Comparison of Solar Photovoltaic – Battery Storage System Against Wind Power – Battery Storage System

By

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ABSTRACT

Renewable energy systems for residential in Australia are developing rapidly in this decade, especially, in South Australia location. There are two the most popular renewable sources which solar and wind. However, there are more. Solar energy is utilised by households to a greater extent than wind energy, even in regions characterised by flat terrain and elevated areas. However, in windy conditions such as high-altitude locations, wind power systems can bring an abundant amount of energy to users. This study examines the analysis and comparison between two practical models of rooftop solar photovoltaic (PV) - battery energy storage systems (BES) and wind turbine (WT) - battery energy storage systems (BES) for grid-connected house (GCH) of two different locations in Adelaide – South Australia. In this project, two system configurations, PV-BES and WT-BES were analysed by choosing the most efficient materials and developing the system simulation in MATLAB/Simulink to generate the maximum energy. During the analysis process, the practical model for each system was established with the actual input weather data, which are solar insolation, temperature, wind speed; in two locations, the materials' specifications on the market, grid constraints and annual electricity demand. Therefore, the simulation models show the total power supply by renewable sources, the battery state-of-charge and the total import and export power of the system to the grid. Moreover, based on the power flow of systems, a precise cash flow analysis of each system is calculated based on three types of the electricity rates which are time-of-use, anytime tariff, and feed-in-tariff. Hence, the cost of electricity (COE), total payment of customers in one year and system capital cost are calculated. As the result of power flow, and cash flow of each system, the comparison between two system in each location is presented. Finally, the results demonstrate a comprehensive sight of advantages/disadvantages of both systems based on the type of area, hence, the customers have the advises in choosing their add-on renewable system for their house.

DECLARATION

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Print name of Principal Supervisor Amin Mahmoudi...

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NOMENCLATURE

Acronym	
BES	Battery storage system
BoM	Bureau of Meteorology
CP	Capital cost
FiT	Feed-in-Tariff
GCH	Grid-connected house
NPC	Net present cost
PV	Photovoltaics
TOU	Time-Of-Use
WT	Wind turbine
Parameters	
COE	Cost of electricity ((¢/kWh))
$C_c/C_m/C_r$	Annual component/maintenance/replacement expenses ($)
E_{load}	Annual electricity demand (kWh)
E_{bes}	Energy of battery (kWh)
E	Export electricity rate (¢/kWh)
I	Import electricity rate (¢/kWh)
i	Interest rate

K	Total hour trading energy with grid (h)
min/max	Minimum/maximum value
NPC_c	Net present cost of component ($)
NPC_g	Net present cost of grid ($)
NPC_{total}	Total net present cost ($)
Δt	Time intervals (h)
N	Number of components
η_{in}/η_{out}	Import/export efficiency of battery (%)
P_{dumped}	Dumped power (kW)
P_{import}/P_{exp}	Power import/export to grid (kW)
P_{in-b}/P_{out-b}	Available power input/output of battery (kW)
P_{ib}/P_{ob}	Battery input/output power (kW)
P_L	Load demand (kW)
P_s	Supply power from renewable source (kW)
$PC_c/PC_m/PC_r$	Capital cost of components/maintenance/replacement ($)
SOC	State-of-charge (%)

1. INTRODUCTION

1.1. Background

Renewable energy such as solar photovoltaic (PV) system or wind turbine (WT) are being widely used rapidly in South Australia. Based on the report of Australia clean energy 2019 [1], more than half (53%) of electrical power of South Australia was generated by renewable source. There are 21322 system of PV are installed in 2018 and it contributed 4.2% of Australia's total electrical generation in 2018. However, percentage of wind generation in South Australia is the highest among Australia which is approximately 35.2% in 2019.

According to Your Home Australia government [2], most residential rooftop photovoltaic (PV) arrays in Australia are 3–5kW. Moreover, in 2019, there are approximately 91 sunny day and 136 cloudy days in Adelaide which was reported by Bureau of Meteorology Australia [3] which is reasonable in building and installing solar panels on the roof. One the other hand, the small WP for household has the typical range from 0.4kW to 20kW with the height from 15-20m. Moreover, for the maximum power, the wind speed must be higher than 5m/s. Based on the data of Weather Spark 2020 [4], the peak and the lowest of wind speed above 4m height in Adelaide are 5.23 m/s and 4.3 m/s respectively. Hence, it is possible to install the household WP in Adelaide.

For the renewable grid connected systems, the residential renewable system has been set up provides power to the load and any surplus is sold back to the grid. Customers typically use flat rates as time-of-use price (TOU) or anytime tariff and feed-in-tariff (FiT) for import/export electricity prices from/to the main grid. Hence, the electricity bills of household can be decreased. Moreover, in grid-connected homes, the incorporation of battery storage system (BES) becomes an attractive option. With battery integration, excess power generated by PV during the day or WT during windy weather can be stored. The battery then releases the stored energy in the evenings during the peak hours for PV or when there is no wind for WT, which is a great way to cut expenses and reduce energy wastes [5].

Currently, in Adelaide, PV-BES is more prevalent than WT-BES. It is due to the cost of installation according to NSW Small Wind Turbine [6]. With strong wind conditions such as those in Adelaide [4], a favourable condition for the development of wind power in homes, the installation of wind power in residentials is entirely feasible [2]. Therefore, a grid-connected household may consider between PV-BES and WT-BES to achieve the greatest financial benefits as well as the power.

1.2. Overview of related literature

The analysis of PV-BES or WT-BES systems was examined in previous study. However, all realistic parameters, such as the current cost of each material of electrical components, actual meteorological based on the locations in a year, the comparison between PV-BES and WP-BES in two distinct places, capture the maximum energy of electrical system and load data, are not explicitly regarded, or considered. Using realistic parameters yields gives more precise results. In [7], hybrid PV-WP was examined with sizing method to research about the cost of energy (COE) by HOMER-MATLAB. The PV-BES system with maximum energy for reducing energy build based on battery and grid pricing variations was investigated, moreover, the effect of a previously installed PV system, and the averaging of generation and load data was also considered in [8]. In [9], flat and time-of-use tariff were used as cases study to examine a comparative of PV system and PV-BES system for GCH and also considered the effect of battery degradation on its lifespan for two cases in the Netherlands and the United States [10]. In [11], the analysis pross of system PV-inverter is determined in Saudi Arabia based on net present cost, renewable power share, excess electricity, and carbon dioxide emissions with HOMER-MATLAB.

There were a huge number of studies about the PV-BESS system, however, the objectives about WP-BESS are rarely. In [12], the comparison between two systems WT and WT-BES for GCH are studied by considering about the actual market price of materials, weather condition, and the real data of GCH demand. In [13], the comparison between PV-BES, WP-BES and PV-WT-BESS system had been made based on charge level in battery and weather conditions. Moreover, in [14], uncertainty in wind speed is examined in WT-BES system. In order to analyse the PV-WT-BES and WT-BES system, simultaneous integration and remote control are investigated in [15] and [16] respectively.

1.3. Project Objectives

The main objective of this project is analysis and comparison between two systems of PV-BES or WT-BES for a grid-connected residential household in Adelaide and Mount Lofty corresponding to two types of geographical location: city side and hill side respectively. It will be divides into 3 steps as follows based on the motivations, contributions and benefits in Figure 1:

- Firstly, two types of practical models with 5 kW on-grid PV and WT system for house is created and developed based on mathematical equations, system controllers, and code in MATLAB/Simulink. Moreover, the BES used will be 10 kWh as the energy storage system in renewable supply system. In addition, the actual weather data in 2023, which are solar isolation, wind speed, temperature from Bureau of Meteorology (BoM) is taken as input data in the simulation blocks as well as the annual load data of house, current market price of components, grid constraint and electricity tariff. Therefore, the power flow of systems is examined for the comparison the advantages and disadvantages of PV-BES and WT-BES system base of the geographic region.
- In the next step, the performance of models is increased by improving the system controller and code in two models. In addition, the signal builders are developed for reading the input data of weather, load data in one year.
- In the results section, the output power flow of supply system and battery storage system is verified. Then, the cash flows analysis of renewable system in GCH will be evaluated according to the power flow analysis. In addition, renewable energy system that is more advantageous economically and energetically will be presented based on the result of power flow and cash flow. Thereafter, consumers will have a clearer understanding of which energy is superior to use in which geographical location.

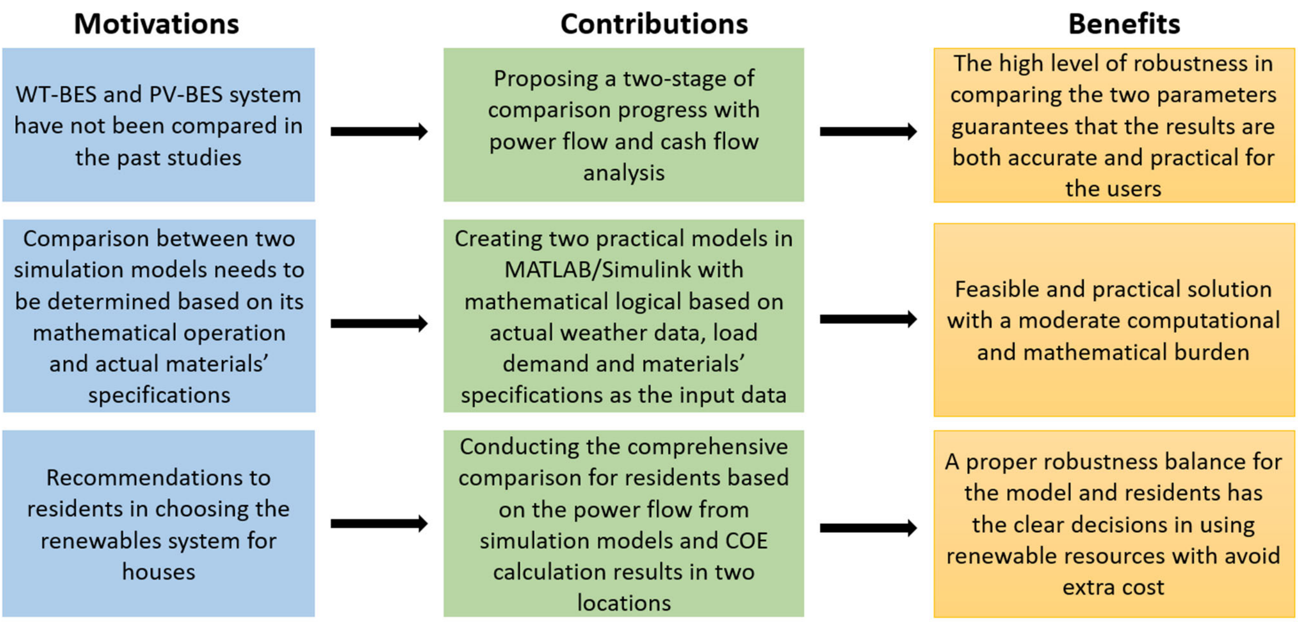


Figure 1: Motivations, contributions, and benefits of current study.

1.4. Assumptions and Constraints

1.4.1. Project Assumptions

In this project, the systems of PV/WT-BES are designed in Simulink environment, hence, several assumptions need to be taking into account. The summary of assumptions is demonstrated as Table 1 below.

Table 1: The summary of assumptions of project

Number	Assumptions
1	The solar panels and wind turbines have optimum efficiency and the materials selections based on the approval list of South Australia. The life span of the systems is based on the material specifications from manufacturer which is 10 years.
2	There are two locations are concerned to install the PV-BES and WT-BES which have two different conditions of weather data.
3	The import/export efficiency of the battery is fixed at 100% and the selected battery needs to have state-of-charge from 10-95%
4	The amount of solar radiation, wind speed and day duration are received at two locations, Adelaide and Mount Lofty, are provided daily.
5	2022 household electricity consumption is estimated and averaged based on the season and daytime temperature.
6	The dumped power is considered for the maximum load feeding or exporting to the grid
7	Based on simulation software and actual data, the optimal systems will be created and combined with the weather data. The cost of electricity (COE) and its reduction will be determined.
8	The investment payment duration of both system is 5 years based on the loan policy of Commonwealth Bank [17].
9	The installation, operation and maintenance cost of the system is assumed to be 3% of total systems cost per year.

1.4.2. Design Constraints

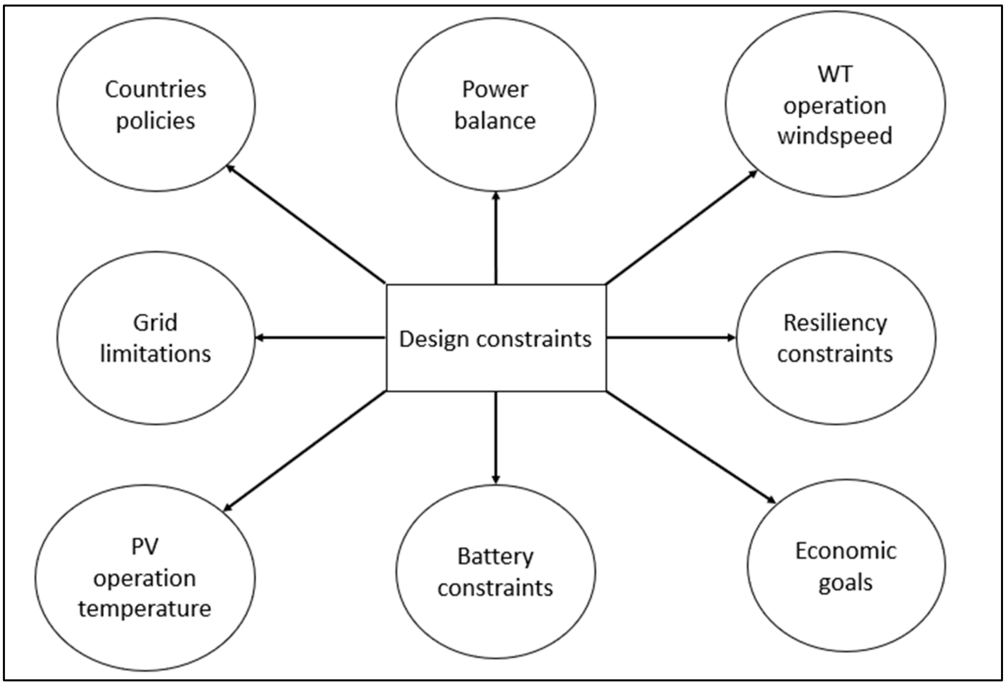


Figure 2: Design constraints of system

Figure 2 above demonstrated the design constraints for optimal PV/WT-BES system in GCH. Based on the list, the primary limiting factor pertains to the equilibrium of power distribution between the generation and consumption aspects of the on-grid residential dwelling [18]. However, the import or export power from the renewable source to the grid must follow the country or state policies. For example, in South Australia state, the maximum export power must not excess 5kW for single-phase and 30kW for three-phase from the residential to the national grid [19]. Moreover, the charging and discharging rate of a battery is contingent upon the battery's available capacity and its power rating, which is constrained [20]. Furthermore, it is noteworthy to consider the limitations imposed by the geographical location of the construction site when implementing the system. In fact, the production of electricity through wind power is contingent upon various factors, including the characteristics of the turbine, the velocity and density of the wind. In instances where wind speeds fall below 2.5 m/s, the generation of electricity through turbines is rendered unfeasible. Conversely, in cases where wind speeds exceed 25 m/s, turbines are deactivated as a safety precaution. In contrast, solar photovoltaic (PV) generation is contingent upon the intensity of light at a given location, which fluctuates on an hourly and seasonal basis and is further influenced by cloud cover. Consequently, the reliability of these two primary sources is called into question [21]. When developing a system, it's important to establish resiliency limitations to make it more resistant to breakdowns during times of extreme conditions.

1.5. Thesis Outline

In Chapter 2, the literature review about simulation of renewable system and analysis is demonstrated. Chapter 3 shows methodology used in the thesis with system configurations, selected materials, calculation formulas. The results are demonstrated in Chapter 4 with the measured power flow and calculated cash flow. In Chapter 5, the comparison between two system is different locations is investigated with the discussions. In the last Chapter, the conclusion and future work of this research topic are presented.

2. LITERATURE REVIEW

2.1. Historical Background

Renewable energy systems (RES) have gained significant attention in recent years due to their potential for reducing greenhouse gas emissions, enhancing energy security, and promoting sustainable development. The renewable energy systems, which combine multiple renewable energy sources such as solar, wind, and energy storage devices, have emerged as a promising solution to address the intermittent and variability of renewable energy generation. The Figure 3 below demonstrates the electricity production of Australia from 1980 to 2019.

Figure removed due to copyright restriction

Figure 3: The electricity production in Australia in the past 30 years

(Picture source: https://en.wikipedia.org/wiki/Renewable_energy_in_Australia#/media/File:Australia_renewable_electricity_production.svg)

The main sources of alternative energy, which are solar and wind power systems, have attracted a lot of attention recently. Due to seasonal and cyclical variations, it is prudent to state that neither an off-grid wind system (WT) nor solar power (PV) can provide a constant supply of energy [22]. Hence, as important solutions, battery storage systems (BES) store the excess power from supply source and release it as needed by the power system [23]. They increase the stand-alone system's reliability by releasing power when the RESs aren't producing power [24]. Furthermore, by storing extra energy during times when electricity prices are low and selling it back to the main grid during times when they are high, BESs can boost the earnings of RESs in grid-connected networks [25].

2.2. Multi-objectives in Analysis of PV/WT – BES System.

2.2.1. Analysis of solar PV system

Table 2 presents the key attributes of research endeavours pertaining to the analysis of PV and BES systems for grid-connected system. Most of existing research considered the PV-BES capacity, however, a few studies also examined the size of PV-Inverter [28], only battery system [29], grid impact [32]. MATLAB/Simulink is the most used as the simulation method in existing papers, but some papers examined the system with HOMER simulation [28, 32], GAMS simulation [33]. Economic goal functions were utilized in the majority of the studies, whereas the optimization of the battery SOC for maximum power was adopted as an aim purpose in [29]. In addition, the amount CO2 emission is also investigated in [28, 30]. Several design restrictions, such as energy equilibrium, battery SOC, and grid constraints, were considered while some authors have not mentioned the design constraints as in [26, 27]. Time-of-use and flat tariff were concerned in most papers as the price of electricity. From that, it can be stated that the utilization of this option is deemed optimal for grid-connected systems to reduce the net present value. Nevertheless, stepwise power tariff and real-time pricing is also demonstrated in optimizing system [33].

Table 2: The key attributes of research in analysis of grid-connected solar PV system.

Reference	Decision variables	Simulation method	Objective functions	Design constraints	Electricity price type
[9]	PV-BES size	MATLAB code based on the home energy management	Net present cost Electricity cost BESS capacity degradation	Grid limits Battery SOC Energy balance	Time-of-use and Flat
[26]	PV-BES size	MATLAB code based on system configuration	Annual energy cost Economic benefit	Not mentioned	Time-of-use
[27]	PV-BES size	SIMULINK simulation	Economic benefits Payback period	Not mentioned	Time-of-use

[28]	PV-Inverter capacity	HOMER simulation	Net present cost CO2 emission	PV-inverter size Energy balance	Time-of-use
[29]	BES capacity in PV-BES system	System with both slow/fast fluctuations Not mentioned simulation method	BESS capacity BESS charge/discharge state	Battery SOC	Not mentioned
[30]	PV-BES size	MATLAB code Simulink for mathematical model	Power reliability CO2 emission Cost of electricity Power autonomy	System reliability Battery/panel energy Number of autonomous daily	Not mentioned
[31]	PV-BES size	MATLAB code Simulation with two-day data each season	Annual energy cost Economic benefit	Battery SOC Energy balance Grid limits	Flat
[32]	PV-BES size and grid impact	HOMER simulation	Net present cost Energy cost	Grid limits Cost limits Power balance	Time-of use
[33]	PV-BES size	CGA programming GAMS simulation	Annual cost	Grid limits Battery SOC Power balance Power export	Time-of-use Stepwise power tariff Real-time pricing

2.2.2. Analysis of WT system

Table 3 displays the fundamental characteristics of research undertakings concerning the optimization of WT and BES systems for WT systems connected to the grid. Optimal WT-BES capacity. Most of existing studies took place into WT-BES system's capacity. Moreover, the problem of system control is significantly distinct and has been resolved through different approaches such as integration control [16], power control [34, 35], output power control [37, 39], and WT penetration degree [40]. MATLAB is a software application that is specifically designed for the purpose of analysing WT-BES systems. The rationale behind this modification stems from the fact that MATLAB possesses significant utility and aptness in the utilisation and examination of the power flow within a wind turbine. However, Monte-Carlo simulation was used as in [14] to obtain the occurrence probability of the system. Economic goal functions were utilized in the majority of the studies of optimizing the capacity of system, while, in control system paper, the battery integration and life cycle were considered for the maximum output and storage power [16]. Many design restrictions have been followed such as energy balance, grid limits, battery SOC, and voltage constraints. Nevertheless, flat tariff was only mentioned in a few papers [12, 38, 40]. Most of the existing research did not specify electricity price in examining the financial analysis of WT-BES system.

Table 3: The key attributes of research in analysis of grid-connected WT system.

Reference	Decision variables	Simulation method	Objective functions	Design constraints	Electricity price type
[12]	WT-BES sizing	MATLAB code	Net present cost Energy cost Payback period	Battery SOC Energy balance Grid limits	Flat
[14]	WT-BES sizing	Mathematical model Monte-Carlo simulation	Energy cost Power reliability Occurrence probability	Energy balance Occurrence probability limits Battery SOC	Not mentioned
[16]	WT-BES control and integration	Simulink simulation model MATLAB code	Modelling WT-BES BES integration Fluctuation harmonic	Battery SOC WT voltage	Not mentioned
[34]	WT sizing and BES location	MATLAB code	Control system Power reliability Annual cost	Battery SOC	Not mentioned
[35]	WT-BES power	Mathematical model in MATLAB	Battery SOC Battery life cycle Annual cost	Not mentioned	Not mentioned
[36]	WT-BES control	Simulink simulation model	WT power Battery power System model	Battery SOC System dynamics	Not mentioned
[37]	WT-BES output power and size	MATLAB code Simulink model	Control system System model	Robust performance	Not mentioned
[38]	WT-BES-Electric Vehicle size	MATLAB solver code	Energy cost Net present cost	Grid limits Energy balance Battery SOC	Flat
[39]	WT-BES system controller and size	Simulink simulation model	Control system Energy control Cost model	Hour-ahead predicted output Energy balance Battery SOC	Not mentioned
[40]	BES capacity and WT penetration degree	MATLAB code	WT penetration Energy cost Annual lost cost	Voltage limits Power flow limits	Flat

2.2.3. Key Findings and Research Gaps

The literature review has uncovered a range of diverse goals that have been utilized in the analysis of PV/WT-BES systems. This section provides a summary of the categorization of prior research, identified limitations and restricted usage in the field of optimization grid connected PV/WT-BES systems.

2.2.4. Keys Findings

The analysis and development of grid-connected PV/WT-BES systems have been the subject of prior research, which has categorized such investigations into those pertaining to energy and control systems. Various objective functions were employed in every system. Most prior research has incorporated the energy cost of green electricity systems as an indivisible objective function in the context of multiple goal issues.

The studies on grid connected renewable energy systems are classified in PV-BES and WT-BES systems. There exist various objective functions that are commonly employed for both systems, such as the minimization of electricity costs, the reduction of air pollution, the computation of annual costs, and the maximization of power reliability. Moreover, the investigation of grid-connected systems places a higher priority on the goal functions that interact with the grid. Factors such as grid voltage stability, grid constraints, imported/export power from/to the grid, and power loss within the network are deemed more significant than considerations of reliability and surplus energy. However, in WT-BES system, several studies investigated control systems by modelling and designing system. As a result, the energy flow of the system was controlled and provided the best efficiency. Hence, the actual system will be applied to have the maximum power and the economic benefits to users.

According to the analysis, MATLAB/Simulink environment are the most employed methods for simulating and developing PV/WT-BES systems. Moreover, several software is used to create PV-BES model such as HOMER, sensitivity tool and GAMS simulation for examine energy issues. For WT-BES system, about 90% of previous studies was ran with MATLAB. In addition, Monte-Carlos's simulation have been applied to create the WT model to solve the problems. Typically, PV-based systems are favoured over WT-based systems in research studies.

2.2.5. Research Gaps and Limitations

Previous studies have not thoroughly and precisely examined several objective functions involved in the analysis problem of the PV/WT-BES systems. For instance, the investigation into the load demand of residential and location were neglected or have not been examined accurately. However, this objective is essential in developing a system with financial analysis. Previous literature on optimal planning with respect to demand side direction fails to incorporate alternative objective functions such as encouragement demand response and customer comfort levels.

For PV-BES existing studies, a few research did not consider the system constraints, however, the results demonstrated about the annual energy cost and economics benefits [26, 27]. Moreover, the price of electricity was not mentioned in [30], but COE calculations were still included in their findings. Consequently, even though the system's input parameters are based on reality, the results are not entirely accurate. The limitations in operating systems are extremely important because it has an impact on putting the research system into action. The way that solar systems work is different from the way that conventional electric power works. The weather, the state of the battery reserve, and the laws of each country all play a significant role. Thus, consideration constraints and electricity price give more intuitive in calculating comprehensive results.

For WT-BES previous papers, there are lack of studies determine the power flow of the system of 5 papers. WT systems are frequently developed with the aim of achieving optimal control of the system, and as a result, many research papers are focused on designing within the constraints established by the system. However, the majority of articles fail to examine the threshold of energy that is exported to the grid. This renders the computation of the system's cash flows unfeasible in practical terms. Moreover, the advantages of an ideal grid-connected system are not explicitly communicated to the end-users. In addition, there are only three papers considering the electrical price which is flat tariff. The circumstance poses a significant challenge in implementing the system, as certain regions or nations impose charges on electric energy consumption based on distinct usage periods. For the minimum NPC and COE of the system, both time-of-use and flat rate need to be applied as in [7].

2.3. Scope of Current Research

The scope for this study is developing two types of renewable grid-connected energy systems: PV-BESS and WP in two different regions includes designing system via Simulink simulation, actual weather conditions data, minimize the investment cost of the system, maximum the energy efficiency, reliability, and cost-effectiveness. Therefore, the systems must meet the energy needs of a particular location while minimizing the cost of grid-sourced electricity consumption and maximum the profit from selling the surplus electricity to the grid. As the result, the comparison between PV-BESS and WP-BESS in two different locations in Adelaide are established. Based on the findings, Australians will be provided with a comprehensive guide outlining what type of renewable system to implement in which areas for the greatest financial and performance benefits. The following Figure 4 demonstrates the summary of objective functions of the project.

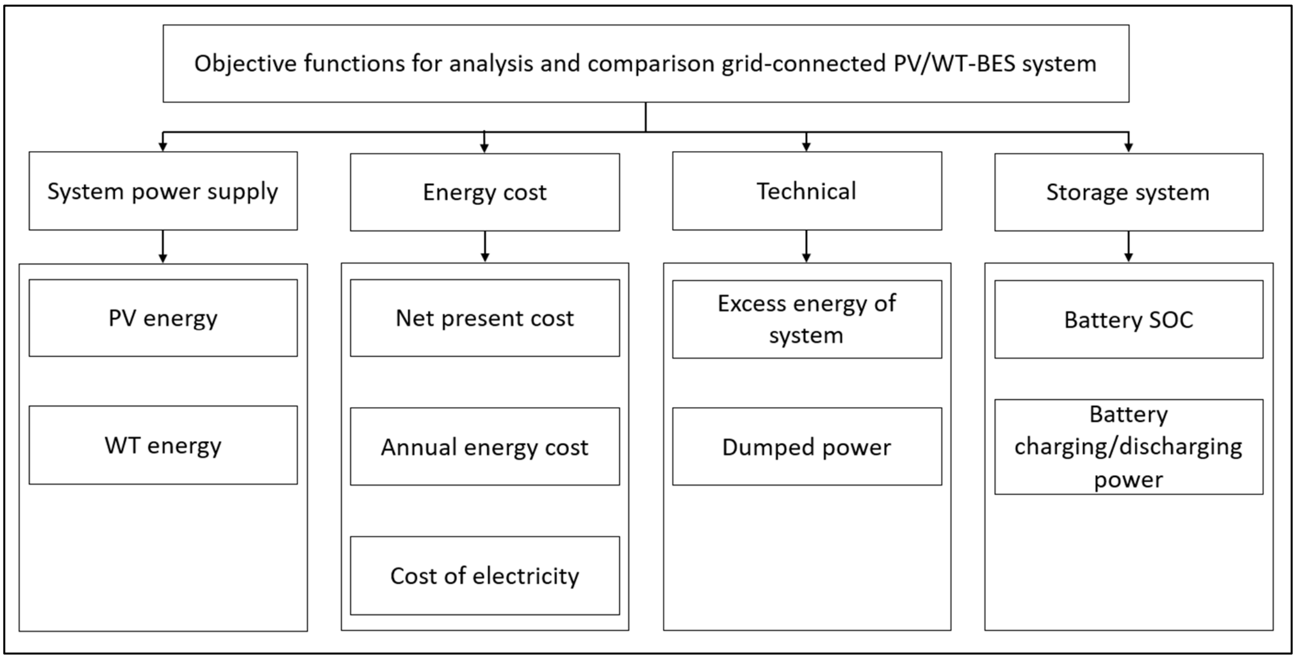


Figure 4: The main objective functions of the project

In this project, the PV-BES does not account for shading on the solar PV panels from nearby trees or buildings, aging of the solar PV panels resulting in decreased efficiency, temperature fluctuations impacting the performance of the battery storage system resulting in lower returns on investment. In addition, the non-coverage areas for the WT-BES system include turbulence due to nearby structures or wind direction changes affecting the performance of the wind turbine, noise pollution from the wind turbine affecting nearby residents, limited availability of suitable locations for wind turbines in densely populated areas, and high up-front for wind turbines relative to other renewable energy sources. The project is also not concerned about the life span of the system after 5 years duration of both PV-BES and WT-BES system.

3. METHODOLOGY

This chapter demonstrated the summary of the methodology of the project. Then the details of the system input data and system design based on system configurations to MATLAB/Simulink will be shown. In addition, all useful formulas, project flow chart and system in simulation software will be provided.

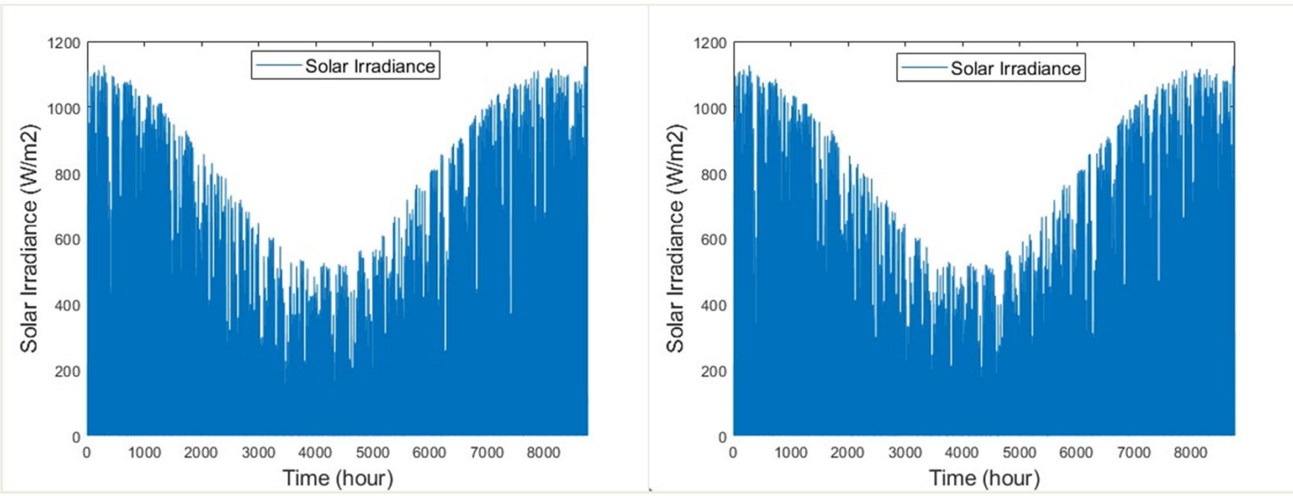
3.1. System Input Data

In this project, the input data are the actual weather in 2022 (solar irradiance, wind speed) from BoM [41], the survey data of load demand of a residential house, the specifications of system's materials.

3.1.1. Weather data

a) Solar irradiance

Figure 5(a) below demonstrates the solar irradiance of Adelaide for one year (8760 hours). It can be claimed that the maximum solar irradiance is 1.128 $\mathrm{kW/m^2}$ with the average is 0.226 $\mathrm{kW/m^2}$. In addition, the minimum value is 0 $\mathrm{kW/m^2}$ corresponding to night period. On the other hand, the solar irradiance data of Mount Lofty was also taken as Figure 5(b) below. It can be observed that the amount of irradiance in Mount Lofty is approximately equal to Adelaide. The maximum solar irradiance was measured is 1.127 $\mathrm{kW/m^2}$ with the average is 0.228 $\mathrm{kW/m^2}$ over one year.

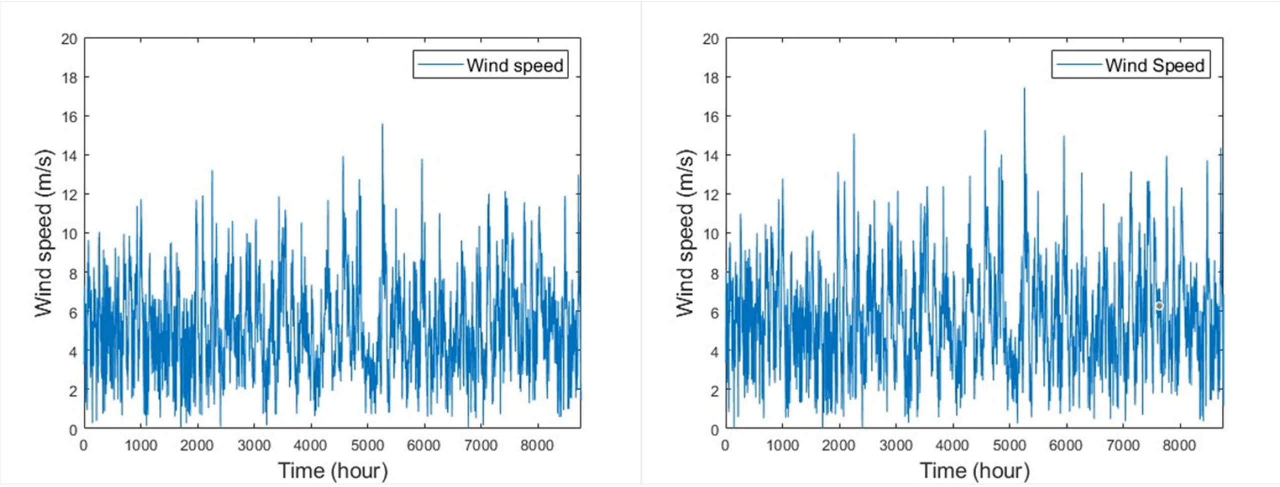


(a) Adelaide **(b) Mount Lofty**

Figure 5: Solar irradiance data of two locations in one year (2022)

b) Wind speed

The wind speed data of Adelaide location was taken as illustrate in Figure 6(a) below. The average wind speed is 5.1129 m/s with the maximum value is 15.59 m/s which is suitable for operating WT system. In contrast, the wind speed in Mount Lofty location is significantly higher than Adelaide with 5.7034 m/s and 17.437 m/s corresponding to average and maximum value. The Figure 6(b) below shows the data of wind speed in Mount Lofty one year.



(a) Adelaide **(b) Mount Lofty**

Figure 6: Wind speed data of two locations in one year (2022)

3.1.2. Load data.

The load demand data was surveyed and taken which is from a residential house with four people as the following Figure 7. The average value of load is 2.01 kW per hour. In addition, the peak load demand is 6.685 kW, and the minimum value is 0.217 kW.

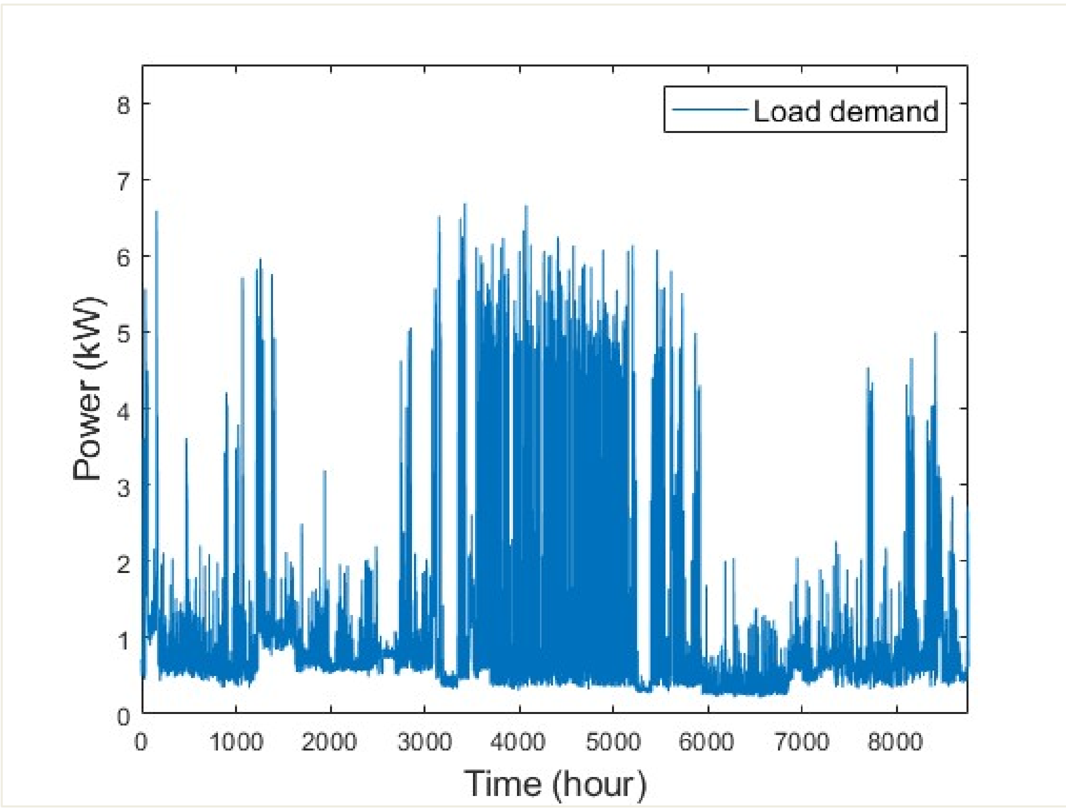


Figure 7: The load data input for simulation model in Simulink from survey

3.1.3. Specifications of Selected Material

The materials of two system PV-BES and WT-BES have been selected which are Sun Earth 295 W solar panel, Tesup Magnum 5 and Growatt 10.24 kWh corresponding to PV, WT, and battery respectively. The specifications of materials were used as the input data of renewable supply source for the designed system in Simulink. Table 4 below demonstrates the summary of materials' key parameters used in developing the simulation system. A comprehensive compilation of the material's details and power curve can be found in Appendix A.

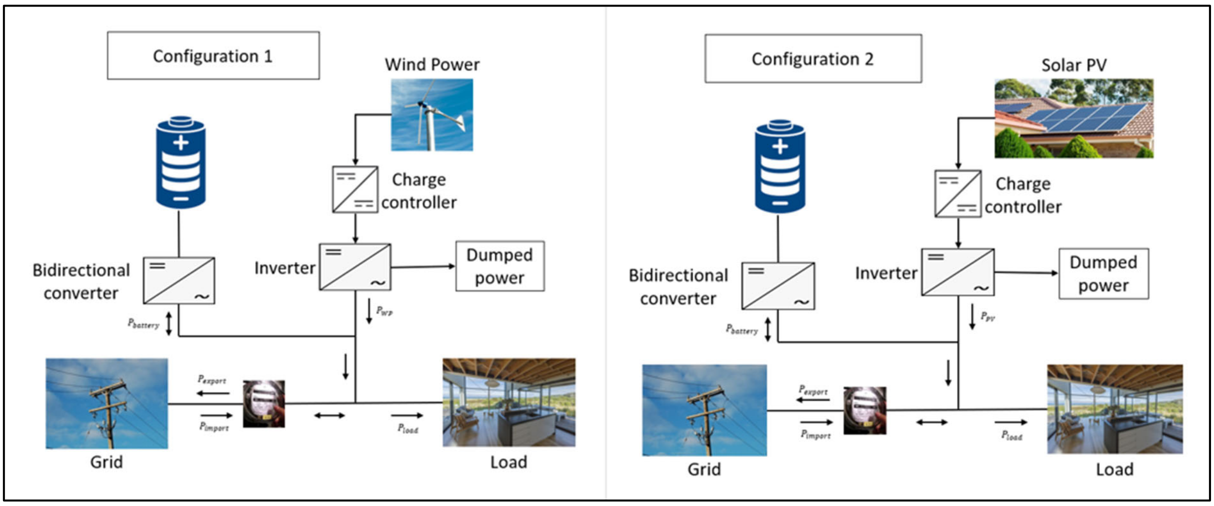
Table 4: The summary of materials' key parameters

PV system		WT system		BES system	
Number of panels	18	Number of wind turbine	1	Number of BES per system	1
Maximum power per panel (W)	295.11	Maximum power (kW)	5	Energy Capacity (kWh)	10.24
Rated power output of PV system (kW)	5.3	Starting wind speed (m/s)	3	Maximum Capacity Usable (kWh)	9.21
Price per panels ($)	280.2	Maximum wind speed (m/s)	13	State-of-charge range (%)	20-90
Price of PV system ($)	5043.6	Price per wind turbine ($)	3230	Price per BES ($)	10589

3.2. Operational Strategies

3.2.1. System configuration

The project is divided into two main parts corresponding to the two locations of house: high wind and low wind. For each location, there are two configurations for an on-grid household with PV-BES or WT-BES. The battery system will be connected parallel with the renewable source. It also can connect in series with PV or WT; however, it was investigated, and the results showed that the economic performance is minimal [42]. Two configurations of WT-BES and PV-BES are illustrated for creating and developing simulation systems in MATLAB/Simulink as Figure 8 respectively below.



(a) WT-BES system **(b) PV-BES system**

Figure 8: The configuration of two systems in GCH

3.2.2. Project Flow Chart and Home Energy Logical

a) Project flow chart

Based on the system configuration and design constraints, the simulation systems of PV-BES and WT-BES have been created and developed in Simulink. The project flow chart demonstrated the steps in getting the results of the project's goals as in Figure 9 below.

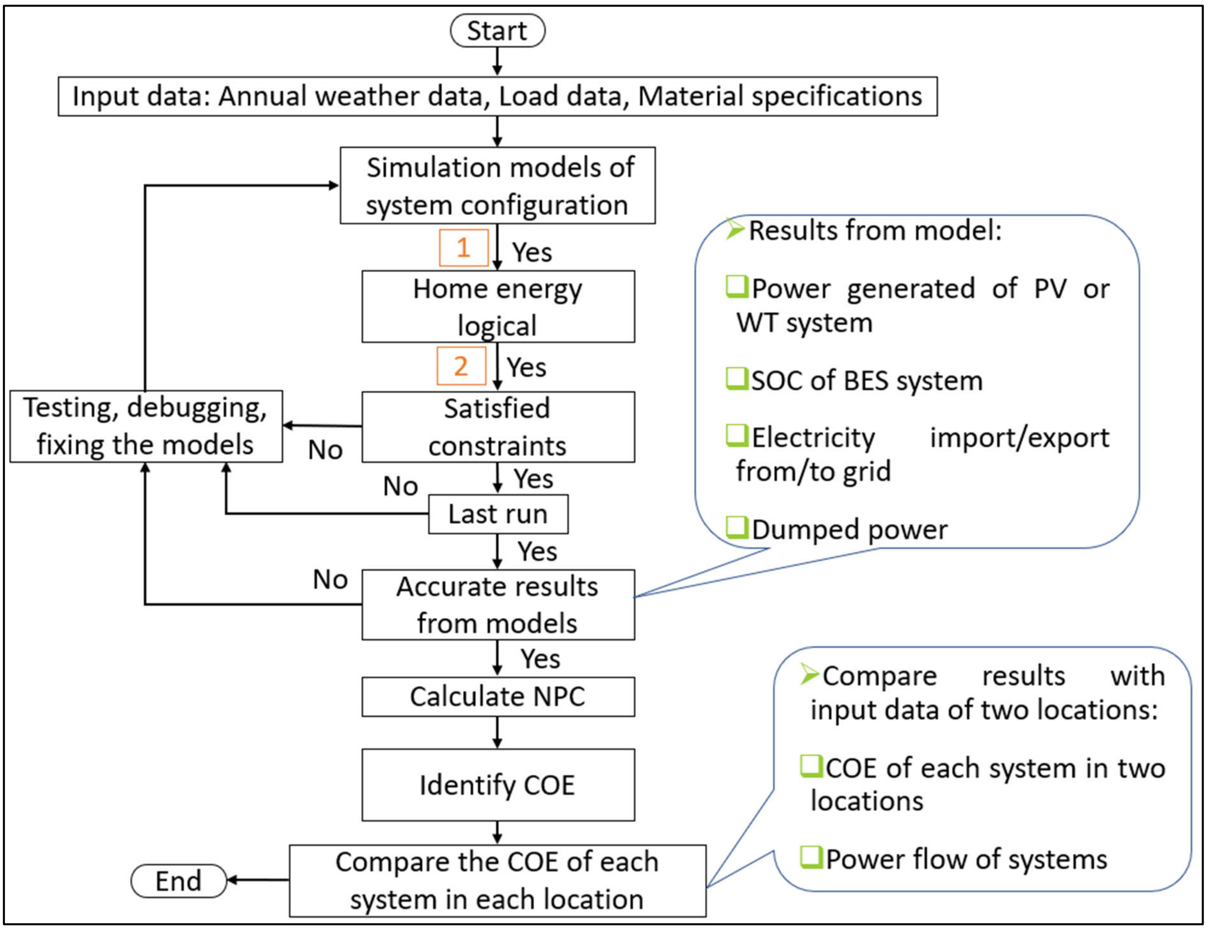


Figure 9: Project's flow chart

Firstly, the input data will be claimed from BoM, surveyed from residential house, and taken from materials' manufacturers website. In the next step, two simulation models were satisfied the home energy logical and design constraints. The third step is getting the results from the model. In the model scope, it contains power supply by renewable sources, state-of-charge (SOC) of battery, amount of electricity import/export from/to grid and dumped power. However, in the process of getting the power flow results, the simulations system needs to be testing, debugging, and developing until the results is accurate. Hence, based on that, the NPC and COE will be calculated, and it will be used to compare two systems in each case. Finally, the benefits and recommendations will be demonstrated.

b) Home Energy Logical

Home energy logical is demonstrated as Figure 10 below which is inside the step 1-2 in flow chart in Figure 9. The efficacy of the system's logic has been empirically demonstrated in achieving optimal energy utilisation with minimal dissipation [42].

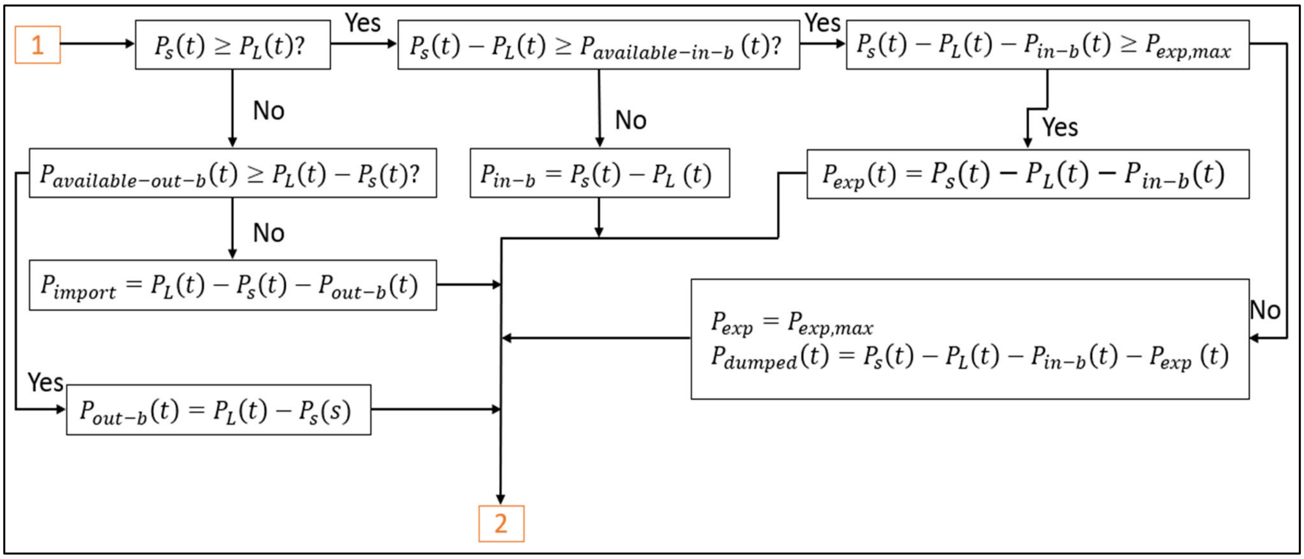


Figure 10: Home Energy Logical used for residential renewable systems.

According to Figure 13, the renewable source will feed the load first. If the source energy is higher than load, then the battery will be charged. If not, the energy will be taken from the BES system. In addition, if there is no energy in the BES system, the electricity will fully import from grid. Moreover, if the energy is battery system is full, the exceed energy will be export to grid based on the grid constraint. In the event that the quantity of energy sold through the grid surpasses the established threshold, it will be the dumped power.

3.3. Analysis System Formulas

3.3.1. Energy flow of system

For both configurations, when the power generated by PV or WP (P_s) exceeds the load (P_L), the excess electricity is first used to charge the BESS according to the input power limit of the battery. The charging power of the BESS (P_{in-b}) can be determined by:

$$\boldsymbol{P_{in-b}(t) = P_s(t) - P_L(t)} \ \ [\mathbf{kW}] \tag{1}$$

When the generated power is higher than load power and the battery power is full. The extra power will be sent into the grid. The export power (P_{exp}) can be calculated as:

$$P_{exp}(t) = P_s(t) - P_L(t) - P_{in-b}(t) \ \ [\text{kW}] \tag{2}$$

And $0 < P_{exp}(t) < P_{exp,max}$ based on the maximum export power to the grid of South Australia regulation.

The extra power will be the dumped power (P_{dumped}) can be determined as

$$P_{dumped}(t) = \ P_s(t) - P_L(t) - P_{in-b}(t) - \ P_{exp}(t) \ [\text{kW}] \tag{3}$$

However, if the generation power is lower than the load. The power from the battery will be taken which is called the discharging power from battery P_{out-b} and calculated as

$$P_{out-b}(t) = P_L(t) - P_s(t) \ [\text{kW}] \tag{4}$$

Moreover, when the generated power is lower than the load and the battery power cannot fully supply the load. The electricity will be taken from the grid. The import power from the grid can be determined as

$$P_{import}(t) = P_L\ (t) - P_s(t) - \ P_{out-b}(t) \ [\text{kW}] \tag{5}$$

The battery state of charge (SOC) for each time interval (Δt) is measured as [9]

$$SOC(t + \Delta t) = SOC(t) + \frac{(P_{in-b}(t)\eta_{in} - P_{out-b}(t)/\eta_{out})\Delta t}{E_{battery}} \ \ [\%] \tag{6}$$

With η_{in}/η_{out} are the import/export efficiency of the battery (%) and $E_{battery}$ is battery capacity (kWh).

Hence, the available BESS input/output power (P_{ib}/P_{ob}) limits is determined as [42]

$$P_{ib}(t) = \frac{E_{bes}}{\Delta t}(SOC_{max} - SOC(t)) \text{ [kW]} \tag{7}$$

$$P_{ob}(t) = \frac{E_{bes}}{\Delta t}(SOC(t) - SOC_{min}) \text{ [kW]} \tag{8}$$

With E_{bes} is the energy of capacity of battery system

3.3.2. Cash flow

The main goal function within the initial category of minimization pertains to the cost of electricity associated with the renewable energy system (RES). The application of electricity cost can be achieved through the utilization of various metrics such as the net present cost (NPC), yearly price of electricity, and cost of energy (COE). The net present cost (NPC) of a RES is calculated by the NPC of components (NPC_c) and NPC of electricity exchange with the grid (NPC_g) [6]. Additionally, the system is considered as connected to the grid, the present value of imported energy is determined, while the present value of all provided power over the system's life cycle is subtracted. The acronym NPC is frequently utilized in scholarly literature interchangeably with other terms such as net present value (NPV), the entire system cost, or the lifespan cost of the system.

The total NPC (NPC_{total}) is determined as [12]:

$$NPC_{total} = NPC_c + NPC_g \text{ [\$]} \tag{9}$$

Moreover, the NPC_scan be formulated from the capital cost (PC_c), replacement present cost (PC_r), maintenance present cost (PC_m), the salvation cost (PC_s) and N is the number of components. Thus, the NPC_s can be calculated as [19]:

$$NPC_c = N(PC_c + PC_m + PC_r) \text{ [\$]} \tag{10}$$

Moreover, the PC_m and PC_r can be calculated as [19]:

$$PC_m = C_m \frac{(1+i)^m - 1}{i(1+i)^m} \text{ [\$]} \tag{11}$$

$$PC_r = \frac{C_r}{(1+i)^m} \text{ [\$]} \tag{12}$$

With C_m and C_r is the fixed maintenance and replacement cost yearly respectively, i is the interest rate, and m is the lifespan of component.

In addition, NPC_g can be calculated by the total import and export electricity based on the retail price (RP) and Feed-in-Tariff (FiT) price in 2023. There are two types of electricity RP which is Time-of-use and Anytime tariff corresponding to residential using only electricity and gas-electricity. Based on the report of David Hilley 2023 [43], the RP, and FiT of Energy Australia retailer in 2023 for South Australia are demonstrated as Table 5 below.

Table 5: The electricity rate in South Australia 2023

Electricity rate	Time period name	Time	Cost (¢/kWh)
Time-of-use Tariff	Off-peak	10am-3pm	20.62
	Shoulder	1am-6am	33
	Peak	6am-10am and 3pm-1am	55
Anytime Tariff	All day		47.28
FiT	All day		8.5

Hence, the NPC_g can be determined as [42]

$$NPC_g = \sum_{t=1}^{K} I(t) P_{import}(t).\Delta t - \sum_{t=1}^{K} E(t) P_{exp}(t).\Delta t \ \ [\$] \tag{13}$$

With I is the import price of electricity and E is the FiT price and K is the total hours.

Finally, the cost of electricity (COE) will be used for the comparison between two systems in same location. In this project, there are two locations will be concerned which are Adelaide city and Mount Lofty. Thus, the COE will be calculated for each system and each location. The COE is the ratio of a household's total net payments in 2023 to its total annual electricity consumption and determined as [9]

$$COE = \frac{NPC_{total}}{E_{Load}} \ [\text{¢/kWh}] \tag{14}$$

With E_{Load} is the total electricity per year of the GCH which is calculated as [13]

$$E_{load} = \sum_{t=1}^{K} P_L(t).\Delta t \ \ [kWh] \tag{15}$$

After the COE is identified, the results of each system in each location will be compared. systems with large COE will bring more economic benefits to users.

3.3.3. Result constraints

Based on Figure 2, the system needs to meet the constraints for the analysis and simulation process. The constraints of PV or WT output power:

$$0 \le P_s(t) \le P_{s,max} \tag{16}$$

With $P_{s,max}$ is the maximum output power of PV or WT based on the specification data of selected material.

The BES constraints can be determined as

$$0 \le P_{imp-b}(t), P_{exp-b} \le P_{battery,max} \tag{17}$$

With $P_{battery,max}$ is the maximum power of the selected battery.

Moreover, the constraint for the SOC of the battery is illustrated as

$$SOC_{min} \le SOC(t) \le SOC_{max} \tag{18}$$

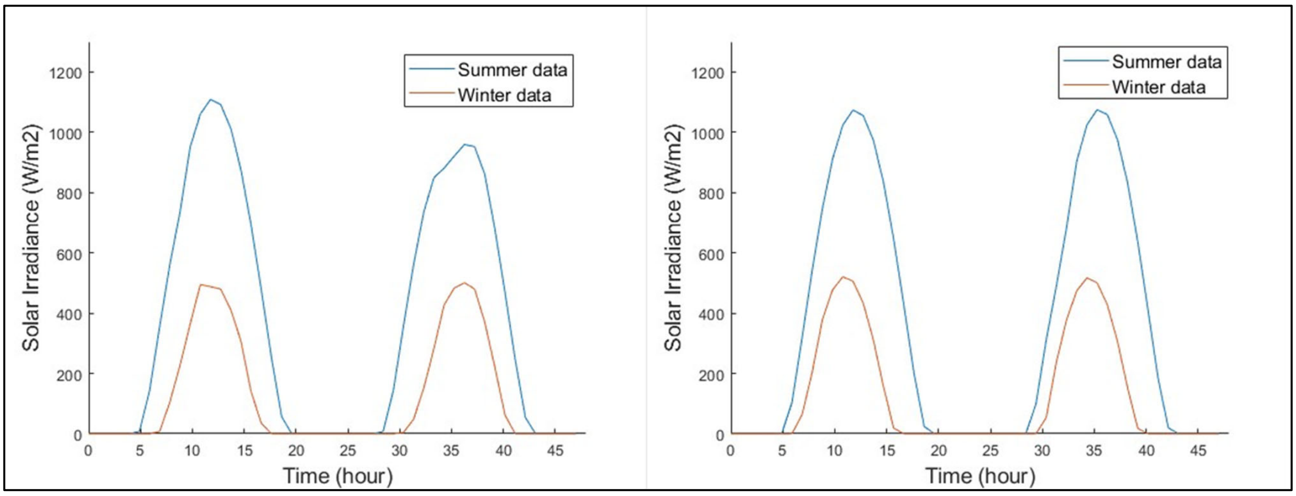
For the export power to the grid, the constraint of it can be determined as

$$0 < P_{exp}(t) < P_{exp,max} \tag{19}$$

In addition, the simulation system will be built, debugged, and tested through MATLAB. The solutions of power flow analysis will be used for calculating the COE. For the uncertainty analysis of the project, the actual data will be taken form BoM daily and the results of COE will be determined into two decimal places.

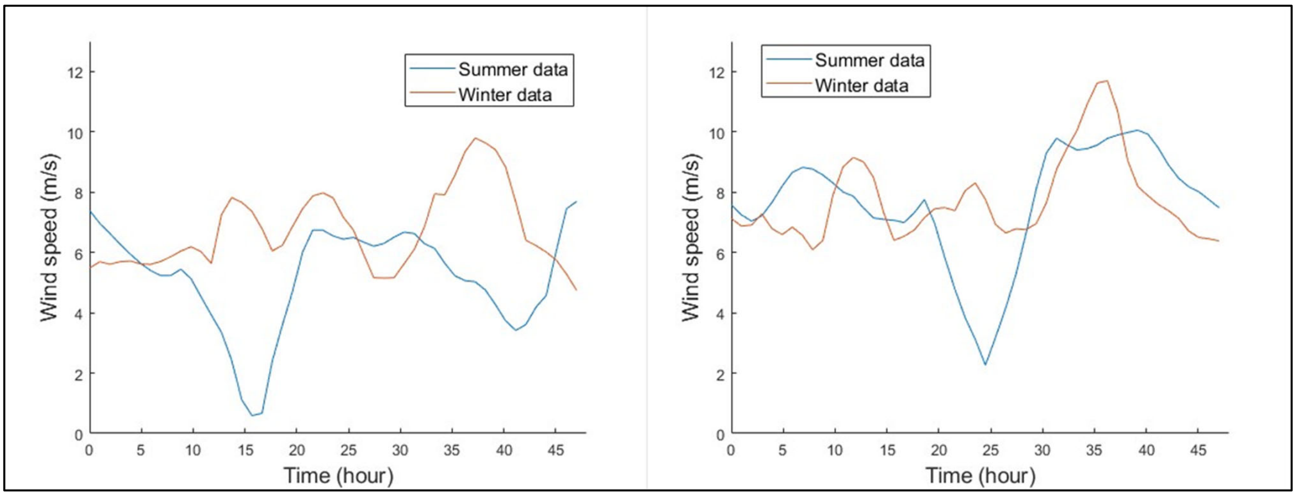
3.4. Additional information about input data to simulation system

To obtain a more comprehensive understanding of the outcomes, the input data will be analysed for a duration of two days across two distinct seasons for each location. The selected data is demonstrated as Figure 11 and 12 below as solar irradiance and wind speed data in two locations respectively. It can be claimed that the solar irradiance during the summer period is significantly higher than winter period of approximately double. On the other hand, the wind speed of city location is slightly lower than Mount Lofty area.



(a) Adelaide **(b) Mount Lofty**

Figure 11: Solar irradiance of two sample days each season in two locations



(a) Adelaide **(b) Mount Lofty**

Figure 12: Wind speed of two sample days each season in two locations

4. RESULTS

In this section, the simulation results of two system PV-BES and WT-BES are presents. The result is made in two phases. Firstly, all the power flow results are generated by MATLAB/Simulink. Secondly, it was used to calculate the NPC and the COE of system in each case. All results will be claimed for the comparison process of two systems each case.

4.1. Power Flow Analysis

4.1.1. Location 1: Adelaide city

a) PV-BES system

In summer of Adelaide, the consumption of electrical energy during extreme climatic events, such as a summer heatwave, exhibits comparable daily variations. Figure 13 illustrates the power load, generated power, and import/export power from the grid over a two-day period in the summer season at the Adelaide location. During daylight hours, the generation of solar energy significantly mitigates the consumption of electricity. However, at sunset, when solar generation ceases, the net demand for electricity experiences a sudden increase, reaching its peak at approximately 17:30 in the evening. Subsequently, as the night progresses and energy demand diminish, the net electricity demand gradually decreases.

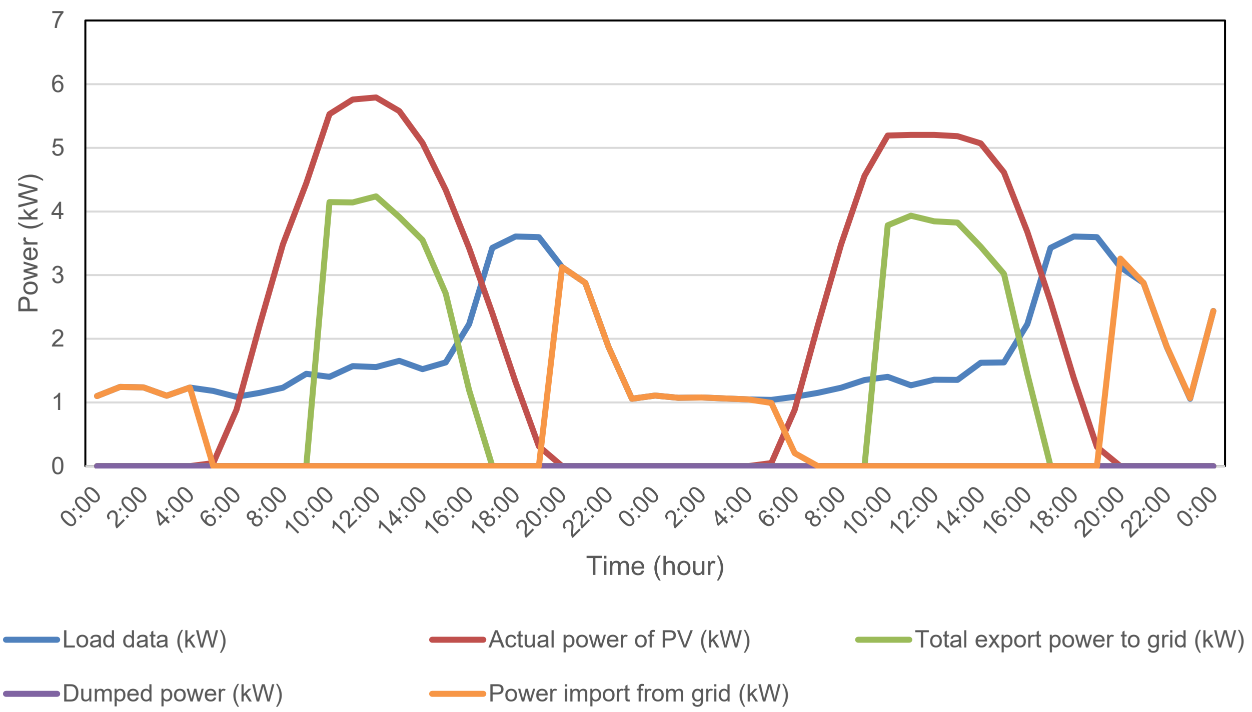


Figure 13: The power flow of PV-BES system of Adelaide residential house (two days in summer)

However, during winter period, the amount energy generated by PV system is significantly decrease of about double compared to summertime. It is due to the solar irradiance in winter is lower. In addition, during the winter season, households frequently find it necessary to increase their electricity consumption due to the usage of various appliances such as heaters and humidifiers. Hence, as depicted in Figure 14 presented below, there will be a notable surge in electricity consumption commencing at 4 pm and persisting until approximately 1-2 am. Furthermore, it is worth noting that the solar system's capacity to generate electrical energy may not suffice, necessitating a significant reliance on the grid for energy supply. It also can be claimed that there is no export power to grid and dumped power in this period.

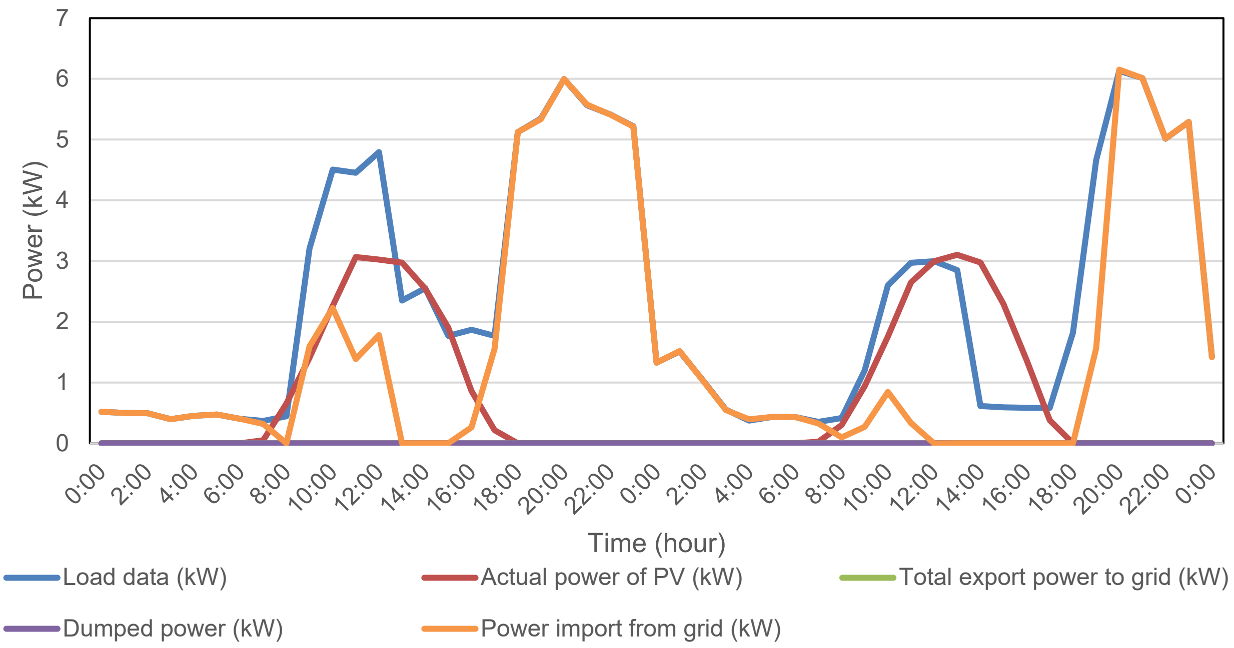


Figure 14: The power flow of PV-BES system of Adelaide residential house (two days in winter)

For the BES system, during the summer, the SOC of battery can reach to its peak of about 89.677% compared with 67.708% as the highest point in winter according to Figure 15 below. In addition, the BES system can reach the maximum during the sunny time in summer from 10am to 6pm. Hence, it can be claimed that the PV system can fully feed the load during this period in summer.

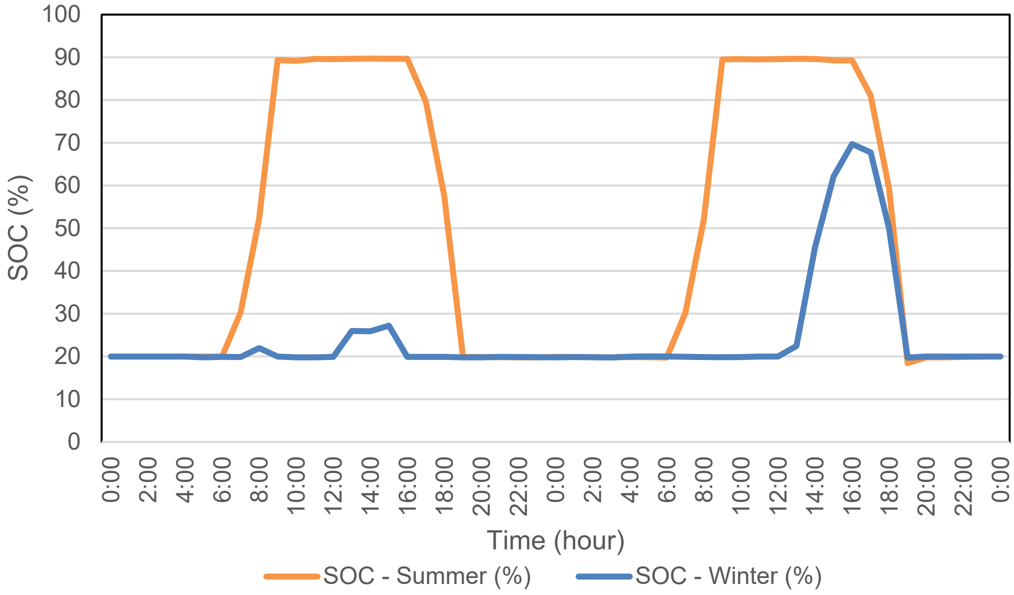


Figure 15: The SOC of battery in PV-BES system two days each season in Adelaide location.

b) *WT-BES system*

During the summer period in Adelaide location, the WT system generated lack of energy as Figure 16 below. In two sample days, it can be observed that the energy supplied is approximately 1.5 kW during 10pm to 10am. Hence, in the peak period, almost all energy is taken from grid. In addition, there is no dumped power and export power to grid during this period.

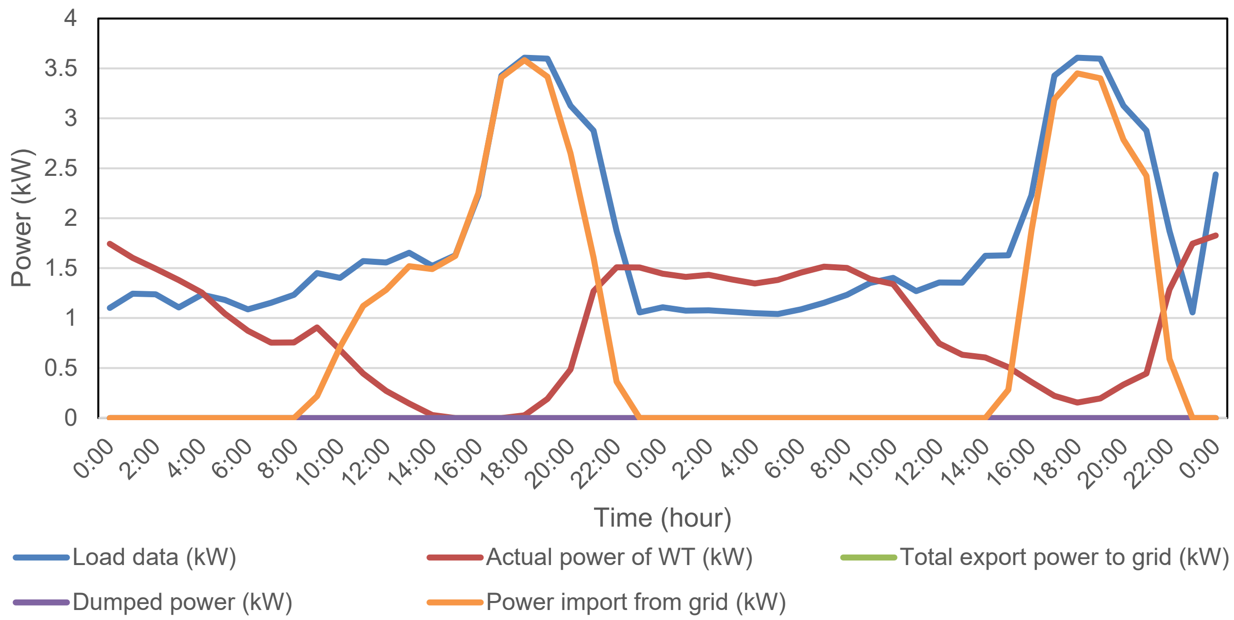


Figure 16: The power flow of WT-BES system of Adelaide residential house (two days in summer)

However, in winter, The WT system exhibits a more consistent and substantial energy generation compared to the summer. According to the following Figure 17, it can be observed that the highest power generated is approximately 4kW at second day 3pm. In addition, during 0am to 10am in first day and 0am to 8pm in second day, the residential house doesn't import energy from grid, WT-BES system can fully feed the load even during the peak period. Moreover, there is a small amount of energy export to grid of approximately 10kWh in two days period.

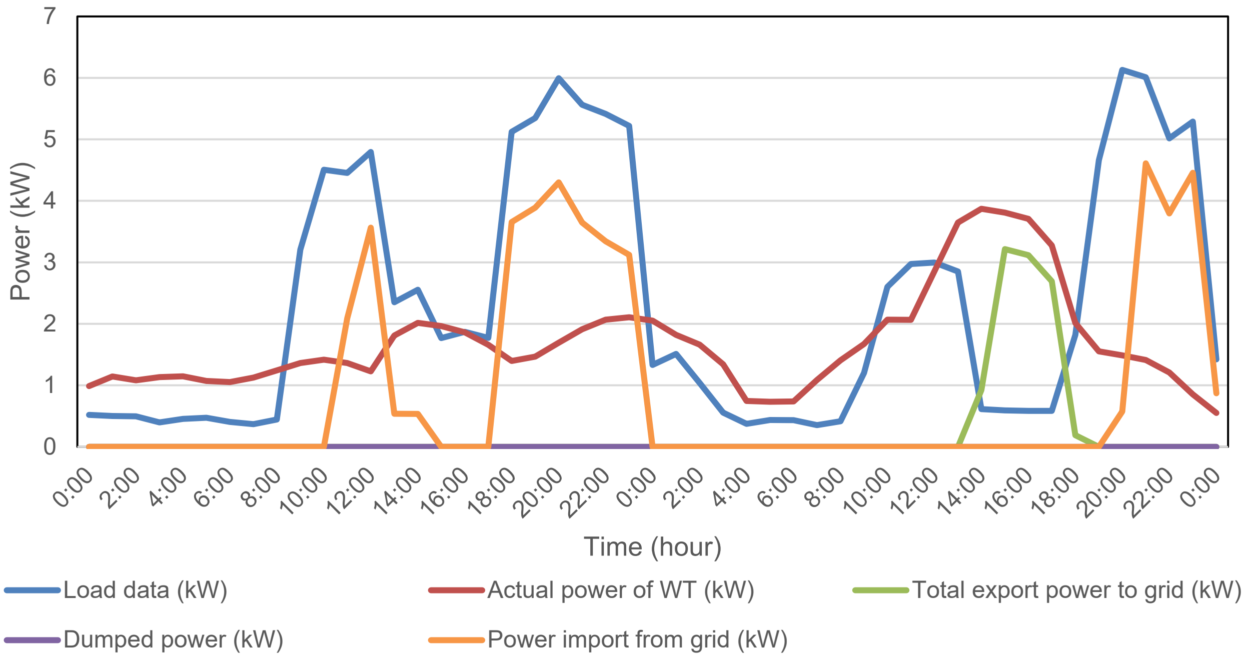


Figure 17: The power flow of WT-BES system of Adelaide residential house (two days in winter)

The SOC of BES system is demonstrated as Figure 18 below. it can be observed that the battery stored more energy in sample days winter than in summer. The BES have energy of about 14 hours over 48 hours in winter with the peak is 89.917%. While in summer, there is about 19 hours BES has energy stored. In addition, the highest point of SOC in summer is only 53.961%. Furthermore, approximately 70% of sample time each season SOC of battery in WT-BES has energy inside. It is means that wind power systems have the capability to consistently and reliably generate energy output.

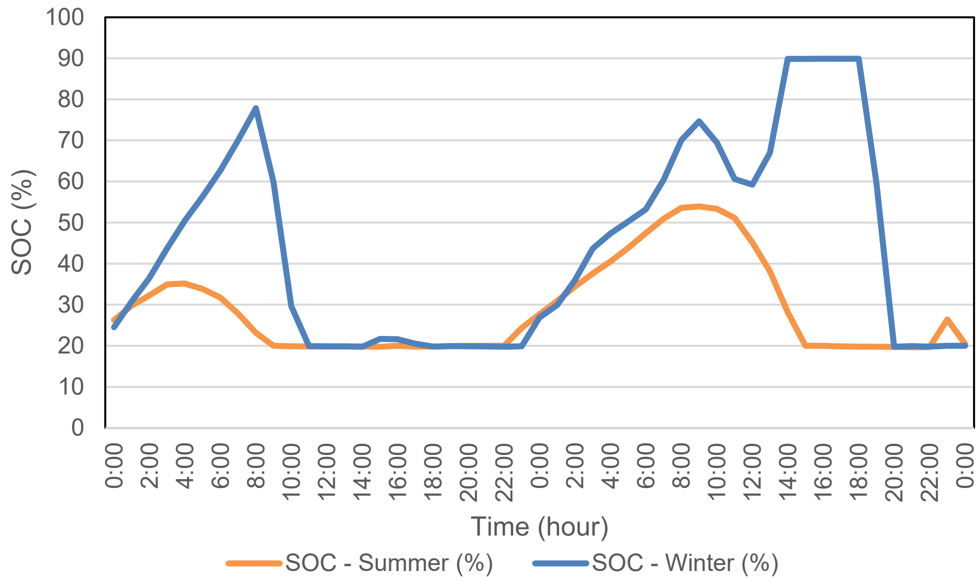


Figure 18: The SOC of battery in WT-BES system two days each season in Adelaide location

4.1.2. Location 2: Mount Lofty

a) PV-BES system

According to Figure 19 and 20 below, it can be claimed that the power flow result of PV-BES in Mount Lofty location is approximately equal to PV-BES system in Adelaide location. The residential house only needs to import a small amount of energy from grid in summer between 8pm to 7am every day, however, the taken power from grid is increase significantly in winter especially during the peak time of the day. It will cause the electricity payment increases.

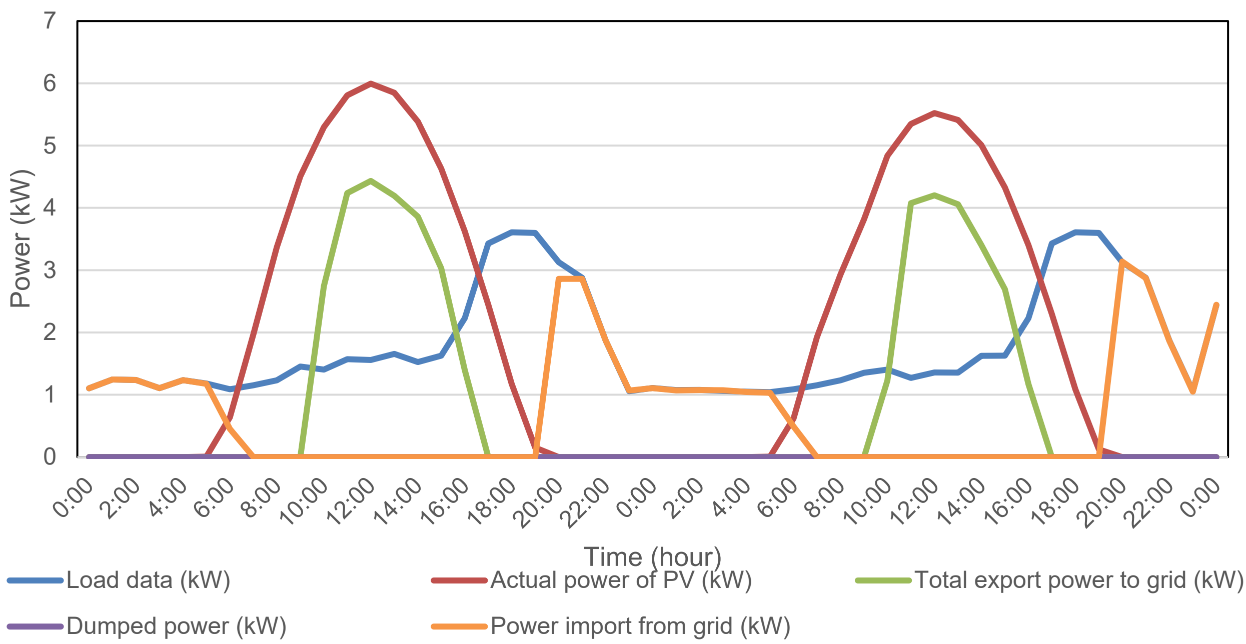


Figure 19: The power flow of PV-BES system of Mount Lofty residential house (two days in summer)

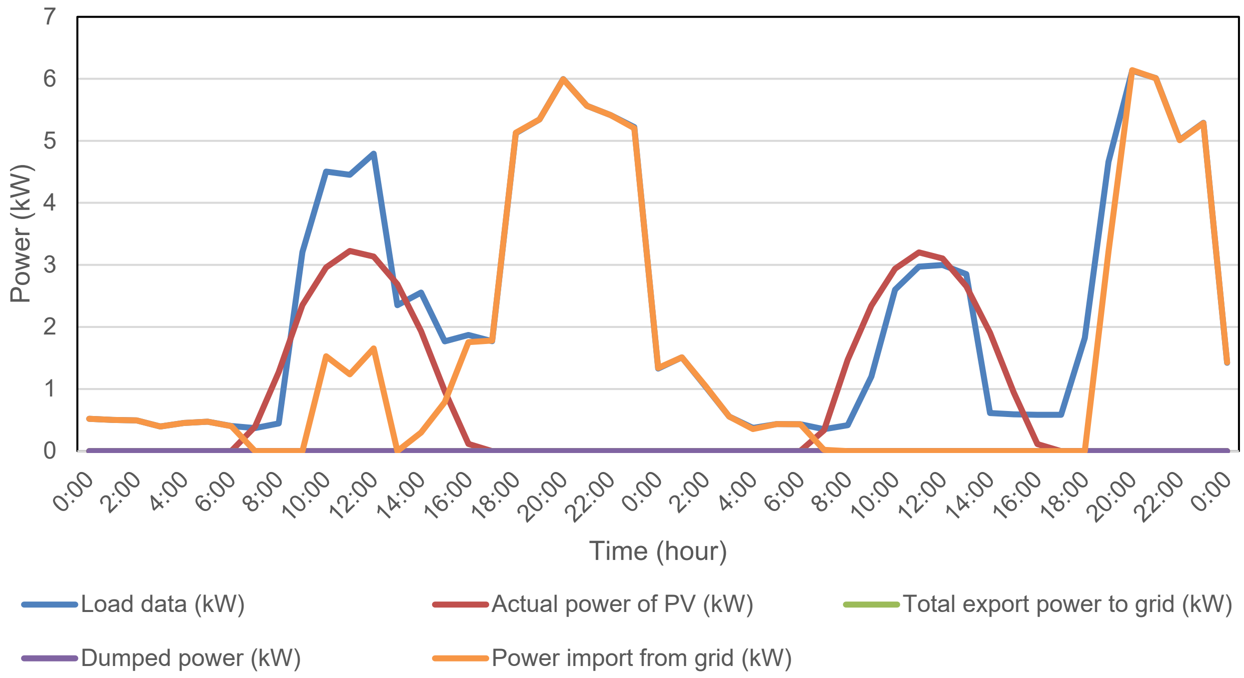


Figure 20: The power flow of PV-BES system of Mount Lofty residential house (two days in winter)

Figure 21 demonstrates SOC of battery of PV system of Mount Lofty residential house. It can be observed that, during winter period, the charging duration of battery is longer than Adelaide location of about 14 hours compared to 10 hours as in Figure 18. However, in summer, the results are approximately equal not duration of charging but also the period SOC reaches to its maximum value.

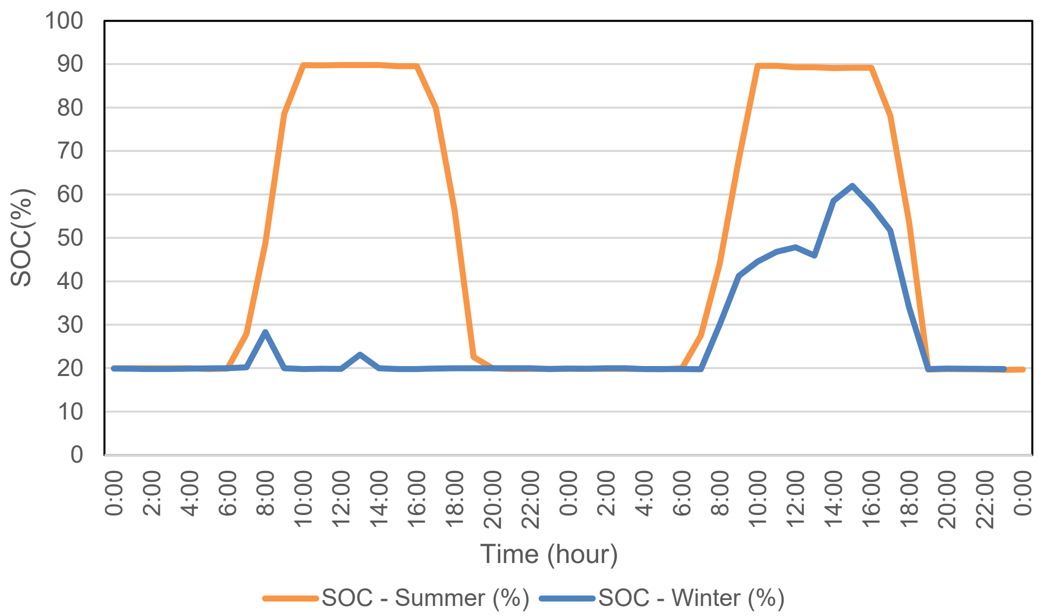


Figure 21: The SOC of battery in PV-BES two days each season in Mount Lofty location

b) WT-BES system

Based on the data presented in Figures 22 and 23, it is evident that wind energy consistently maintains a level of generation that is sufficient to meet the energy demands of households. This is substantiated by empirical evidence indicating that during the summer season, the energy consumption from the power grid experiences a consistent pattern of minimal usage, specifically within the time frame of 0:00 to 4:00, where the recorded energy taken from grid amounts to 3.2 kWh. Despite the considerable energy generated by the wind system, it is unable to adequately meet the demand during peak hours in winter. Nevertheless, throughout daylight hours, the system retains the capability to vend surplus electricity to the power grid, thereby mitigating electricity expenses. In contrast to wind systems implemented in urban areas, wind systems deployed in highland regions have the potential to generate approximately 20% more energy.

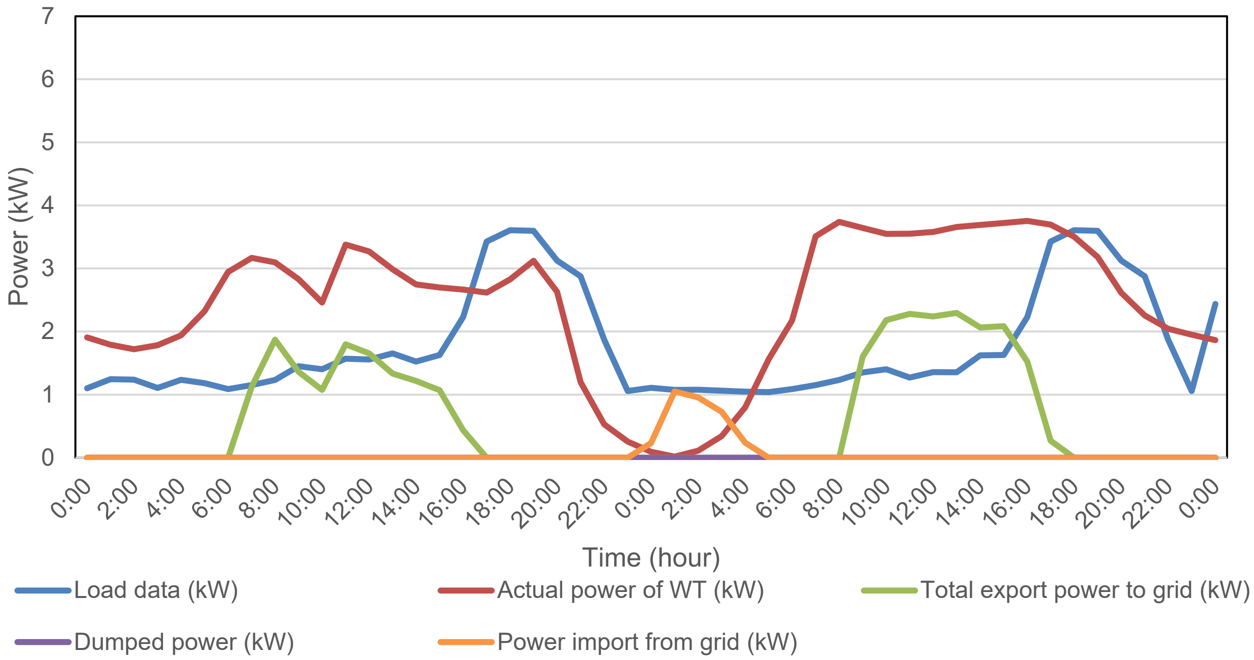


Figure 22: The power flow of WT-BES system of Mount Lofty residential house (two days in summer)

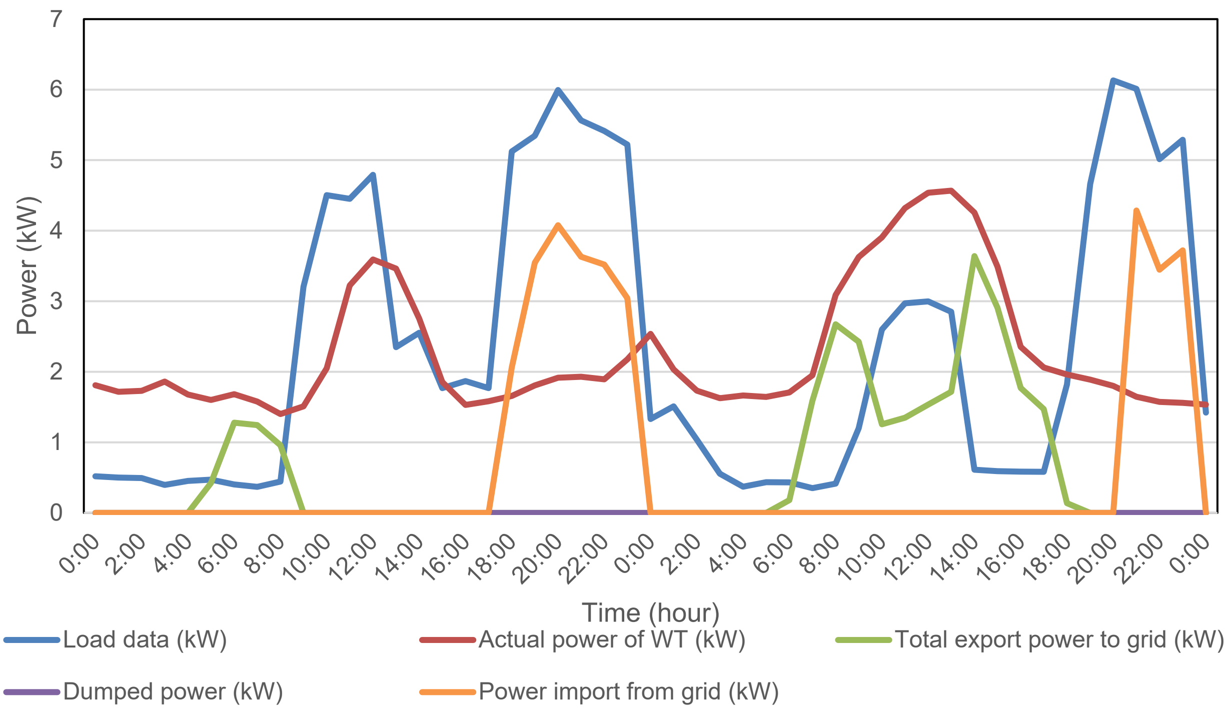


Figure 23: The power flow of WT-BES system of Mount Lofty residential house (two days in winter)

In regions characterised by high elevation, wind velocities surpass those observed in low-lying areas, resulting in a substantial yield of energy from wind turbines. As previously stated, the quantity of wind energy produced has the capacity to fulfil the demand for energy consumption. The surplus energy will be allocated primarily towards charging the battery system. Figure 24 illustrates that the state of charge (SOC) of the battery can attain its highest level, indicating full charge, during both winter and summer seasons. Furthermore, it is worth noting that the battery requires a total duration of 24 hours to achieve a fully charged state within a span of two days during the summer season, whereas it takes 16 hours over 48 hours during other seasons.

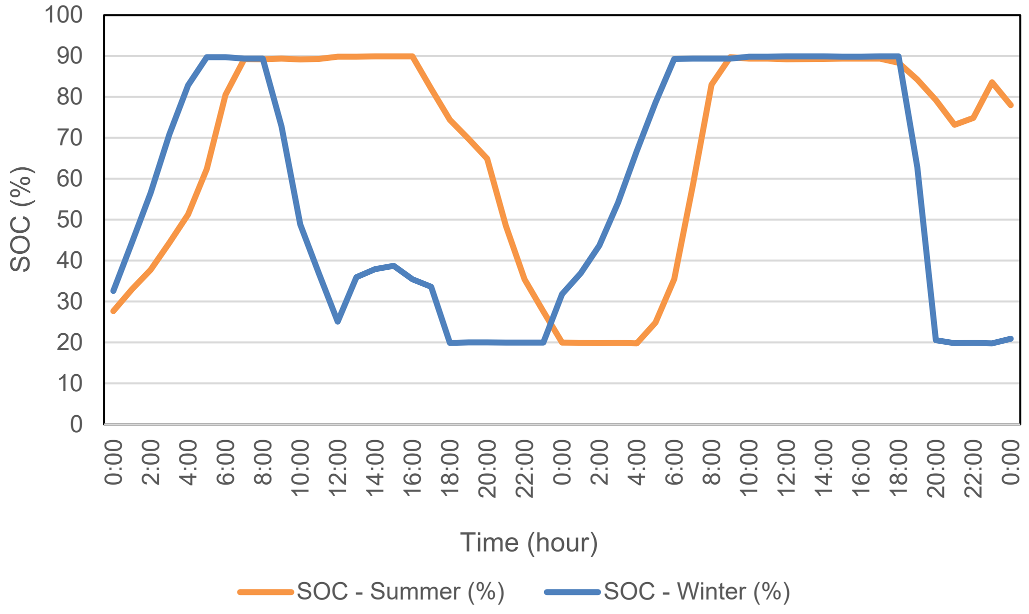


Figure 24: The SOC of battery in WT-BES system two days each season in Mount Lofty location

4.1.3. Summary of power flow analysis

The following Figure 25 illustrates the summary of power flow analysis of two system in all cases. It can be observed that PV-BES supply more electricity than WT-BES in Adelaide location of total approximately 135 kWh in two days two season compared to 126 kWh. However, In Mount Lofty area, WT-BES produces huge of energy of about 20kWh larger in two days summer and approximately triple during winter period.

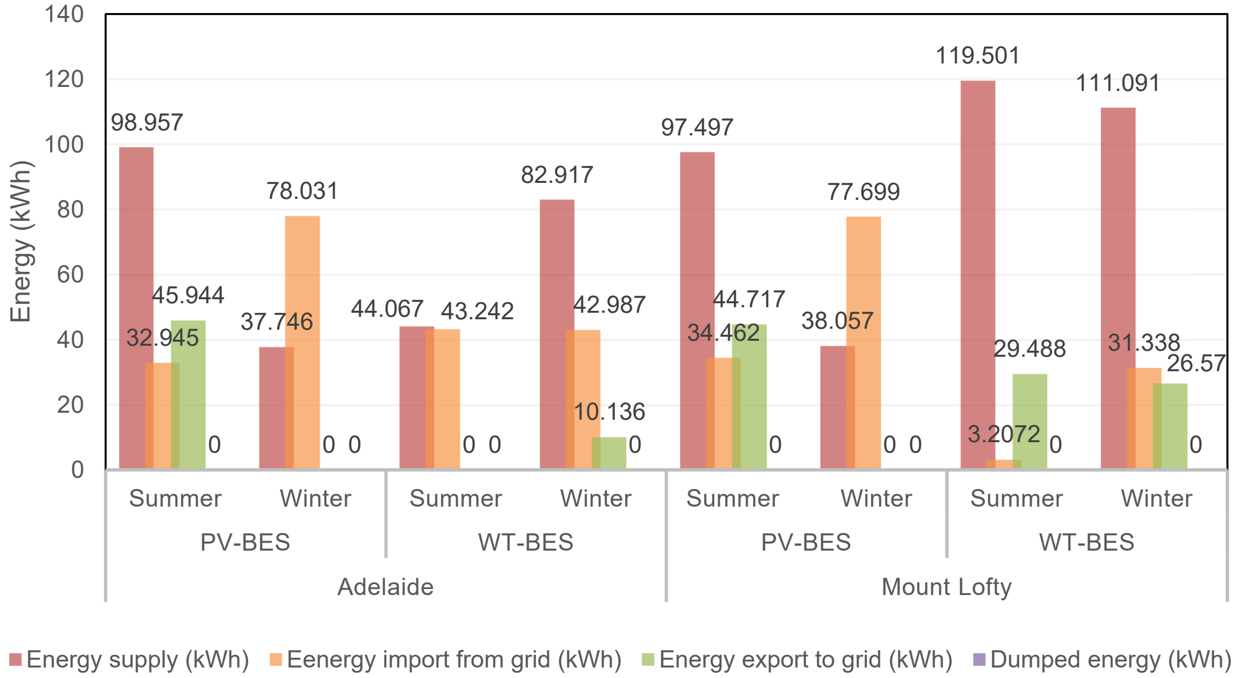


Figure 25: The summary of power flow of two system all cases

The energy export to grid of PV-BES in Adelaide and Mount Lofty is approximately equal of 49.5/0 kWh and 44.7/0 kWh in two seasons respectively. When conducting a comparison between PV systems and WT situated on elevated terrain, it becomes evident that WT has the capacity to generate a greater amount of electricity for grid integration. Specifically, WT can supply approximately 56 kWh of electricity to the grid within a span of two days per season, whereas PV systems alone are able to generate approximately 45.9 kWh of electricity within the same timeframe. During the winter season, the solar power system experiences a shortage of electricity, resulting in an insufficient supply to be sold back to the grid. Moreover, based on Figure 25, in all instances, the export power to the grid has not surpassed the grid constraint of 5kW, thus eliminating any occurrence of excess power being discarded.

In the next stage, the simulation models of two systems also ran with the input data in one year. The annual energy of two system in each case is demonstrated as Figure 26. below. The total energy charge into BES system is approximately 3700 kWh in one year for PV-BES system in both locations and WT-BES system in Adelaide, however, this number is increased about 25% for WT-BES in Mount Lofty location. Furthermore, in two investigated area, the energy export to grid of PV-BES system is around 8200 kWh while this variable of WT-BES is 1850 kWh and 10231 kWh for Adelaide and Mount Lofty respectively. For the annual energy supply, WT-BES system can bring a huge amount of energy for the residential house as same as 2 sample days results of about double to others cases.

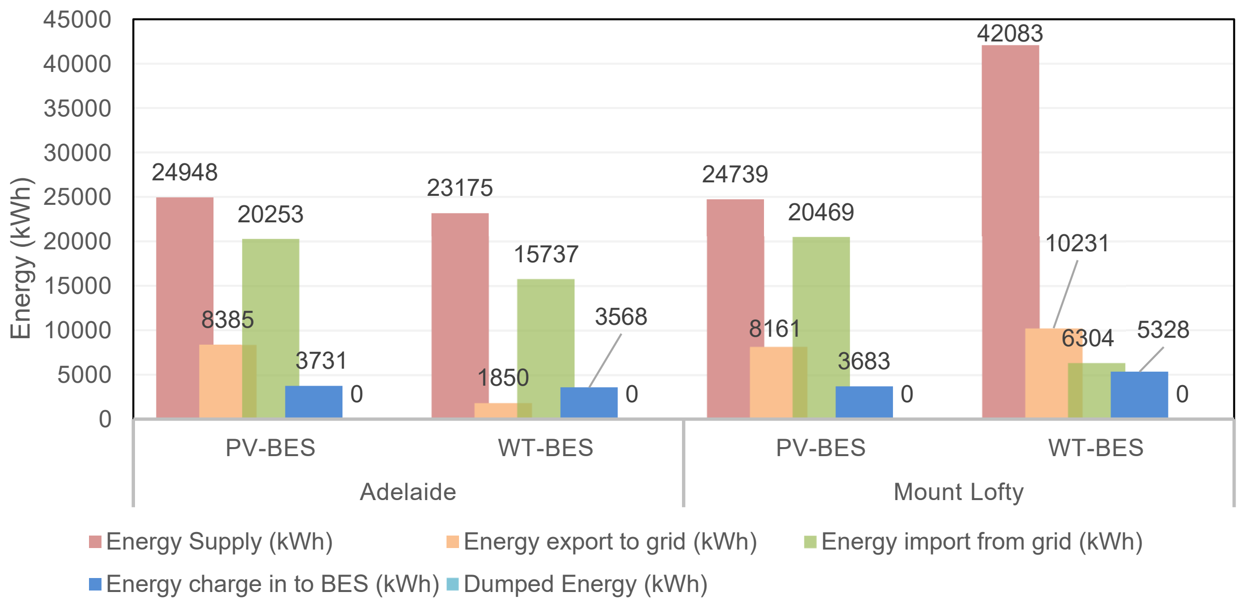


Figure 26: The results of annual power flow of two system PV/WT-BES in two investigated locations.

4.2. Cash Flow analysis

Based on the system specifications and price on the market in Table 5, the capital cost (PC) of each material has been calculated as Table 6 below. It can be claimed that the capital cost of PV system is higher than WT system of approximately $300/kWh. In addition, the battery is the most expensive material in both system of $1034.08/kWh.

Table 6: The calculation of capital cost of PV, WT, and BES material

Component	Component cost each ($)	Total component cost in system ($)	Capital cost ($/kWh)
Solar Panel	280.2	5043.6	951.51
Battey System	10589	10589	1034.08
Wind Turbine	3230	3230	646

According to interest rate and investment loan of Commonwealth Bank 2023 [17], the deposit rate is 10% with the interest rate is 6.35% per year in 5 years investment payment duration. In addition, the maintenance, installation, and replacement cost of each system is 3% per year as the assumption. These values will be combined with the power flow analysis from simulation model in Simulink, material cost and electricity rate in Table 6 to determine the annual NPC of each system in each case. Moreover, the annual load demand of sample residential is 17.61 MWh. Table 7 below demonstrates the calculated number of NPC and COE of systems in all cases.

Table 7: The results of total NPC and COE of two system in all cases.

Location	System	Load data one year (MWh)	Total NPC one year ($)		COE (¢/kWh)	
			Anytime tariff	TOU tariff	Anytime tariff	TOU tariff
Adelaide	PV-BES	17.61	8920.92	8959.43	50.65	50.87
	WT-BES		7609.55	7755.7	43.21	44.04
Mount Lofty	PV-BES		8963.08	9006.29	50.9	51.1
	WT-BES		5204.39	5463.59	29.55	31.3

Based on the result in Table 7, it can be claimed that the NPC of PV-BES system in both cases is higher than WT-BES system in both locations with approximately $1300 and

$3600 for Adelaide and Mount Lofty respectively. In addition, according to the calculated value of total NPC, the COE had been determined as two cases of electricity rate. It can be observed that the COE of PV-BES system is higher than WT-BES system of about 17% and 30% corresponding to two locations Adelaide and Mount Lofty. Furthermore, with TOU electricity rate case, the results of COE are always higher than anytime tariff cases of approximately from 1-5% in both cases of systems and locations.

5. DISCUSSION

Within the discussion section, it is imperative to thoroughly analyse the findings in correlation to the project objectives delineated earlier within this investigation. The main objective of the project is to compare PV-BES system and WT-BES system based on the generated energy of system and the reduction of COE from actual electricity rate. According to the results of power flow analysis in last section and calculated COE, the comparison between two system PV-BES and WT-BES is illustrated in discussion section with recommendations to residents in choosing their add-on renewable source for houses. Moreover, future works is also demonstrated based on the limitations of project.

5.1. Discussion

5.1.1. Energy flow comparison

According to the summary of system power flow Figure 25, it is noted that PV-BES system can supply more energy than WT-BES system in Adelaide location corresponding to approximately 137 kWh of 2 days each system compares to 127 kWh. Research findings indicate that solar panels have the capacity to generate electricity in urban areas at a rate exceeding 9%. In contrast, WT generates significant larger amount of energy than PV in the highland location of approximately 38%. It is due to the fact the wind flow within an urban environment exhibits mean velocities that are approximately 20 to 30% lower compared to the velocities of winds traversing the surrounding rural areas or elevated terrain [44].

Furthermore, based on the result of SOC of BES system in PV-BES system and WT-BES system with Adelaide location in Figure 17 and 20 respectively, the period BES system reaches its peak of SOC is longer than WT-BES system in summer. It means PV-BES system produce more energy than WT-BES in summer, however, in winter, PV shows its disadvantages with low solar irradiance. For Mount Lofty location, the energy capacity of a wind power system's battery surpasses that of a solar power system. Additionally, it is evident that the rate of growth of SOC over a period of time is 20% greater as demonstrated in Figure 21 and 24. In addition, with 5kW of PV-BES and WT-BES system, the energy export to grid cannot exceed the grid constraint. Hence, there is no dumped power during the sample days period.

Based the annual energy flow of two systems in Figure 26, it can be overserved that WT-BES system can supply more energy than PV-BES of about double and export energy grid higher than 20% PV-BES system in Mount Lofty. While PV-BES system can provide/export 3%/80% respectively energy larger than WT-BES in Adelaide case.

5.1.2. COE comparison

Based on the result in Table 6, the capital cost of WT-BES system is low than PV-BES of approximately $300/kWh. It is due to the new technology of wind turbine; the price of wind turbine is decreased of about 40% in 2021 compared to its in 2010 [45]. Hence, according to the result of total NPC, WT-BES system has the total NPC lower than PV-BES in all cases. As the calculated results in Table 7, the COE for the WT-BES system exhibits a notable reduction compared to the PV-BES system, with values of approximately 43.5 ($¢/kWh$) for the city of Adelaide and 30.5 ($¢/kWh$) for Mount Lofty. Therefore, The COE for PV-BES exhibits variations ranging from 7 to 20, depending on the geographical location.

Compared to previous study, for WT-BES system, the COE results in this project are lower than COE previous study (31.07 $¢/kWh$) of 30% for Adelaide locations and higher than 10% for Mount Lofty locations [46]. In addition, the previous investigation COE of PV-BES system is 28 ($¢/kWh$) which is higher than this study of approximately 40% [24]. It is due to the fact that the electricity tariff in South Australia have been increase of up to 30% in 2023 [12].

5.1.3. Recommendations to residents

As the result of power flow analysis, in urban areas, the PV-BES system offers a greater number of advantages compared to the WT-BES system. However, this scenario is reversed in the context of Mount Lofty. In addition, from cash flow analysis results, the WT-BES system offers greater advantages compared to the PV-BES system, particularly in highland areas like Mount Lofty, in terms of cash flow and power flow analysis. The homeowner can decide to utilise a WT-BES system as an alternative to a PV-BES system for their supplementary renewable energy supply for their residential property. However, it is worth noting that PV-BES exhibits a distinct advantage over WT-BES in terms of noise generation, as it produces no noise. Thus, PV-BES is more suitable for urban area than WT-BES system even it brings fewer financial benefits than WT-BES system.

5.2. Limitations and suggestions for future work

In the project, there are several limitations of project. Firstly, the PV-BES does not account for shading on the solar PV panels from nearby trees or buildings, aging of the solar PV panels resulting in decreased efficiency, temperature fluctuations impacting the performance of the battery storage system, and high grid electricity prices resulting in lower returns on investment. In addition, the non-coverage areas for the WT-BES system include turbulence due to nearby structures or wind direction changes affecting the performance of the wind turbine, noise pollution from the wind turbine affecting nearby residents, limited availability of suitable locations for wind turbines in densely populated areas, and high up-front for wind turbines relative to other renewable energy sources. Furthermore, the consideration of system lifespans in NPC calculations has been omitted. According to the manufacturer's data, the solar panel has a warranty period of 25 years, whereas the WT system has a warranty period of 10 years. Finally, the optimal sizing progress of PV-BES and WT-BES system are not considered. The used capacity of PV-BES and WT-BES systems are based on the material selected on market.

For the suggestions of future works, the available are of rooftop, lifespan of each material and the performance of system based on weather conditions to be surveyed, hence, the results of power flow analysis will be more accurate. Consequently, the advantages of PV-BES system may increase for hill area case. In addition, the input data need to be used in 15-20 years with considered the life span of system. Hence, the result of total NPC and COE is closer to the reality system. Lastly, an optimize sizing algorithm such as PSO or GA algorithm need to be developed and improved; hence, the comparison between two system will be more sensible.

6. CONCLUSIONS AND FUTURE WORKS

In conclusions, the main aim of this project is the comparison between PV-BES system and WT-BES system of residential house in two selected locations, which are Adelaide and Mount Lofty, using simulation models in MATLAB/Simulink. In the working progress of project, goals and objective functions must be achieved. The study investigates in creating two simulation model of PV-BES and WT-BES based on mathematical theory, system controller and code in MATLAB/Simulink environment. Moreover, the database of PV, WT and BES have been set up based on the theorical power capacity of manufacturers which is 5kW for supply source and 10kWh for battery. Furthermore, the input data for the system is the actual weather data from BoM in 2022, the load demand of a residential in South Australia and the electricity rate of South Australia in 2023. Afterwards, in the system testing progress, the performance of models was increased by improving system controller value and code in two model. These goals have been met thorough the results of power flow analysis of systems in cases as well as the calculated COE from simulation models. In Mount Lofty location, WT-BES can bring more advantages than PV-BES in the first 5 years of payment duration. It is due the results that the supplied energy from WT-BES system is significantly higher than PV-BES system of about 30%. However, in Adelaide location, Solar systems have more benefits due to their ability to export a higher amount of energy to the grid even the generated energy of both system is approximately equal. In the cash flow analysis, in both cases of tariff, the electricity cost of WT-BES system is lower due to the capital cost of WT cost is less than PV panels. As the results, the recommendations for residential houses have been made. PV-BES is suitable for urban area while WT-BES can bring a financial benefit for highland area.

The aim of this study is to evaluate the relative merits and drawbacks of PV-BES and WT-BES systems under varying weather conditions. This will be accomplished through an analysis of power flow and cash flow. The research aims to provide a comprehensive analysis for residents in selecting a renewable energy source for their residential properties. As the results power flow and cash flow analysis, residential houses in city area can choose PV-BES system as the add-on renewable sources for their house because it can bring lower low price of electricity and stable system. While, in hill area, WT-BES is a better option with significantly reduce the cost of electricity and huge amount of supply power.

The preceding section encompasses an analysis of the findings, constraints encountered, and recommendations for future research. To solve the limitations, the prediction calculation with sensitivity tool needs to be employed within 20 years of project's lifespan. In addition, algorithm method such as PSO, GA is also essential and added on to optimize sizing of the system as well as increase the energy efficiency. Hence, the comparison progress will be more accurate. Furthermore, in the future researches, the comparison between optimal two system PV-BES and WT-BES can also investigate for various state of Australia. In addition, the predication of systems for 15-20 years durations also need to be considered in comparison progress with the probability of risks, system error and replacement period for comparison in the stability of systems.

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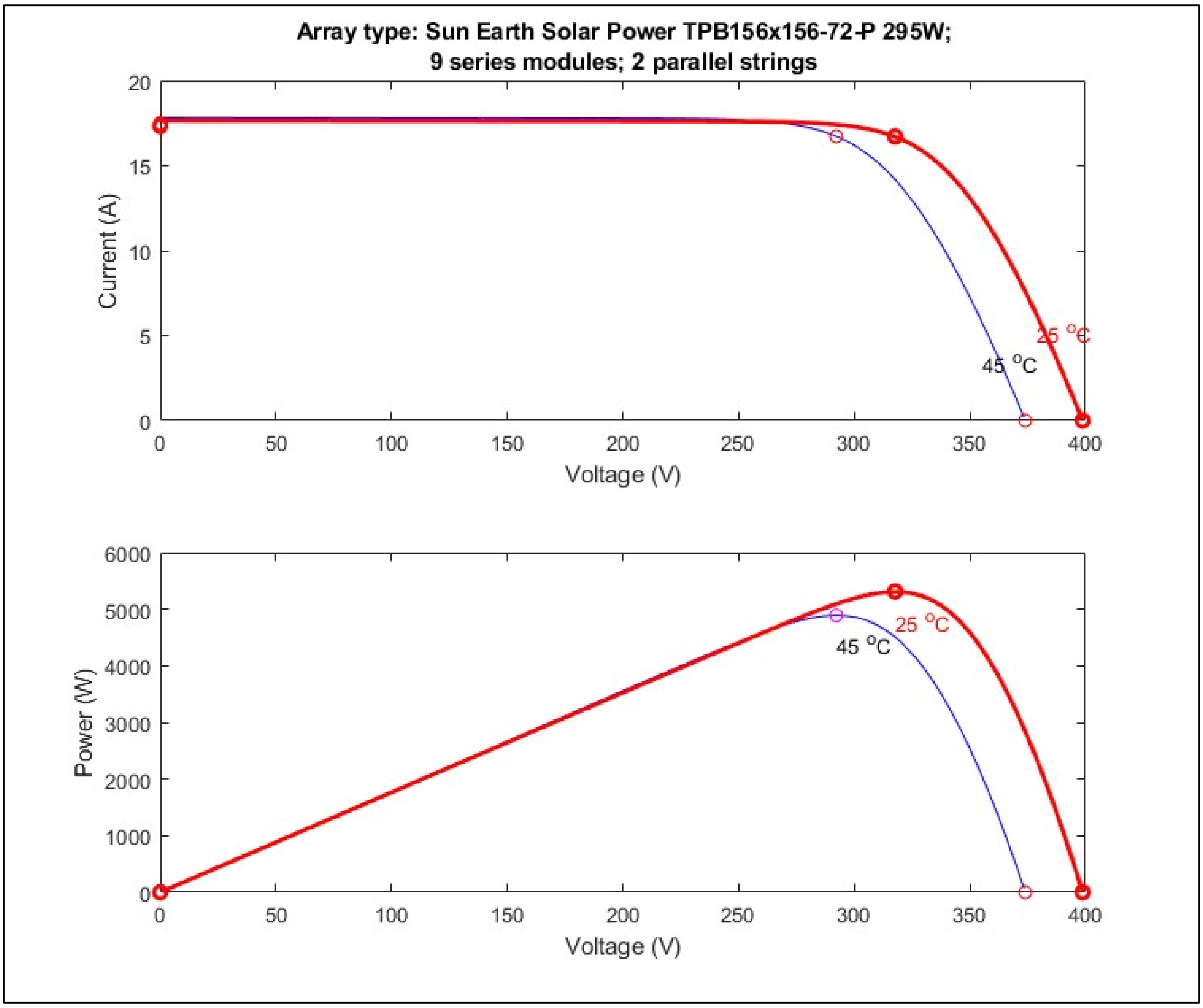
APPENDICES

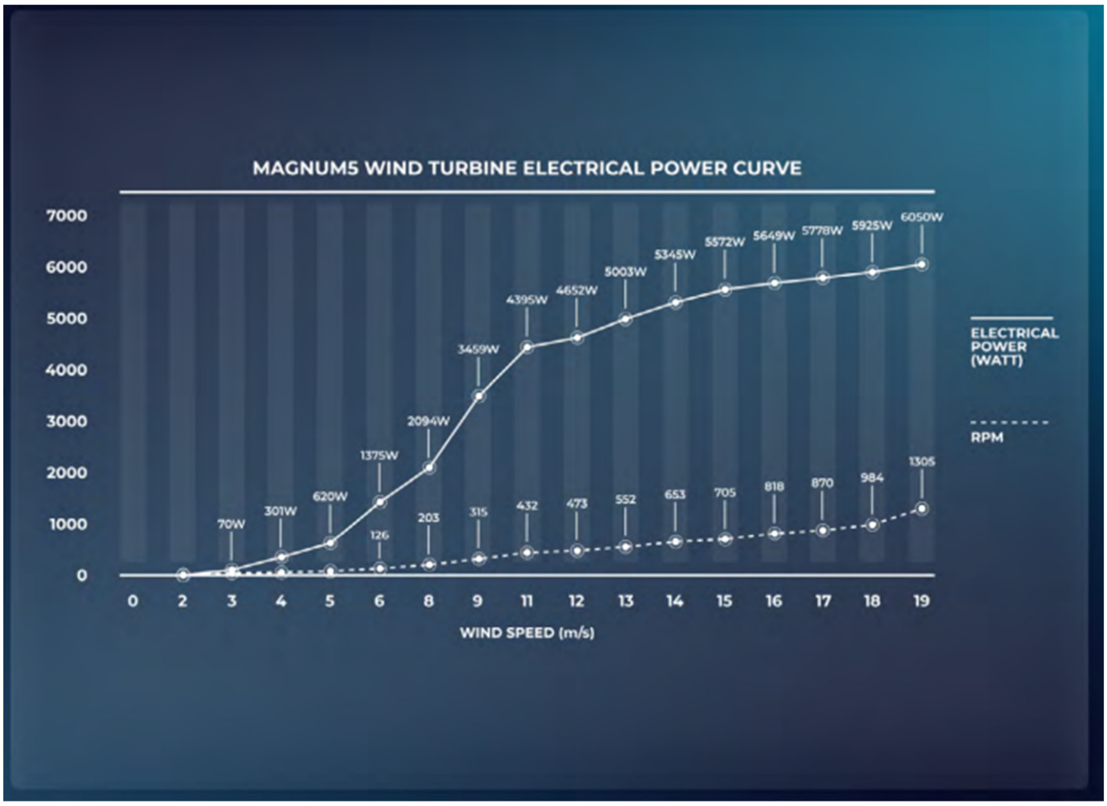
1. APPENDIX A: Material specifications and power curve

A. PV panels power curve



B. WT specifications and power curve

SPECIFICATIONS	
Designation	24V to 48V (Regulated by the Charge Controller)
GENERATOR	
Type	5KW horizontal axis wind permanent magnet generator
Weight	23 kg (51 lbs)
Max. Power	5kW
Operating Circuit Voltage	0-220V
Current	3-Phase
Start Of Charging	3 m/s
Base Plate Material	Metal
Direction Of Rotation	Clockwise
Test Standards	EN 61000-6-1 (electromagnetic compatibility – immunity) EN 61000-6-3 (electromagnetic compatibility – emissions)
ROTOR BLADES	
Material	Composite Materials & Aluminium
Diameter	2350 mm (7.71 Feet)
Weight Per Rotor Blades	990 g (2.18 lbs)
Direction Of Rotation	Clockwise
Starting Wind Speed	3 m/s
No. Of Blades	3
Max Rpm	1500
Max Wind Speed	50 m/s
Noise	35 dB



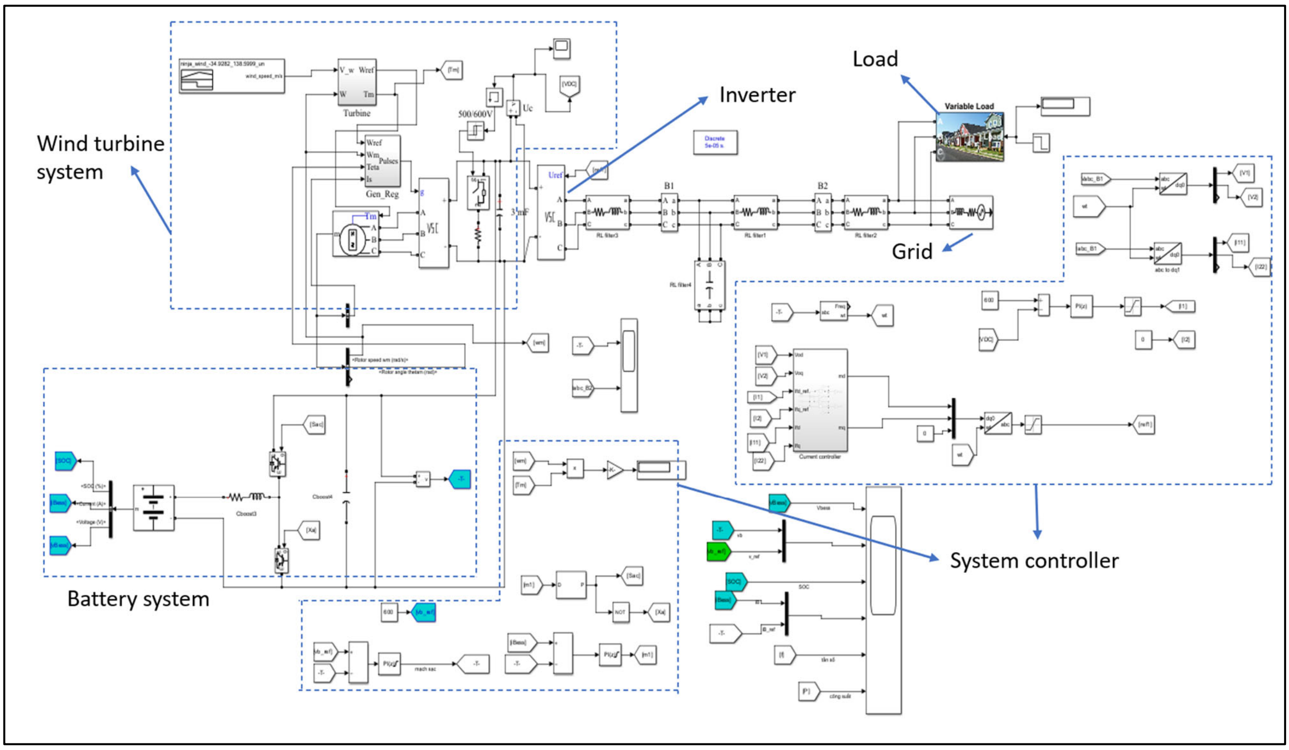
C. BES system specifications

Basic specifications of Growatt battery ARK 2.5H-A1

Datasheet	ARK 7.6H	ARK 10.2H	ARK 12.8H
System Demo			
Battery Module			
Number of Modules	3	4	5
Energy Capacity	7.68kWh	10.24kWh	12.8kWh
Usable Capacity	6.9kWh	9.21kWh	11.52kWh
Nominal Voltage	153.6V	204.8V	256V
Operating Voltage Range	141.6~170.4V	188.8~227.2V	236-284V
Dimension (W/D/H)*1	650/260/725mm	650/260/905mm	650/260/1085mm
Weight	91kg	118kg	145kg

2. APPENDIX B: Simulation models in MATLAB/Simulink

A. WT-BES system simulation model



B. PV-BES system simulation model