road	Average Speed (km/hr)	Range Achieved (km)
Motor Way	101	86
Rural	70	103
Inner City	30	150

Table 5: Average Speed and Range Achieved of three different road types. (Maxwell, 2011)

As the result from table 3, the type of road has a large effect to the range of electric vehicles driving. Motor way is the road which consumes the most battery because it is comfortable to drive and speed up that makes the range as short as 86 kilometers. Rural and the inner city roads generally require less speed which improves range. Hence the distance for rural road and inner city driving are longer than motor ways that are 103 and 150 kilometers respectively.

Therefore the distance of electric car running is nearby 150 kilometers as the Mitsubishi vehicles were claimed when most of using the electric car is inner city. Moreover the range of driving will drop significantly, if electric vehicle user drives with high speed and turn on air conditioning or heater in their car always. However the electric vehicle is more suitable for people who drive the car within short range as the Mitsubishi cars were claimed because user do not need to find the service station for refueling their car. Only plug their car into the socket when the user arrive at home and the next day electric vehicle will has the full energy for driving.

Chapter 3: Current Electric Vehicles Charging System by Renewable Energy Resource

3.1 Existing Systems in the U.S.A.

In the United Stated, existing renewable energy charging station is mostly generated from solar energy (Goldin et al, 2014). The number of electric vehicle charging stations which has integrated photovoltaic panel systems is still increasing rapidly in many states in U.S.A. The table 4 below shows the important characteristic of existing renewable energy electric vehicles station in four different locations in U.S.A. The information in table 4 includes the installation date, overall cost of construction and size of these systems.

Location	Date installed	Cost of Construction (US $)	Number of Charging space	Daily power Generating (kwh)
University of Central Florida campus	Jan-2010	380,000	4	50
Saint Paul, Minnesota	Apr-2012	70,000	4	61
Eugene, Oregon	Sep-2010	800,000	18	106
Western Michigan University Campus	Feb-2012	700,000	15	168

Table 6: Existing Solar Powered Charging Station of U.S.A. (Maloney, 2015)

According to table 6, it can be seen that the number of space for vehicles charging is still not too large when compare with the general car that use in U.S.A. The installation cost of solar powered charging station is rather expensive due to this technology is in the early stage. Hence if the cost of electric vehicles, PV equipment and battery system are reduced from status, it can motivating for the electric vehicles to become more common in U.S.A. However, the electric vehicles charging station will have more potential when the place to locate charging station can generate the power from various renewable energy resources such as wind turbine, tidal and PV system etc. together.

For the United State of America, the average solar radiation received is 4 kWh/m², which generates the energy of nearly 5.7 kWh for a-by 12 m² of PV area for single parking space and is 12% efficient. This scale of solar powered charging station can produce the energy approximately 64 kilometers for the range of electric car driving. (Tulpule et al, 2013)

Meanwhile the demand of renewable powered charging station is continuously increases, the amount of power generating from renewable energy also increase. Some unused electricity can be fed back into local grid or system for reducing the losses of power. For example, the installation of solar powered charging station at department store car park, the excess energy from the system should be sent back to the department store for use.

In the future, the cost to install solar powered charging station is expect to decrease and the technology of photovoltaic system, battery storage and electric vehicles are further developed. If the installation cost of solar powered charging station is able to reduce approximately $10,000 per parking space, the solar powered charging station will be more successful to general using in U.S.A. (Shen, 2010).

3.2 Existing Systems in the U.K.

At present, there are fewer established renewable energy-powered charging stations in U.K. because the electric vehicles users and owners of charging station still use and charge their cars from the main electricity grid. However the renewable energy charging stations already exist in some areas in the U.K. The one of interesting electric charging station by renewable energy, is located at Westminster in London, was shown the detail in table below (City of Westminster, 2009).

Technology	Capacity for one charging point	Installation Cost	Note
Solar PV	10.35 kW	£50,000	Area to install the PV (10.35 kW) is approximately 80 m²
Wind Turbine	4.14 kW	£17,500	Under condition of wind turbine 6 kW and average wind speed is 5 m/s
CHP	1.23 kW	£ 2,200	Not only to sell back the electricity to third company but also supply direct to EV charging station

Table 7: Existing Example of Renewable Energy Charging Station in U.K. (City of Westminster, 2009)

The table 7 shows the data of charging station by various renewable energy resources in U.K. that use electric vehicle of 'GWiz' brand for testing. The average time for charging per day is 2.75 hours and consumes approximately 8,300 kWh per year. Now the integration of renewable energy resource in U.K. is still low. However if the cost to install the renewable energy technology is lowered the number of electric vehicles will increase and hence more investment will be driven towards the renewable energy charging station.

3.3 Existing Systems in the Thailand

Thailand has a policy to promote their country as an electric vehicles production hub. As a plan of policy, the government has reviewed the regulation deal with the transmission line of electric and retailer for vehicles fuel. This policy may change to allow the petrol retailers can adapt their stations to be electric vehicles charging stations in the future.

This action will help to improve the number of electric vehicle's selling in Thailand and support people who use electric vehicle will have enough public charging station. This policy is subsidized by Government of Thailand that involve with many organization such as Provincial Electricity Authority, Metropolitan Electricity Authority and Petroleum Authority of Thailand.

There is pilot project to locate electric vehicles charging stations for testing in seven different location of Thailand such as Bangkok, Chon Buri, and Ayutthaya etc. The government have been developing and testing this project more than four years. If the use of electric vehicles is successful, the government will extend the charging station in a commercial scale.

The policymakers have suggested the factors to develop electric vehicle using more sustain in the future, the demand and supply of power that using for electric vehicle should be optimize. Now the demand of using electric vehicles in Thailand is not too high, however there is an expectation of power requirement for charging electric vehicles will increase rapidly in next five years. Hence preparing the resource for supply the power as adequate demand is very important.

At present the main source of power for charging electric vehicles in Thailand comes from grid, which is mostly powered by non-renewable energy. However if the demand of electric vehicle's rapidly grows, as predicted, the integration of renewable energy resource in charging station is one method that will reduce the cost while being much more environmentally friendly than diesel electric generation. Moreover integration of renewable energy in charging station will develop electric vehicle's using more sustain in country that has high potential of renewable energy as Thailand.

3.4. Summary of Existing Systems

In conclusion for this chapter, we looked at the key aspects on electric vehicles. We introduced the battery technology and the several factors which affect the range of the vehicles (speeds, driving conditions, driving style, temperature, air condition). We also introduce the charging stations in the USA and UK, which are powered by renewable energy. In contrast, power stations in Thailand are not powered by renewable energy.

In this project, the geographic focus is based on Thailand climate. This investigate has the purpose for finding the best solution and percentage to install renewable energy system into charging station in Thailand. The main technology will be focused is solar power because there is high potential of sun lighting in Thailand and has already been used to work in many country such as U.S.A. and U.K. Hence in Thailand, an integration of solar energy into charging station is suitable than other technology, for example wind turbine which is difficult to install in specific area as city or town. However, some areas that has high wind potential to produce the power could be study in this report as well for finding the best solution to install renewable energy charging station in Thailand.

Chapter 4: Solar Photovoltaic & Wind Turbine Technology

4.1 Solar Photovoltaic Technology

A solar photovoltaic system for power generation includes many components such as a photovoltaic panel, a mechanical part, an inverter, converter, connections, mountings and many parts to regulate the electrical power. These systems can generate the power at high potential they receive the sun light on a clear day. This technology has a unit of power generation called peak kilowatts (kWp). (Maloney, 2015)

The power from photovoltaic panel is converted by sun lighting which goes to the solar panel directly and creates free electrons. When the sunlight takes enough energy to the photovoltaic panel, free electrons will be generated which can be used for charging electric vehicles. The potential to produce electricity from photovoltaic panel does not only depend on the sun light but the material of photovoltaic panel also has an important effect. The general types of material that use for producing electricity in present normally made from silicon, cadmium, amorphous and poly-crystalline etc. (Parida, Iniyan and Goic, 2011)

Nowadays, the trend of using solar power is becoming popular. The International Energy Agency has expected the efficiency target for using the solar power from crystalline silicon since 2010 to 2050. There was the detail which is summarized as the table 6 below.

Efficiency Target		
2010-2015	**2015-2020**	**2020-2030/2050**
Single crystalline : 21%	Single crystalline : 23%	Single crystalline : 25%
Multi crystalline : 17%	Multi crystalline : 19%	Multi crystalline : 21%

Table 8: Efficiency targets for crystalline silicon technologies (International Energy Agency, 2015)

As the table 6 show the increasing of efficiency target in every period. We can safely assume that the solar panel electricity generation will become more highly efficient in the future. Hence if the charging station can integrate the solar panel into electric vehicles charging systems, it will be very useful and worthwhile for charging station development.

4.2 Wind Turbine Technology

As the feasibility study of Bellés (2012), one of the most effective renewable energy resources is wind turbine which transforms kinetic energy to be electricity by rotating turbine from wind. The most general wind turbine is consisted with three blades which are designed to capture maximum energy in swept area of wind turbine. The power output of wind turbine is controlled by rotor speed as the pitch function which turn the blade in different angle for finding the optimize operation.

The efficiency to produce the power from wind does not depend on only on the technology but the location installed also has an important effect. The coast and island is the most popular location to install wind turbines for getting high potential, since the average wind speed at islands and coasts is high and the wind flows constantly which are factors to favor wind turbine technology when compared with other locations.

Nowadays, there is some wind power charging stations implement in USA. For example, Crissy Field Public Park in San Francisco which has the wind charging station is located on shore nearby San Francisco bay. It is free charging station which generates the power from five different types of vertical axis wind turbines. There is noenergy storage system onsite, all of the power is sent direclyt to electric vehicles charging station. In case there is no car charging, the power will sent to other facilities nearby, in order to power lighting systems for museum and café (Herron, 2015). The figure1 below shows the wind power charging station at Crissy Field.

Figure 1: Wind power charging station in San Francisco, USA. (Herron, 2015)

Normally, the large wind turbines are located from human house at least 500 meters in a rural environment. However in the urban environment, if the wind turbines are positioned on small structure, it will be cause many difficulties for wind turbine working such as the hazard of rotating machinery, noise of generation, vibrational dynamic loading, and the possibility to collapse. Moreover, they are subject to turbulence which have to repair and to non -optimal wind condition. (Ragheb, 2014)

According to the example of wind power charging station above, it will increase the performance to charging if some locations which has high potential of wind also integrate the wind turbine into their charging station. Although in some locations, there is potential to generate energy from wind but not enough to charging. The wind turbine can be choice to install for surplus energy with other resources as well.

4.3. Generation Capability in UK

At present, the scale of electricity is generated by solar and wind energy in U.K. are increasing continuously because the government have supported people who generate electricity by buying solar and wind energy back to the grid with high price. The number of PV installation dramatically increased after using feed-in-Tariff policy of government from 26.5 MWp in 2009 to 594 MWp in 2011. (Maloney, 2015) Meanwhile the number of wind turbine installations also grew up from 4,051 MW in 2009 to 12,440 MW in 2014. The table 9 below shows the number of wind turbine installation capacity in U.K. during 2008-2014 MW

Year	2008	2009	2010	2011	2012	2013	2014
Installed Capacity (MW)	2,974	4,051	5,204	6,540	8,871	10,976	12,440
Generation (GW·h)	5,357	6,904	7,950	12,675	20,710	24,500	28,100
% of electricity use	1.50	2.01	2.28	3.81	5.52	7.39	9.30

Table 9: Installed capacity of wind turbine in UK (The European Wind Energy Association, 2015).

According to the information of PV and wind installation above, it clearly seen that the number of PV and wind energy installations in U.K. is increasing rapidly. Not only is the Feed-in-Tariff policy which make solar and wind power generated popular in U.K. but the cost of PV and wind turbine installation and component are also decreasing that make this technology becoming more common in U.K. Even though the funding for wind turbine and PV research in U.K. is less than in many countries such as German, Japan and U.S.A. but the number of installation are expected to increase gradually in the future. (Maloney, 2015)

4.4. Generation Capability in USA

The average capacity for solar and wind power generation in U.S.A. is higher than U.K. significantly because the installation locations for PV and wind turbine installation in U.S.A. has high potential to produce electricity. This especially true for solar power. There were some states such as California, Arizona and Nevada etc. that receive high level of solar radiation annually as shown in the figure 2 below

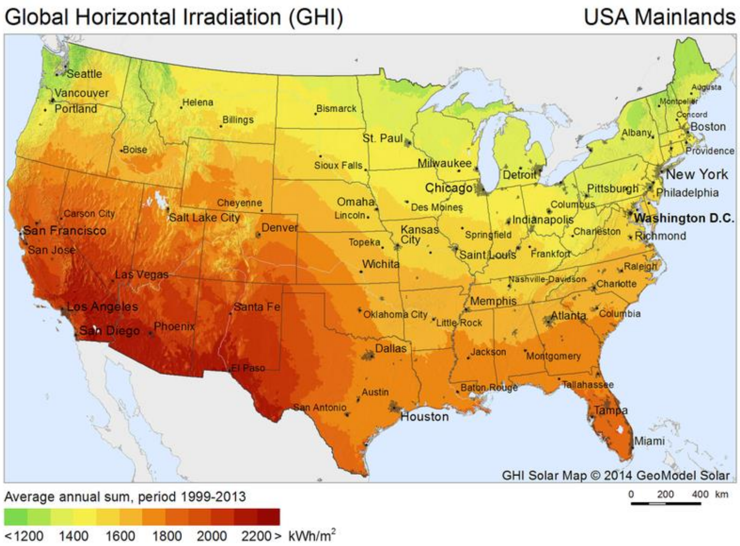


Figure 2: Annual average map solar radiation in the USA (Archangel, 2013).

The number of PV installation sites in U.S.A. increased rapidly since 2008 that grew from 298 MWp to 6,201 MWp in 2014 (Solar Energy Industry Association, 2014) as show in the figure 3 below.

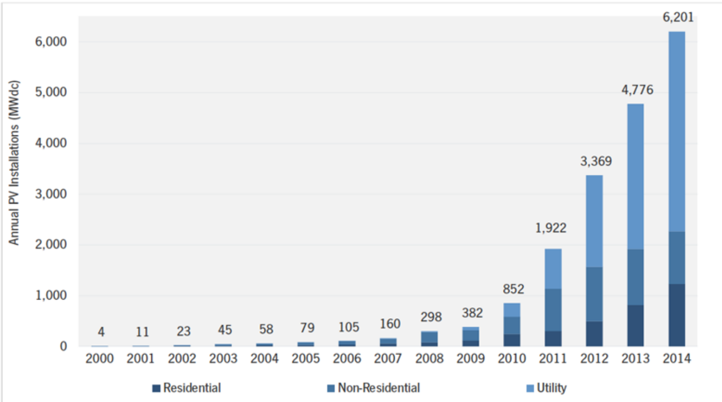


Figure 3: Installed capacity of PV in U.S.A (Solar Energy Industry Association, 2014).

While the number of wind power generation in U.S.A. is increasing well, from 5,593 MW in 2000 to181,791 MW in 2014. . Many locations in U.S.A. are suitable for producing electricity from wind such as Texas, California and Iowa etc. which have the detail of wind power capacity in U.S.A. as shown in Figure 4 below.

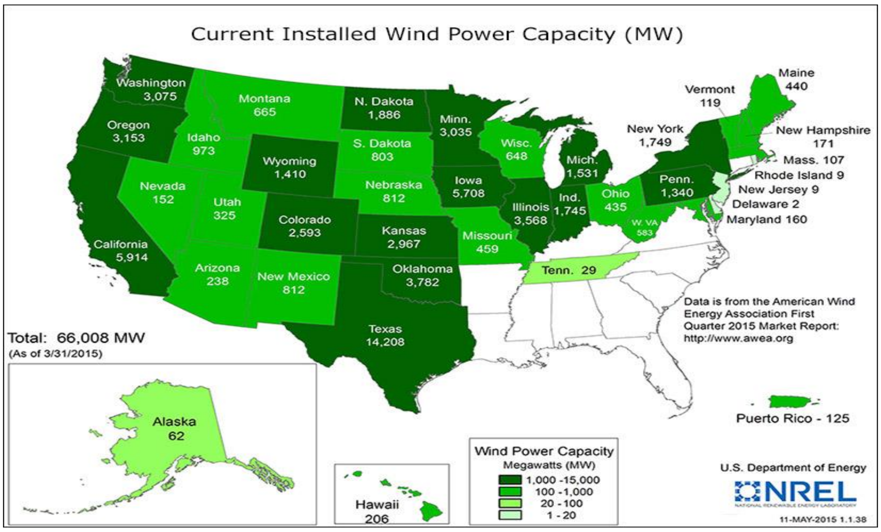


Figure 4: Current Installed wind power capacity in the USA (U.S. Department of Energy, 2015).

4.5 Generation Capability in Thailand

Thailand is a tropical country which has high potential to absorb sunlight which can produce electricity for year round. Contrast with the potential of wind, there was some location that can generate electricity from wind turbine. The capacity to install PV panel in Thailand was increasing continuously from 193.46 MW since 2011 to 474.71 MW in 2014 (Photovoltaic Power System Program, 2015). Almost the location in Thailand can produce electricity from sun light especially northeastern region and central area such as Ubon Ratchathani, Nakhon Ratchasima and Nakhon Sawan province that receive high level of solar radiation annually as shown in the figure 5 below.

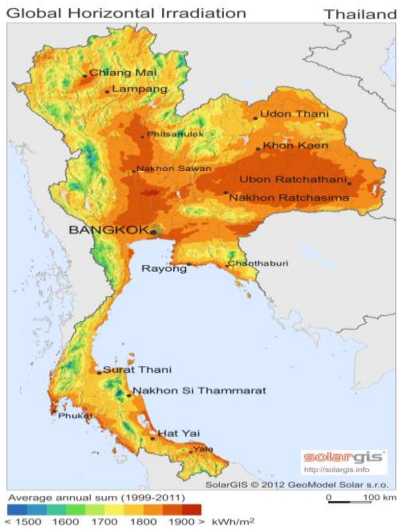


Figure 5: Annual average map solar radiation in Thailand (Solar GIS, 2015).

This project has the purpose for finding the best solution and percentage to install renewable energy system into charging station in Thailand. The geographic will be focused is based on Bangkok the capital of Thailand because this area is where electric vehicles will be used in the short term. Bangkok always has a high solar radiation for year round, the average of solar radiation approximately at 5 hours of sun per day as show the detail in figure 6 below.

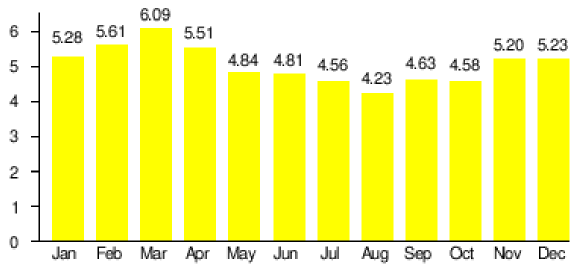


Figure 6: Annual average solar radiation hour/day in Bangkok
(National Renewable Energy Laboratory, 2015).

Meanwhile the wind potential in Thailand includes Bangkok, is not good enough to produce electricity as general because the wind speed in Thailand is rather low. Hence the capacity of installation of wind turbine in Thailand is also low as well. In the end of 2013, the number of wind turbine installation is 223 MW which is 34th in the world by wind turbine capacity ranking. However some locations in Thailand such as Nakhon Srithamarat, Chaiyapoom and Suratthani are able to produce electricity from wind turbine. The figure 8 shown the annual average map of wind speed in Thailand.

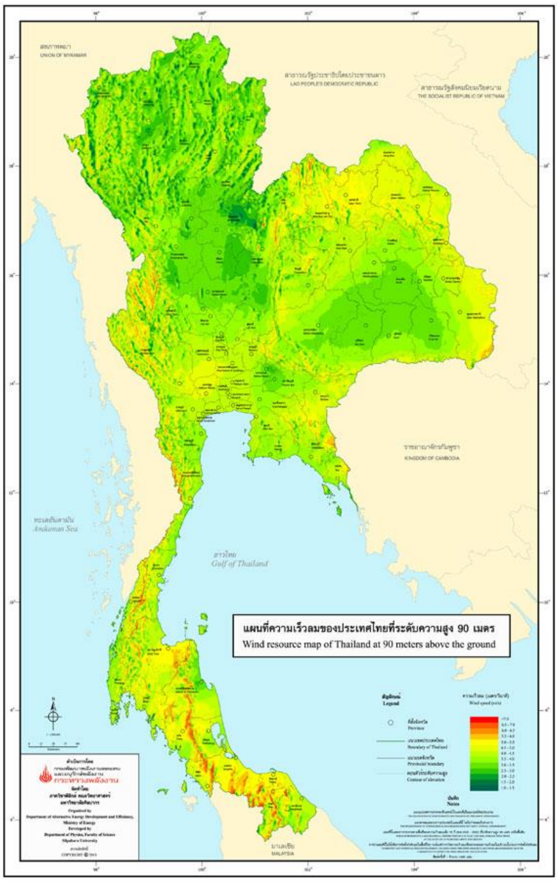


Figure 7: the annual average map of wind speed in Thailand.

(Department of Alternative Energy Development and Efficiency Ministry of Energy, 2015)

Chapter 5: Batteries for Energy Storage

5.1 Batteries for Energy Storage

Energy storage is an important component in renewable energy charging station because the energy which generate from renewable resource does not give the energy output as charging demand always. Hence the energy storage is the main equipment that can control to keep and supply energy on time as the load of charging station required (Energy Storage Association, 2015).

To keep the energy from solar and wind power generated as high capacity, the energy storage is required to retain the power which does not used in any time that no car for charging. The type of charging energy storage could different form the storage of solar thermal because this storage has the purpose to supply the electricity only does not concern about the heat output. However, the energy storage especially batteries, is still researched to develop charging systems has high ability of charging station (Maloney, 2015)

In Chapter 2 (section 2.5), there is review about the lithium ion batteries that used as general for electric vehicles. This type of batteries has many benefits and suitable for storing energy from solar and wind power as well. The lead-acid is the most of batteries type that was used in common. However, after further research these types of batteries are not suitable for keep the energy of renewable energy resource. The Lithium-ion is becoming commercial type of battery instead of Lead-acid because it proved to be high quality and keeps energy from renewable energy resource better when compare with the Lead-acid. The Lithium-ion has many advantages over conventional Lead-acid batteries as follows:

- Low loss from heating because there has high efficiency of charging and discharging.
- Light weight because there has high energy with high energy density.
- Short time to charge because there has high current for charging
- Long battery life (more than 6 months) when compare with the conventional lead acid battery

Moreover, the Lithium ion batteries can give the power back to the main grid when the supply exceeds demand that make the electrical grid system does not have a problem with quality and stability of power systems. There is benefit for the owner of charging station also that can gain the money back from selling the energy to the main grid when the charging system already enough using energy.

The main purpose of this project is optimize the supply and demand of renewable energy charging systems in Thailand include with investigation of using software for finding the best solution of this project analysis. Hence, with the principle concept of Electric vehicles, charging station, renewable energy technology, energy storage and existing project (U.S.A., U.K. and Thailand) were established in this chapter. In the next chapter the software and simulation program for this project will be discussed.

Chapter 6: Software Review

6.1 Requirement of software for electric vehicles charging station.

In current integrated usage of renewable energy within both grids connected and stand-alone includes electric vehicles charging station system is becoming popular in many countries. The main driving factors for these are fuel cost for electricity generating is rising and environmental impact become more pronounced, such as local air pollution and climate change. Moreover, installing stand-alone system of renewable energy in a remote location or islanding area can be more cost-effective than extending a power line to the electricity grid. However, to make the integrated renewable energy system more effective, this system needs to consider local exploitable resources and local demand needs with local climate (annual, seasonal and daily). Hence, it would be very useful if the integrated renewable energy project was designed by the program which can match the demand of user and supply of renewable energy source properly before the renewable energy system was installed on location (Energy System Research Unit, 2008).

At present, there were widely successful for using computer programs that simplified the task of renewable energy system, whether remote or connected to a electric vehicles charging station. For this project, the software program that is able for matching the profile of electric vehicles demand and the supply from renewable energy resource and the grid as user setting is required. Not only the software program should provide the information to manage and improve ability of charging station more stable under the condition of using renewable energy as priority but the program should also show the financial analysis and environmental effect is an ideally for this program. However, the common procedure of the simulation software for this project should be as follow.

- Setting the size of electric vehicles demand
- Evaluating the energy supply from renewable energy resource and the grid.
- Matching demand with supply.
- Investigating varied seasoning with local climate
- Managing systems with energy storage and control for better benefit.

6.2 Homer Software

HOMER model, it is one of successful renewable energy assessment tool that can evaluate the economic and technical feasibility of technology options which has the principle to access as figure below. It is capable of determining the optimal size of each component of the system and providing detailed information about energy flows among various components. Homer models are adaptable to a range of projects, from community-scale power systems to larger scale industrial systems. The built in sensitivity analysis helps to determine the potential impact of variable factors such as fuel prices or solar radiation on a system, over time. Homer program was developed by National Renewable Energy Laboratory, USA and it is commercial now. (Homer energy, 2015)

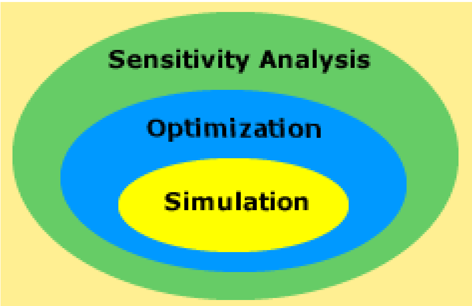


Figure 8: The HOMER principle to evaluate integrates renewable energy system. (Homer energy, 2015)

6.3 RETScreen Software

Another one of successful example of renewable energy assessment tool is RETScreen model which significantly reduces the costs (both financial and time) associated with identifying and assessing potential energy projects. These costs, which arise at the pre-feasibility, feasibility, development, and engineering stages, can be substantial barriers to the deployment of Renewable-energy and Energy-efficient Technologies (RETS). By helping to break down these barriers, RETScreen reduces the cost of getting projects on the ground and doing business in clean energy. RetScreen program was developed by National Resources Canada, it is a proven enabler of clean energy projects worldwide. (RETScreen, 2015)

6.4 Merit Program

From the two examples of renewable energy assessment tools above, it can be seen that the program is very helpful to develop effectiveness of using renewable energy systems in the world. University of Strathclyde in the UK is also concerned about the development of the renewable energy project. A program was developed to evaluate using renewable energy system more effective that it is called "MERIT" program.

MERIT is an energy supply and demand matching tool designed to support renewable energy integration scenario based planning. It can be applied independent of scale, i.e. from optimizing supply technologies for the single building/component demand up to that for a community/region. The Proposal of using MERIT program is to meet the residual data demand, minimize the capacity of the required energy storage system and maximize the capacity utilization factor from the renewable energy system. (Morton, Grant, and Kim, 2014)

6.4.1 MERIT Program Description

The MERIT framework, which uses a remote SQL database via on the internet to be standard information of system, enables exchange of information with other energy assessment tools. MERIT simulation can use both real data demand and ideal assumptions of power supply to evaluate the system before determine to install the system on real location. Moreover, the users can set the power demand, climate location, auxiliary database and renewable energy resource information to evaluate the effective of the system in many categories by themself. The main result of MERIT simulation is a matching number which is shown by percentage. If the system has high matching percentage, it means this system can balance the power supply and demand to be highly optimized. (Morton, Grant, and Kim, 2014)

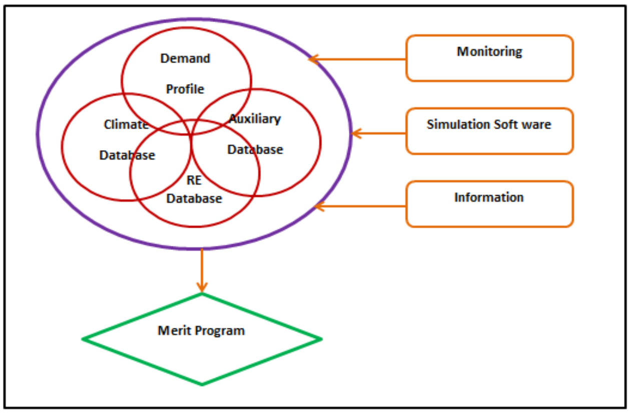


Figure 9: Frame work of MERRIT program (Morton, Grant, and Kim, 2014)

The application of MERIT program was used in multi-function as follows:

- Demand and supply matching analysis to find the optimize systems of renewable energy generating that suitable with the user in many criteria such as increasing renewable energy utilizations or using renewable energy technology which is advantages in different seasons and location.
- Assume the situation when the renewable energy system use the energy storage or battery in the systems for see the overall the performance of system after install the auxiliary tool in to the system in different criteria.
- Reported statistics include unbalance of power demand and supply. The system will show the number of energy surplus and energy deficit which user can develop the waste energy to be more useful in these simulation period.
- Evaluate the cost of renewable energy system for planning before use this system for back-up the traditional system. In commercial case, This system can calculate to the time of pay-back period as well.
- This program can simulate the same combination of renewable energy system in different season or climate to compare the effectiveness of the system.

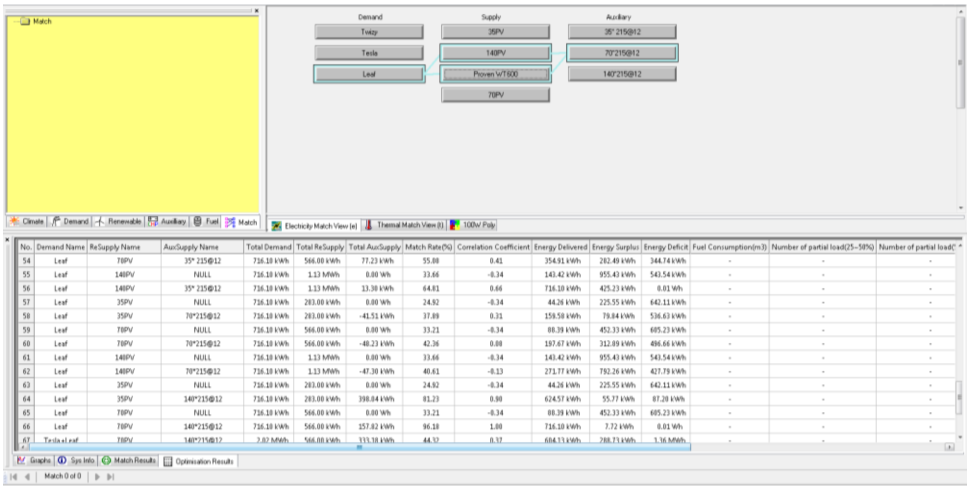


Figure 10: The feature of MERIT Program.

6.5. Summary of Software

In this project, the merit program has been chosen as the suitable tool to analyses the information as the proposal were require. Moreover the merit was created by University of Strathclyde which has great expertise in this topic and as a result the software can be learnt in a short amount of time. One more significant property of merit that convinced me to use this program is inputting of location and climate data. This program also simulate the exactly location, weather, load demand and supply in many different categories as user require. The time to get the result of this program is very short as approximately, no more than half an hour you will get all as require in term of graph and number in one season. All of these reasons will make merit program to be outstanding software which can apply to help the user design the suitable percentage of demand and supplied of Renewable Energy Resource for Electric Vehicles Charging Station in Thailand.

Chapter 7: Modeling Analysis and Results.

7.1 Technical and Modelling Analysis

As mentioned in the first chapter, the final objective of this project is to optimization for renewable energy system of EV charging station in Thailand such as the percentage of energy matching power demand, power supply from renewable energy resource, the ability of energy storage in charging station, capital cost of renewable energy system, amount of surplus renewable energy and amount of deficit renewable energy. To achieve the final objective, this section describes about the simulation of matching supply with demand and the best match electric vehicles charging station in Thailand.

In order to complete the final objective of this project, Merit was selected to do simulation of matching supply of renewable energy resource and demand of electric vehicles charging station at located in Thailand. There are two reasons to use merit program as mention in chapter 6 (6.5) that merit program can be inputted specific data of climate and location which can show the information of energy such as matching percentage of demand and supply, surplus energy, deficit energy and cost of systems. Moreover, the merit program was created by professional in University of Strathclyde that can give new user advice properly in short time.

7.1.1 Renewable Energy System Design for Charging Station

The aim of this feasibility is to find the best renewable energy system that suitable to install for the electric charging station in Thailand. Many Renewable energy resources in Thailand are available to use for energy generating, however the most effective renewable energy which is high potential is solar and wind power as mentioned in chapter 4 (4.5). Hence, photovoltaic panel and wind turbine, which can convert solar lighting and wind to electricity which can then be used were designed to be main component of systems to see the size of each part that most suitable for the system. However, the system should have energy storage for maintain the energy from the renewable resource when the charging has low demand or high supply. Therefore in this simulation will be concern the different size of PV panel, Wind turbine and energy storage to find the best matching of supply for charging demand in different cases. The figure below is show the component diagram model of renewable energy resource of electric vehicles charging system in Thailand.

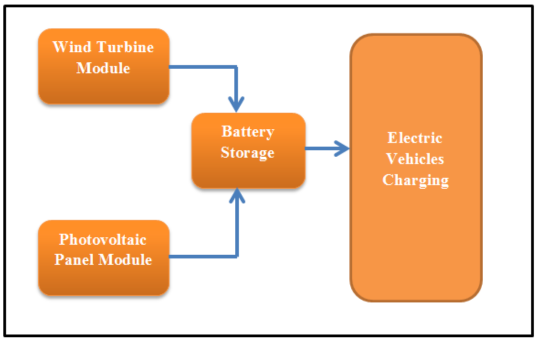


Figure 11: Renewable Energy System Design for Charging Station.

7.1.2 Model of matching supply

In order to estimate the match renewable energy system for electric vehicles charging station, Merit is required to do the supply and demand matching. Therefore, the following inputs are required to be defined in merit before running the matching supply and demand simulation. As mention in section 7.1.1, there are components in design renewable energy charging station systems which are described as follow

- **Photovoltaic Panel module**

The purpose of this feasible study is to find the best of renewable energy system for electric vehicles charging station in Thailand. Hence all of component in this system should come from local company or available to use in Thailand. The main potential of renewable energy in Thailand comes from solar power. Therefore the energy that will produce for this charging station of renewable energy resource will be mainly from solar power as well. In this feasible study solar panel from Siemens was selected to simulate. This PV panel is Poly-Crystalline which has standard maximum output is 100 W which has the size is 0.812 m^2 that can see the detail of this PV panel as an Appendix 1.

- **Wind turbine Panel Module**

As the specification of PV panel and wind turbine that were mention above, the bus voltage of the design renewable energy system is 12 V DC. Therefore the battery storage which will install in the simulation should be 12 V DC as same as the renewable energy system. Hence the size of battery storage was used to do in this simulation is 12 V 215 Ah for renewable energy system. However the battery storage of this system has the minimum state of charge is 40% that means the power in storage cannot fall below 40% and the power able to be used when the battery is charged is approximately 60% of total capacity from charging. (Chungrakkiat, 2011)

Battery Storage

As the specification of PV panel and wind turbine that were mention above, the bus voltage of the design renewable energy system is 12 V DC. Therefore the battery storage which will install in the simulation should be 12 V DC as same as the renewable energy system. Hence the size of battery storage was used to do in this simulation is 12 V 215 Ah for renewable energy system. However the battery storage of this system has the minimum state of charge is 40% that means the power in storage cannot below than 40% and the power able to be used when the battery is charge approximately 60% of total capacity from charging. (Chungrakkiat, 2011)

The table below shows the summary detail of supply options for renewable energy system of electric vehicles charging station in Thailand.

Type	Specification	Cost (£/unit)
Wind Turbine	600 W	1,850
Solar Panel	100 W (Poly-Crystalline)	325
Battery	215Ah at 12V (2.58 kWh)	300

Table 10: Detail of Renewable Energy Supply (Appendix 1-3)

7.1.3 Size of Supply to Consider

According to the highest potential of renewable energy the area that this project was plan to install solar roof top for electric vehicles charging station in Thailand is 120 m^2 whiles the size of solar panel which was mentioned in 7.1.2 is 0.812 m^2. Hence the maximum number that can install the solar panel in this project is 120/0.8712 = 137.74 panel (≈ 140 panel). For the ideal systems the each panel should has have their own battery to store their energy in each their own that make the renewable energy system can supply the energy to the electric vehicle for charging most effective and reliable. So the maximum number of batteries which is possible is 140 units as well.

To achieve the purpose for matching supply and demand of this system, the renewable energy resource should have many categories to see the different effect that most suitable to install for electric vehicles charging station systems in Thailand. Hence this feasible study will separate the category into four criteria as ratio of maximum number as follow.

Ratio of maximum number	Solar Panel (Unit)	Battery (unit)
Zero	0	0
Quarter of maximum number	35	35
Half of maximum number	70	70
Maximum number	140	140

Table 11: The number of criteria supply in 4 different categories.

According to the reason was mentioned in 7.1.2 above that show the wind energy is not the main power for generating energy in Thailand. However the low wind speed turbine was concerned to be the alternative category for this feasible study. Hence this report will add the low wind speed only one unit to see the effect of low wind speed potential for electric vehicles charging station system in Bangkok as well.

Hence the case study for this project was separated into 28 different categories of renewable energy source to supply the power is shown in details as the table below.

Case	Wind (N)	PV (N)	Battery (N)
1.	1	0	0
2.	1	35	0
3.	1	70	0
4.	1	140	0
5.	1	0	35
6.	1	35	35
7.	1	70	35
8.	1	140	35
9.	1	70	0
10.	1	35	70
11.	1	70	70
12.	1	140	70
13.	1	140	0
14.	1	35	140
15.	1	70	140
16.	1	140	140
17.	0	35	0
18.	0	70	0
19.	0	140	0
20.	0	35	35
21.	0	70	35

22.	0	140	35
23.	0	35	70
24.	0	70	70
25.	0	140	70
26.	0	35	140
27.	0	70	140
28.	0	140	140

Table 12: The number of renewable energy resource in 28 different categories.

7.1.4 Model of matching demand

In a more realistic model, in order to match the supply and demand of electric vehicles charging station in Thailand, the demand model was separated into three different sizes of electric vehicles as small, medium and large as used in general. While the time for charging is 7 hours between 9.00 am- 16.00 pm which is the normal office hour in Thailand that mean the users can charging their electric car during they work. Hence the electric charging demand for this simulation is the capacity of battery in each types of electric car multiply by hour of charging as the formula below;

(Maximum Capacity/ Full hour for charging) x Charging hour per day x day of month

However, in this initial study we assume the battery is able to charge energy from 0 to 100 % as mention in more detail at chapter 7.1.6 and total of charging demand in each type of vehicle has the detail as the table below

Name of Electric vehicle Model	(Maximum Capacity/ Full hour for charging) x Charging hour per day x day of month	Total of Charging Demand (monthly)
Twizy	(6.1/3.50) x 3.5 x 30	183 kWh
Leaf	(24/8) x 7 x 30	630 kWh
Tesla	(85/14) x 7 x 30	1275 kWh

Table 13: Charging demand per month for electric vehicle in 3 different models.

The demand model, which was used in this simulation program, was described in more detail as follow.

- Small size

Renault Twizy was selected to represented for a small car follow as their capacity of battery is 6.1 kWh which consume least energy when compare with others type of electric vehicle. There was 3.5 hours for full charging of Renault Twizy with domestic power at home that can drive approximately 80 kilometres. While the power demand of Renault Twizy per month (30 days) is 183 kWh.

- Medium size

Nissan Leaf was selected to represented for a medium car follow as their capacity of battery is 24 kWh which consume medium energy when compare with others type of electric vehicle. There was 8 hours for full charging of Nissan Leaf with domestic power at home that can drive approximately 160 kilometres. Whereas the power demand of Nissan Leaf per month (30 days) is 630 kWh.

- Large Size

Tesla was selected to represented for a large car follow as their capacity of battery is 85 kWh which consume most energy when compare with others type of electric vehicle. There was 14 hours for full charging of Tesla with domestic power at home that can drive approximately 480 kilometres. While the power demand of Tesla per month (30 days) is 1,275 kWh.

The table below shows the summary detail of electric vehicle charging demand for renewable energy system in Thailand.

Size	Model	Battery Capacity (kWh)	Time for full charging (hour)	Range for full charging (kilometer)	Power demand per month (kWh)
Small	Twizzy	6.1	3.5	80	183
Medium	Nissan Leaf	24	8	160	630
Large	Tesla	85	14	480	1,275

Table 14: Detail of Electric Vehicles Charging Demand

7.1.5 Model of Climate and Time

In this feasible study, the climate of Bangkok is selected to represent the city of using electric vehicles in Thailand. The reason that Bangkok is most suitable to be the location of this simulation not only it is the capital of Thailand but it is also big city that has the trend and possible to use the electric vehicle car as general much more others city in Thailand. In Thailand include Bangkok, there is normal three season that consist of winter, summer, rainy. In this simulation, some months are selected to represent of season as show in the table below.

Month	Seasoning
January	Winter
April	Summer
September	Rainy

Table 15: Months which represent to be a season for simulation

7.1.6 Assumption of model simulation

- The first assumption of this report is the profile of climate data which use the information base on the location of Bangkok, Thailand in 1982. According to the merit program allow user simulate this climate in 1982 that's mean this feasible study will be not accurately predict in advance because the climate is change in every year. However, using information base on last year or any year to predict the climate next year is still inaccurately as same as use the climate in 1982
- The second assumption is the time for charging electric vehicles in this feasible study which assumes 7 hours between 9.00 am -4.00 pm for charging every day. This means that the Twizy car (small model) can charge two times per day but it is not real situation, as it is unlikely the the car will charge continuously twice time in the same day (Twizy car require 3.5 hour for full Charging). Hence this report assumes that simulation of Twizy car is charged for 3.5 hours per day
- The third assumption is the profile demand that this feasible study assume the demand of battery will require for full charging every time to charge. This is not realistic in charging behavior of electric vehicle. However it is adequate to simulate for initial basic experiment of electric vehicle charging station rather than extreme factorial to simulate.
- The last assumption of this feasible study is the performance of renewable energy resource components which were assumed that their efficiency always constant such as PV panel, wind turbine and battery storage.

7.1.7 Matching Analysis and Design Suggestion

After input the data of energy supply, energy demand, climate and time for simulation, the result of information such as percentage of matching supply demand, energy deficit, energy surplus and cost of systems will be shown for discussion. The best matching supply should support the demand of electric vehicles all the time for charging properly without surplus and deficit energy. However the high matching of supply and demand system may be not good for the total capital cost and energy generating from renewable energy resource but it only support the demand with supply properly. This procedure analyses the 28 systems in terms of the level of correlation between the supply profile of each combination and the hourly energy demand profile. Finally, the user will get the result of simulation program to find out the most effective integration of renewable energy system for electric vehicles charging station in Thailand that meet four criteria as mention in 1.2 (Aim and Objectives). The procedure for analysis the integration renewable energy resource of electric vehicles station in Thailand is shown in the figure 1 below.

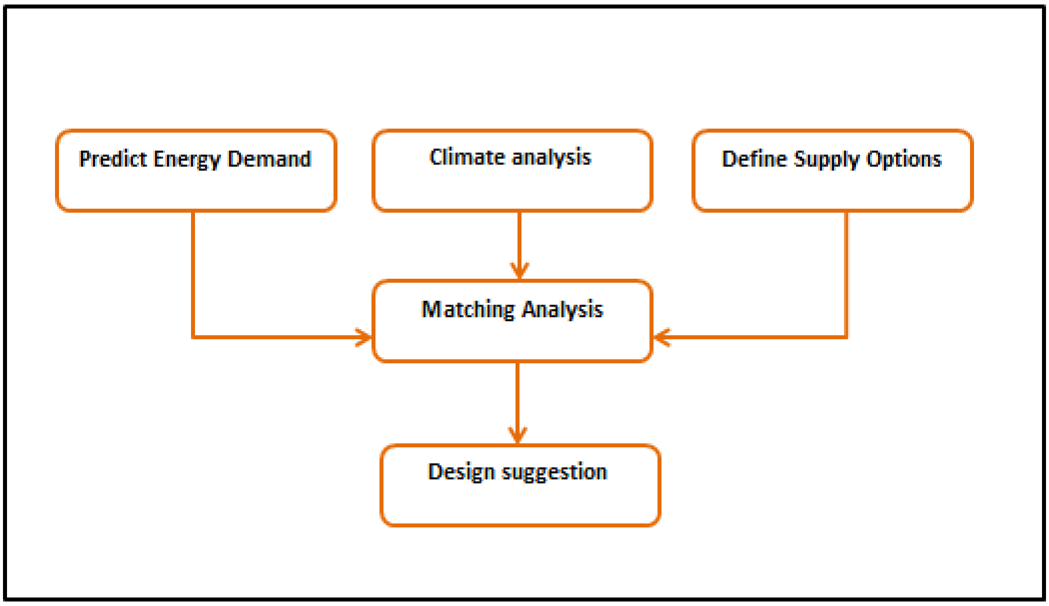


Figure 12: The procedure for analysis the integration of renewable energy resource of electric vehicles station in Thailand.

7.2 Modelling Results

According to using of Merit program for finding the best matching of this feasible study. The 3 demand profiles of electric vehicles (small, medium, large) were match with the different renewable energy resources for Bangkok, Thailand as mention in 7.1. The simulation results were divided into 3 main cases follow as 3 demand profile, in each case of simulation result was divided into 3 different seasons (winter, summer, rainy) to find the best matching of renewable energy supply and electric vehicles demand as realistic as possible that can use for design the most effective of electric vehicles charging station system in Thailand. There are 3 simulation results as follow.

7.2.1 Small Case Model

The Twizy Renault was selected to represent a small case model that requires power for charging of approximately 183 kWh per month as mention in chapter 7.1. The best matching percentage of energy demand and supply of this model is 100% which supply energy by the one unit of wind turbine (600W) and 140 unit of battery storage (140x2.58 kWh) in every seasons (winter, summer and rainy). In contrast with supply energy by a wind turbine without energy storage, the matching percentage in winter, summer and winter is 8.68%,18.89%, 10.87% respectively which is worst of matching percentage when compare with all 28 categories for integration of renewable energy resource. However the high matching of supply and demand system may be not good for the total capital cost and energy generating from renewable energy resource but it only support the demand with supply properly. The best option for small case vehicle charging station in Thailand is supplied the energy by 35 unit of PV which has high deficit and low cost that is most effective and suitable to install that will be describe after table below.

Even though the matching percentage of small model demand and power supply by 600 watt of wind turbine integrate with 140 unit of 2.5 kWh battery storage is highest matching number when compare with others renewable energy supply but the total energy that the system use directly from renewable energy resource is only 27.67kWh, 88.32kWh, 39.32 kWh in winter, summer and winter respectively from 183 kWh of total demand. It means that this battery storage can support the demand as the system required more than 90 kWh. In contrast with the bigger system, which supply energy by the one unit of wind turbine (600W), 140 units of PV panel (140x100W) and 140 units of battery storage (140x2.58 kWh) that can generate the huge power directly from renewable energy resource more than 3000 kWh in every seasons, has low matching percentage because it cannot support the demand without surplus and deficit energy on time properly.

The capital cost of the best matching system is higher than the worst matching system more than 45,500 pounds however it is cheaper than the system which use the maximum unit of renewable energy resource by 42,000 pounds Hence it cannot be implied that the biggest systems of renewable energy resource always has the best performance and suitable in every types of load demand.

The 3 tables below is shown the number of matching percentage, total small case demand , total supply direct from renewable energy resource, energy surplus, energy deficit and capital cost of 28 different categories of renewable energy resources in 3 different seasons; winter, summer and rainy by respectively. (= lowest matching percentage system, = highest matching percentage system)

Combination	% Match	Total Demand (kWh)	Total Delivered (kWh)	Total RE-Supply (kWh)	Surplus Energy (kWh)	Deficit Energy (kWh)	Capital Cost (£)
WT600	12.63	183	7.35	27.67	19.47	166.74	1850
WT600+35PV	39.02	183	183	861.06	677.98	0	13225
WT600+70PV	23.34	183	183	1690	1510	0	24600
WT600+140PV	12.83	183	183	3360	3180	0	47350
WT600+35Batt	39.02	183	183	861.06	677.98	0	12350
WT600+35PV+35Batt	39.72	183	183	833.39	649.66	0.1	23725
WT600+70PV+35Batt	23.34	183	183	1690	1510	0	35100
WT600+140PV+35Batt	12.83	183	183	3360	3180	0	57850
WT600+70Batt	37.78	183	183	27.67	0.04	146.27	24600
WT600+35PV+70Batt	39.02	183	183	861.06	677.96	0	34225
WT600+70PV+70Batt	23.34	183	183	1690	1510	0	45600
WT600+140PV+70Batt	12.83	183	183	3360	3180	0	68350
WT600+140Batt	100	183	183	27.67	0	0	47350
WT600+35PV+140Batt	39.03	183	183	861.06	677.59	0	55225
WT600+70PV+140Batt	23.34	183	183	1690	1510	0	66600
WT600+140PV+140Batt	12.83	183	183	3360	3180	0	89350

35PV	39.72	183	183	833.39	649.76	0.10	11375
70PV	23.58	183	183	1670	1480	0	22750
140PV	12.90	183	183	3330	3150	0	45500
35PV+35Batt	39.72	183	183	833.39	649.66	0	21875
70PV+35Batt	23.58	183	183	1670	1480	0	33250
140PV+35Batt	12.90	183	183	3330	3150	0	56000
35PV+70Batt	39.72	183	183	833.39	649.74	0	32375
70PV+70Batt	23.58	183	183	1670	1480	0	43750
140PV+70Batt	12.90	183	183	3330	3150	0	66500
35PV+140Batt	39.72	183	183	833.39	649.36	0.10	53375
70PV+140Batt	23.58	183	183	1670	1480	0	64750
140PV+ 140Batt	12.90	183	183	3330	3150	0	87500

Table 16: The result for small case model simulation (winter).

Combination	% Match	Total Demand (kWh)	Total Delivered (kWh)	Total RE-Supply (kWh)	Surplus Energy (kWh)	Deficit Energy (kWh)	Capital Cost (£)
WT600	12.01	183	17.59	88.32	68.57	150.45	1850
WT600+35PV	38.16	183	183.01	937.32	754.16	0	13225
WT600+70PV	23.37	183	183	1790	1600	0	24600
WT600+140PV	13.02	183	183	3480	3300	0	47350
WT600+35Batt	93.70	183	176.12	88.32	0.12	6.69	12350
WT600+35PV+35Batt	38.16	183	183	937.32	754.10	0	23725
WT600+70PV+35Batt	23.37	183	183	1790	1600	0	35100
WT600+140PV+35Batt	13.02	183	183	3480	3300	0	57850
WT600+70Batt	59.54	183	84.91	88.32	0.18	97.74	24600

WT600+35PV+70Batt	38.16	183	183	937.32	754.15	0	34225
WT600+70PV+70Batt	23.37	183	183	1790	1600	0	45600
WT600+140PV+70Batt	13.02	183	183	3480	3300	0	68350
WT600+140Batt	100	183	183	88.32	0	0	47350
WT600+35PV+140Batt	38.17	183	183	937.32	753.80	0	55225
WT600+70PV+140Batt	23.37	183	183	1790	1600	0	66600
WT600+140PV+140Batt	13.02	183	183	3480	3300	0	89350
35PV	40.01	183	183	849	665.99	0	11375
70PV	24.03	183	183	1700	1510	0	22750
140PV	13.22	183	183	3400	3210	0	45500
35PV+35Batt	40.01	183	183	849	665.89	0	21875
70PV+35Batt	24.03	183	183	1700	1510	0	33250
140PV+35Batt	13.22	183	183	3400	3210	0	56000
35PV+70Batt	40.01	183	183	849	665.97	0	32375
70PV+70Batt	24.03	183	183	1700	1510	0	43750
140PV+70Batt	13.22	183	183	3400	3210	0	66500
35PV+140Batt	40.01	183	183	849	665.60	0	53375
70PV+140Batt	24.03	183	183	1700	1510	0	64750
140PV+ 140Batt	13.22	183	183	3400	3210	0	87500

Table 17: The result for small case model simulation (summer).

Combination	% Match	Total Demand (kWh)	Total Delivered (kWh)	Total RE-Supply (kWh)	Surplus Energy (kWh)	Deficit Energy (kWh)	Capital Cost (£)
WT600	16.20	183	10.60	39.32	27.64	159.56	1850

WT600+35PV	41.92	183	183	820.44	637.43	0	13225
WT600+70PV	25.58	183	183	1600	1420	0	24600
WT600+140PV	14.22	183	183	3160	2980	0	47350
WT600+35Batt	41.92	183	183	820.44	637.43	0	12350
WT600+35PV+35Batt	41.92	183	183	820.44	637.33	0	23725
WT600+70PV+35Batt	25.58	183	183	1600	1420	0	35100
WT600+140PV+35Batt	14.22	183	183	3160	2980	0	57850
WT600+70Batt	43.20	183	46.80	39.32	0	135.90	24600
WT600+35PV+70Batt	41.92	183	183	820.44	637.41	0	34225
WT600+70PV+70Batt	25.58	183	183	1600	1420	0	45600
WT600+140PV+70Batt	14.22	183	183	3160	2980	0	68350
WT600+140Batt	100	183	183	39.32	0	0	47350
WT600+35PV+140Batt	41.93	183	183	820.44	637.04	0	55225
WT600+70PV+140Batt	25.59	183	183	1600	1420	0	66600
WT600+140PV+140Batt	14.22	183	183	3160	2980	0	89350
35PV	42.85	183	183	781.13	598.11	0	11375
70PV	25.93	183	183	1560	1380	0	22750
140PV	14.33	183	183	3120	2940	0	45500
35PV+35Batt	42.85	183	183	781.13	598.02	0	21875
70PV+35Batt	25.93	183	183	1560	1380	0	33250
140PV+35Batt	14.33	183	183	3120	2940	0	56000
35PV+70Batt	42.85	183	183	781.13	598.09	0	32375
70PV+70Batt	25.93	183	183	1560	1380	0	43750
140PV+70Batt	14.33	183	183	3120	2940	0	66500
35PV+140Batt	42.86	183	183	781.13	597.72	0	53375

70PV+140Batt	25.93	183	183	1560	1380	0	64750
140PV+ 140Batt	14.33	183	183	3120	2940	0	87500

Table 18: The result for small case model simulation (rainy).

As the result of simulation above it can be seen that the maximum matching percentage is not the best of renewable energy supply. The power was produce from 35 unit, 70 unit and 140 unit of 100 W PV panel is able to support the demand for small electric vehicle model but it is not the high matching percentage of supply-demand because it still has high surplus energy after deliver power to electric vehicle charging model. Especially in summer, the PV panel can produce the maximum power to 849kWh, 1700 kWh and 3400 kWh by 35 unit, 70 unit and 140 unit of 100 W PV panel by respectively. As you can see the detail of PV supply and small model demand in summer as weekly graph below.

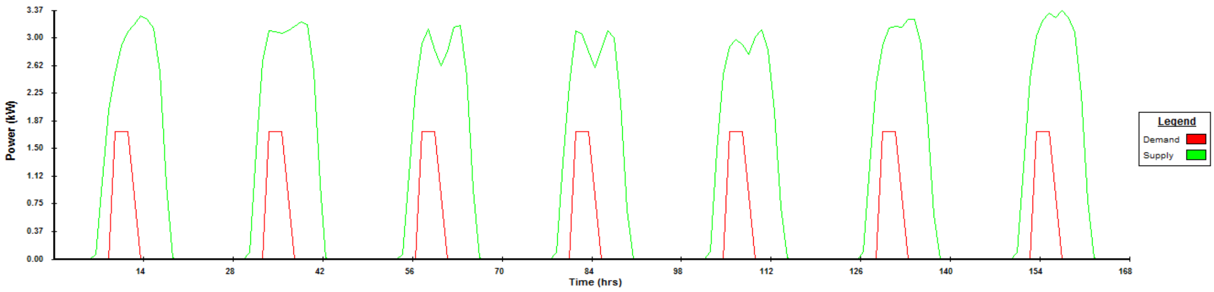


Figure 13: The Graph for small case model simulation in summer (35 unit of PV 100 W).

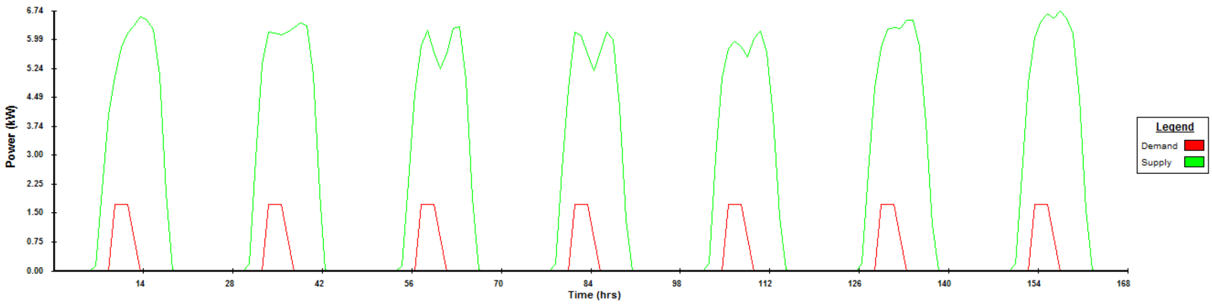


Figure 14: The Graph for small case model simulation in summer (70 unit of PV 100 W).

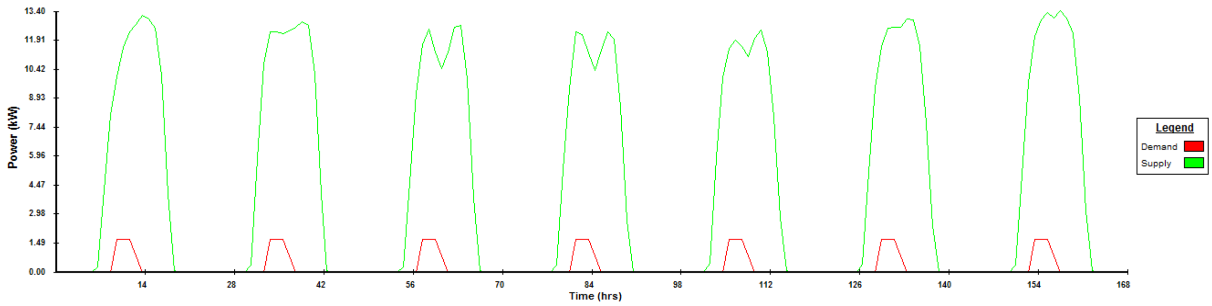


Figure 15: The Graph for small case model simulation in summer (140 unit of PV 100 W).

According to the result of small model, it can be conclude that the data of highest and lowest matching percentage as the table below.

Season	Type	Combination	% Match
Winter	Lowest	WT600	12.63
	Without Battery	WT600+140Batt	100
	Highest	WT600+140Batt	100
Summer	Lowest	WT600	12.01
	without Battery	WT600+140Batt	100
	Highest	WT600+140Batt	100
Rainy	Lowest	WT600	16.2
	without Battery	WT600+140Batt	100
	Highest	WT600+140Batt	100

Table 19: The data of highest and lowest matching percentage of small model

7.2.2 Medium Case Model

In medium case model, the Nissan Leaf was chosen to represent as prototype of electric vehicle. This car requires power for charging of approximately 630 kWh / month as mention in chapter 7.1. According to this number demand is higher than small model, the number of deliver power for charging from renewable energy resource will be higher than small model that were describe in 7.2.1 as well. However the main concept is still the same in small model where the installed systems should have the energy resource combined with battery storage so that the demand and supply has high matching percentage. The detail of information will be described as follow.

The best matching percentage of energy demand and supply of this model is 80%, 79.36%, 82.60% in winter, summer and rainy by respectively which integrate by 35 unit of solar panel (70x100W) and 70 unit of battery storage (70x2.58 kWh). In contrast with supply energy by only 35 unit of PV without energy storage, the matching percentage in winter, summer and winter is 77.61%,77.73% and 79.34% respectively which is lower than from the number of high matching percentage about 3%. Nevertheless the worst of matching percentage is 6.15%, 13.98% and 7.95% that generate power from only one unit of wind turbine (600 W) without battery storage which is most unsuitable to use this model for medium electric vehicle charging when compare with others 28 categories for integration of renewable energy resource. However the high matching of supply and demand system may be not good for the total capital cost and energy generating from renewable energy resource but it only support the demand with supply properly. The best option for medium case vehicle charging station in Thailand is supplied the energy by 70 unit of PV which has high deficit and low cost that is most effective and suitable to install that will be described after the table below.

Even though the matching percentage of medium model demand and power supply by 35 unit of 140W PV panel and 70 unit of 2.5 kWh battery storage is highest matching number when compare with others renewable energy supply but the total energy that the generate direct from renewable energy resource is around 833 kWh from 630 kWh of total demand without deficit energy. It means that this model has surplus energy approximately 205 kWh. In contrast with the bigger system, which supplies energy by the one unit of wind turbine (600W), 140 unit of PV panel (140x100W) and 140 unit of battery storage (140x2.58 kWh) that can generate the huge power directly from renewable energy resource more than 3000 kWh, has low matching percentage because it cannot support the demand without surplus and deficit energy on time properly.

The capital cost of the best matching system is higher than the cost of matching system without battery by more than £21,000. However, it is cheaper than the biggest system of renewable energy resource by £56,975. Hence it cannot be implied that the biggest systems of renewable energy resource always has the best performance and suitability in every types of load demand as same as was described in 7.2.1 small model case before.

The 3 tables below is shown the number of matching percentage, total medium case demand , total supply direct from renewable energy resource, energy surplus, energy deficit and capital cost of 28 different categories of renewable energy resources in 3 different seasons; winter, summer and rainy by respectively.

(= lowest matching percentage system, = highest matching percentage system, = highest matching percentage system without battery)

Combination	% Match	Total Demand (kWh)	Total Delivered (kWh)	Total RE-Supply (kWh)	Surplus Energy (kWh)	Deficit Energy (kWh)	Capital Cost (£)
WT600	6.15	630	13.87	27.67	13.01	592.33	1850
WT600+35PV	76.95	630	597.72	861.06	246.72	26.57	13225
WT600+70PV	54.70	630	629.70	1690	1060	0.15	24600
WT600+140PV	33.82	630	630	3360	2730	0	47350
WT600+35Batt	76.95	630	597.72	861.06	246.72	26.570	12350
WT600+35PV+35Batt	78.61	630	630	861.06	239.90	0	23725
WT600+70PV+35Batt	54.71	630	630	1690	1060	0	35100
WT600+140PV+35Batt	32.82	630	630	3360	2730	0	57850
WT600+70Batt	16.73	630	34.97	27.67	0.04	592.13	24600
WT600+35PV+70Batt	78.84	630	630	861.06	232.51	0	34225
WT600+70PV+70Batt	54.71	630	630	1.69	1.06	0	45600
WT600+140PV+70Batt	32.82	630	630	3360	2730	0	68350
WT600+140Batt	65.01	630	378.74	27.67	0	250.54	47350
WT600+35PV+140Batt	78.51	630	630	861.06	243.13	0	55225
WT600+70PV+140Batt	54.71	630	630	1690	1060	0	66600

WT600+140PV+140Batt	32.83	630	630	3360	2730	0	89350
35PV	77.61	630	593.47	833.39	221.35	30.60	11375
70PV	55.61	630	629.57	1670	1040	0.21	22750
140PV	32.98	630	630	3330	2700	0	45500
35PV+35Batt	79.70	630	630	833.39	213.79	0	21875
70PV+35Batt	55.17	630	630	1670	1040	0	33250
140PV+35Batt	32.98	630	630	3330	2700	0	56000
35PV+70Batt	80	630	630	833.39	205.74	0	32375
70PV+70Batt	55.16	630	630	1670	1040	0	43750
140PV+70Batt	32.98	630	630	3330	0	0	66500
35PV+140Batt	79.56	630	630	833.39	217.23	0	53375
70PV+140Batt	55.17	630	630	1670	1040	0	64750
140PV+ 140Batt	32.99	630	630	3330	2700	0	87500

Table 20: The result for medium case model simulation (winter).

Combination	% Match	Total Demand (kWh)	Total Delivered (kWh)	Total RE-Supply (kWh)	Surplus Energy (kWh)	Deficit Energy (kWh)	Capital Cost (£)
WT600	13.98	630	36.70	88.32	49.29	556.21	1850
WT600+35PV	76.31	630	611.65	937.32	315.31	15.36	13225
WT600+70PV	55.50	630	630	1790	1160	0	24600
WT600+140PV	33.78	630	630	3480	2850	0	47350
WT600+35Batt	42.68	630	161.38	88.32	0.12	466.18	12350
WT600+35PV+35Batt	28.21	630	84.07	88.32	0.18	543.75	23725
WT600+70PV+35Batt	55.50	630	630	1790	1160	0	35100
WT600+140PV+35Batt	33.78	630	630	3480	2850	0	57850

WT600+70Batt	28.21	630	84.07	88.32	0.18	543.75	24600
WT600+35PV+70Batt	77.33	630	630	937.32	307.93	0	34225
WT600+70PV+70Batt	55.50	630	630	1790	1160	0	45600
WT600+140PV+70Batt	33.78	630	630	3480	2850	0	68350
WT600+140Batt	72.52	630	452.84	88.32	0	175.33	47350
WT600+35PV+140Batt	77.15	630	630	937.32	313.90	0	55225
WT600+70PV+140Batt	55.50	630	630	1790	1160	0	66600
WT600+140PV+140Batt	33.78	630	630	3480	2850	0	89350
35PV	77.73	630	606.10	849	225.47	20.17	11375
70PV	56.68	630	630	1700	1070	0	22750
140PV	34.21	630	630	3400	2770	0	45500
35PV+35Batt	79.08	630	630	849	225.46	0	21875
70PV+35Batt	79.31	630	630	849	219.95	0	33250
140PV+35Batt	34.21	630	630	3400	2770	0	56000
35PV+70Batt	79.36	630	630	849	219.95	0	32375
70PV+70Batt	56.68	630	630	1700	1070	0	43750
140PV+70Batt	34.21	630	630	3400	2770	0	66500
35PV+140Batt	78.99	630	630	849	227.68	0	53375
70PV+140Batt	56.68	630	630	1700	1070	0	64750
140PV+ 140Batt	34.21	630	630	3400	2770	0	87500

Table 21: The result for medium case model simulation (summer).

Combination	**% Match**	**Total Demand (kWh)**	**Total Delivered (kWh)**	**Total RE-Supply (kWh)**	**Surplus Energy (kWh)**	**Deficit Energy (kWh)**	**Capital Cost (£)**
WT600	7.95	630	18.77	39.32	19.51	578.80	1850

WT600+35PV	78.92	630	594.14	820.44	203.56	28.74	13225
WT600+70PV	58.86	630	630	1600	971.57	0	24600
WT600+140PV	35.99	630	630	3160	2530	0	47350
WT600+35Batt	35.49	630	112.08	39.32	0	514.39	12350
WT600+35PV+35Batt	81.05	630	630	820.44	200.7	0	23725
WT600+70PV+35Batt	58.86	630	630	1600	971.47	0	35100
WT600+140PV+35Batt	35.99	630	630	3160	2530	0	57850
WT600+70Batt	19.21	630	46	39.32	0	582.11	24600
WT600+35PV+70Batt	81.36	630	630	820.44	192.83	0	34225
WT600+70PV+70Batt	58.86	630	630	1600	971.55	0	45600
WT600+140PV+70Batt	35.99	630	630	3160	2530	0	68350
WT600+140Batt	66.32	630	393.91	39.32	0	234.81	47350
WT600+35PV+140Batt	80.91	630	630	820.44	204.20	0	55225
WT600+70PV+140Batt	58.87	630	630	1600	971.18	0	66600
WT600+140PV+140Batt	35.99	630	630	3160	2530	0	89350
35PV	79.34	630	585.98	781.13	172.33	36.45	11375
70PV	59.48	630	630	1560	932.25	0	22750
140PV	36.22	630	630	3120	2490	0	45500
35PV+35Batt	82.26	630	630	781.13	163.70	0	21875
70PV+35Batt	59.48	630	630	1560	932.16	0	33250
140PV+35Batt	36.22	630	630	3120	2490	0	56000
35PV+70Batt	82.80	630	630	781.13	153.56	0	32375
70PV+70Batt	59.48	630	630	1560	932.24	0	43750
140PV+70Batt	36.22	630	630	3120	2490	0	66500
35PV+140Batt	82.05	630	630	781.13	167.98	0	53375

70PV+140Batt	59.48	630	630	1560	932.25	0	64750
140PV+ 140Batt	36.22	630	630	3120	2490	0	87500

Table 22: The result for medium case model simulation (rainy).

As show in in the table above, it can be clearly seen that the maximum matching percentage is not the best of renewable energy supply. The power was produce from 70 units and 140 units of 100 W PV panel is able to support the demand for medium electric vehicle model but it is not the high matching percentage of supply-demand because it still has high surplus energy after deliver power to electric vehicle charging model. Especially in summer, the PV panel can produce the maximum power to 849kWh, 1700 kWh and 3400 kWh by 35 unit, 70 unit and 140 unit of 100 W PV panel by respectively. As you can see the detail of PV supply and medium model demand in summer as weekly graph below.

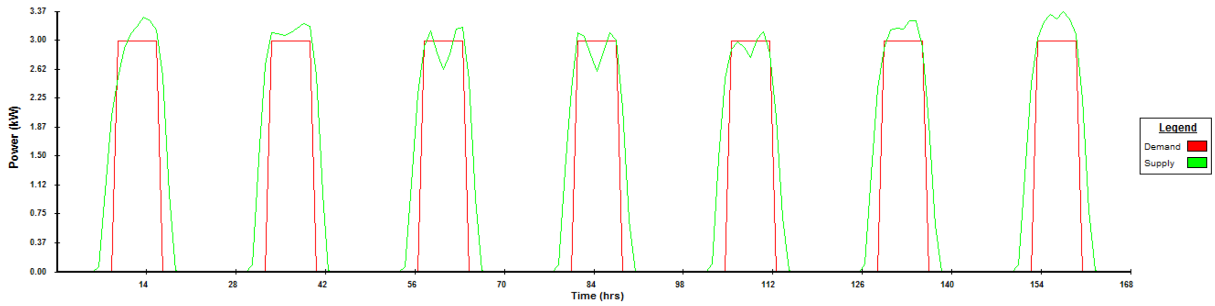


Figure 16: The graph for medium model simulation in summer (35 unit of PV 100 W).

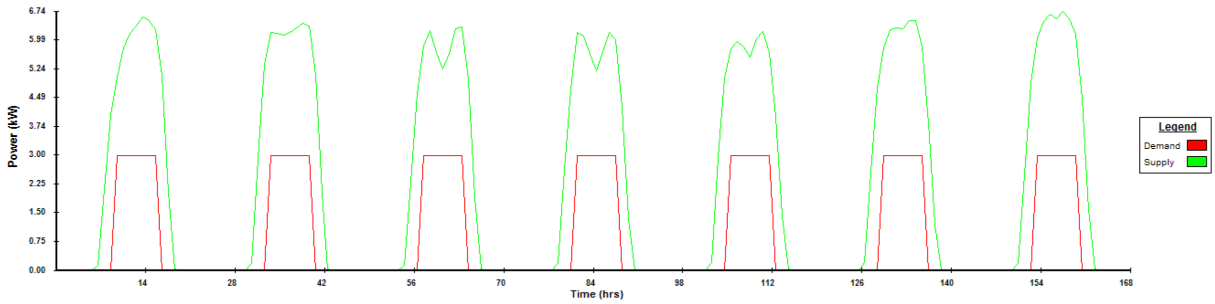


Figure 17: The graph for medium model simulation in summer (70 unit of PV 100 W).

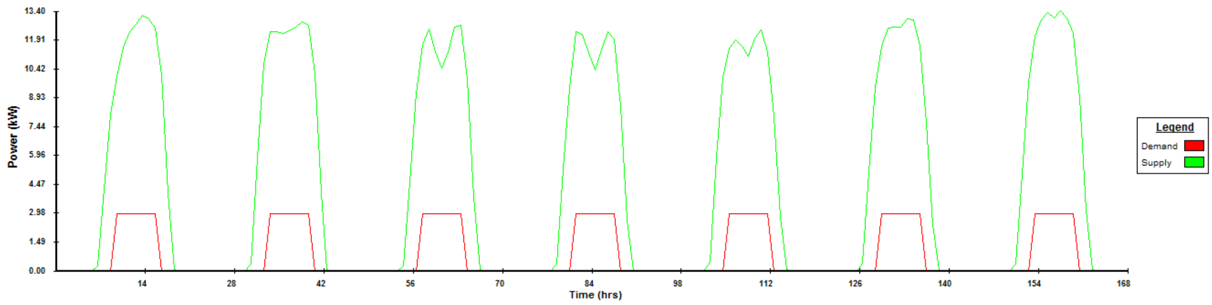


Figure 18: The graph for medium model simulation in summer (140 unit of PV 100 W).

According to the result of medium model, it can be conclude the data of highest and lowest matching percentage as the table below.

Season	Type	Combination	% Match
Winter	Lowest	WT600	6.15
	Without Battery	35PV	77.61
	Highest	35PV+70Batt	80
Summer	Lowest	WT600	13.98
	without Battery	35PV	77.73
	Highest	35PV+70Batt	79.36
Rainy	Lowest	WT600	7.95
	without Battery	35PV	79.34
	Highest	35PV+70Batt	82.8

Table 23: The data of highest and lowest matching percentage of medium model.

7.2.3 Large Case Model

In large case model, the Tesla was selected to represent as prototype of electric car which has a huge number of energy consume. This car requires power for charging approximately 1270 kWh / month as mention in chapter 7.1. According to this demand which is highest number when compare with others model , the number of deliver for charging from renewable energy resource in this case will be higher than two types of case model that were describe in 7.2.1 and 7.2.2 before. However the main concept still as same as in small and medium model which is the systems should install the energy resource with battery storage that made the demand and supply has high matching percentage. The detail of information will be described as follow.

The best matching percentage of energy demand and supply of this model is 88.53%, 91.58%, 86.27% in winter, summer and rainy by respectively. All the best case of power supplying of three seasons are integrate by a wind turbine (100W), 35 unit of solar panel (140x100W) and 140 unit of battery storage (140x2.58 kWh). In contrast with supply energy by only wind turbine and 35 unit of PV without energy storage, the matching percentage in winter, summer and winter is 67.64%, 66.64% and 64.12% respectively which is lower than from the number of high matching percentage around 20%. The worst of matching percentage is 3.12%, 7.32% and 4.06% that generate power from only wind turbine (600 W) without battery storage which mean this system is most unsuitable to charge for the large electric vehicle when compare with others 28 categories for integration of renewable energy resource. However the high matching of supply and demand system may be not good for the total capital cost and energy generating from renewable energy resource but it only support the demand with supply properly. The best option for large case vehicle charging station in Thailand is supplied the energy by 140 unit of PV which has high deficit and low cost that is most effective and suitable to install that will be describe after table below.

Even though the matching percentage of large model demand and supply the power by one unit of wind turbine (600W), 35 unit of 140W PV panel and 140 unit of 2.5 kWh battery storage is highest matching number when compare with others renewable energy supply but the total energy that generate direct from renewable energy resource is around 861 kWh from 1270 kWh of total demand with surplus and deficit energy. It means this model cannot support and arrange the demand and supply effectively.

The capital cost of the best matching system is higher than the cost of matching system without battery more than £42,000. However, it is cheaper than the biggest system of renewable energy resource by £34,125. Hence it cannot implied that the biggest systems of renewable energy resource always has the best performance and suitable in every types of load demand as same as was described in 7.2.1and 7.2.2 small and medium model case before.

The 3 tables below is shown the number of matching percentage, total large case demand , total supply direct from renewable energy resource, energy surplus, energy deficit and capital cost of 28 different categories of renewable energy resources in 3 different seasons; winter, summer and rainy by respectively.

Combination	% Match	Total Demand (kWh)	Total Delivered (kWh)	Total RE-Supply (kWh)	Surplus Energy (kWh)	Deficit Energy (kWh)	Capital Cost (£)
WT600	3.12	1270	13.87	27.67	13.01	1210	1850
WT600+35PV	67.64	1270	693.68	861.06	135.37	536.90	13225
WT600+70PV	77.51	1270	1200	1690	457.72	63.74	24600
WT600+140PV	55.35	1270	1270	3360	2090	0.40	47350
WT600+35Batt	21.83	1270	88.54	27.67	0	1180	12350
WT600+35PV+35Batt	74.70	1270	841.79	861.06	76.53	408.96	23725
WT600+70PV+35Batt	79.67	1270	1270	1690	433.36	0.86	35100
WT600+140PV+35Batt	55.36	1270	1270	3360	2090	0	57850
WT600+70Batt	9.03	1270	33.51	27.67	0.03	1.23	24600
WT600+35PV+70Batt	71.52	1270	754.24	861.06	73.02	486.23	34225
WT600+70PV+70Batt	80.06	1270	1270	1690	411.93	0.87	45600
WT600+140PV+70Batt	55.36	1270	1270	3360	2090	0	68350
WT600+140Batt	43.80	1270	348.84	27.67	0	927.89	47350
WT600+35PV+140Batt	88.53	1270	1160	861.06	67.85	107.47	55225
WT600+70PV+140Batt	79.49	1270	1270	1690	443.31	0.86	66600
WT600+140PV+140Batt	55.36	1270	1270	3360	2090	0	89350

35PV	67	1270	680.73	833.39	120.47	548.74	11375
70PV	77.82	1270	1190	1670	434.83	68.04	22750
140PV	55.58	1270	1270	3330	2060	0.46	45500
35PV+35Batt	73.78	1270	817.33	833.39	71.17	431.26	21875
70PV+35Batt	80.26	1270	1270	1670	408.81	0	33250
140PV+35Batt	55.59	1270	1270	3330	2060	0	56000
35PV+70Batt	70.62	1270	1270	833.39	68.06	504.24	32375
70PV+70Batt	80.71	1270	1270	1670	387.22	2.77	43750
140PV+70Batt	55.59	1270	1270	3330	2060	0	66500
35PV+140Batt	88.06	1270	1270	1670	419.11	0	53375
70PV+140Batt	77.82	1270	1190	1670	434.83	68.04	64750
140PV+ 140Batt	55.59	1270	1270	3330	2060	0	87500

Table 24: The result for large case model simulation (winter).

Combination	% Match	Total Demand (kWh)	Total Delivered (kWh)	Total RE-Supply (kWh)	Surplus Energy (kWh)	Deficit Energy (kWh)	Capital Cost (£)
WT600	7.32	1270	36.70	88.32	49.29	1160	1850
WT600+35PV	66.64	1270	680.57	937.32	220.46	549.02	13225
WT600+70PV	77.26	1270	1230	1790	528.27	39.19	24600
WT600+140PV	56.51	1270	1270	3480	2210	0	47350
WT600+35Batt	27.50	1270	149.71	88.32	0.12	1120	12350
WT600+35PV+35Batt	76.34	1270	879.82	937.32	115.38	373.01	23725
WT600+70PV+35Batt	78.53	1270	1270	1790	520.56	0	35100
WT600+140PV+35Batt	56.51	1270	1270	3480	2210	0	57850
WT600+70Batt	15.87	1270	82.73	88.32	0.16	1190	24600

WT600+35PV+70Batt	71.88	1270	763.46	937.32	114.88	484.66	34225
WT600+70PV+70Batt	78.88	1270	1270	1790	503.81	0.74	45600
WT600+140PV+70Batt	56.51	1270	1270	3480	2210	0	68350
WT600+140Batt	48.12	1270	415.50	88.32	0	855.88	47350
WT600+35PV+140Batt	91.58	1270	1250	937.32	86.80	26.31	55225
WT600+70PV+140Batt	78.43	1270	1270	1790	526.31	0	66600
WT600+140PV+140Batt	56.51	1270	1270	3480	2210	0	89350
35PV	64.84	1270	643.88	849	171.17	583.02	11375
70PV	77.87	1270	1220	1700	438.76	45.42	22750
140PV	57.10	1270	1270	3400	2120	0	45500
35PV+35Batt	73.01	1270	799.55	849	101.23	450.01	21875
70PV+35Batt	79.50	1270	1270	1700	433.89	0	33250
140PV+35Batt	57.10	1270	1270	3400	2120	0	56000
35PV+70Batt	69.39	1270	708.64	849	99.74	533.24	32375
70PV+70Batt	79.61	1270	1270	1700	425.52	8.02	43750
140PV+70Batt	57.10	1270	1270	3400	2120	0	66500
35PV+140Batt	87.02	1270	1140	849	80.63	121.93	53375
70PV+140Batt	79.35	1270	1270	1700	440.77	0	64750
140PV+ 140Batt	57.10	1270	1270	3400	2120	0	87500

Table 25: The result for large case model simulation (summer).

Combination	% Match	Total Demand (kWh)	Total Delivered (kWh)	Total RE-Supply (kWh)	Surplus Energy (kWh)	Deficit Energy (kWh)	Capital Cost (£)
WT600	4.06	1270	18.77	39.32	19.51	1190	1850

WT600+35PV	64.12	1270	628.06	820.44	161.83	596.69	13225
WT600+70PV	79.25	1270	1190	1600	368.10	72.79	24600
WT600+140PV	59.60	1270	1270	3160	1890	0	47350
WT600+35Batt	22.95	1270	101.30	39.32	0	1170	12350
WT600+35PV+35Batt	72.38	1270	788.54	820.44	89.63	459.49	23725
WT600+70PV+35Batt	82.13	1270	1270	1600	345.18	0	35100
WT600+140PV+35Batt	59.60	1270	1270	3160	1890	0	57850
WT600+70Batt	10.43	1270	44.54	5.23	0	1230	24600
WT600+35PV+70Batt	68.70	1270	697.29	820.44	84.89	542.95	34225
WT600+70PV+70Batt	82.92	1270	1270	1600	313.96	0	45600
WT600+140PV+70Batt	59.60	1270	1270	3160	1890	0	68350
WT600+140Batt	44.64	1270	357.71	39.32	0	914.01	47350
WT600+35PV+140Batt	86.27	1270	1130	820.44	64.52	134.99	55225
WT600+70PV+140Batt	81.88	1270	1270	1600	356.56	0	66600
WT600+140PV+140Batt	59.60	1270	1270	3160	1890	0	89350
35PV	63.04	1270	609.29	781.13	142.32	614.10	11375
70PV	79.41	1270	1180	1560	338.76	81.34	22750
140PV	59.90	1270	1270	3120	1850	0	45500
35PV+35Batt	70.85	1270	753.71	781.13	81.75	491.74	21875
70PV+35Batt	82.88	1270	1270	1560	307.69	0	33250
140PV+35Batt	59.90	1270	1270	3120	1850	0	56000
35PV+70Batt	67.29	1270	670.21	781.13	79.94	566.94	32375
70PV+70Batt	83.80	1270	1270	1560	275.06	1.87	43750
140PV+70Batt	59.90	1270	1270	3120	1850	0	66500
35PV+140Batt	83.92	1270	1080	781.13	67.38	184.21	53375

70PV+140Batt	82.53	1270	1270	1560	320.62	0	64750
140PV+ 140Batt	59.90	1270	1270	3120	1850	0	87500

Table 26: The result for large case model simulation (rainy).

As shown in the result of simulation above, it can be clearly seen that the maximum matching percentage is not the best of renewable energy supply. Only the power was produce from 140 unit of 100 W PV panel is able to support the demand for large electric vehicle model but it is not the high matching percentage of supply-demand because it still has high surplus energy after deliver power to electric vehicle charging model. Especially in summer, the PV panel can produce the maximum power to 849kWh, 1700 kWh and 3400 kWh by 35 unit, 70 unit and 140 unit of 100 W PV panel by respectively. As you can see the detail of PV supply and medium model demand in summer as weekly graph below.

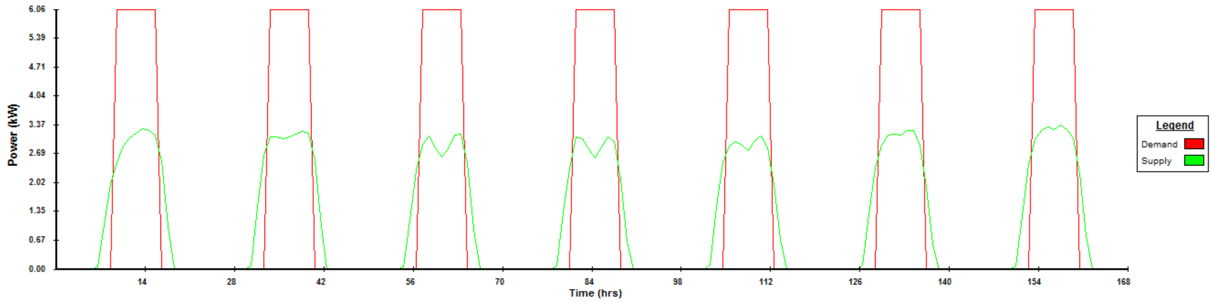


Figure 19: The graph for large model simulation in summer (35 unit of PV 100 W).

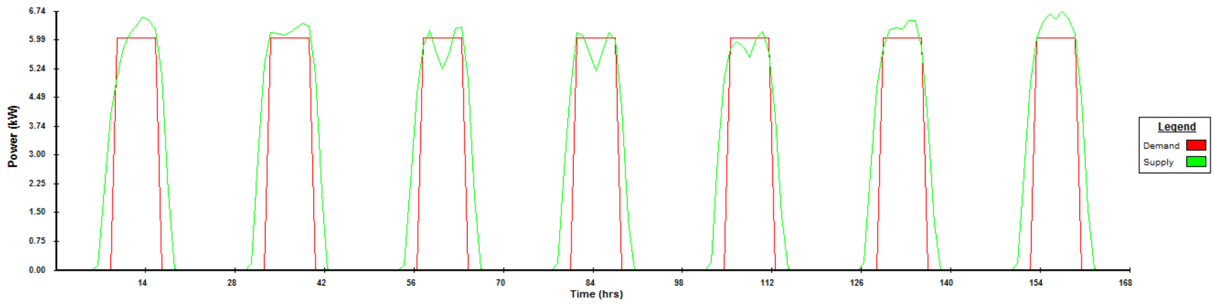


Figure 20: The graph for large model simulation in summer (70 unit of PV 100 W).

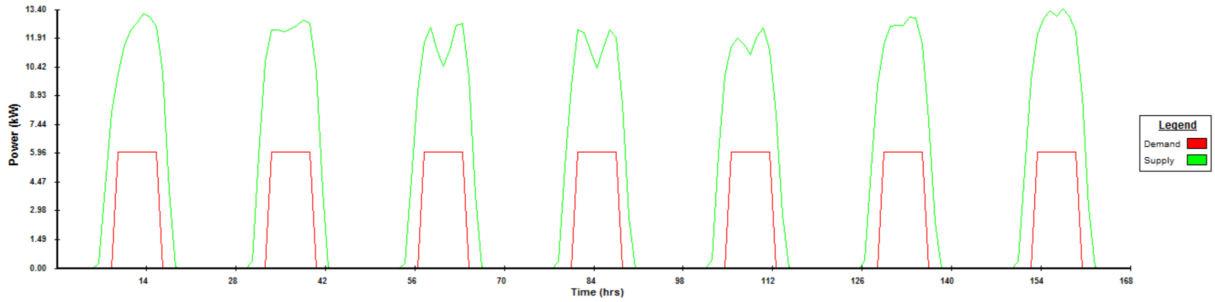


Figure 21: The graph for large model simulation in summer (140 unit of PV 100 W).

According to the result of large model, it can be conclude the data of highest and lowest matching percentage as the table below.

Season	Type	Combination	% Match
Winter	Lowest	WT600	3.12
	Without Battery	WT600+35PV	67.64
	Highest	WT600+35PV+140Batt	88.53
Summer	Lowest	WT600	7.32
	without Battery	WT600+35PV	66.64
	Highest	WT600+35PV+140Batt	91.58
Rainy	Lowest	WT600	4.06
	without Battery	WT600+35PV	64.12
	Highest	WT600+35PV+140Batt	86.27

Table 27: The data of highest and lowest matching percentage of large model.

As all results and explanations were mentioned above, it can be clearly seen that the highest number of matching percentage is not the best of renewable energy supply because it can only generate the power as the demand required or nearly but it does not has the surplus energy which possible to support the extending system in the future. Hence the system which is most effective and reliable should have the high surplus energy, less deficit and low cost to install the system when compare with 28 other categories. The detail of the best renewable energy system in each model were show in the table below that it is most effective and suitable to install into the location in Thailand.

Model	Combination	Surplus (kWh)	Deficit (kWh)	Cost (£)
Small	35 PV	665.99	0	11375
Medium	70 PV	1510	0	22750
Large	140 PV	2120	0	45500

Table 28 : The data of most effective and suitable system to install in Thailand.

Chapter 8: Modeling Discussion

8.1 Modelling discussion

To achieve the project objective and integrate renewable energy resources for electric vehicle charging stations in Thailand we will now discuss the following features of the modeling:

- Matching Percentage
- Power demand and supply
- Amount of surplus renewable energy
- Amount of deficit renewable energy
- Capital cost of renewable energy system for charging station

8.1.1 Matching Percentage

In three bar charts below, it can be seen that all the best of matching percentage in every seasons of each model has to include the maximum of energy storage into the electric vehicle charging station systems. Especially in case of small model that the best matching system that generate the power by a wind turbine (600W) and 140 unit of energy storage (2.54 kWh) will change to be the worst matching system by take-off the battery storage from system. In case of medium and large model, even though the matching percentage does not convert to be a worst case, when one takes off the battery storage from the system, the matching percentage will decrease the performance from the best matching percentage as well. At the same time,, the worst matching percentage of both models (medium and large) is the system which supplied the power from wind turbine only without any energy storage in the system. Therefore the best matching percentage is not necessary to be a big system.

However the matching percentage system will be the best when the system can support the demand on time as load required with the less of surplus and deficit energy. However the high matching of supply and demand system may be not good for the total capital cost and energy generating from renewable energy resource but it only support the demand with supply properly. Hence the system which is most effective and reliable should have the high surplus energy, less deficit and low cost to install the system when compare with 28 other categories.

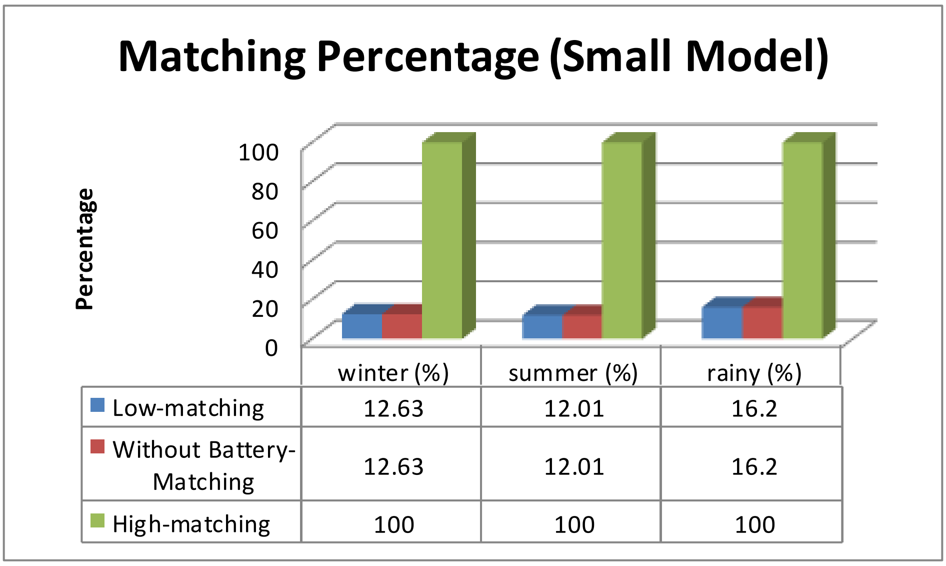


Figure 22: The matching percentage of small model.

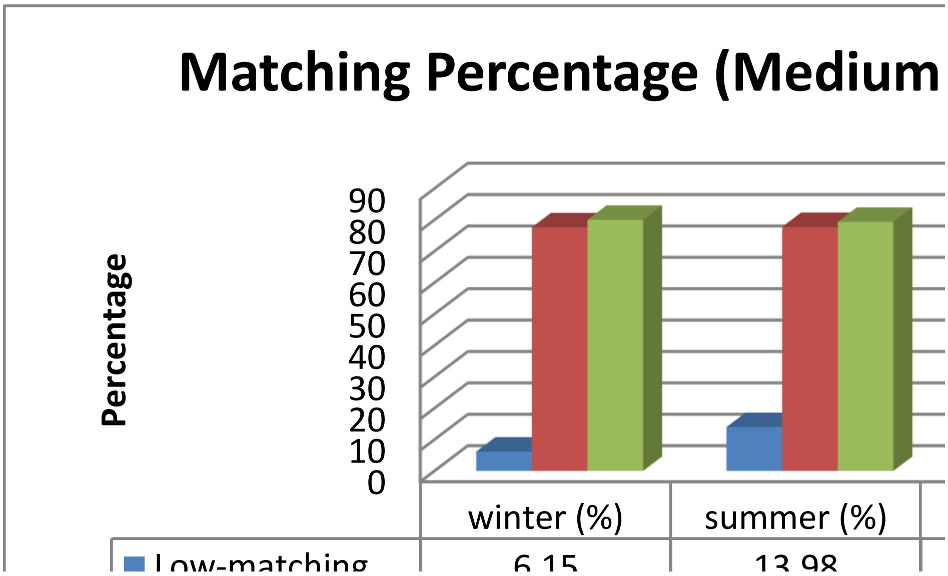


Figure 23: The matching percentage of medium model

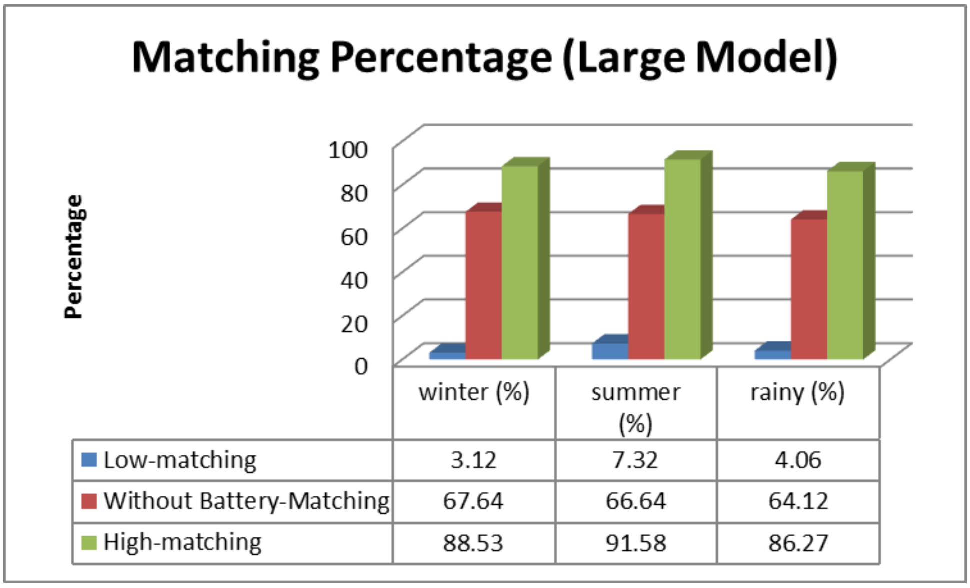


Figure 24: The matching percentage of large model.

8.1.2 Power Demand and Supplied

In three figures below, it can be seen that all the best case of matching percentage in every seasons of each model has to include of energy storage into the electric vehicle charging station systems. Particularly the energy supply by wind turbine in small model that it supply the power to charging station from energy storage higher than import energy direct from renewable energy resource in every period. In contrast with the medium which supply energy direct from PV panel higher than import from energy storage. However in the large model, using 35 unit of battery storage (2.54 kWh) cannot support all demand of electric vehicle cannot support all demand of electric vehicles but make both surplus and deficit energy of the system is lower than other categories in the same model.

The reason that wind power supply energy for charging station in small model come from auxiliary source more than direct source due to the charging time of electric vehicle in this project is between 09.00 am -04.00 pm that can use the power from wind energy which store in battery at night time without the load require.

In contrast with PV panel that can generate power only during the day time, hence the power for charging is come from the lighting directly except in early morning and late afternoon that can store the energy in battery. However if the load is not too high, using power only from PV panel is acceptable.

However, the best of matching percentage supply by both PV panel and wind turbine is necessary to install the system with battery storage for back up the power when the energy cannot supply the power directly on time as load require.

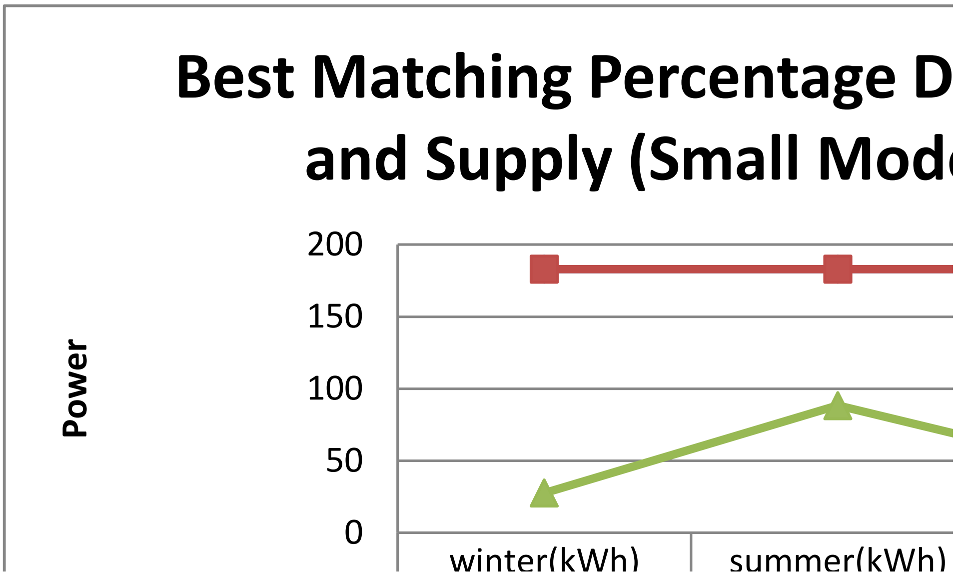


Figure 25: The best matching percentage demand and supply of small model.

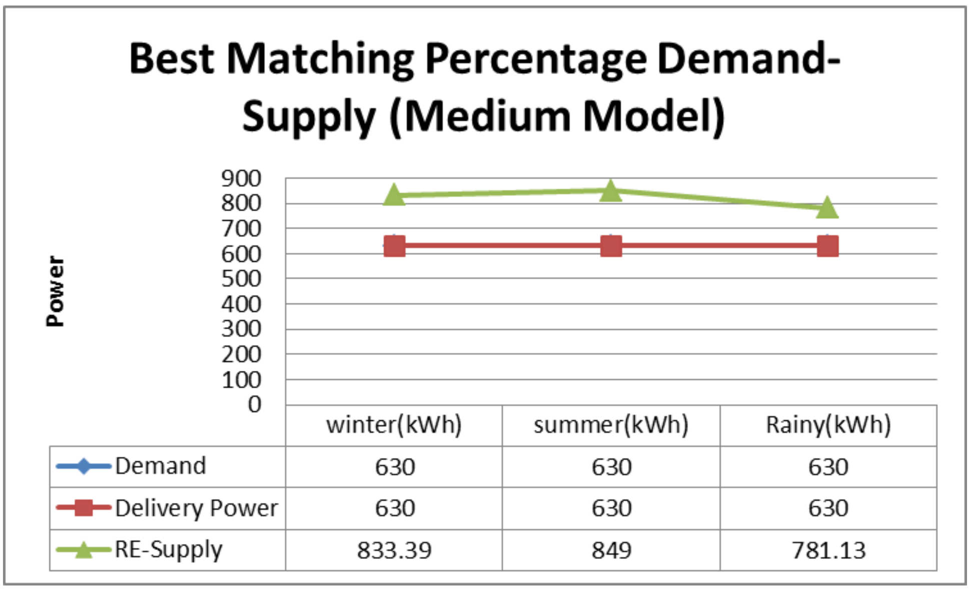


Figure 26: The best matching percentage demand and supply of medium model.

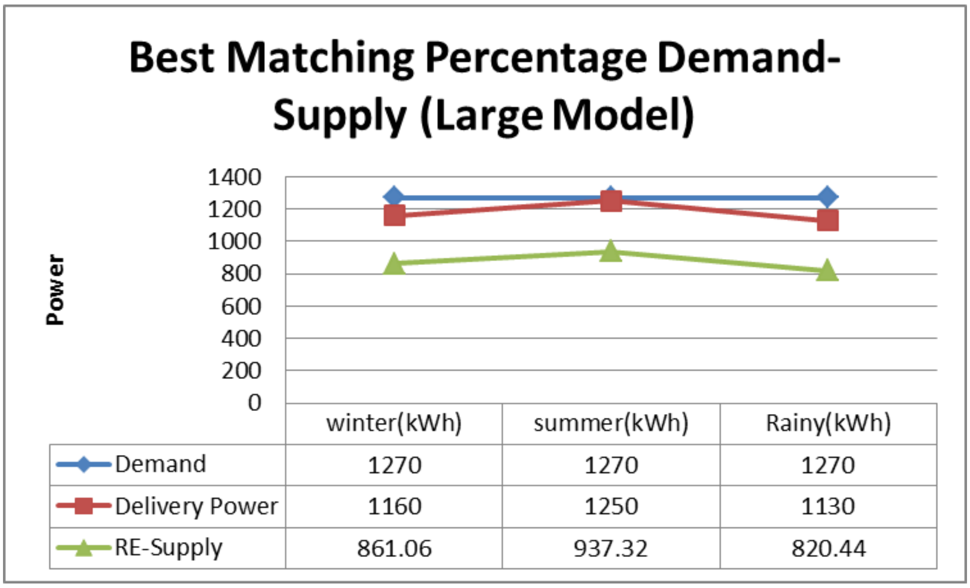


Figure 27: The best matching percentage demand and supply of large model.

8.1.3 Amount of Deficit Energy

In three bar charts below, it can be seen that all the best of matching percentage in every seasons of each model has the less deficit energy. In small model, the deficit energy of worst matching percentage is less than the case of best matching percentage by nearly 150 kWh. However, when the best matching percentages take-off the battery storage from the system, the deficit of energy is equal as worst case of matching percentage. In medium model, even though the deficit energy of worst matching percentage is not equal as the deficit energy of best case of matching percentage which take-off the battery storage from the system but it is almost to be zero as same as the best case. In large model, the deficit energy of best case matching model still appear because the best case model is not model which has the lowest of deficit energy but it has less of both surplus and deficit energy when compare with other categories. Hence, it implied that the storage energy which was installed into the system will be helpful for the renewable energy resource to supply the power on time as load required. However the best case of matching system may be not the best case for deficit energy because they still has deficit energy in the system but both of surplus and deficit energy is less than other categories in the same model.

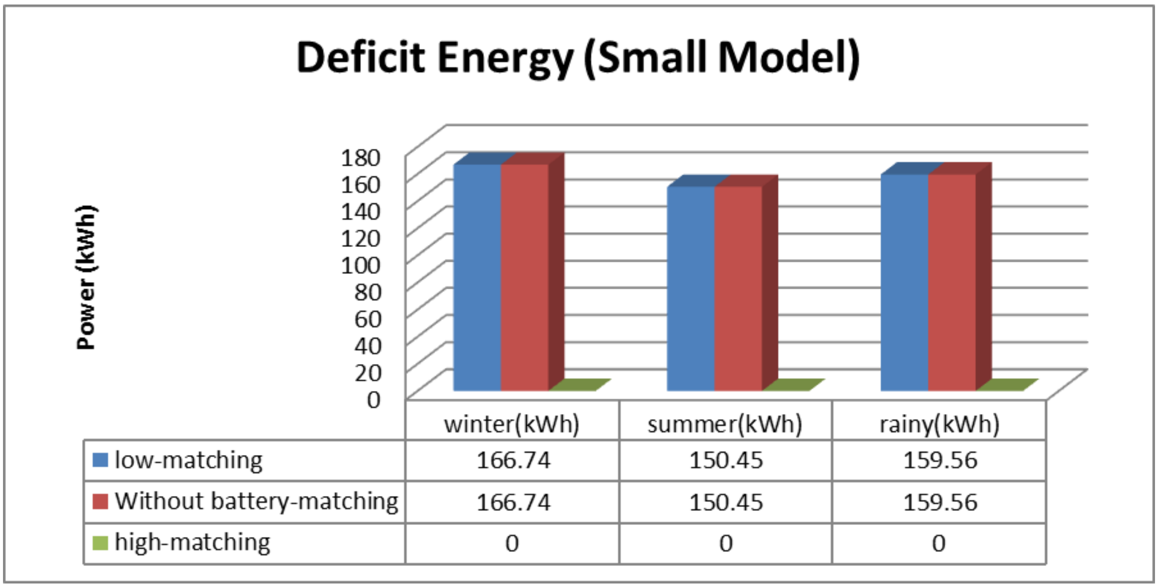


Figure 28: The deficit energy of small model.

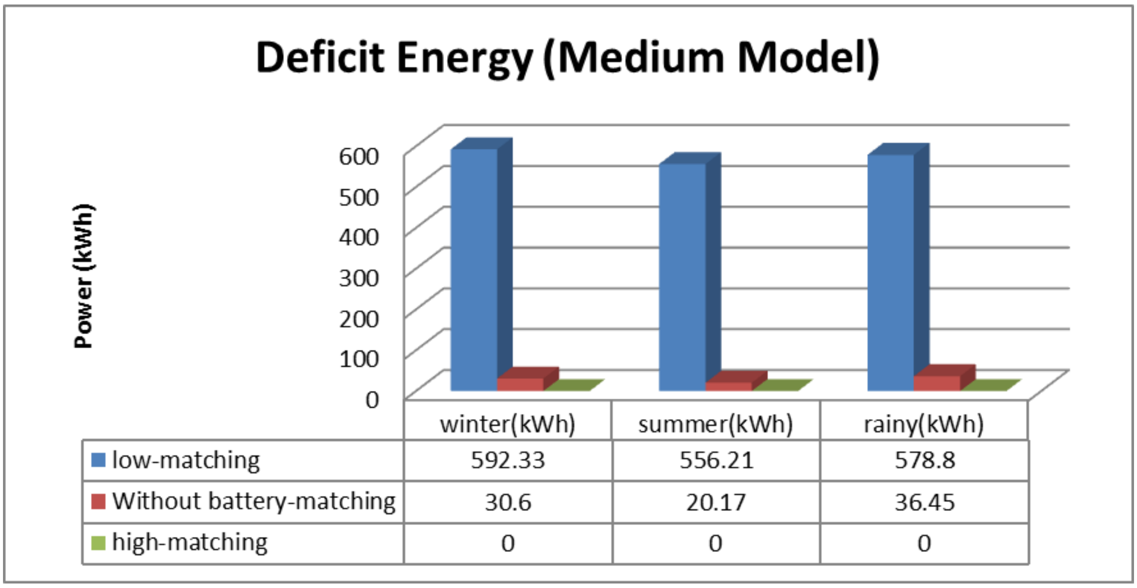


Figure 29: The deficit energy of medium model.

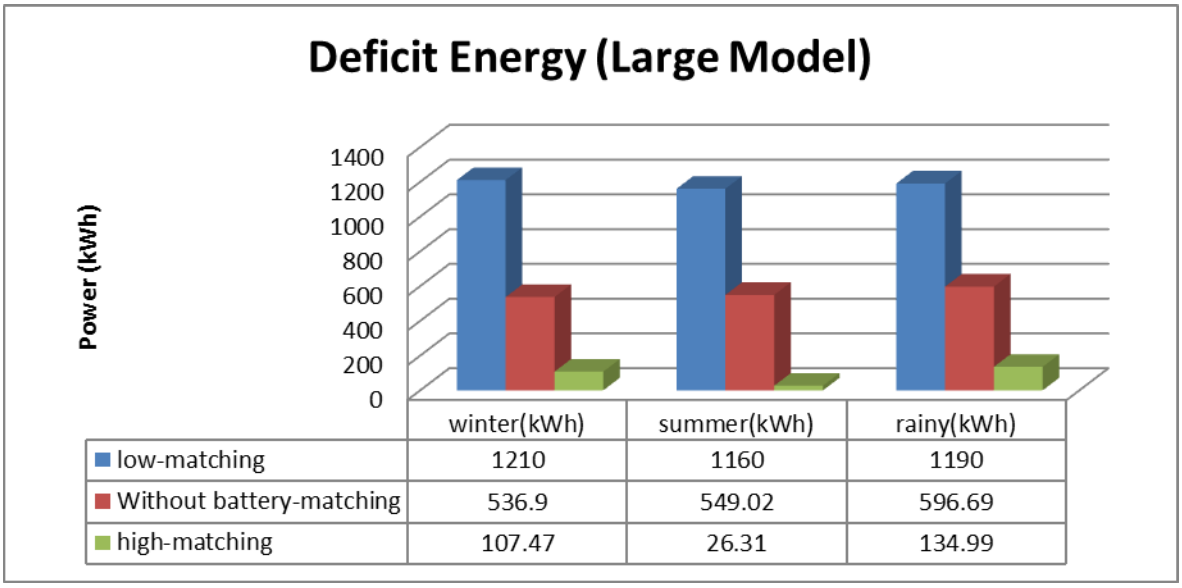


Figure 30: The deficit energy of large model.

8.1.4 Amount of Surplus Energy

In three bar charts below, it can be seen that all the best of matching percentage in every seasons of each model has the different amount of surplus energy. In small model, the surplus energy of worst matching percentage is higher than the best case of matching percentage in every season. However, when the best cases of matching percentages take-off the battery storage from the system, the surplus of energy is equal as worst case of matching percentage. In medium model, even though the surplus energy of best matching percentage is not equal as the surplus energy of best case of matching percentage which take-off the battery storage from the system but it is almost to be similar. In large model, the surplus energy of best case matching model still appear because the best case model is not model which has the lowest of surplus energy but it has less of both surplus and deficit energy when compare with other categories. Hence, it implied that the storage energy which was installed into the system will be helpful for the renewable energy resource to supply the power on time as load required. However the best case of matching system may be not the best case for surplus energy because they still has surplus energy in the system but both of surplus and deficit energy is less than other categories in the same model.

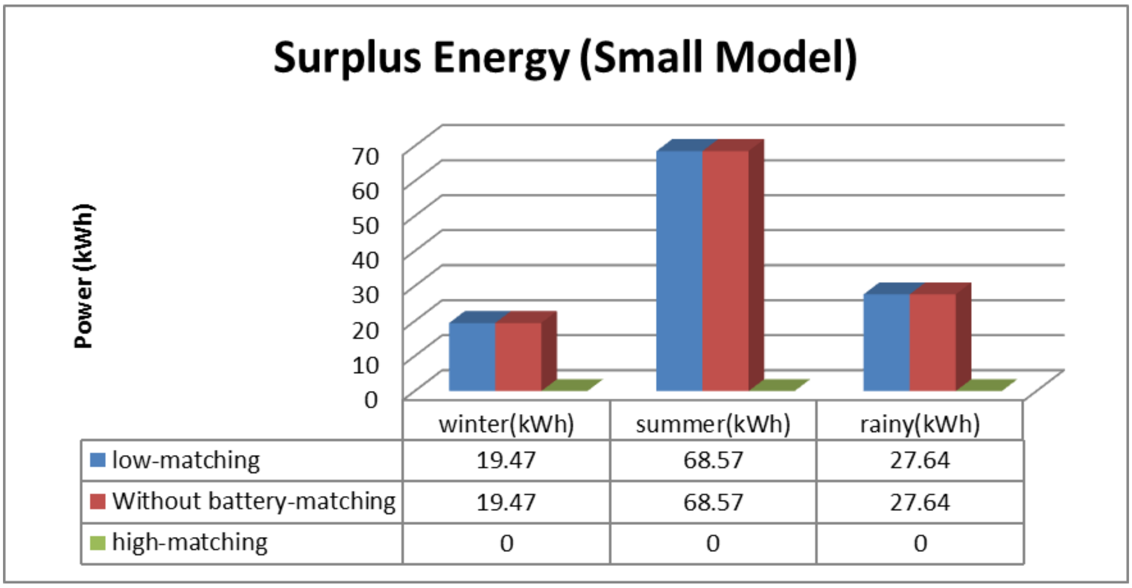


Figure 31: The surplus energy of small model.

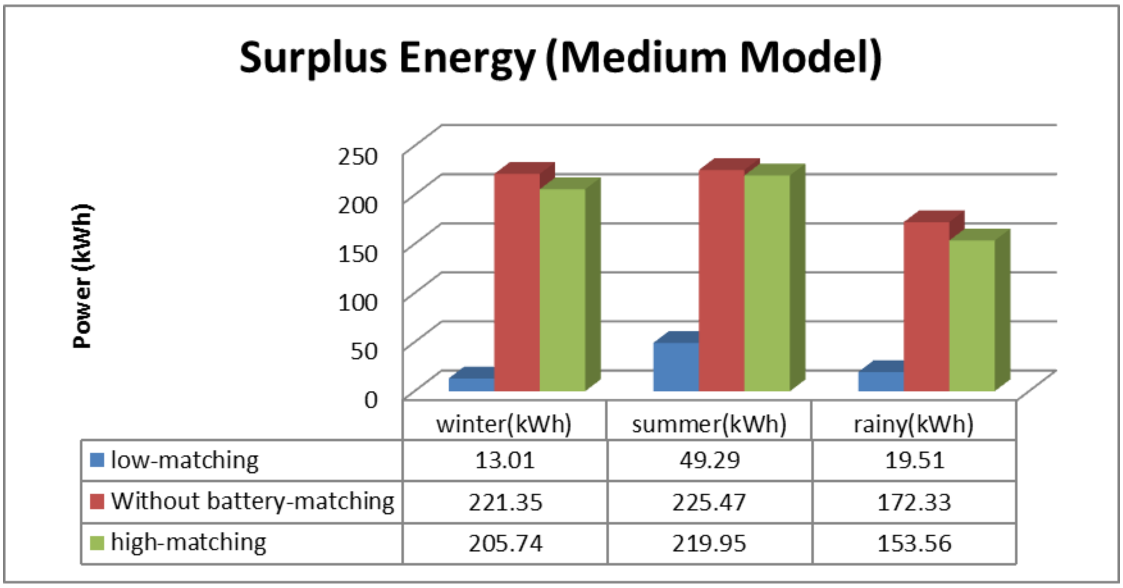
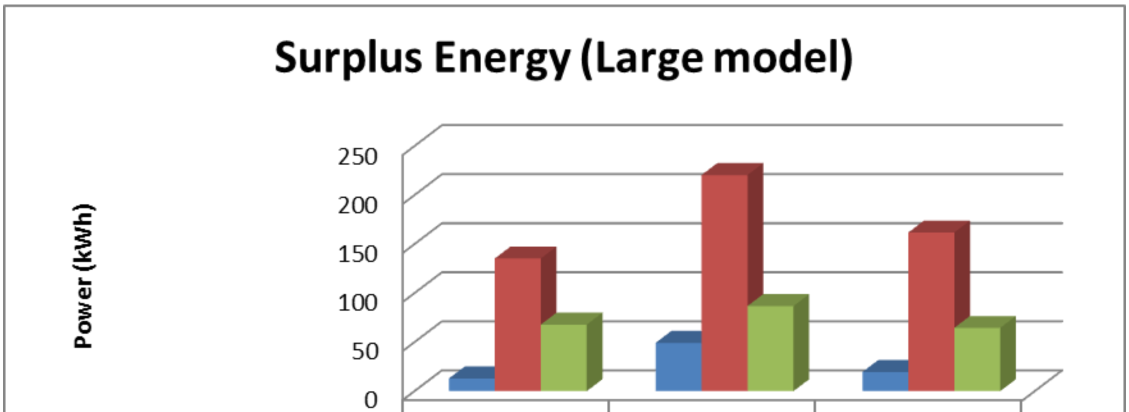


Figure 32: The surplus energy of medium model.



	winter(kWh)	summer(kWh)	rainy(kWh)
low-matching	13.01	49.29	19.51
Without battery-matching	135.37	220.46	161.83
high-matching	67.85	86.8	64.52

Figure 33: The surplus energy of medium model.

8.1.5 Cost

In the three figures below, it can be seen that the system cost of best matching percentage in every seasons of each model is most expensive systems when compare with the worst case of matching percentage and the best case which take-off battery from the system because the performance of the best matching percentage able to supply energy on time as load required better than both of these systems. However the huge system which able to generate huge power is not necessary to be the best model due to the load in their system may be not require the power as much as the system can produce. Hence the best system is not the huge system which able to produce highest energy or most expensive but it is able to support the load demand on time that made the systems is most effective.

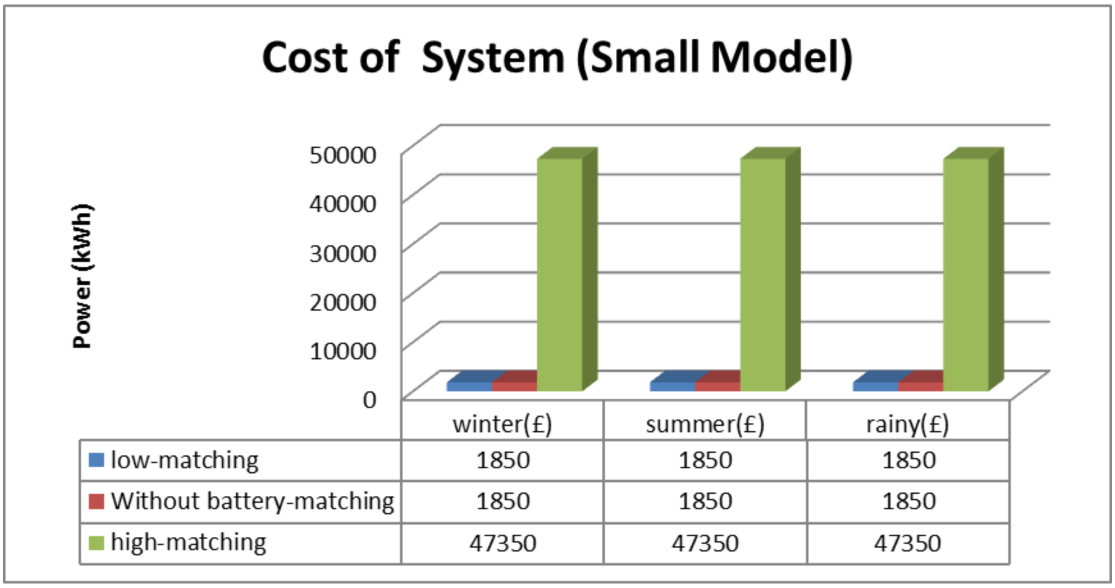


Figure 34: The cost of small model.

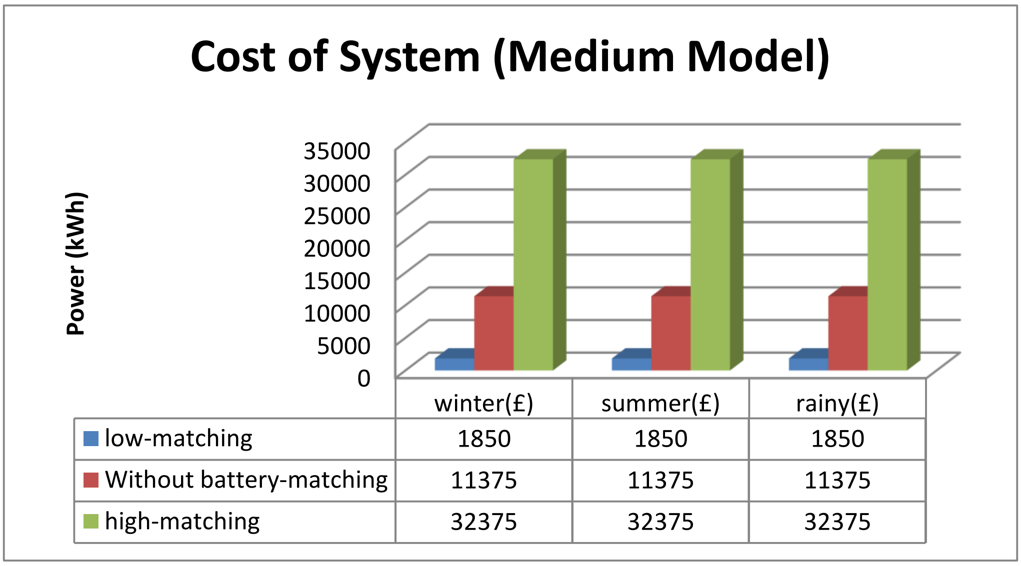


Figure 35: The cost of medium model.

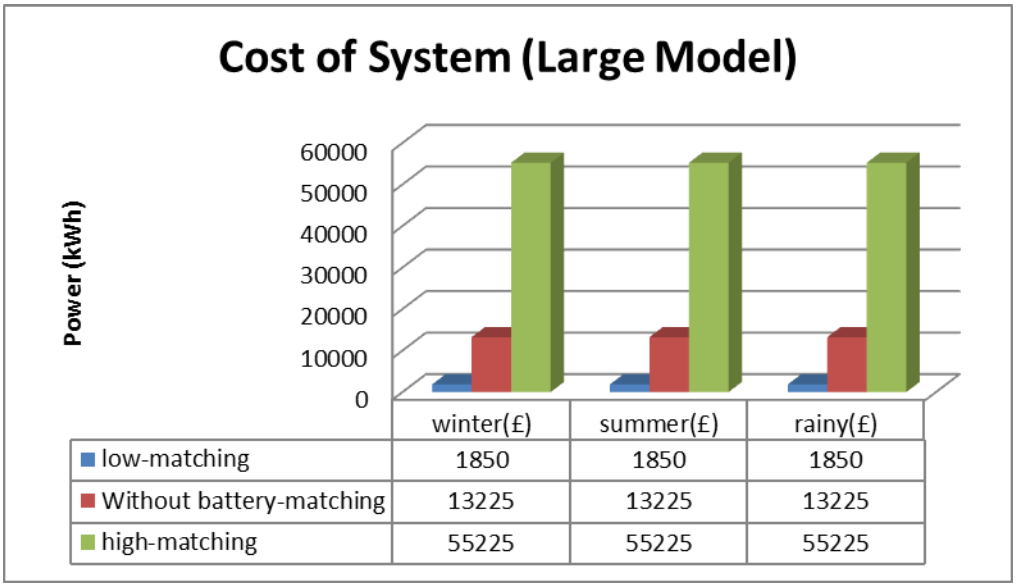


Figure 36: The cost of large model.

8.1.6 Overall

Overall, the integrated of renewable energy resource for electric vehicle charging station in Thailand has a highest matching percentage in different categories of renewable energy resource. For small model, the number of highest matching percentage is 100% which supply by 600 W of wind turbine and 140 unit of 2.58 kWh of battery storage. Whiles approximately 80% is the highest number of matching percentage for medium model which supply the energy by 35 unit of PV (100 W) and 70 unit of battery storage (2.58 kWh) and the highest matching percentage of large model is around 90% which supply energy by a wind turbine (600 W), 35 unit of PV (100 W) and 140 unit of batter storage (2.58 kWh). However, every model for this feasible study can use only 140 unit of PV (100 W) to supply the energy for supporting and surplus energy in every demand of case study and every period of season contrast with the system which has highest number of matching percentage for large model that has deficit energy about 134 kWh which cannot support the demand on time as the load required.

It can be implied that the system which has highest number of matching percentage is not the best case model. The owner of electric charging station should consider about the demand and supply of this system before installation. Especially the location in Thailand should consider for charging electric vehicle by PV panel directly because it can support the high demand as the system required for today and future. Moreover, it does not need to use the energy storage to keep the energy in the system that make the cost of systems will decrease as same as wind turbine supply. In summary, the biggest system for renewable energy producing is not always to be most effective system. However, an effective system does not need to be only a big system but also must be well optimized in the reliability of the system, demand and supply, capital cost, surplus energy as well.

Chapter 9: Conclusions & Further Work

9.1 Conclusion & Further Work

To success the proposal of this project as mention in the first chapter, this feasible study can reach those aims by using the program of merit to find the optimization of supply and demand of renewable energy resource which is integrated for electric vehicle charging station in Thailand. This report divided the case study into 3 model (small, medium, large) in every season of Thailand that make the result be useful for the realistic situation as much as possible that will be conclude as follow.

In this report, there was an example that can show the matching percentage in different seasons and load demand, which can help the user to adjust the system before implementing these on location in Thailand.

For small model, the number of highest matching percentage is 100% which supply by 600 W of wind turbine and 140 unit of 2.58 kWh of battery storage. Whiles approximately 80% is the highest number of matching percentage for medium model which supply the energy by 35 unit of PV (100 W) and 70 unit of battery storage (2.58 kWh) and the highest matching percentage of large model is around 90% which supply energy by a wind turbine (600 W), 35 unit of PV (100 W) and 140 unit of batter storage (2.58 kWh).

However, every model for this feasible study can use only 140 unit of PV (100 W) to supply the energy for supporting and surplus energy in every demand of case study and every period of season contrast with the system which has highest number of matching percentage for large model that has deficit energy about 134 kWh which cannot support the demand on time as the load required. It means that the system which has highest number of matching percentage may be not the best case model always. The owner of electric charging station should consider about the demand and supply of this system before installation. Especially the location in Thailand should consider for charging electric vehicle by PV panel directly at first because it can support the high demand as the system required for today and future. Moreover, it does not need to use the energy storage to keep the energy in the system that make the cost of systems will decrease as same as wind turbine supply.

From these simulation results, it can be concluded that using the program to evaluate the effectiveness of integrated renewable energy system will be helpful and useful for increasing the capacity and reliability of renewable energy system before installation at a real location as Thailand. As can see It is not only the size of renewable energy system that is most advantageous for generating the power from natural sources but the reliability to supply energy which can support the demand, the cost and technology of system, the climate of location and the surplus energy which the system can produce over the demand affects the effectiveness of integrated renewable energy system in the specific location as well.

In summary, this report has successfully investigated the technical and economic of installing renewable energy system for charging station in Thailand. This is based on different scales of load demand. As from the result of simulation, Thailand has the potential which can generate the energy from low wind speed turbine and PV for charging all model of electric vehicle. Especially with PV systems which can supply the energy to the load as system required without of battery storage. However if the system would to extend the station for more large scale, the energy storage will be need to install for keep and supply the energy on time. This report will be help to increase the system of renewable energy charging station in Thailand more effective. However, it will be more successful in the future, if the program can be improved by suggesting how to increase the percentage the load of this system or manage the system when the load will be increased in upcoming. Additional simulation quick charging for electric vehicle has been suggested for the case study in future work, including increasing the range of climate data for different locations and an extensive financial analysis as well.

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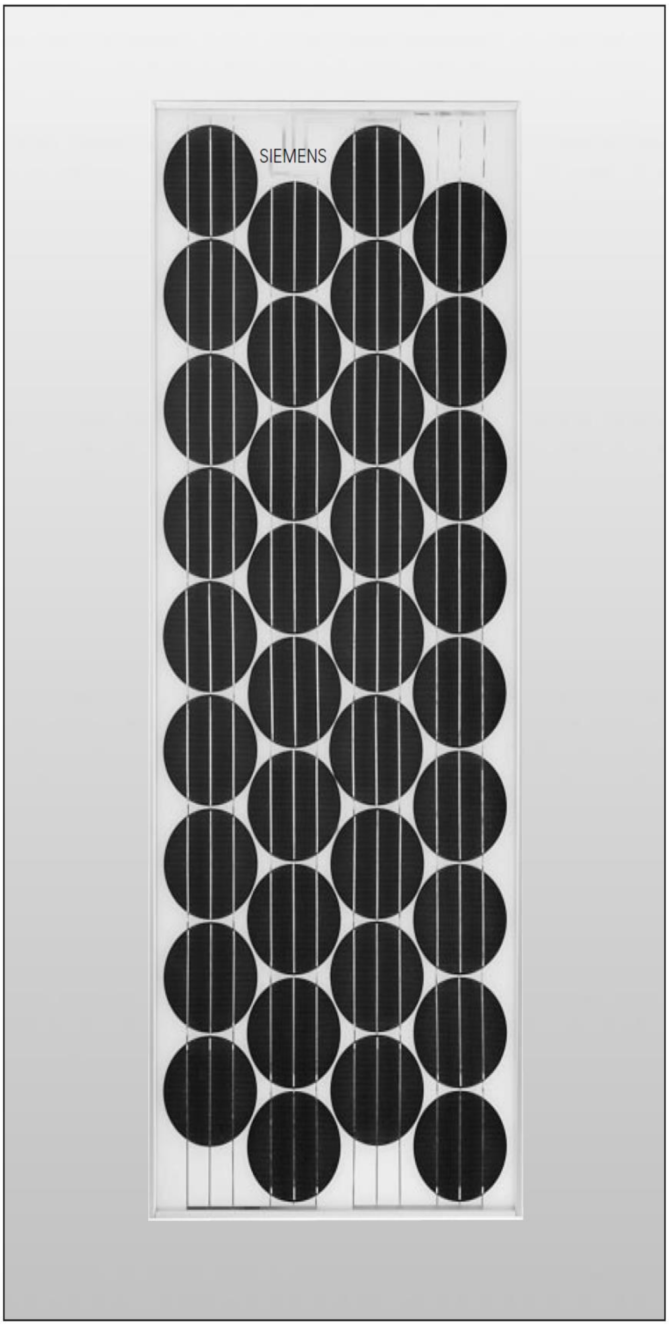
Appendix1 Solar Panel

SIEMENS

Solar module SR100



The Siemens SR100 solar (photovoltaic) module efficiently generates power by converting the energy contained in sunlight directly into electricity. It has no moving parts, operates silently, uses no fuel, and produces no waste. Built for long-term dependability, the SR100 has a twenty-five year limited warranty on power output.

PowerMax® technology

Siemens PowerMax® solar cells give the SR100 its outstanding energy performance characteristics. A proprietary process increases the ability of the single-crystal silicon cells to absorb light-energy and generate electricity efficiently. This enables the SR100 to produce power even in low light and deliver excellent performance under any operating condition.

Engineered for strength, durability and dependable operation in any climatic region, the SR100 is able to endure even severe environmental conditions and continue to generate power reliably and efficiently.

Siemens manufactures solar modules to exacting standards of quality in our ISO 9001 certified facilities. We control every phase of production to assure optimal product performance.

Outstanding power performance and reliability, along with easy wiring, installation and system expansion, make Siemens SR100 modules an excellent choice for many industrial, commercial and consumer solar electric power systems.

Solar module

Model:	**SR100**
Rated power:	**100 Watts**
Limited Warranty:	**25 Years**

Certifications and Qualifications

- UL-Listing 1703
- IEC 61215
- JPL Specification 5101-161
- MIL Standard 810

Intelligent module design

- All cells are electrically matched to assure greatest power output.
- Ultra-clear tempered glass provides excellent light transmission and protects from wind, hail, and impact.
- Torsion and corrosion resistant anodized aluminum module frame assures dependable performance, even through harsh weather conditions and in marine environments.
- Built-in bypass diodes (12V configuration) help system performance during partial shading.

High quality

- Every module is subject to final factory review, inspection and test to assure compliance with electrical, mechanical and visual criteria.
- PowerMax® single-crystalline solar cells deliver excellent performance even in reduced-light or poor weather conditions.
- Cell surfaces have Texture Optimized Pyramidal Surface (TOPS™) to process more energy from available light.
- Fault tolerant multi-redundant contacts on front and back of each cell provide superior reliability.
- Solar cells laminated between a multi-layered polymer backsheet and layers of ethylene vinyl acetate (EVA) for environmental protection, moisture resistance, and electrical isolation.
- Durable multiple-layered backing system provides the module underside with protection from scratching, cuts, breakage, and most environmental conditions.
- Laboratory tested and certified for a wide range of operating conditions.
- Ground continuity of less than 1 ohm for all metallic surfaces.
- Manufactured in ISO 9001 certified facilities to exacting Siemens quality standards.

Easy installation

- ProCharger™-CR junction box accepts conduit, cable or wire and is designed for easy field wiring.
- Lightweight aluminum frame and pre-drilled mounting holes for easy installation.
- Modules are factory configured for 12 volt operation and may be reconfigured in the field for 6 Volt operation.
- Modules may be wired together in series and parallel to attain required power levels.

Performance warranty

- 25 Year limited warranty on power output.

Further information on solar products, systems, principles and applications is available in the Siemens Solar product catalog.

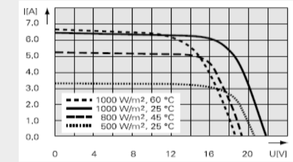
Siemens modules are recyclable.

Solar module SR100

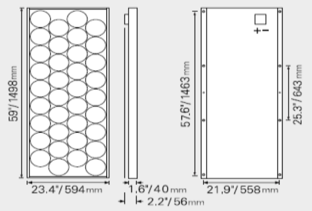
Electrical parameters			12V / 6V
Maximum power rating P_{max}		[Wp] 1)	100
Rated current I_{MPP}		[A]	5.6/11.2
Rated voltage V_{MPP}		[V]	17.7/8.85
Short circuit current I_{SC}		[A]	6.3/12.6
Open circuit voltage V_{OC}		[V]	22/11
Thermal parameters			
NOCT 2)		[°C]	45 ±2
Temp. coefficient: short-circuit current			2.1mA / °C
Temp. coefficient: open-circuit voltage			-.079V / °C
Qualification test parameters 4)			
Temperature cycling range		[°C]	-40 to +85
Humidity freeze, Damp heat		[%RH]	85
Maximum system voltage		[V]	1000 (per ISPRA/CEC) 600 (per U.L.)
Wind Loading	PSF	[N/m²]	50 [2400]
Maximum distortion 3)		[°]	1.2
Hailstone impact	Inches	[mm]	1.0 [25]
	MPH	[m/s]	52 [v=23]
Weight	Pounds	[kg]	24.0 [10.9]

1) Wp (Watt peak) = Peak power (Minimum Wp = 90 Watts) under standard test conditions:
Air Mass AM = 1.5
Irradiance E = 1000 W/m²
Cell temperature T_c = 25 °C
2) Normal Operating Cell Temperature at:
Irradiance E = 800 W/m²
Ambient temperature T_u = 25 °C
Wind Speed v_W = 1 m/s
3) Diagonal lifting of module plane
4) Per IEC 61215 test requirements
5) 12 Volt configuration

Voltage-current characteristic 5)

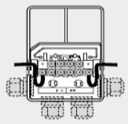


Module dimensions



Hole Diameter 0.26 inch (6.6mm)
Mounting hole dimensions are center to center

ProCharger™-CR Junction-box



Maximum cable diameter: 4mm²
Type of protection: IP44

Your address for photovoltaics from Siemens Solar

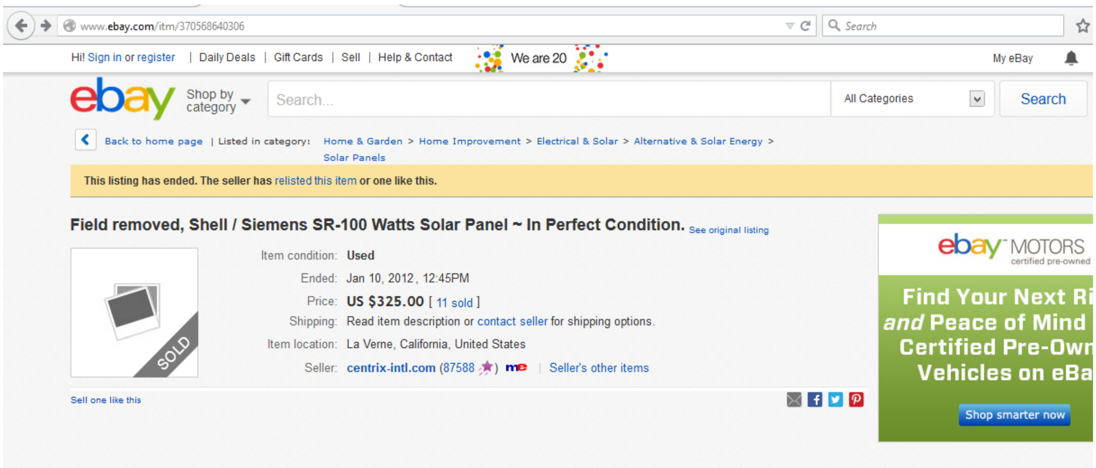
TÜV Rheinland ISO 9001

Siemens Solar GmbH
A joint venture of Siemens AG and Bayernwerk AG
Postfach 46 07 05
D-80915 München
Germany

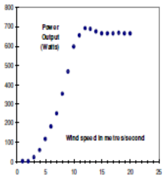
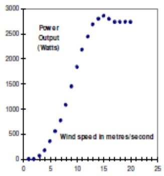
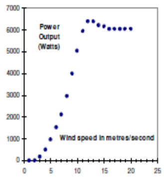
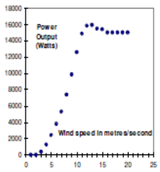
Siemens Solar Industries
P.O.Box 6032
Camarillo, CA 93011, U.S.A.
Web site: www.siemenssolarpv.com
E-mail: sunpower@solarpv.com
Tel: 805-482-6800
Fax: 805-388-6395

Siemens Showa Solar Pte. Ltd.
166 Kallang Way
Singapore 349248
Tel: 65-842-3886
Fax 65-842-3887

Order No. 020149, Rev. D



Appendix2 Wind turbine

Proven Wind Turbines - Technical Specification Sheet				
Rotor Speed Control Above 12m/s or 25mph) blades twist to limit power in response to high rpm *Low Speed Equals Durability*				
Marine Build Quality All machines *galvanised* steel, *stainless* steel & *plastic* components				
WT MODEL	**WT600 (0.6kW)**	**WT2500 (2.5kW)**	**WT6000 (6kW)**	**WT15000 (15kW)**
Cut In (m/s)[1]	2.5			
Cut Out m/s)	None!			
Survival m/s)	65			
Rated (m/s)	12			
Rotor Type	Downwind, Self Regulating			
No. of Blades	3			
Blade Material	Polypropylene	Polypropylene	Wood/Epoxy	Glass Polypropylene
Rotor Diameter(m)	2.55	3.5	5.5	9
Generator Type	Brushless, Direct Drive, Permanent Magnet			
Battery charging	12 , 24 ***or*** 48V DC	24 ***or*** 48V DC	48V DC	48V DC
Grid connect with *Windy Boy Inverter*	230Vac 50Hz ***or*** 240 Vac 60Hz	230Vac 50Hz ***or*** 240 Vac 60Hz	230Vac 50Hz ***or*** 240 Vac 60Hz	230Vac 50Hz ***or*** 240 Vac 60Hz
Direct Heating	n/a	120Vac ***or*** 240Vac	120Vac ***or*** 240Vac	120Vac ***or*** 240Vac
Rated RPM	500	300	200	140
Annual Output[2]	900-1,500 kWh	2,500 – 5,000 kWh	6,000 – 12,000 kWh	15,000 – 30,000 kWh
Head Weight (kg)	70	190	500	1100
Mast Type	Tilt-up, tapered, self-supporting, no guy wires (Taller guyed towers also available on request)			
Hub Height (m)	5.5 ***or*** 12	6.5 ***or*** 11	9 ***or*** 15	15
WT Found (m)	1x1x1 ***or*** 1.6x1.6x1	1.6x1.6x1 ***or*** 2.5x2.5x1	2.5x2.5x1 ***or*** 3x3x1.2	3.7x3.7x1.2
Winch Found (m)	0.65x0.65x0.65	0.65x0.65x0.65 ***or*** 1x1x1	1x1x1 ***or*** 1.5x1.5x1	1.5x1.5x1.2
Tower Weight (kg)	120 ***or*** 350	241 ***or*** 445	360 ***or*** 656	1200
Mechanical Brake	No	Yes	Yes	Yes
Noise[3] **@ 5m/s**	35 dBA	40 dBA	45 dBA	48 dBA
Noise @ 20m/)	55 dBA	60 dBA	65 dBA	65 dBA
Rotor Thrust (kN)	2.5	5	10	26
Sample of UK commercial customers	British Telecom / Scottish Youth Hostel Association / British Rail / Irish Lighthouse Authority UK Lighthouse Authority / T-mobile /Orange / Saudi Aramco / Shell / B&Q / BP / Sainsbury's			

[1] 1 metre/second = 2.24 miles per hour=3.6kph.
[2] Based on an ideal site and average wind speed of 5m/s - please refere to our website at www.provenenergy.com for further information
[3] All readings taken with an ATP SL-25 dBA meter at the base of the tower at a height of 1.5m.
* A car passing 20m away @ approx 40 mph is 70-80dBA

PROVEN ENERGY LTD, WARDHEAD PARK, STEWARTON, AYRSHIRE, KA3 5LH
TEL: ++44 (0) 1560 485 570 FAX: ++44 (0) 1560 485 580 EMAIL: info@provenenergy.com
p:\sales & marketing\literature & promotional\info pack\2005\seperate infopack files\information pack 05c.doc

Domestic Roof-Mounted Wind Turbines

The Current State of the Art

a publication for the RES-e project

support tool for small wind development

mid wales energy agency
asiantaeth ynni canolbarth cymru

Appendix

<u>Other Small UK Wind Turbines</u>

The main focus of this document is on domestic-scale rooftop systems. There are larger rooftop systems which would be more appropriate for larger buildings such as schools or other public buildings with the capacity to bear the necessary forces on a larger turbine.

A report on domestic roof-mounted wind turbines

Appendix

<u>Other Small UK Wind Turbines</u>

The main focus of this document is on domestic-scale rooftop systems. There are larger rooftop systems which would be more appropriate for larger buildings such as schools or other public buildings with the capacity to bear the necessary forces on a larger turbine.

The main company involved in this field is Proven Energy of Stewarton, Scotland. They install roof-mounted systems of 600W, 2.5kW and 6kW, and a larger tower-mounted 15kW turbine.

As a guide, the table below indicates typical payback times assuming use of a clear-skies grant (up to 50% for local authorities, community groups etc, smaller for domestic users) and an average windspeed of 5.5ms^{-1}. Costs include tower, VAT and a surcharge of 15% to cover installation. This is an indicative value only. Payback time has been calculated approximately against an equivalent cash investment.

For the 2.5kW and 6kW turbines a ROC payment has been included at 4p/kWh. Full load matching is also assumed, as for larger generators it is more usual to have an export agreement with a DNO.

	Cost (£)	Annual Output (kWh)	Payback time (yrs)
0.6kW (domestic)	1850	1315	23.3
2.5kW (community)	3760	4383	9.5
6.0kW (community)	7320	10520	7.7

A list of UK-based turbine manufacturers and their contact details follows:

Manufacturer	Turbine Size (kW)	Website	Telephone
Iskra	5	www.iskrawind.com	0115 841 3283
Gazelle	20	www.mkw.co.uk	0191 413 0012
Proven	0.6-15	www.provenenergy.co.uk	0156 048 5570
Swift	1.5	www.renewabledevices.com	0131 535 3301
Windsave	1	www.windsave.com	0141 353 6841

Appendix3 Battery