EFFECTS OF SEASONAL CLIMATE VARIATIONS ON HYBRID POWER SYSTEM USING POWER PINCH ANALYSIS

by

Muhammad Syu`aib Bin Mohamed Yahaya
15492

Dissertation submitted in partial fulfilment of

the requirements for the

Bachelor of Engineering (Hons)

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CERTIFICATION OF APPROVAL

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Approved by,

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(Dr. Nor Erniza Binti Mohammad Rozali)

UNIVERSITI TEKNOLOGI PETRONAS
BANDAR SERI ISKANDAR, PERAK.
September 2015

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgement, and the original work contained herein have not been undertaken or done by unspecific sources or persons.

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MUHAMMAD SYU`AIB BIN MOHAMED YAHAYA

ABSTRACT

The global warming nowadays is one of the result from burning of fossil fuels for electricity power generation. Due to this world problem, the world shift on to the more environmental power generation which is by applying Hybrid Power System (HPS) which use renewable energies as the power source. The challenge of using Renewable Energy (RE) is the climate variation which need to be considered in the HPS design. In this project, the performance of HPS during summer and winter for a site located in Toronto, Canada with population around 30,000 has been studied. The factors been looking forward in design the HPS are the Minimum Outsource Electric Source (MOES) and the Available Excess Electricity for the Next Day (AEEND) at the end of the day for both season by using the new approach of analysis which is Power Pinch Analysis. As a result, the demand situation are taken based on summer as the demand are higher than winter season while the power generation taken based on winter season.

ACKNOWLEDGEMENT

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Special thanks to the examiners for the Proposal Defence and Poster Presentation who being very supportive and guiding me through my mistake to make their project even better. Not to forget coordinator for her continuous monitoring and guidance. Last but not least, thanks to my friends, and to those who assisted me directly or indirectly in helping and supporting me to complete my project. Thank you very much, may ALLAH repays your kindness.

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CHAPTER 1

INTRODUCTION

1.1 Background

Energy is an important element in our daily life. One of the energy that is widely used is electrical energy. The electric energy is used to function any machine. Glowing light bulb or rotate a motor are generated by electric (Meier, 2006). The electrical energy is widely used in industry and household appliances (Diesendorf, 2014). Electrical energy is important but there is a problem about this energy, as it is not accessible in every place such as rural area and also may be caused by insufficient power generation. Globally, there are still some of the developing countries are living without access to electricity. The most affected party with insufficient electrical energy is the industrial as they suffered losses, and the power cut almost brought industries to stop from operating as they gain more losses that profit. All the economic growth and the human development sustainability cannot be achieved with such insufficient electricity (Mohammad Rozali N.E., 2014).

In order to overcome the power supply to the rural area where the electrical grid cannot reach, a new technology of electricity generation had been introduced which called as renewable energy (RE) technology. The possible solution to overcome this problem is to combine the different RESs, such as solar, wind, geothermal, and biomass as a hybrid renewable energy system (Janghorban Esfahani et al., 2015). The generation of energy from RE also had increased from years. For example, the wind power grow about 20% in Denmark, while the share of renewable energy from 3.1% to 16.8% in Germany (Wüstenhagen et al., 2012).

HPS is combines two or more sources, typically renewable energy-based electricity generators. HPS may also consists of power storage system, and may has diesel electric generator as backup for electric generation (Ho et al., 2013).

1.2 Problem Statement

The discovery of RE is a good technology because it is more environmental friendly. The conventional electricity generation systems have been established based on the fossil fuel fired generation technologies. As a result, the electricity generation and consumption are contributing to significant portion of the global Greenhouse Gas (GHG) emissions where this type of gas can contribute to global warming (Abdullah et al., 2015). Growing concern over greenhouse gas emissions and its impact on climate change have increased significantly the role of renewable energy resources (Ho et al., 2013). Interest in renewable energy sources (RESs) as a means of overcoming the dependency of the power generation on fossil fuels and the subsequent climate change (Janghorban Esfahani et al., 2015).

Although RE is a very good technology and environmental friendly but there are some challenge if we using RE only as the power generation. RE are classified as uncontrolled sources which produce power that are unpredictable and independent of human action (Paska, 2009). Besides, the RE generation is stochastic in nature (Abdullah et al., 2015). The intermittent and unpredictable availability of some renewable energy sources create a new challenge for matching electricity generation and consumption (Chen et al., 2014).

For example, the production of energy by using solar energy is uncertain because of the weather variation. The same occurs to the production of energy by using wind turbine where the weather variations always become the challenge. The production of electrical energy by REs are varies as there are climate changes and seasonal climate variations. The intermittency greatly affects the systems performance because electricity should be produced and supplied instantaneously when needed (Mohammad Rozali N.E., 2014). In the event of insufficient energy source to supply the demand, electricity needs to be imported from external sources such as from power grid or the electric need to be generated by the backup diesel generator.

Follow is the problem statement of this work:

> The study on effects of climate changes of winter season and summer season on the performance of hybrid power system in a part of Toronto, Canada by using power composite curve of power pinch analysis.

1.3 Objective of Study

The objective of this project is to study the effects of HPS performances for different climates which are winter and summer seasons on the performance using PoPA.

1.4 Scope of Study

This study focussed on the performance of HPS in winter and summer season. The approach method applied in this research is the Pinch Analysis. The scope of this research includes;

1. Use Power Composite Curve (PCC) to determine of the minimum outsourced electricity source (MOES) and maximum amount of excess electricity for the next day (AEEND) in the hybrid power systems for the first day.
2. Use Continues Power Composite Curves (CPCC) to determine the daily MOES needed to be purchased or generated by diesel power generation during normal operations in the hybrid power systems.
3. To analyse the performance of HPS in winter and summer seasons.

CHAPTER 2

LITERATURE REVIEW AND THEORY

2.1 Hybrid Power System (HPS)

Continual development of hybrid power systems (HPS) technology has led to the extensive research in this area for the past decades. HPS generally consists of two or more types of generation sources that are combined to produce electricity. The generation sources is mainly generated by the RE sources which are solar and wind energy with a diesel generator as a power backup (Mohammad Rozali N.E.,, 2014). Electricity generation using RE generation technologies is one of the most practical alternatives in order to achieve national and international Greenhouse Gas (GHG) emission reduction targets (Abdullah et al., 2015).

A HPS consists of RE sources as electricity producer, a power conditioning system and a power storage which store excess unused electricity generated from RE and discharge electricity when needed. The examples of power storage can be a battery bank, pumped-hydro, compressed air or thermal storage. (Mohammad Rozali et al., 2013a).

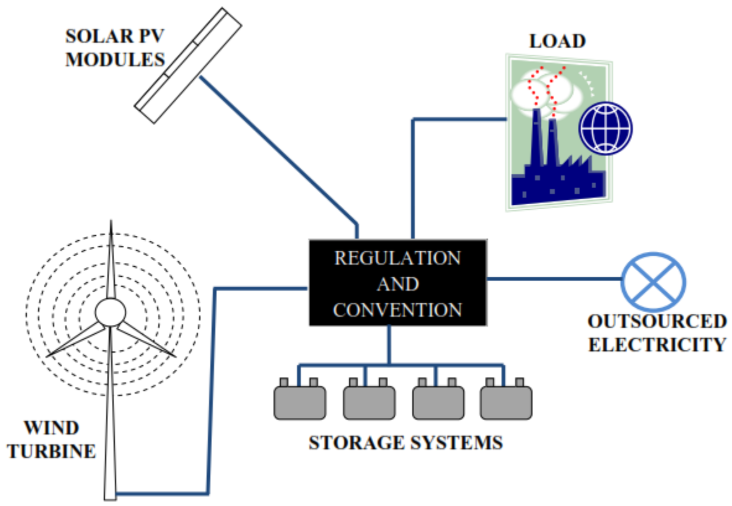

FIGURE 2.1 A hybrid power system (Mohammad Rozali N.E., 2014)

From Figure 1, it shows that an example of HPS where this HPS use wind energy and solar energy or solar PV module as its REs. The electrical energy had been centralized and manage by the regulation and convection which manage the input of electrical energy which came from the RE and the outsourced electricity, then manage the storage of electricity and supply the electricity to the consumer.

2.2 HPS Performance on Seasonal Climate Variation

The Earth is spinning and move around the sun on its axis. By this natural phenomena, there are changing of night and day around the world where the area expose to the sun have the sunny day while the area not exposed to sun will experienced night (Williams, 2014). There are also some parts on Earth experience the 4 season's climate change due to the rotation and spinning of the Earth. The Earth can be divided into 3 parts, the pole which cover North Pole and South Pole, the equator and lastly the rest is the other parts. The poles area will experience one sunrise and one sunset in each year where this makes these area experiences 6 months of sunny day and six month of night. The equator does not experience extreme climate change as they are located at the equator. The last part is the parts nor of equator and poles. This parts at the Earth will experience the 4 season climate change consist of summer, winter, spring and autumn. The most contradict season is between summer and winter where this is between a cold season and a hot season (Cain, 2009).

The climate seasonal variation affects the performance of HPS where the energy is produces by REs of wind and solar source. The best condition of energy production by the solar which using PV panel is during the summer where in this timeframe, the maximum exposure of sun is experienced while during winter season, the production of energy by solar is not the best way. The same situation occur to the wind where the condition is vice versa to the solar (Albadi et al., 2010).

2.3 Power Pinch Analysis (PoPA)

Pinch Analysis is a method widely used in process integration for minimising energy consumption by calculating minimum energy consumption and achieving them by optimising heat recovery systems, energy supply methods and process operating conditions. Pinch analysis is the key approach to design inherently energy-efficient plants, where energy use in processes, whether large or small is optimised (Kemp, 2007). The pinch analysis technique originally found applications in heat exchanger network design for the process industry (Ho et al., 2013). PoPA is important where this method in process design is used to reduce the cost of power system if it design to work more than it need to work. PoPA is used in HPS to ensure optimal design of HPS by considering crucial aspects including cost factor and system reliability. Various methods have been proposed for the design of such systems including model based optimisation or mathematical programming (Ho et al., 2013).

The PoPA concept is to optimise the transfer of electricity from power sources and battery to power demands. PoPA can be used to determine the minimum required external electricity source and wasted electricity sources (Janghorban Esfahani et al., 2015). There are two common numerical techniques had been introduced by PoPA known as the Power Cascade Analysis (PoCA) and the Storage Cascade Table (SCT) while the common graphic method is the Power Composite Curve (PCC). The difference between the graphical techniques the numerical tools is graphical techniques provide useful visualisation insights while numerical tools enable more rapid and precise allocation of power as well as the determination of electricity targets (Mohammad Rozali et al., 2013b).

2.4 Research Gap

Systematic strategies are proposed in this research in order to address all of the research gaps. The existing research are using others method such as mathematical modelling, software or programming. Moreover, the existing research are more focusing on to the optimization of the HPS without considering the effect of seasonal climate changes. In this study, the gap will be addressed as the performance of HPS will be studied on winter and summer season by using power pinch analysis.

CHAPTER 3

METHODOLOGY OF PROJECT

3.1 Project Flow Chart

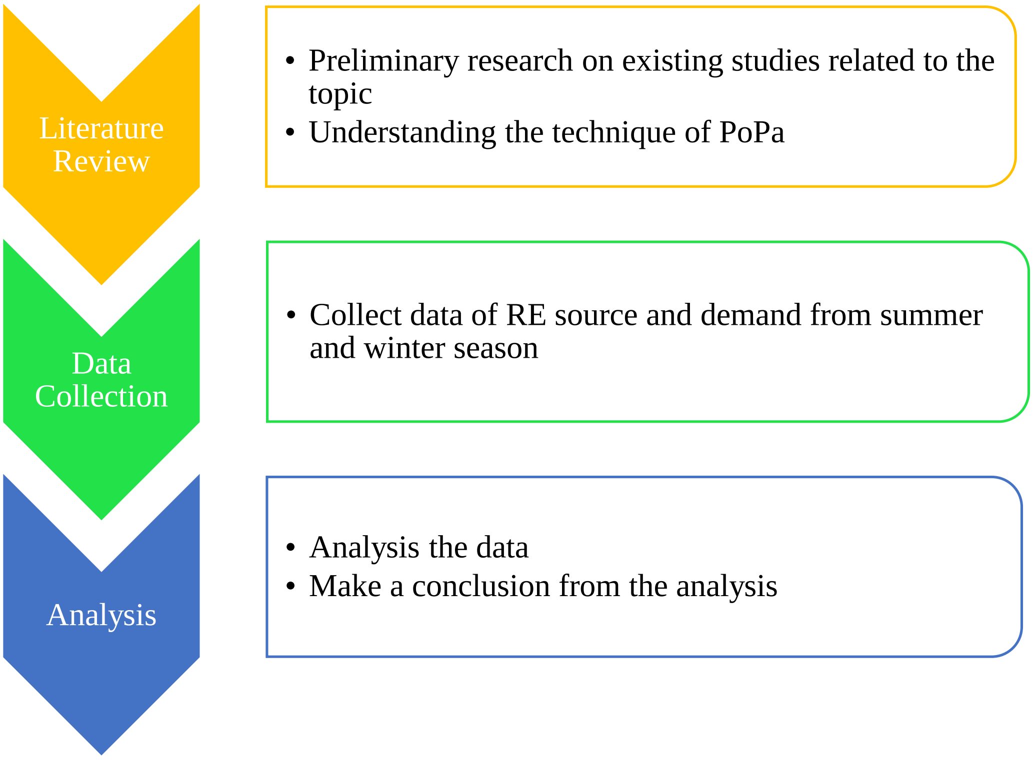

FIGURE 3.1 Methodology to complete the research

Figure 3.1 shows the flowchart that need to be followed in order to complete the research. At the beginning, the literature review is needed by doing preliminary research to understand the technique to be used in this research which is PoPA. After that, the data of production of electricity by RE and the demand of electricity in winter and summer seasons for a location were collected. Lastly the data was analysed using PoPA and the effects of each were identified.

3.1.1 Data Collection

The first step of this work involves data extraction of a system's sources (resource availability) and demands (resource requirements) from two climate seasons which are summer and winter season. These two season had been selected as the sun radiation were drastic change (Williams, 2014). In the case of hybrid power systems, power sources are the instantaneous onsite electricity generation from the available renewable energy sources such as solar photovoltaic, wind or biomass. The power demands represent equipment electricity consumption that can be determined from equipment power ratings. The power sources and power demands are recorded at the time they are available (Wan Alwi et al., 2012).

The power source from RE which are from solar and wind can be calculated from the locations' solar insolation and wind speed. In order to calculate the power generated by solar, the equation (Wan Alwi et al., 2012) is ;

$$P_S = I(t) \times A \times \eta_S \quad (1)$$

Where;

P_S is the power generated by solar, kW

$I(t)$ is the insolation data at time t, kW/t^2

A is the area of the solar panel, m^2

η_S is the efficiency of the solar panels.

While to calculate the power generated by the wind turbines was calculated using equation as follows;

$$P_W = \frac{1}{2} \times \rho \times v(t)^3 \times A \times C_P \tag{2}$$

Where;

P_w is the power generated by wind turbine, kW

ρ is the density of air, kg/m^3

$v(t)$ is the wind speed data at time t, m/s

A is the area of the swept area of the rotor, m^2

C_p is the efficiency of the wind turbine

The data for each type of power generation as well as the demand data need to be collected hourly. Same situation need to be considered for both seasons where one day will be chosen for each season. The daily power generation and power demand profiles are identical throughout the season. The uncontrollable and unpredictable characteristics of the data should be considered in deriving the limiting power data. Based on the time series meteorological data for a location to forecast the availability of the REs, limiting power data is assigned to the minimum available power sources and maximum load demand for every time intervals.

3.1.2 Analysing PCC and CPCC

PCC is used to determine the maximum power transfer from power sources to power demands, the Minimum Outsourced Electricity Supply (MOES) and Available Excess Electricity for the Next Day (AEEND) for storage.

The PCC can be constructed as follows:

1. A graph of y-axis and x-axis was plotted based on where electricity generation or consumption in a day where these axis represent the time scale from ‘0’ to ‘24’ h and the electricity generation or consumption in kWh in a day.
2. The sum of electricity sources in a given time interval used to form composite source
3. Step 2 was repeated for the demand
4. The source composite curve was shifted until it touches the demand composite curve which made the demand composite curve at the left side.
5. The MOES needed for the start-up had been determined by the excess demand line below the pinch point while the AEEND is represented by the excess electricity source above the pinch.

CPCC were plotted by combining the end point of composite source of PCC to the first point of composite curve of the duplicate PCC. All the graphs were plotted to study the behaviour of HPS on different climate season. The CPCC is constructed for the considered seasons, i.e. summer and winter. Apart from the seasons, CPCC for average data was also plotted to study the differences between summer, winter and average data. The results from the CPCC were extracted and compared to determine the effects of climate on the performance of HPS.

3.2 Gantt chart and Key Milestone

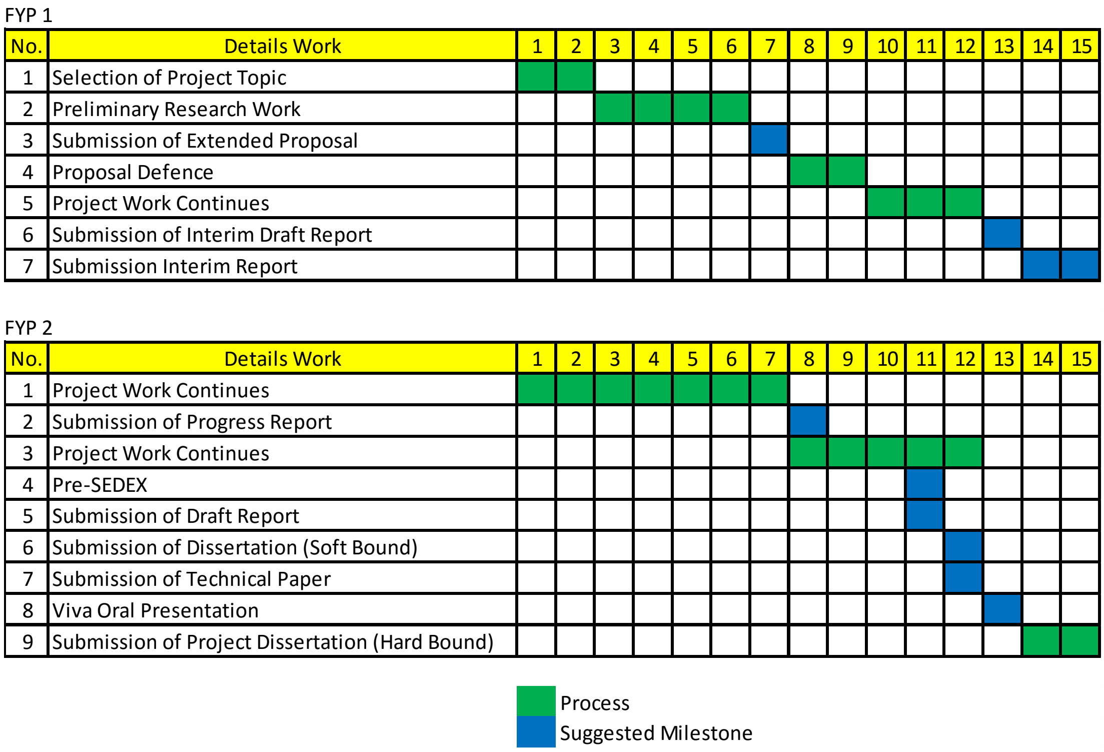

FIGURE 3.2 Gantt Chart

Figure 3.2 shows the Gantt chart that need to be followed in order to complete the project. The suggested Gantt chart is very important to make sure the project will going smooth from scratch into a complete perfect work

CHAPTER 4

RESULTS AND DISCUSSION

This chapter starts with data collection following by the constructions of graphs of individual power sources, PCC and CPCC and end with discussion.

4.1 Results

The case study is a location in Toronto, Canada which have population of 31,900 people where this considered the micro grid. A micro grid is a small-scale power grid that can operate independently or in conjunction with the area's main electrical grid. Any small-scale localized station with its own power resources, generation and loads and definable boundaries qualifies as a micro grid (Stadler et al., 2016).

The data collected during winter is on 10th January 2015 while during summer seasons where the chosen date during winter is on 10th July 2015. Figure 4.1 and Figure 4.2 shows power generated by solar on respective season while Figure 4.3 and Figure 4.4 shows power generated by wind turbine where these graphs were plotted to shows the behaviour of power generation depend on season. These power generated graphs were plotted based data collected in Table 4.1 to Table 4.3. Table 4.1 shows the data collected for winter. From the data obtained, the individual power source and demand was constructed as shown in Figure 4.5. After that, PCC was constructed in Figure 4.6 based on the individual power graph. Lastly, the CPCC was constructed in Figure 4.7 based on PCC. The same steps were repeated for summer case and average case study. For summer scenario, the data was tabulated in Table 4.2 while for average in Table 4.3. The individual power graph for summer constructed as shown in Figure

4.8 and Figure 4.11. The PCC and CPCC for summer constructed and shown in Figure 4.9 and 4.10 while for average is 4.12 and Figure 4.13.

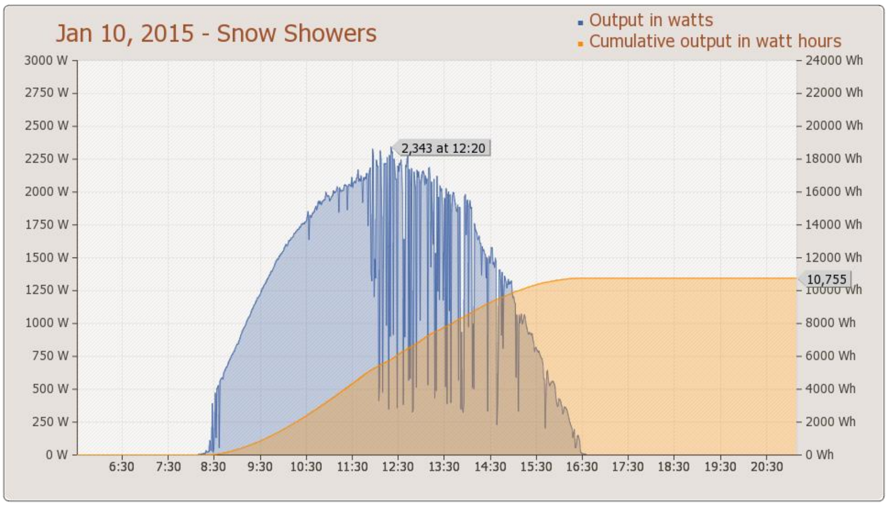

FIGURE 4.1 Solar Power generated during winter (Egelstaff J., 2015)

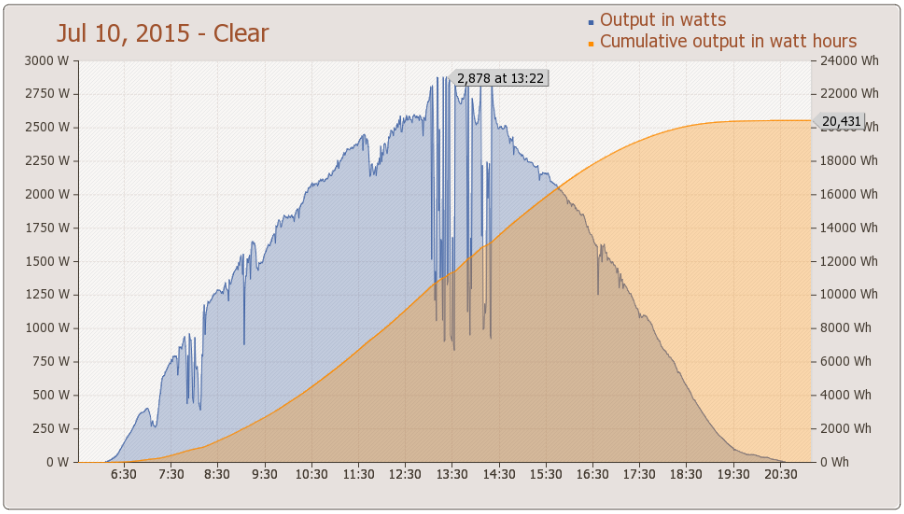

FIGURE 4.2 Solar Power generated during summer (Egelstaff J., 2015)

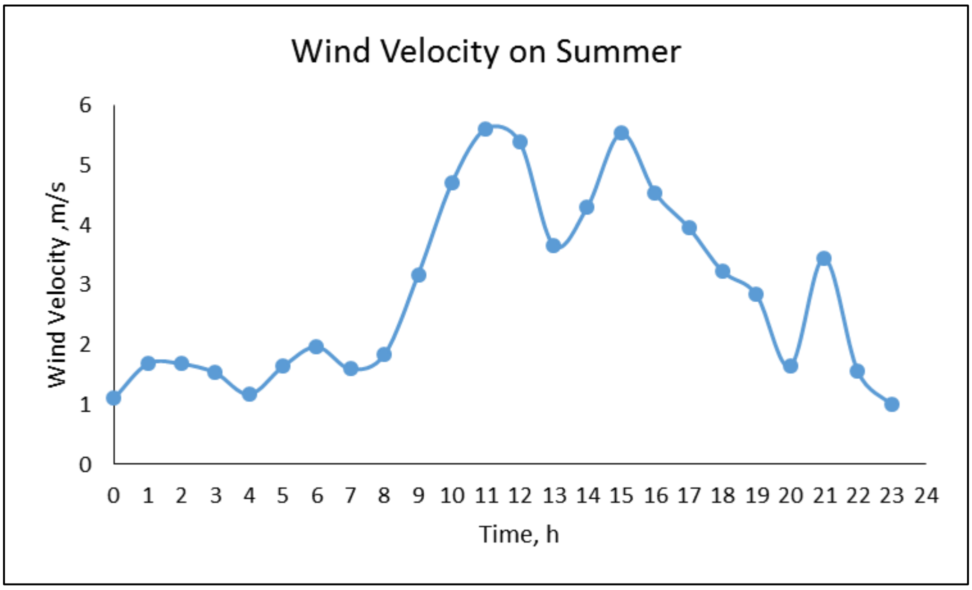

FIGURE 4.3 Wind Velocity during summer

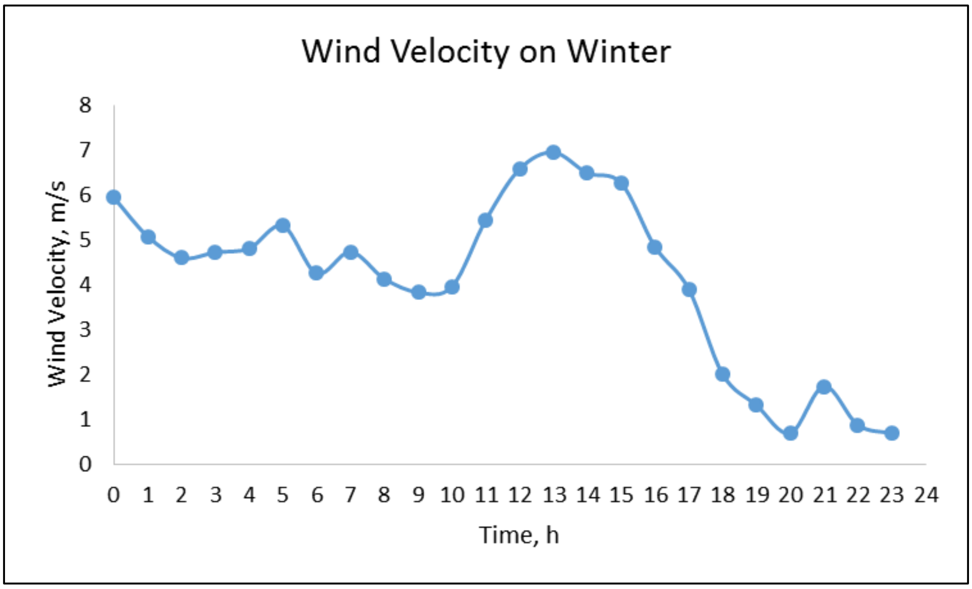

FIGURE 4.4 Wind Velocity during winter

TABLE 4.1 Data of REs and Demand During Winter

Time	PV Power (kW)	Wind Power (kW)	Total Power Generated (kW)	Demand Power (kW)
0-1	0.000	200600.0	200600.0	181489.0
1-2	0.000	170400.0	170400.0	176473.0
2-3	0.000	137100.0	137100.0	170126.0
3-4	0.000	124800.0	124800.0	166947.0
4-5	0.000	95400.0	95400.0	165022.0
5-6	0.000	108500.0	108500.0	165506.0
6-7	0.000	86300.0	86300.0	166727.0
7-8	0.000	137200.0	137200.0	169741.0
8-9	0.026	156300.0	156300.0	174977.0
9-10	0.105	155900.0	155900.1	182402.0
10-11	0.245	146000.0	146000.2	189244.0
11-12	0.479	138700.0	138700.5	191950.0
12-13	0.700	136600.0	136600.7	190839.0
13-14	1.213	139700.0	139701.2	189013.0
14-15	0.587	119100.0	119100.6	188166.0
15-16	0.243	107800.0	107800.2	187715.0
16-17	0.074	132960.0	132960.1	78939.0
17-18	0.000	147960.0	147960.0	82030.5
18-19	0.000	135000.0	135000.0	88456.5
19-20	0.000	147120.0	147120.0	87201.0
20-21	0.000	187080.0	187080.0	84298.5
21-22	0.000	169440.0	169440.0	82966.5
22-23	0.000	165240.0	165240.0	80037.0
23-24	0.000	150120.0	150120.0	76081.5

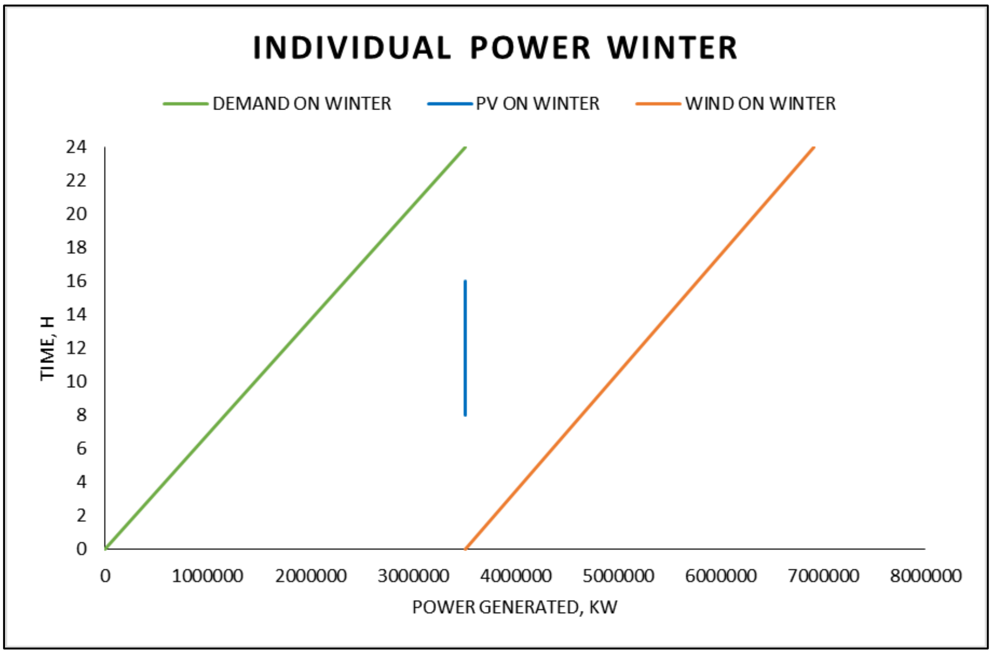

FIGURE 4.5 Individual power source during winter

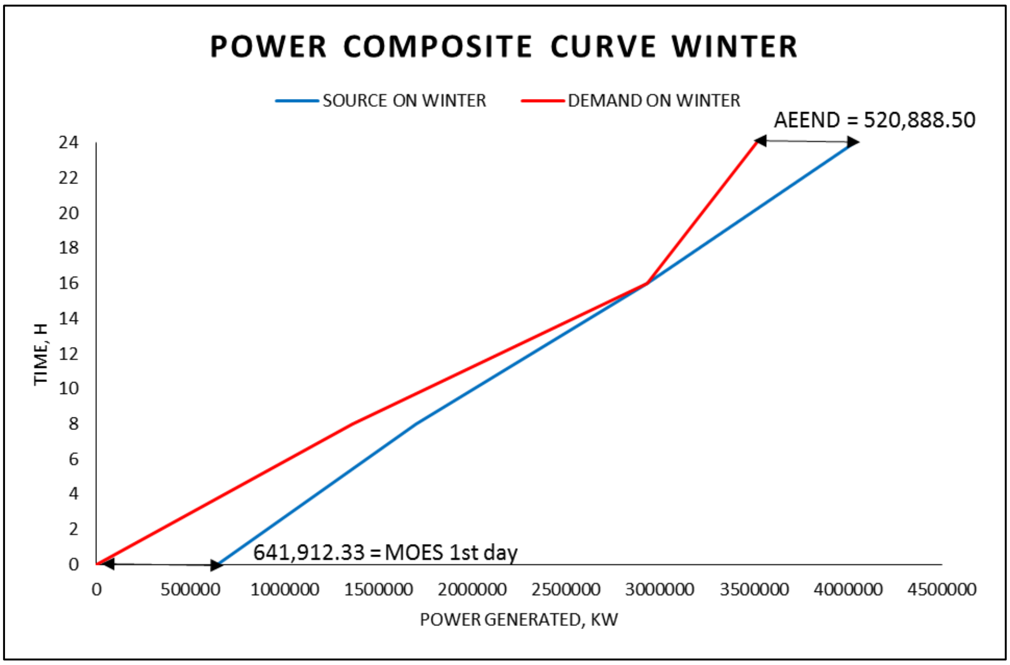

FIGURE 4.6 PCC during winter

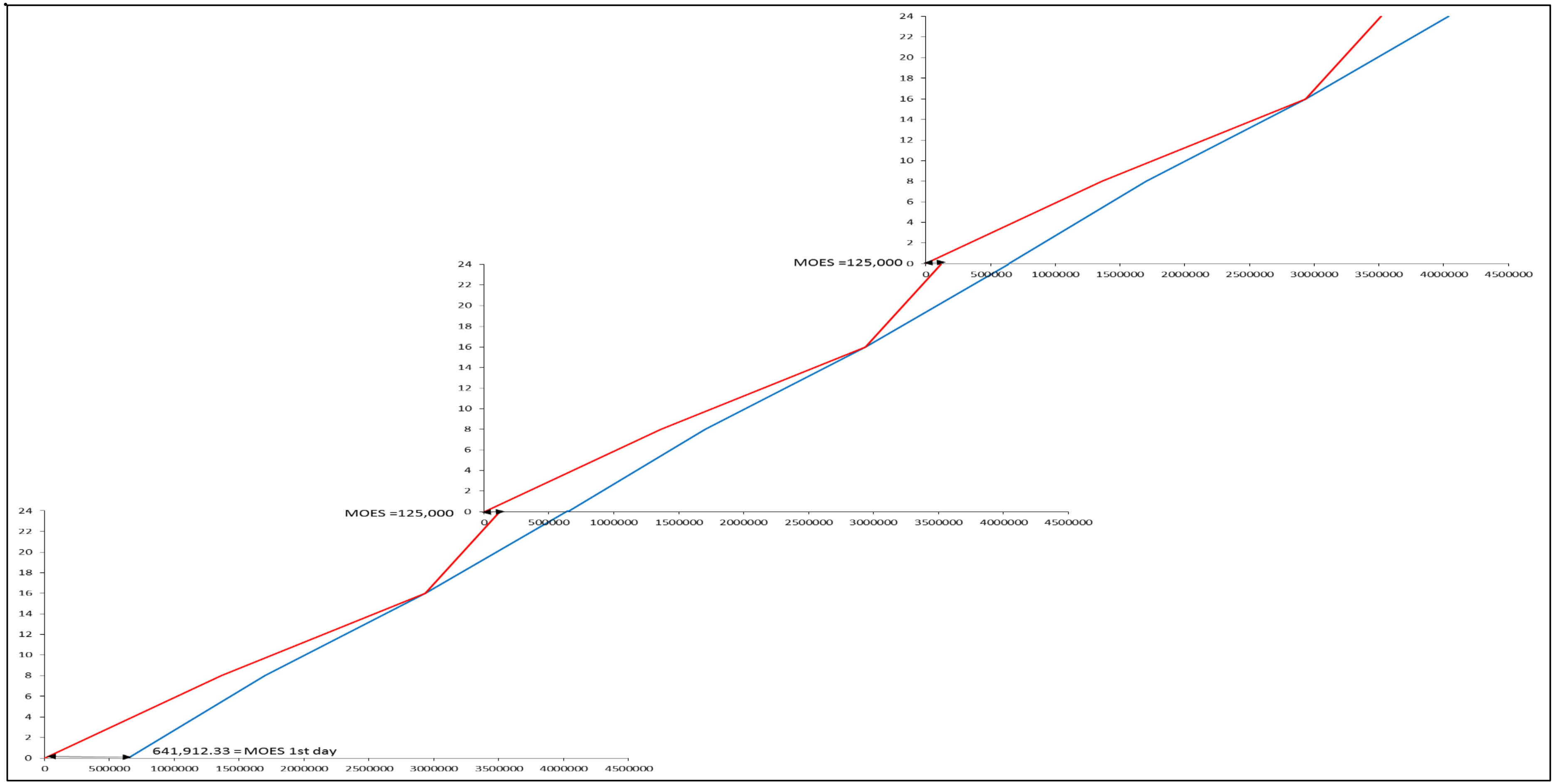

FIGURE 4.7 CPCC during winter

TABLE 4.2 Data of REs and Demand During Summer

Time	PV Power (kW)	Wind Power (kW)	Total Power Generated (kW)	Demand Power (kW)
0-1	0.000	139300.0	139300.0	95704.0
1-2	0.000	156100.0	156100.0	91140.0
2-3	0.000	178500.0	178500.0	88074.0
3-4	0.000	139300.0	139300.0	86058.0
4-5	0.000	185500.0	185500.0	85225.0
5-6	0.006	162400.0	162400.0	86954.0
6-7	0.196	142100.0	142100.2	91973.0
7-8	0.671	137900.0	137900.7	102620.0
8-9	1.237	74900.0	74901.2	108416.0
9-10	1.683	42700.0	42701.7	111524.0
10-11	2.116	37800.0	37802.1	115143.0
11-12	2.415	44800.0	44802.4	117215.0
12-13	2.644	44800.0	44802.6	118881.0
13-14	2.238	60200.0	60202.2	120694.0
14-15	2.392	81900.0	81902.4	121723.0
15-16	2.234	116900.0	116902.2	123067.0
16-17	1.768	127400.0	127401.8	124096.0
17-18	1.198	114100.0	114101.2	126546.0
18-19	0.609	114100.0	114100.6	127008.0
19-20	0.155	114800.0	114800.2	126903.0
20-21	0.036	69200.0	69200.0	17773.0
21-22	0.000	81200.0	81200.0	17624.0
22-23	0.000	81200.0	81200.0	16894.0
23-24	0.000	88800.0	88800.0	15425.0

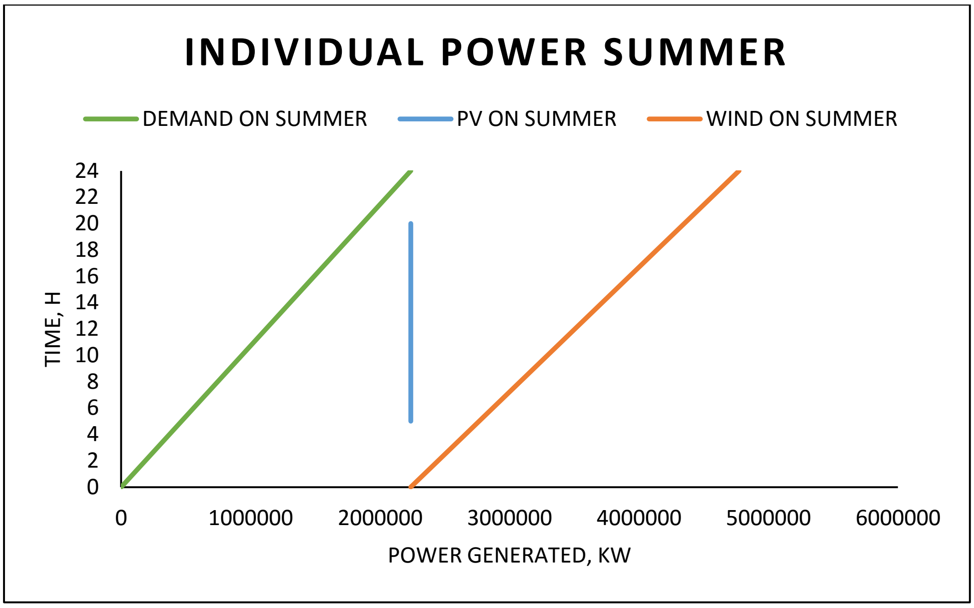

FIGURE 4.8 Individual power source during summer

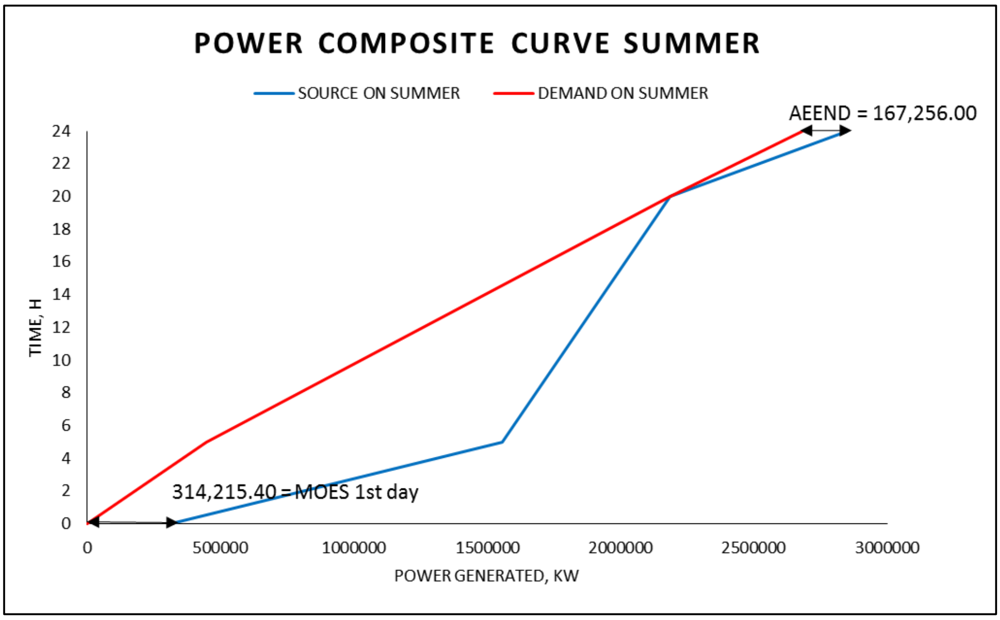

FIGURE 4.9 PCC during summer

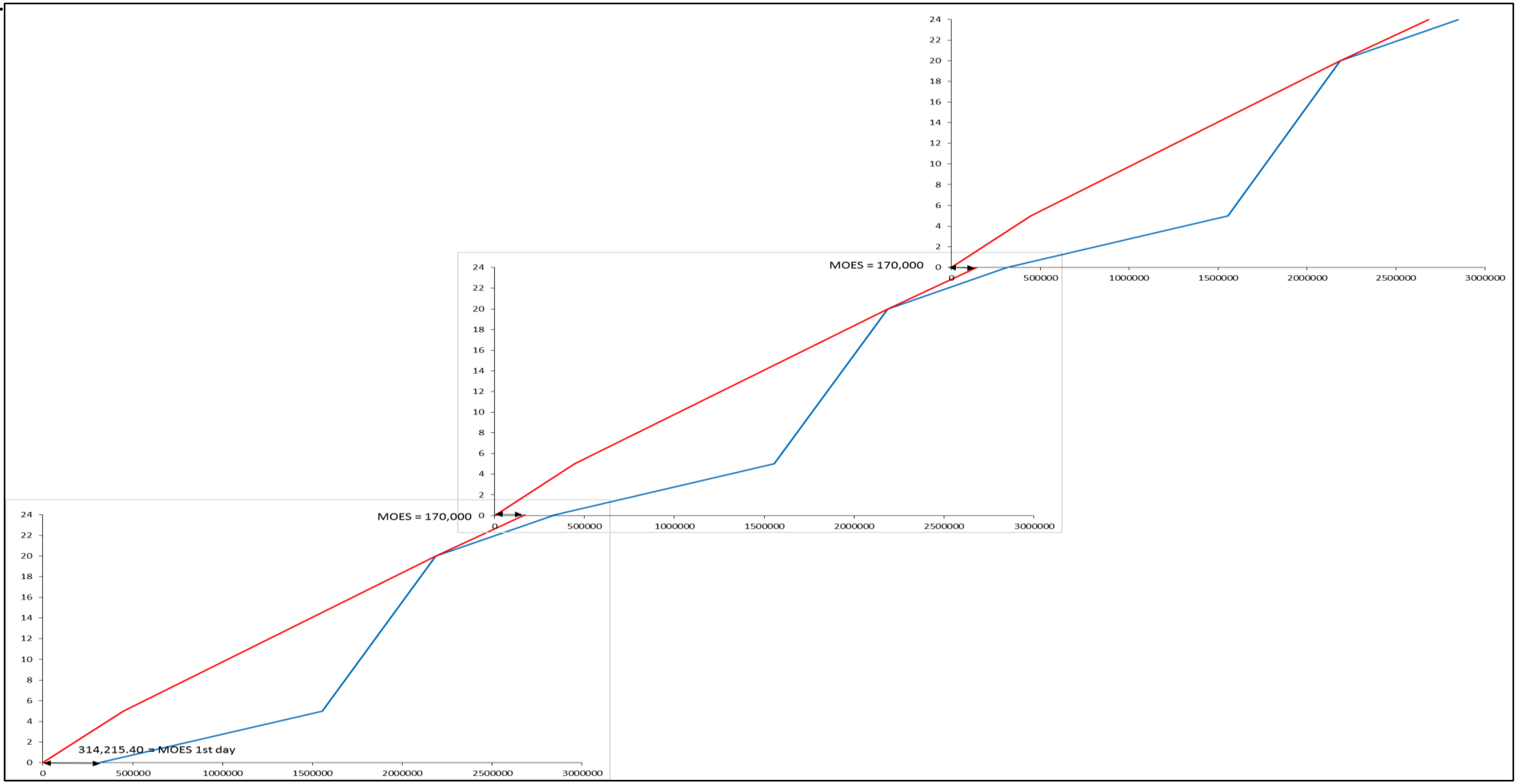

FIGURE 4.10 CPCC during summer

TABLE 4.3 Data of REs and Demand for Average Year

Time	PV Power (kWh)	Wind Power (kWh)	Total Power Generated (kWh)	Demand Power (kWh)
0-1	0.000	103350.0	103350.0	95704.0
1-2	0.000	103220.0	103220.0	91140.0
2-3	0.000	112190.0	112190.0	88074.0
3-4	0.000	109720.0	109720.0	86058.0
4-5	0.000	93860.0	93860.0	85225.0
5-6	0.000	108680.0	108680.0	86954.0
6-7	0.000	112060.0	112060.0	91973.0
7-8	0.004	111150.0	111150.0	102620.0
8-9	0.356	118300.0	118300.4	108416.0
9-10	1.287	111540.0	111541.3	111524.0
10-11	1.873	99710.0	99711.9	115143.0
11-12	2.106	123500.0	123502.1	117215.0
12-13	1.810	118040.0	118041.8	118881.0
13-14	1.697	114400.0	114401.7	120694.0
14-15	1.434	104780.0	104781.4	121723.0
15-16	0.811	109330.0	109330.8	123067.0
16-17	0.155	111410.0	111410.2	124096.0
17-18	0.085	135460.0	135460.1	126546.0
18-19	0.020	163020.0	163020.0	127008.0
19-20	0.010	185900.0	185900.0	126903.0
20-21	0.000	98100.0	98100.0	88865.0
21-22	0.000	110580.0	110580.0	88120.0
22-23	0.000	115800.0	115800.0	84470.0
23-24	0.000	115500.0	115500.0	77125.0

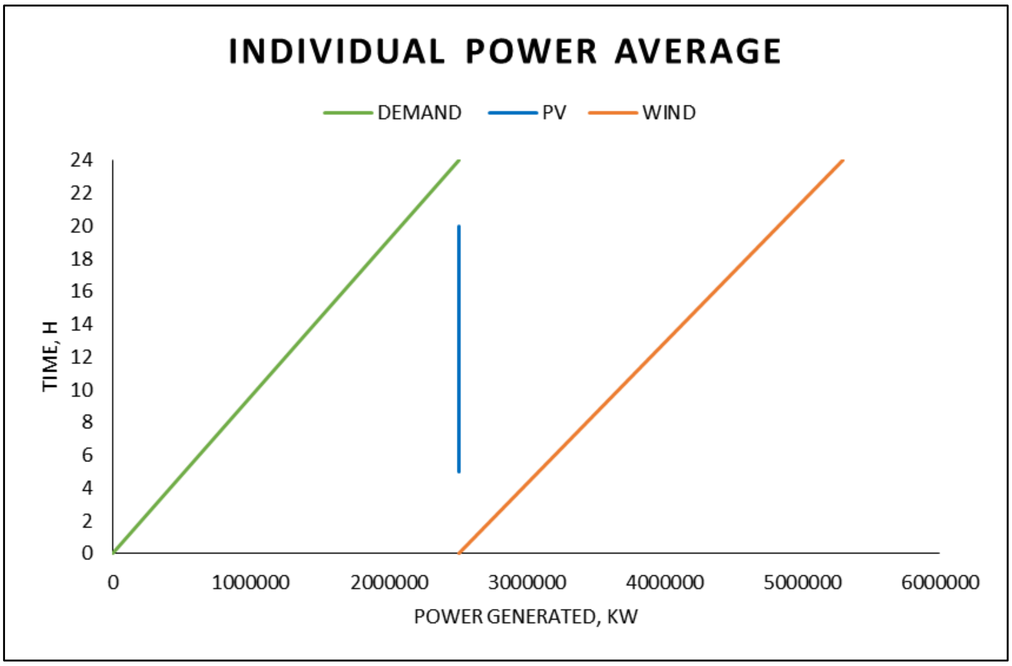

FIGURE 4.11 Individual power source for average

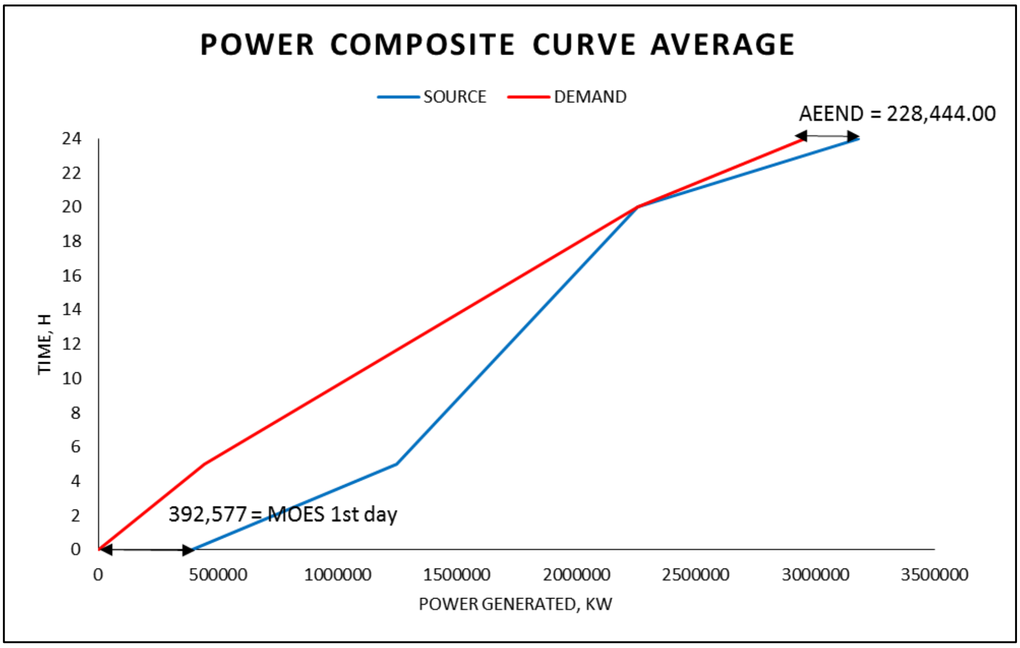

FIGURE 4.12 PCC for average

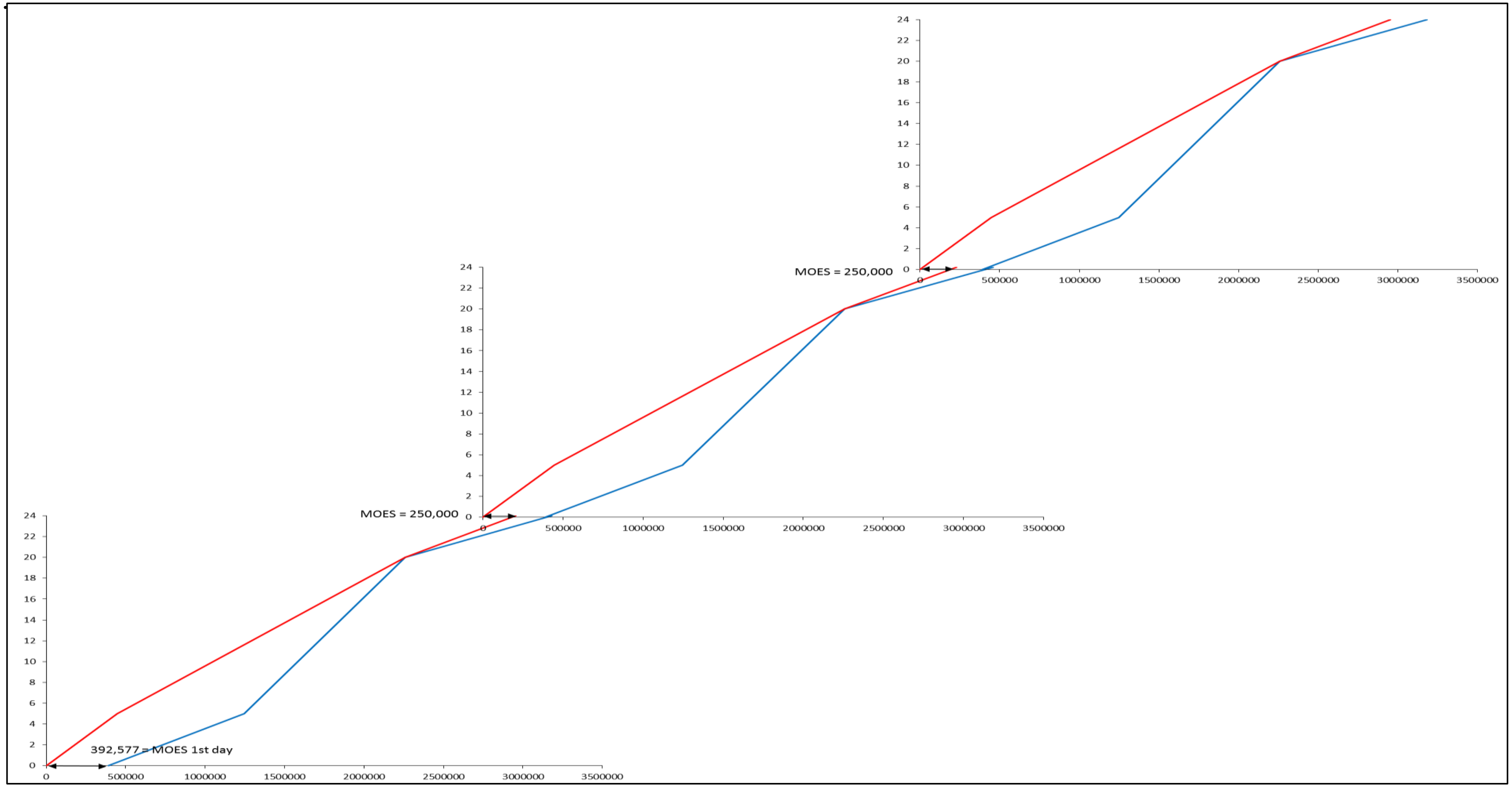

FIGURE 4.13 CPCC for average

TABLE 4.4 Summary of results

Scenario	MOES (kW)	AEEND (kW)
Winter	125,000	520,888
Summer	170,000	167,256
Average	250,000	228,444

4.2 Discussion

Figure 4.1 and Figure 4.2 shows that the power generated by solar during summer is higher compared to winter. Table 4.1 shows that the power generated by solar is in short period which is start from 8.00 am until 4.00 pm while the period for solar power generation is longer during summer where the solar power generated early from 5.00 am until 7.00 pm. The total hour of solar power generated during winter is 8 hours while in summer is 13 hours which results in solar power generated during summer is higher compared to winter. Moreover, Table 4.1 had showed that the highest power generated by solar during winter is 1,213.05 kW while in Table 4.2 shows that the highest power generated by solar during summer is 2,643.85 kW. The difference of 1,430.80 kW. Based on equation 1 in Chapter 3 shows that the factor contributing to solar power generation by solar panel is the insolation of sun. During winter the insolation of sun is low as the cloud is thick with cold air which minimizing the sun insolation while during summer season, the insolation of sun is at maximum.

Figure 4.3 and Figure 4.4 shows that the power generated during winter is higher compared to summer. From Table 4.1, the highest power generated during winter is 200,600 kW and Table 4.2 shows the highest power generated during summer is 178,500 kW. The difference of 22,100 kW had proved that the power generated during winter is higher compared to summer. Based on equation 2 in Chapter 3, the factors that lead to power generation by turbine is the air velocity. During winter season, the high velocity of cold air had led to high power generation by wind turbine compared to summer season.

On the other hand, Table 4.4 had showed that the MOES for the first day for winter is 641,942 kW and 314,215 kW for summer. The MOES for the first day during winter is higher than summer by 327,697 kW. The MOES for the first day can be outsource outside from the grid. For example, the outsource can be either from generation from diesel generator or from the major grid.

Based on Table 4.4, the higher AEEND during winter compared to summer by 353,632 kW. This results is due to the power generation by the sources. Based on the data in Table 4.1 and Table 4.2, the power generation from the wind turbine is higher which give winter season as the highest power generation although the solar power generation during summer is higher than winter season.

The MOES for the consequent days after the first day in the season given by winter season is 125,000 kW and for summer season is 170,000 kW. The MOES results is depend on the source demand profile, where the higher the AEEND, the lower the MOES but this hypothesis is valid if the last point of demand composite curve located at the right side from the first point of the demand composite curve in CPCC on respective season. As the AEEND during winter is higher by 353,632 kW than summer season, which result in lower MOES by 45,000 kW during winter compared to summer. Both season had showed that there is no waste in energy. If the last point of demand composite curve located at the left side from the first point of the demand composite curve in CPCC, which result in waste of energy.

The results from the difference profile can suite on the decision of HPS sizing. This decision is needed as these factors will led to the cost. There are two options can be considered by the designer of HPS which are ;

1. high capacity of generator that have high AEEND where led to waste electricity with no MOES which can save the electricity cost but need to consider cost on maintenance of big generator size and high cost on big generator

2. moderate or small capacity of generator that have low AEEND where led to high MOES which consume cost but can save in term of maintenance of small generator and initial investment on small generator.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This project is useful as the exploration of RE had been increased from years. This research can be used as a reference to the four seasonal climate countries and also as a big recommendation to promote RE as power producer. As the technology of RE is developing and the research on how to manage them by using HPS is increasing, we can reduce or prevent the worldwide use of fossil fuels to produce electrical energy in order to keep the sustainable of the environment by reduce the emission of GHG gaseous by burning the fossil fuels. In addition, this study can help the designers to design the HPS for the micro grid which can supply power into the rural area. This work study the effects of HPS performances for different climates to guide the HPS sizing process by investigating the minimum outsourced electricity source (MOES) and maximum amount of excess electricity for the next day (AEEND) in two different seasons namely winter and summer seasons by using power composite curve. Results can also ensure reliability of HPS design and provide optimal utilisation of RE.

5.2 Recommendation

After completing this study, there are several recommendations, which are;

1. Research including performance of HPS during autumn and spring seasons to ensure the suitable profile for source and demand for a system are more reliable and more optimal utilisation of RE.
2. The loss of energy need to be considered also in future research for more reliable results in HPS design.

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