Energy Management for Residential Houses

By

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ABSTRACT

Nowadays, the energy management is the solution for adapting as a key solution for reducing dependence on the national grid, thereby reducing the disturbance of the national grid and this can help to strengthen grid recovery. Furthermore, energy management plays an important role in green energy development trend on over the world, it can be enabling the integration of the growing deployments of distributed energy resources such as renewable as solar, wind in the areas, from there can consider “off-grid”. Hence, during the recent years, there are enormous number of research cases, studies has been conducted in order to introduce innovative methodologies for effective energy management for Residential Houses. However, in this article, the author will propose a methodology in order to response the energy management for residential houses considering off-grid. The basic proposal is the integration of Solar Panels (PV) and Micro Wind Turbines (WT) which called Hybrid mode, this will be installed with Battery Energy Storage System (BESS) for household. But there are two scenarios power flow from renewable resources about energy for household. The case study will consider two Adelaide households with basic and equivalent electricity consumption and the potential to become part of an energy management program in an Adelaide area. From that, this typical consideration will be developed and proposed for more larger area. Besides that, this hybrid mode with BESS will be developed based on the selection of the suitable components and developed the system in MATLAB/Simulink to generate the power flow and energy. Moreover, the real data including typical data load, solar irradiance, wind speed, temperature, the actual cost of energy (COE) will be used to forward the expected results. The power from supply side and load side with exportation – importation power to the grid will be considered with cash flow including Times-of-Use (ToU), capital cost will be presented. From that, the results will present the benefits and drawbacks of each scenario from that, this can offer to establish the better scenario for the purpose of transferring, storing energy and adapting electricity demand in special times. And it can be called that the energy management for residential houses considering “off- grid”.

DECLARATION

I certify that this thesis:

1. does not incorporate without acknowledgment any material previously submitted for a degree or diploma in any university.
2. and the research within will not be submitted for any other future degree or diploma without the permission of Flinders University; and
3. to the best of my knowledge and belief, does not contain any material previously published or written by another person except where due reference is made in the text.

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Date: 16th October 2023

I certify that I have read this thesis. In my opinion it is/~~is not~~ (please circle) fully adequate, in scope and in quality, as a thesis for the degree of Master of Electrical and Electronics Engineering. Furthermore, I confirm that I have provided feedback on this thesis and the student has implemented it minimally/partially/fully (~~please~~ circle).

Signature of Principal Supervisor Amin Mahmoudi .... Digitally signed by Amin Mahmoudi Date: 2023.10.16 09:29:11 +10'30'

Print name of Principal Supervisor: Amin Mahmoudi

Date: 16/10/2023 ……………………………….

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LIST OF SYMBOLS AND ABBREVIATIONS

Abbreviations	Description
BESS/ESS	Battery Energy Storage System/ Energy Storage System
BoM	Bureau of Meteorology
CoE	Cost of Energy
CRF	Capital Recovery Factor
EM	Energy Management
FRP	Feed Retail Price
MGs	Micro Grids
NEM	National Electricity Market
NPC	Net Present Cost
NPC_C	Net Present Cost of Component
NPC_G	Net Present Cost of Grid Reflection
OECD	Organisation for Economic Co-operation and Development
PV	Photovoltaics
SOC	State of Charge
ToU	Time of Use
WT	Wind Turbines
Mathematical notation	**Description**
P_{Re}	Power from Renewable Energy Resources
$P_{in}^{battery}$	The charged power of Battery
$P_{out}^{battery}$	The discharged power of Battery
P_{wind}	The generated power from wind turbine
P_{PV}	The generated power from solar panel
P_L	The power/energy of load consumption at household
P_{import}^{grid}	The power which imported from grid (purchase)
P_{export}^{grid}	The power which exported to grid (sell)
$E_{battery}$	The power/energy of battery.

CHAPTER 1: INTRODUCTION

1. Background

Many nations have made recent commitment to invest in the research and development of alternative energy sources as a solution to the challenge posed by the depletion of traditional energy sources [1]. Furthermore, combined with the development of the infrastructure system along with the massive increase of residential areas is leading to an imbalance in the national grid system, putting pressure on the national grid system. Also, combined with the trend of the world moves towards renewable energy, energy management for residential houses considering “off-grid” is mentioned to become an increasingly popular solution to meet energy demands in a more sustainable and efficient way.

Renewable energy sources, an energy storage system, and local loads like households and companies that can serve as consumers all make up the energy system. This system is able to switch between on-grid and off-grid modes under centralized management [2].

The grid which are smaller-scale grids that can function independently of the larger grid. This can continue to function even when the main grid is down, can improve grid resilience, aid in the mitigation of grid disturbances, and serve as a grid resource for quicker system response and recovery [3]. By facilitating the incorporation of expanding deployments of distributed energy sources like renewables like solar, wind, and it can also support the flexible and efficient grid. In addition, the efficiency of the power distribution system is enhanced by the use of on-site energy sources to meet local loads, which helps to cut down on energy losses during transmission and distribution [3].

Within the scope of this project incorporate the aspects listed above. This article will be interested in the process of energy management for South Australian households in the grid, even though South Australia has achieved around 45% of its electricity production from renewable energy sources such as renewables, large-scale wind power and small-scale solar power, but because of high electricity prices and recent concerns about the reliability of power supply. Therefore, some households are using micro-generators using wind energy, solar energy or combined with battery storage systems when the electricity output reaches a state of self-sufficiency, then consider to the off- grid. Also, the study of control strategy meets the needs and actual implementation of the conversion between different energy resources. Furthermore, the traditional electricity prices are quite high at the moment and the recent concerns about the reliability of the power supply. And The need for grid balancing in a small residential area is directed towards a large residential area. Reduce pressure on the national power grid.

In addition, the paper will also discuss the challenges households face in managing their energy use and how smart technology can help overcome these challenges. Furthermore, we will explore the benefits of energy management in terms of cost savings, environmental impact, and energy security.

Overall, this article aims to provide a comprehensive overview of energy management for residential houses and considering “off-grid”, highlight its importance in the transition towards a more sustainable energy future.

2. Problem Statement

Several previous articles have researched the problem of energy management for households with different methodologies to achieve efficiency in energy management. However, there are limited previous research articles on hybrid mode (PV+WT) incorporating battery storage systems for the home. In [1], the Energy Management strategy for residential microgrid system using Model Predictive Control based on Reinforcement Learning and Shapley Value was proposed. In [2], the Energy Trilemma Perspective including flexible, affordability, and security will be investigated to review the energy management in MGs. In [4], an adaptive real time energy management system for a renewable energy based microgrid will be proposed. In [5], An efficient energy management system is presented and implemented as a multi objective optimisation problem for use in integrated building and microgrid systems. In [6] This paper presents an energy management system for a standalone microgrid in an everyday setting. In [7], it presents that the purchase of residential PVs and BESSs can be made affordable when a three-tier rate TOU is paired with a 4-kWh household BESS. It is anticipated that the high-cost issue, which previously mainly restricted the actual application of BESSs, will be resolved.

In [8], this article presents a microgrid in a residential energy management system, with designed algorithms and methods for accurately predicting future electrical demand and reducing energy use. In [9], In this article, authors take a critical look at the optimisation formulations used in the design and management of isolated microgrids. Author cover topics like objectives, constraints, and control variables. In [10], This paper proposes a smart charging scheme for plug-in hybrid electric vehicles that can reduce their reliance on the grid while simultaneously increasing their utilisation of renewable or distributed energy resources. In [11], It is proposed in this article that Lyapunov optimisation be used for real-time energy management in a microgrid that includes renewable generation, energy storages, flexible loads, and combined heat and power units. In [12], this paper introduces a Model Predictive Control (MPC)-based Reinforcement Learning and Shapley Value-based energy management strategic plan for housing microgrid systems. In [13], location on the loess plateau of China is recommended, which is the use of a hybrid residential area microgrid with different resources adequate for both off grid and utility grid situations, and experimental results verify the efficacy of this microgrid scheme and validate the proposed energy management strategies. In [14], in this paper, authors present the optimisations that were carried out using actual annual load data from the Tonsley building and weather data; the optimisation of the system was carried out in three modes, from which authors derived the optimal sizing of battery storage, wind turbine, and solar photovoltaics. In [15], Microgrid modelling, smart home energy management system integration, and a Demand Response strategy to cut peak demand and energy costs are all part of the sophisticated Demand Side Management framework developed in this paper.

3. Objectives

Based on a review of relevant previous articles and a list of criteria for potential enhancements to energy management. Also, policymakers have been establishing energy management system in order to adapt rising grid prices, fears about power transmission reliability, and the general trend towards decentralisation. Some households have already invested in off-grid systems like solar panels, batteries, and even micro wind turbines. In this paper, it will discuss the energy management for households considering "off-grid" in illumination of the alternative energy supply (off-grid) option this based on the hybrid mode (PV+WT) run together and the BESS will play a role as the storage the energy. As part of this endeavour, it will also investigate demand response control strategies and put them into practise in the form of a switch between various energy sources. It will be presented as following:

- The actual daily load demand of the household will be utilized with typical load profiles, from that two typical equivalent load profiles will be utilized with two scenarios.
- The weather data including temperature, solar irradiance, wind speed will be collect in the reliable source from Bureau of Meteorology (BoM). These data will be utilized as input data in simulation model.
- A typical hybrid models with 5kW PV and 5kW WT system for house is conducted and simulated in MATLAB/ Simulink. Moreover, the Battery Storage System will be utilized 10 kWh as the energy storage system in renewable supply system.

- Understand basically the market for producing, developing, and purchasing the electricity market and electrical renewable components.
- The better scenario will be determined based on the cash flow analysis and power flow analysis. From that, the energy management for residential households will be basically established with some benefits and limited withdraws. This is what will be achieved from the objectives from the project as presented as Figure 1.

The objective of this study is to create a hybrid renewable energy system, specifically a combination of photovoltaic (PV), wind turbine (WT) sources and battery energy storage system, for two typical consumption loads at households. The research will involve designing the system and conducting simulations using Simulink, while also collecting relevant data. The objectives encompassed in this study are the analysis of practical meteorological circumstances, the reduction of initial investment expenses, the management of energy efficiency, the enhancement of system reliability, and the achievement of cost-effectiveness.

- Hence, it is essential for systems to fulfil the energy requirements of a particular area while simultaneously minimising expenses associated with power consumption from the grid and maximising revenues derived from the sale of surplus electricity to the grid. Consequently, a comprehensive analysis was conducted to compare the ***economic, technical, and energy aspects*** of two representative load residential households in Adelaide. This analysis involved the consideration of one scenario for each load household.
- Based on the aforementioned findings, design engineers will develop a detailed guide outlining the specific power flow scenarios in which the deployment of this renewable system model will provide both financial and efficiency advantages. The highest capacity. Figure 2 illustrates a concise overview of the target objectives of the project.

In addition, the Figure 1 will present the inspirations, motivations and benefits for development of this study.

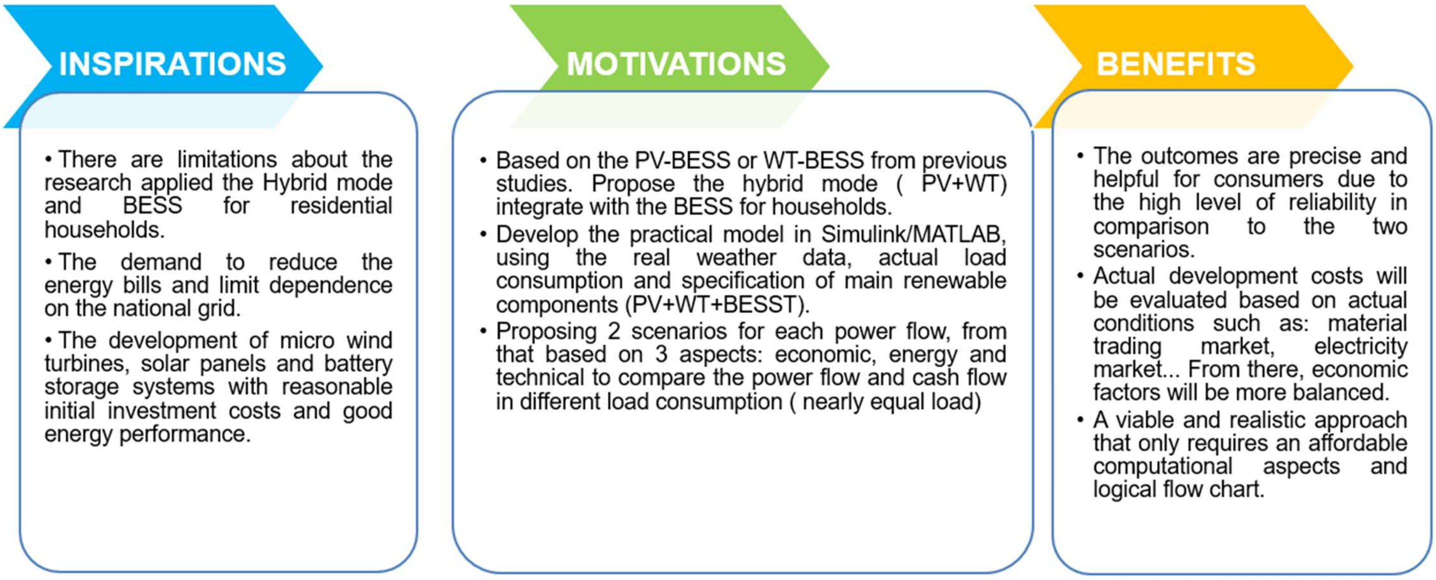


Figure 1. The inspirations, motivations and benefits for development of this study

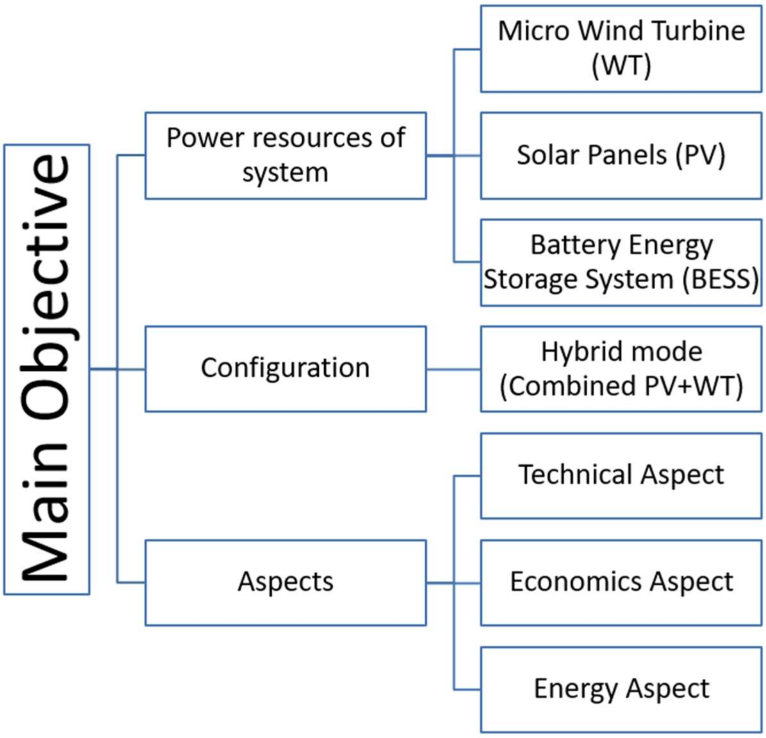


Figure 2. The overview objective of this project.

4. The Assumptions – Constraints of this project

4.1. The Assumptions

Based on the overall objective of this project. The Hybrid system (PV+WT) with BESS will be developed in the MATLAB/Simulink. There will have some assumption in this project which need to be considered and shown in Table 1.

Table 1. The summary assumptions of this project.

No.	Description of Assumptions
A1	The necessity to generate and utilise power for the majority of households in Adelaide. Making a contribution towards the reduction of utility expenses, as well as diminishing reliance on the national power grid system.
A2	The typical residential households which utilized with nearly consumption load (but not equal) are concerned to develop the Hybrid mode and BESS with different power flow scenario in configuration.
A3	Although the SOC of BESS is 100%. But it should be considered in reality with SOC in range 10% - 90%.
A4	The weather data including: solar irradiation, wind speed, temperature will be collected and provided from BoM - it is a reputable data source.
A5	The COE will be determined and it should be reduced based on the actual data
A6	According to the loan policy from ANZ bank. The investment payment will be approved with 5 year duration.
A7	The installation, operation and maintaince cost will be considered in final COE.

4.2. The Design Constraints

The constraints of the design will be demonstrated; it includes the vital key design constraints for energy management system for household considering on grid and off grid (stand-alone). Reliability constraints may be taken into account to facilitate a predetermined reduction in load, thereby reducing the expenses associated with the system [21, 28]. The management model needs to take consideration of the policy implemented by nations concerning renewable energy installations and energy storage systems as a constraint such as in the state of South Australia, there are regulations in place regarding the maximum allowable export power from residential properties to the national grid. Specifically, for single-phase systems, the maximum export power should not exceed 5kW. [31,32]. And according to the Appendix D. The design constraints Figure will be illustrated.

In accordance with requirement, integrate the aforementioned facets. The requirement aims to explore the energy management procedures adopted by households in South Australia's power grid. Despite the fact that South Australia has made significant strides in generating approximately 45% of its electricity from renewable energy sources, including large-scale wind power and small-scale solar power, the region continues to grapple with high electricity tariffs and concerns regarding the reliability of power supply. As such, certain households have opted to utilise micro-generators that harness wind or solar energy, or a combination thereof, in conjunction with battery storage systems. Once the electricity output attains a level of self-sufficiency, these households contemplate transitioning to an off-grid arrangement. Finally, combine with the [12] and [33] which presented as figure 3, the author proposed, offered and developed the basic configuration for residential houses which presented in chapter 3 with different power flow scenarios in hybrid configuration.

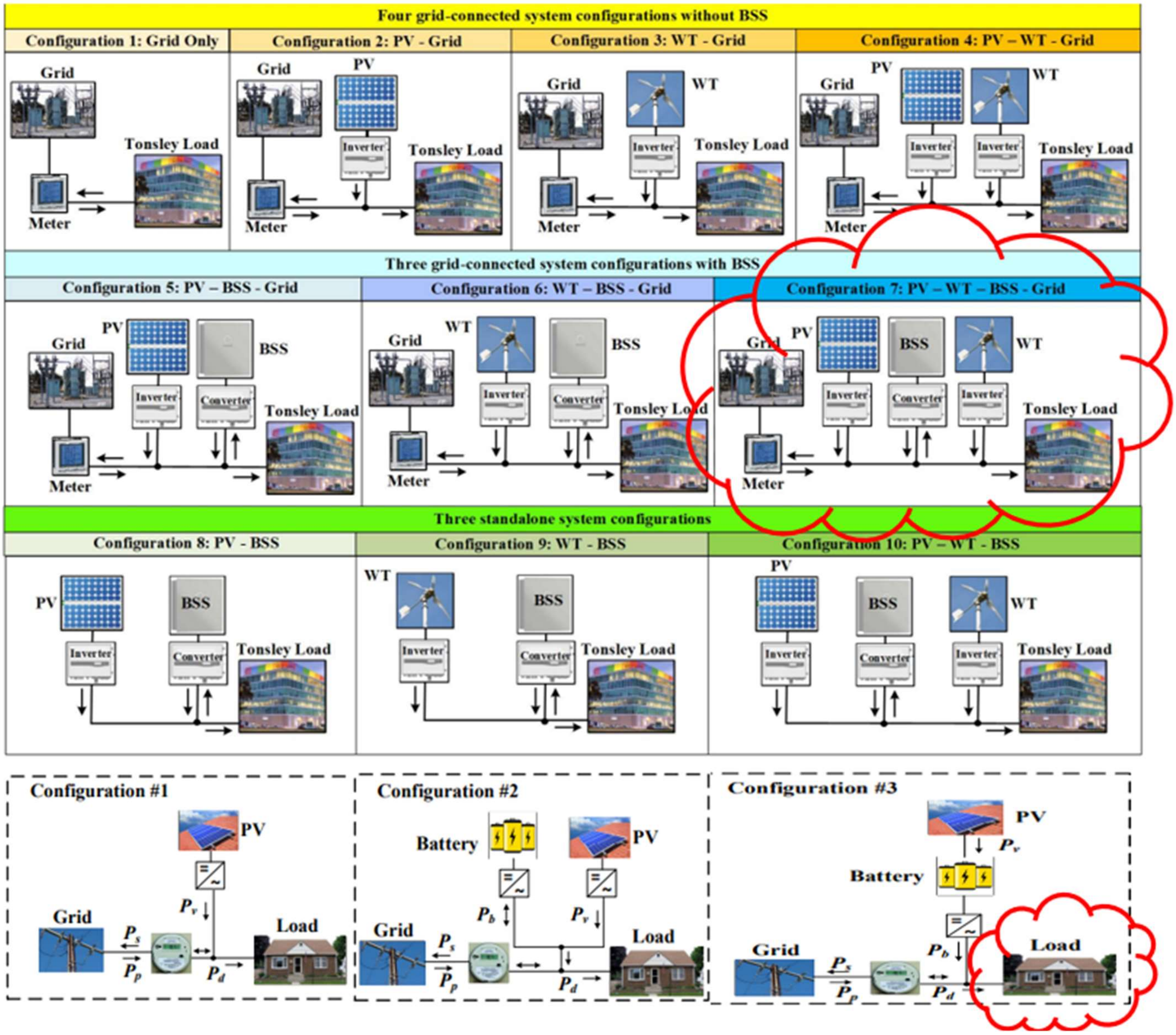


Figure 3. The related works configurations [12], [33]

5. Thesis Outline

Chapter 1: Introduction

This chapter provides a concise and brief overview of energy management for households, including fundamental existing works. This chapter encompasses the statement of the problem, research objectives, methodology, as well as the background of the project.

Chapter 2: Literature Review

This chapter will present and provide them with detailed the previous research with related with this project. The specified fields in which the study project can potentially provide a valuable contribution are delineated.

Chapter 3: Methodology

This section will outline the methodology that was used for carrying out the project, including the fundamental configuration, component selections, mathematical formulas, and logical charts.

Chapter 4: Results

This section will present the results from generated methodology.

Chapter 5: Discussion

This chapter will outline and present the comparison and discussion for each scenario, from that it will aim to select the better scenario to construct, propose and apply for implementation in real daily life.

Chapter 6: Conclusion and Future works

This chapter will present the conclusion, limitations and future works for this project.

CHAPTER 2: LITERATURE REVIEW

1. Introduction with historical background

In recent years, the increasing demand for electricity is leading to a depletion of fossil fuels, which may not be sustainable beyond a few decades [14], which presented in the Figure 4. Moreover, the development of the infrastructure system and the rapid expansion of residential areas have led to an unbalanced in the national grid system, putting pressure on it. In addition, as the world shifts towards the trend of the world- renewable energy, "off-grid" energy management for residential homes is predicted to become an increasingly popular means of achieving energy needs in a more environmentally friendly and effective manner.

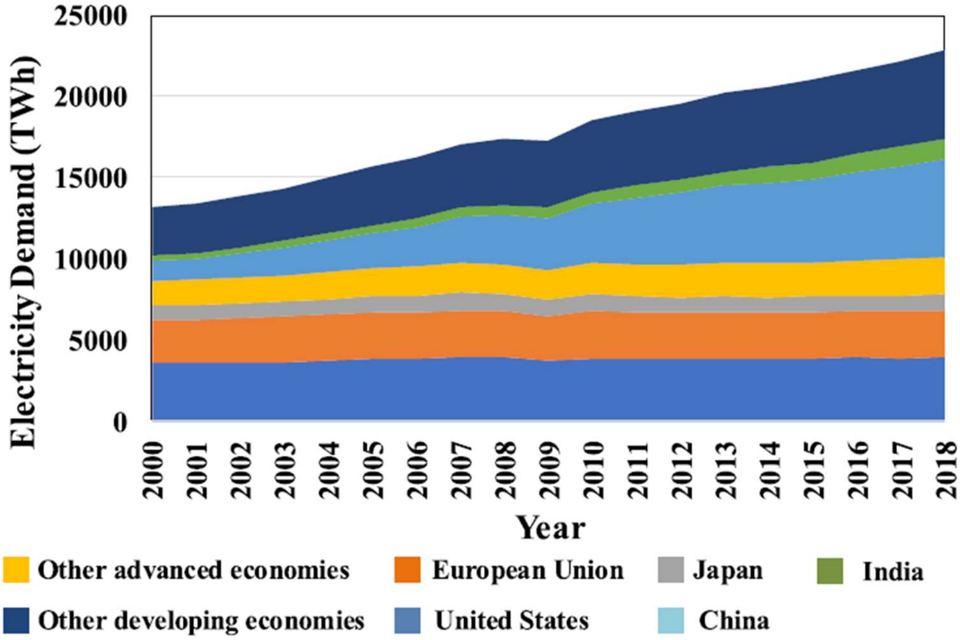


Figure 4. The worldwide level for demand energy [14]

According to the [14], the global market is currently experiencing a rise in the demand for electricity. A comprehensive analysis of the electricity demand across various regions from 2000 to 2018 reveals a significant rise. Between 2000 and 2018, there was a 72% increase in electricity demand, with an average annual growth rate of approximately 4%. As of the conclusion of 2018, the worldwide requirement for electricity exceeded 23,000 TWh [14]. The majority of the increase in demand for electricity is concentrated in developing nations, particularly China [14]. The previously mentioned outcome is a direct consequence of the advancement of industrialization, the enhancement of residential households, and the rise in population. Hence, there is a growing demand for renewable energy resources as viable replacements for non-renewable fossil fuels on a global scale [14]. So, the increasing demand for electricity has led to a rapid depletion of traditional energy sources such as fossil fuels and oil, thereby causing significant harm to the biosphere [15]. However, how to manage and optimize the renewable energy source as well as combine it with the national electricity system for households is a problem because of the uncertainty of renewable energy [16]. So, the issue of energy management for residential houses has emerged as a prominent concern and has attracted significant attention during recent research [16]. In addition, electrical price is also one of the current issues of countries around the world, and so is Australia. According to [6], the current retail prices household’s energy costs in the National Electricity Market (NEM) of Australia have reached their lowest point in eight years. In comparison to other countries within the Organisation for Economic Co-operation and Development (OECD), Australia ranks as the 10th country with the lowest electricity prices out of a total of 38 countries. Furthermore, as per reference [6]. The main reason for cost reductions during the previous fiscal years has been the wholesale discounts. This can be attributed to the enhanced flow of renewable energy production into the system, coupled with decreased fuel expenses for coal and gas production. The decrease in demand for energy can be attributed to various factors, including the impact of COVID-19 on economic activity, milder weather patterns in certain regions, and the growing number of residential rooftop solar or micro wind turbine installations. Thereby, the implementation of an efficient energy management strategy can lead to a reduction in electricity costs for consumers, thereby contributing to a more effective improvement of the economy. Furthermore, the investigation of control strategies addresses the requirements and practical carrying out of transitioning between diverse energy sources. Prior to the implementation of the project, a comprehensive survey of existing research literature revealed that numerous studies have been conducted regarding developing energy management systems. However, certain limitations still persist.

2. Existing Techniques – Methodology pathway

A summary of literature provides that several studies have been conducted to evaluate the process of developing and implementing energy management systems, both in a general context and with a specific focus on residential households. The author has conducted a comprehensive review of various research articles and has synthesised the fundamental factors associated with energy management, including pricing techniques, methodologies, risk management. The articles relevant to said factors will be sequentially clarified upon below. Subsequently, the suggested approach for the initial carrying out will be established on the basis of the shortcomings identified in prior articles.

In article [18], the energy management will be reviewed and assessed demand side management based on the pricing techniques. In article [19] will explore the economic benefits associated with the implementation of rolling horizon optimisation techniques, interval optimisation, and scenario-based methods. In the research [20] places forth a strategy for the electricity market that aims to achieve optimal operation of multi-microgrids. The proposed function of objective incorporates techno-economic considerations, including the profitability of microgrid proprietors, mitigation of energy deficit, and improvement of microgrid dependability. The determination of the optimal size of a rooftop solar power and battery energy storage system can be achieved through an analysis of the available Flat rates and time-of-use (TOU) electricity rate options. Subsequently, the net present cost of electricity can be evaluated for four different electricity rate options, with the aim of minimising the system configurations, this will be presented in the [21]. In order to provide additional clarification on the methodology of the electricity pricing scheme, distinct academic papers related to the subject matter will be referenced. The stepwise tariff model involves a gradual rise in the price of electricity as the level of electrical usage rises in [22]. The pricing strategy known to be vital highest costs is predicated on the dynamics of the entirely market in [23]. The electricity price is dependent on dynamic changes on a per-hour basis. In excitement of significant developments in the electricity market, utility companies may institute high pricing during specific time periods, such as between 2 p.m. and 5 p.m. on a hot day in the summer in [24]. The decision of the cost of electricity is dependent on the market value as assigned by the operator. The selection of an appropriate electricity pricing model is a crucial factor in the optimisation of energy management strategies aimed at maximising profitability. Moveover, there are also numerous previous research about the Energy Management for households, so the 2 next sections will present some typical shortcomings and key findings of previous works.

3. Current research shortcoming and Key findings.

The reviewed literature indicates that incorporating variety into the function of objective has been utilized to tackle energy management challenges, both in general terms and specifically for residential energy management. The present section provides a summary of the categorization of present research, its deficiencies and restricted applicability, and prospective possibilities for future investigation in the domain of household energy management organizing. The following Table 2 provides a summary of previous study literature, covering various aspects including energy management, household, real data.

Table 2. The summary table for the shortcomings and limitations of the related works.

Ref	Components (decision factor)	Methodologies	Grid Consideration		Functions	Design constraints
			On-Grid	Off- Grid		
[1]	PV-ESS-Shiftable Load-Home appliances	Model Control Predictive-Energy Management Strategy	✓	✗	Economic benefit	SOC battery
[5]	Integrated residential building (household): PV-WT-ESS	Energy management system, Real-time systems	✓	✗	Total operation cost (TOC) minimization The user's convenience and comfort level	N/A
[6]	PV-WT-ESS-diesel gen	Hybrid Optimization – integration for village- Energy management system	✗	✓	The cost-effective sizing	The PV-WT-ESS-Diesel Gen integration
[8]	PV-ESS-Home applicants-	Forecasting-Optimization	✗	✗	Forecasting-Optimization-Management model	Large data info with historical data
[11]	PV- hybrid islanded and grid connected, households	Energy management strategies	✓	✓	Reliability, Economic benefit	Power balance, SOC battery
[12]	PV-WT-BESS-Tonsley building	Compare Configurations: from stand-alone to hybrid mode	✓	✓	Cost of Electricity	Cost of Electricity Economic benefits
[13]	PV-WT- diesel gen	Home Energy management system- demand side	✓	✗	Economic benefit	N/A
[18]	EV-ESS-PV-WT	Centralized-Distributed EMS	✗	✗	Pricing techniques Stable benefit	Load balance info
[25]	PV-ESS	Optimization – Energy Management Strategy	✗	✗	Electricity price Energy storage life SOC battery	Energy balance SOC battery
[26]	PV-ESS-EV	Energy management–model predictive control	✓	✗	Energy trading policy, economic benefit	Long training system time,
[27]	PV-WT-ESS	Energy management, big data analysis platform	✗	✗	Economic benefit, energy consumption	SOC battery Power balance

Previous research has concentrated on household energy management and has classified these investigations into two categories: those associated with energy and those related to control systems. Distinct objective functions were employed in each system. Prior research has commonly integrated the energy expenditure of environmentally friendly power systems as an inseparable objective function within the framework of multi-objective issues. Several target functions are frequently employed for the entire system, including but not limited to the minimization of electricity expenses, economic benefit, computation of yearly costs, and optimization of power reliability. In the realm of power systems, the prioritization of factors is such that grid voltage stability, grid limitations, power input/output from/to the grid, and power loss in the network are deemed more significant than considerations pertaining to reliability and redundancy in power.

The collected information reveals that numerous research have been conducted on the subject of residential energy management, particularly with respect to the utilisation of renewable energy sources and energy storage battery systems. While the PV-WT-BESS system plays a significant role in the decision-making process, there are other factors to consider. From that, the author will present an optimal, straightforward, and efficient solution including electricity price benefits with CoE, energy consumption consideration, Grid balance in the following section. Finally, in order to achieve the goals for this project, based on the limitations from existing works and main objective from previous Chapter, the three aspects will be investigated and utilized the better scenario to get the energy management for household.

CHAPTER 3: METHODOLOGY

In this chapter, based on the limitations mentioned in the previous chapter, the author proposes a general method of using different power flows for each different scenario, applied to hybrid systems integrated with battery storage system and configured in MATLAB/Simulink. From there, based on the resulting aspects: economic, technical, and energy, a better scenario will be selected corresponding to that power flow and proposed for utilization by households in the future.

1. The system configuration

According to the related works from the previous sections, the system configuration will be developed in this section with system configuration, basic logical flow chart of system configuration, energy management logical chart with mathematics.

1.1. The configuration of the system.

Based on the current requirements and the shortcomings of previous works, the Figure 5 below will illustrate the basic concept of the configuration of this system.

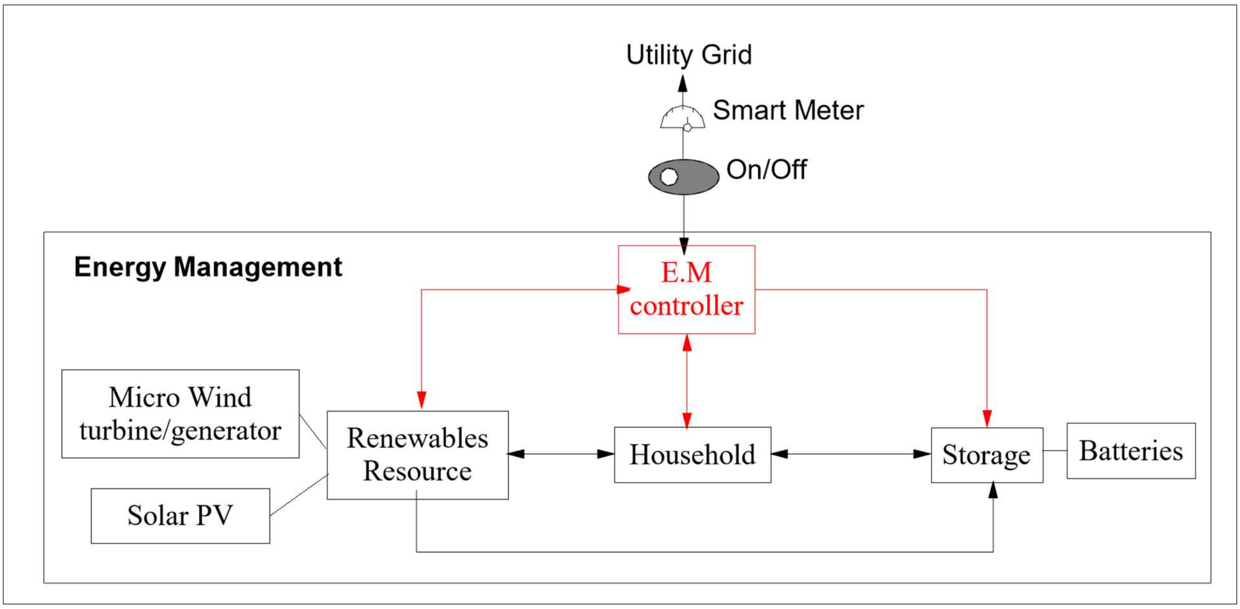


Figure 5. The basic concept of the configuration for energy management for residential households [drawn- self]

According to the Figure 5, the hybrid mode will be offered and utilized, the model is PV-WT with the Battery Energy Storage System will be connected for storage. As the Figure 5 can be easily to observe that this is the single line diagram. To enhance the comprehensibility of the system setup, the Figure 6 will visually depict the arrangement of components and the flow of power within the system.

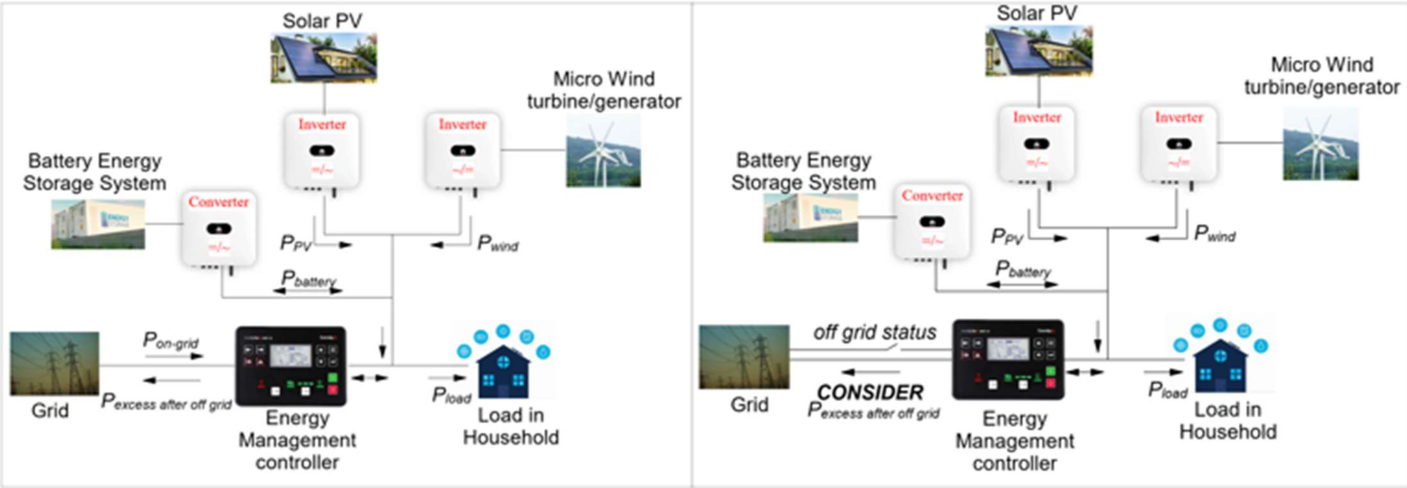


Figure 6. The configuration system with visualization [drawn self]

According to the Figure 6, this is only one system configuration, but the author divided into two parts in that Figure due to grid considerations (off gird and on grid), this will be easily to observe, and this configuration will be developed in Simulink. With this configuration, two scenarios will be applied to investigate, and the better scenario selection in the section 1.3 will be choose based on the minimal economic efficiency [33].

1.2. The basic logical flow chart of the system configuration.

According to the configuration of the system above and the constraints of the design. The basic logical flow chart of this system will be illustrated as the Figure 7 with steps by steps for achieving the desired goals.

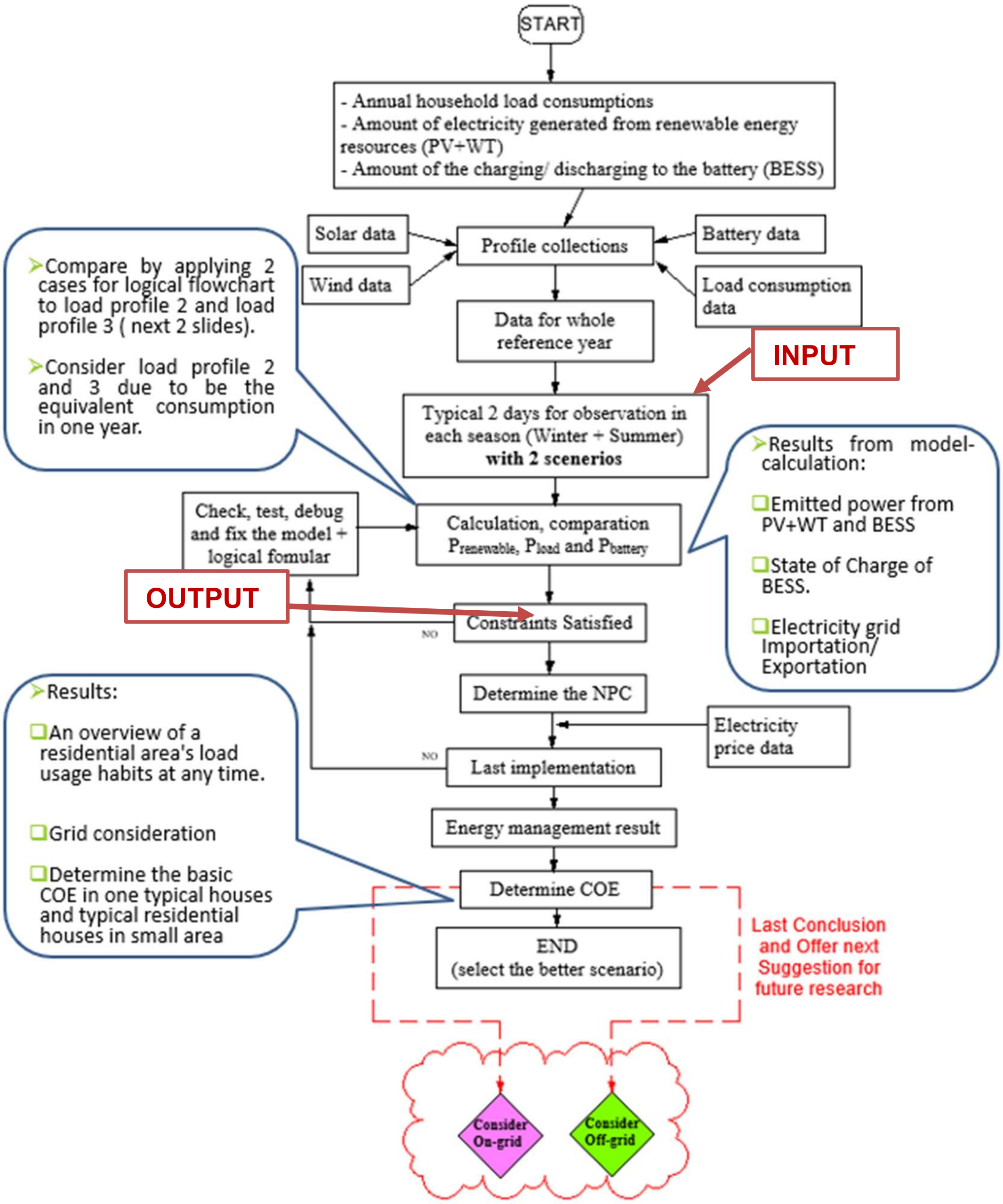


Figure 7. The flow chart of the system configuration [drawn self]

At the initial, the input side of the system configuration including the weather data, collected residential load data, and the specification of the components data. Next, all the selected profiles will be observed and calculated in whole year, however, two typical days in summer season and winter season will be utilized to learn the habit of the loads and the power of the renewable energy resources will be generated from solar panels and micro wind turbines. The power flow will be explained detailed in next section. Then, the Net Present Cost (NPC) and Cost of Energy (CoE) will be determined from that. Finally, based on the comparison COE of each scenario, the better scenario will be offered and finalized.

1.3. Energy management logical chart with mathematics logical.

According to the Figure 8 and Figure 9, these will present each scenario with mathematics logical. Empirical evidence has proved the effectiveness of the system's logical framework in attaining maximum energy while minimising dissipation [33].

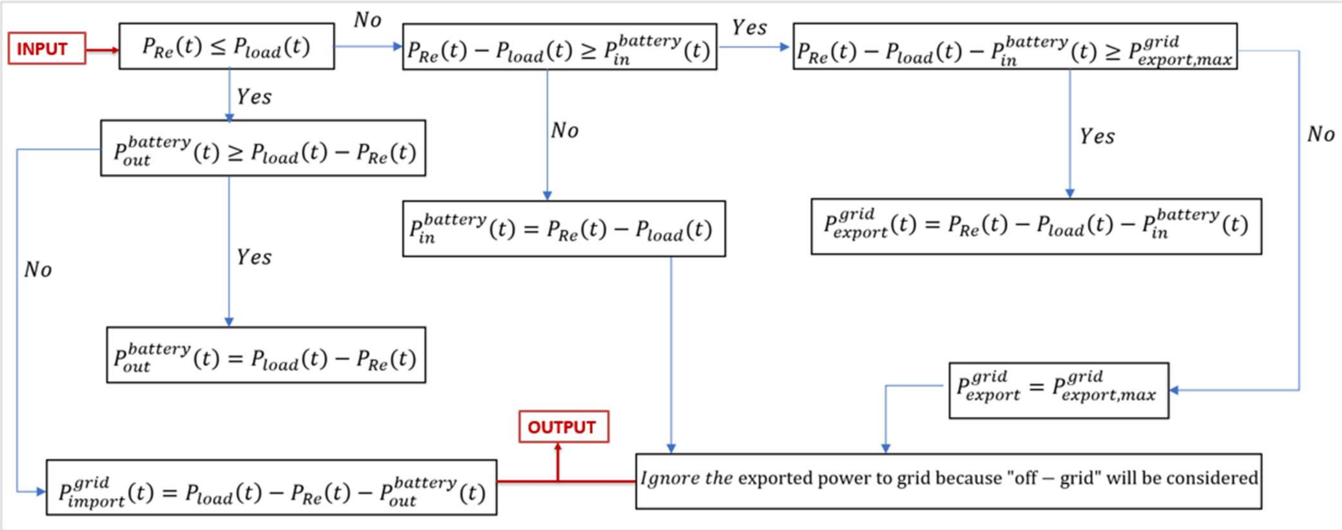


Figure 8. The scenario 1 for energy management [drawn self]

According to the Figure 8, if the power of load is larger than power of renewable resources the power of renewable resources P_{Re} will be only feed the load first, that means, the rest of the power will be supplied to battery for storage, if the power of load is less than power of load, the load will be supplied by grid and the power of renewable resources will feed to batteries for storage. In the event that the BESS system lacks energy, it will rely entirely on importing electricity from the grid. Furthermore, in the event that the energy stored in the battery system reaches its maximum capacity, any excess electricity will be exported to the grid in accordance with the limitations imposed by the grid. If the amount of energy sold through the grid exceeds the limit set in advance, it will be classified as dumped power.

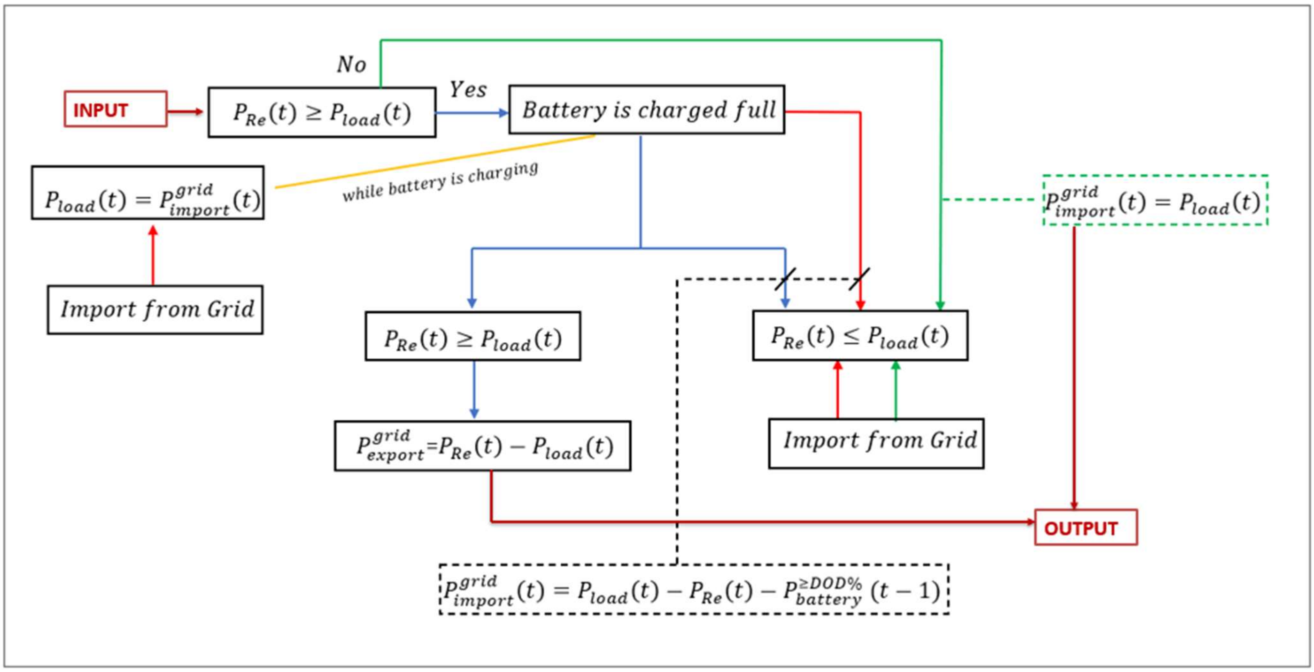


Figure 9. The scenario 2 for energy management [drawn self]

According to the Figure 9, the load will be considered and feed first with any situation. That means that regardless of whether the electricity output from the renewable energy source is smaller or larger than the load, the electricity from the renewable energy source is always charged into the storage battery system first until full, while that time, the load will use the power from grid. After the BESS is full, the energy for load will be utilized by combining the power from BESS and the renewable sources, while that time, the grid can be considered as off.

1.4. The specification of the components (materials) and system simulation

In this project, the main component for 5kW solar power system is selected as Sun Earth solar panels. For 5kW micro wind turbine is Tesup Magnum 5 and for 10.24kWh for Battery Energy Storage System of Growatt manufacture. There are some main specifications of each component to developed utilized as the input data side for configured system in Simulink. And the Table in Appendix E will present the summary main components for system.

Based on the system configuration and components selection and specifications. The Appendix A will present the simulation model in Simulink with Hybrid mode (PV-WT) with BESS. And Appendix B will present the specification of material with power curve.

2. Mathematical Equations for power flow and cash flow

In this part, the Power from Renewable Energy side (P_{Re}) will be calculated as formular (1):

$$\boldsymbol{P_{Re}(t) = P_{PV}(t) + P_{wind}(t)} \quad (1)$$

In case, the P_{Re} will generate excess the load (P_L). The Battery will be charged by the electricity excess following the limitation of the battery input power. The battery input power (P_{in}^{batter}) will be determined as formular (2) and (3):

$$\boldsymbol{P_{in}^{battery}(t) = \ P_{Re}(t) - P_L(t)} \text{ [kW] for scenario 1} \quad (2)$$

$$P_{in}^{battery}(t) = \ P_{Re}(t) \text{ [kW] for scenario 2} \quad (3)$$

In case, when the power is generated by renewable energy resources is larger than the load demand, and the power of the battery is charging by renewable sources. Until the battery is full, the exportation energy from renewable sources will be sold to grid with the maximum export power should not exceed 5kW which called ($P_{in}^{battery}$). . However, if the generated energy is larger than 5kW, the rest of the power will be called as dump power. The formular and (4) will present 2 considerations:

$$\boldsymbol{P_{export}^{grid}(t) = \ P_{Re}(t) - P_L(t) - P_{in}^{battery}} \text{[kW]} \quad (4)$$

In case, when the power is generated by renewable energy resources is lower than the load demand, the power from battery will take care the load demand in case the battery is full which called the discharge power pin ($P_{out}^{battery}$) as displayed as formular (5):

$$\boldsymbol{P_{out}^{battery}(t) = P_L(t) - P_{Re}(t)} \text{[kW]} \quad (5)$$

However, when the battery cannot take care as full load demand. So, the electricity is still utilized from grid as parallel and the electricity from grid $\left(P_{grid}\right)$ will be calculated as formular (6):

$$\boldsymbol{P_{import}^{grid}(t) = P_L(t) - P_{Re}(t) - P_{out}^{battery}(t)} \text{ [kW]} \quad (6)$$

According to the [17], the battery State of Charge (SOC) with time interval (Δt) will be calculated as formular (7).

$$\boldsymbol{SOC}\ (\boldsymbol{t}+\boldsymbol{\Delta t}) = \boldsymbol{SOC}(\boldsymbol{t}) + \frac{\boldsymbol{\Delta t}\ [\boldsymbol{P_{in}^{battery}}\boldsymbol{\eta_{in}}\ - \frac{\boldsymbol{P_{out}^{battery}}}{\boldsymbol{\eta_{out}}}]}{\boldsymbol{E_{battery}}}\ [\%] \tag{7}$$

Where, η_{in} is efficiency of the battery at input side, the η_{out} is efficiency of the battery at output side, and the $E_{battery}$ [kWh] is the energy capacity of battery.

According to the [21], the power of input side of Battery energy storage system ($P_{input}^{battery}$), and ($P_{output}^{battery}$) is the power of output side of the Battery energy storage system will be present as formular (8) and (9).

$$P_{input}^{battery} = \frac{E_{battery}}{\Delta t}(SOC_{max} - SOC(t))\ \text{[kW] (8)} \tag{8}$$

$$P_{output}^{battery} = \frac{E_{battery}}{\Delta t}(SOC(t) - SOC_{min})\ \text{[kW] (9)} \tag{9}$$

The Cost of Energy (COE) will be determined for the objective function of the energy management of this project. According to the [18], the COE will be performed as formular (10).

$$\boldsymbol{COE} = \frac{\boldsymbol{NPC_c}.\boldsymbol{CRF_c} + \boldsymbol{NPC_e}.\boldsymbol{CRF_e}}{\boldsymbol{E_{load}}}\ [\ \text{¢}/\mathbf{kWh}] \tag{10}$$

Where, NPC_c is the Net Present Cost of Component and NPC_e is Net Present Cost of Electricity trade on grid. And the Capital Recovery Factor is CRF

However, the CRF_c will be presented based on the interest rate and CRF_e will be performed based on the escalation rate with interest rate. According to [18], these will be formulated as follows (11) and (12).

$$\boldsymbol{CRF_c} = \frac{\boldsymbol{i}(\mathbf{1}+\boldsymbol{i})^{\boldsymbol{n}}}{(\mathbf{1}+\boldsymbol{i})^{\boldsymbol{n}} - \mathbf{1}} \tag{11}$$

$$\boldsymbol{CRF_e} = \frac{\boldsymbol{g}(\mathbf{1}+\boldsymbol{g})^{\boldsymbol{n}}}{(\mathbf{1}+\boldsymbol{g})^{\boldsymbol{n}} - \mathbf{1}} \tag{12}$$

Where, $g = \frac{1-q}{1+q}$ is the real interest rate.

With the NPC_c and according to the [18], it will be included aspect about costs such as: capital, replacement, the detailed formular (13) will be shown as

$$\boldsymbol{NPC_c = N_{solar}.\left(C_{solar}^{capital} + C_{solar}^{OM} + C_{solar}^{replacement} - C_{solar}^{salvation}\right) + N_{wind}.\left(C_{wind}^{capital} + C_{wind}^{OM} + C_{wind}^{replacement} - C_{solar}^{salvation}\right) + N_{bat}.\left(C_{bat}^{capital} + C_{bat}^{OM} + C_{bat}^{replacement} - C_{bat}^{salvation}\right)} [\$] \quad (13)$$

Where, the component's final cost is used to determine its "salvation value." The component's expected lifetime is required for determining the salvation value. It is estimated that solar systems have a 25-year lifespan. [34]. Besides that, the estimation of the wind turbine system achieves 20 years lift time [35]. So, in order to manage the energy, author will consider the battery’s life and it will be based on the capacity degradation. The Depth of Discharge (DOD) must be measured in for the purpose of determining the state of battery deterioration. The following battery degradation is found in [21]. The BESS lifetime is, however, determined based on the capacity degradation in the system operation, and it is reached when the degradation reaches 20% [36].

Furthermore, the NPC_e on grid reflects both the price at which electricity is imported from the grid and the price at which it is exported to the grid. [36], and the NPC_ewill be determined as follows (14):

$$\boldsymbol{CNPC_g = NPC_e = \sum_{t=1}^{U}\left(P_{grid}^{import}.C_p(t) - P_{grid}^{export}.C_s(t)\right)\Delta t} \ [\$] \quad (14)$$

So, in order to determin the cost of the exporation to grid and importation from grid, the Retail Price (RP) based on ToU and Feed In/Out Tariff (FiT/FoT) from electricity rate of Energy Australia in South Australia 2023 [37] will be utilized for calculation. However, the gas will not be included in the prices, so there is not “anytime Tariff” for this, and the Table 3 based on [37] will present the Prices with electricity rate and time period name with cost (¢/kWh)

Table 3. The Electricity Rate in South Autralia in 2023

Electricity rate	Time period name	Cost (¢/kWh) [1]
Retail Price based on Time-of-Use	Off-peak (Appendix)	36.06
	Shoulder (Appendix)	37.95
	Peak (Appendix)	63.03
Feed-out-tariff	All day	48
Feed-in-tariff	All day	8.5

Besides that, with the interest rate and investment from bank, in this project the ANZ investment loan will be considered for 5 years with interest rate 6.59% per year [38] with $M_{interest}^{paid}$ $(\$/year)$, deposite rate is 8% with the loan payment have to pay $M_{loan} = \Sigma\ Price_{Res}$ $(\$)$, so based on the formular (13), NPC_C will be determined as formular (14).

$$NPC_C = \frac{\Sigma Price_{Res}}{No.of\ considered\ year} + \frac{M_{loan}}{No.of\ considered\ year} + \frac{M_{loan}\ * 6.59\%}{No.of\ considered\ year} \quad (14)$$

Finally, the Cost for Maintainance will be considered with assuming the inflationary will be ignored, and the table x in next Chapter will demonstrate the maintainance pricing.

3. The input data for system

In this project, the real weather data in 2022 including the solar irradiance, temperature, wind speed which taken from Bureau of Methodology (BoM) [39] will be utilized as input data. And based on surveying, the typical residential loads will be collected in real consumption situation with the average comsumption in one year is 5-6kW and 8.37MWh for whole year for load profile 1 which used for scenario 1. And the average comsumption in one year is 5-6kW and 9.14MWh for whole year for load profile 2 which used for scenario 2. The Figure 10 will illustrate the load profile 1 and load profile 2, respectively.

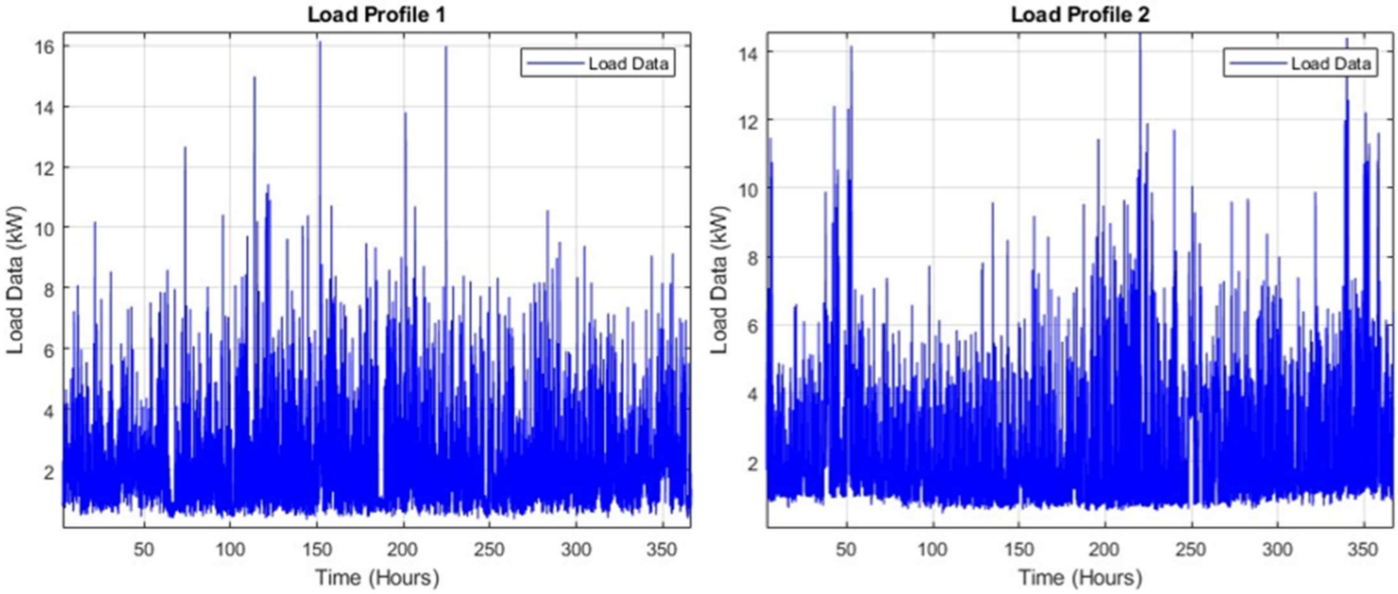


Figure 10. The data for load profile 1 and load profile 2

In addition, the Figure 11 will present the solar irradiance at Adelaide for whole year in 2022 with 8760 hours with average value for whole year is $0.226\ kW/m^2$. And the Figure 12 will present the wind speed profile for whole year in 2022 with average wind speed is nearly 5 m/s.

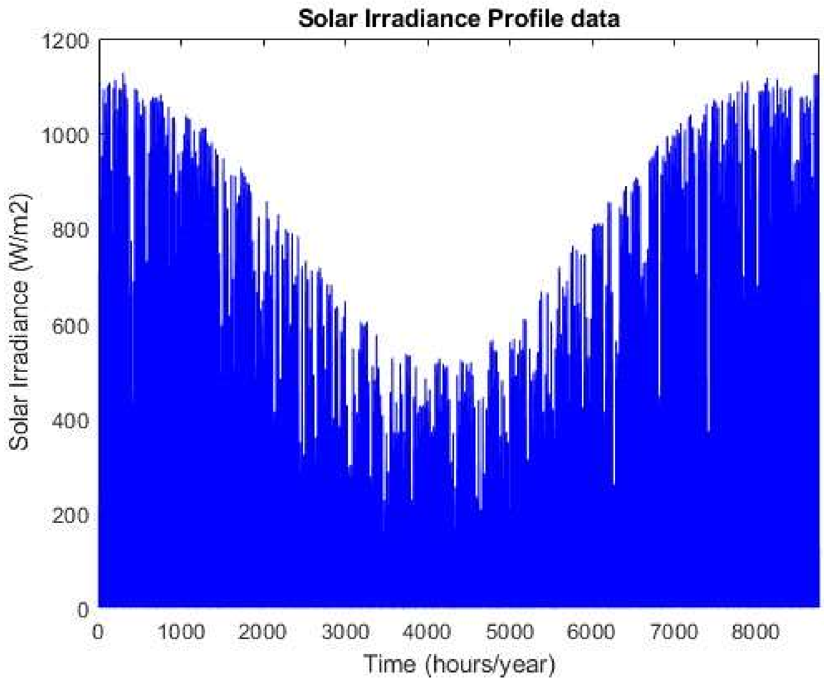


Figure 11. The data for solar irradiance for whole year

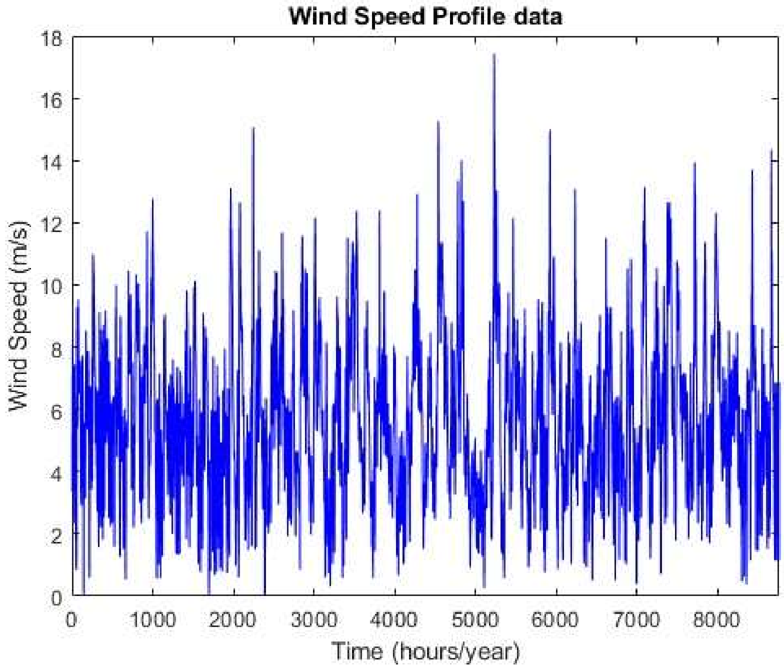


Figure 12. The data for wind speed profile for whole year

According to the requirement of this project, the 2 typical days in each season (Winter and Summer) will be collected and monitored to learn and achieve the habitats of the load demand and power flow with hybrid mode. And the Figure 13 will present the solar irradiance and wind speed in each season.

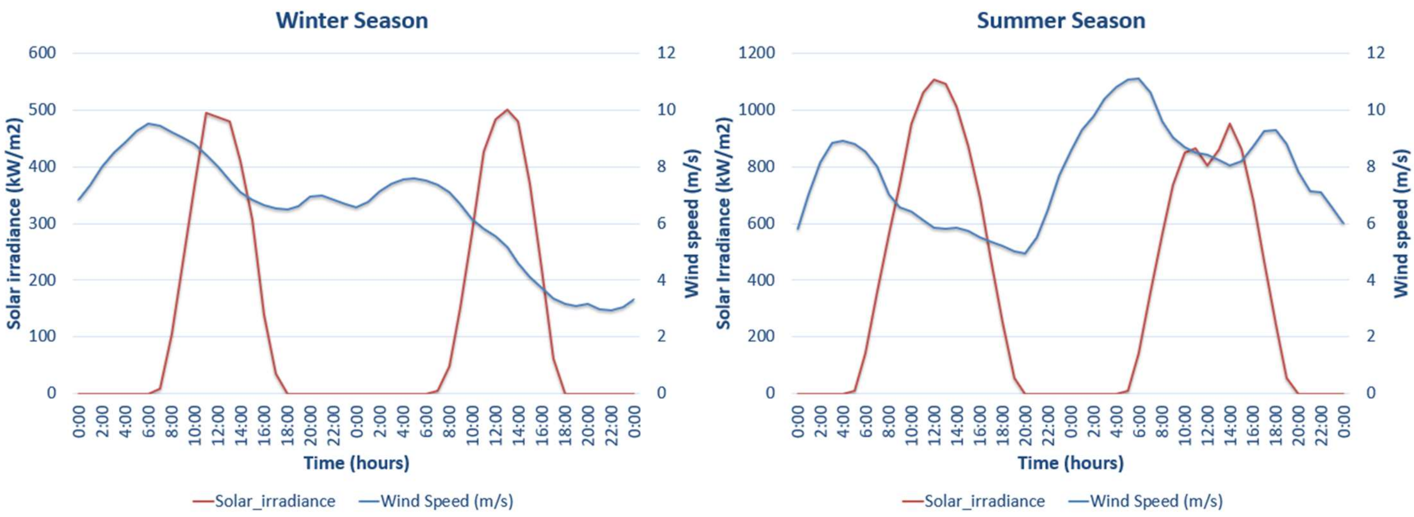


Figure 13. The solar irradiance and wind speed in each season

It can be easily to observe that Wind is always present at all times of the day but the solar irradiance is only present during the day. So, in case the hybrid mode PV + WT, The amount of electricity from renewable energy sources is always produced, which is an advantage when using hybrid mode because almost the amount of electricity will always be generated at all times of the day including daytime (with PV+WT) and night (WT)

CHAPTER 4: RESULTS

1. Analysis the Power flow

This section gives the modelling results of the hybrid mode (PV-WT) with battery energy storage system (BESS). The outcome is derived from two distinct aspect such as:

- By using MATLAB/Simulink, the results of power flow will present for each scenario at this section in chapter 4.
- Additionally, the calculation of the Net Present Cost (NPC) and the Cost of Energy (COE) for the system was performed in each scenario at section 2 in chapter 4. The comparison procedure between two scenarios will involve the assertion of all findings.

1.1. Scenario 1 with load profile 1 and logical flow chart 1

Figure 14 below depicts a comparison of the power flow with the total power generation of the hybrid system (PV+WT) (shown in green lines) and the amount of power stored for the BESS system in time (shown in along the purple line). Besides, with the amount of power load consumption in a certain period of time (shown in blue line), there will be the amount of power exported to the grid (shown in orange line) and the amount of power generated imported from the grid (represented by the red line) for different time periods.

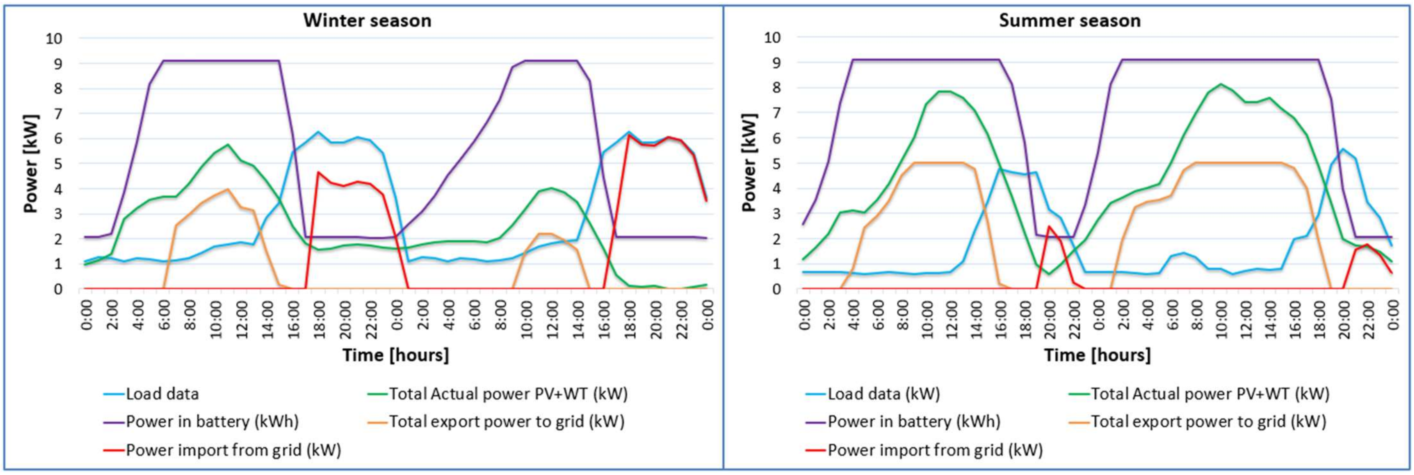


Figure 14. The comparison the power flow for load profile 1 with scenario 1 in two typical days in Summer and Winter season with 48 hours.

As shown in Figure 14, it can be easily observed that the load consumption is mostly concentrated in the time period from 15:00 to 22:00. This is natural in everyday life. In addition, the total electricity output produced from renewable energy sources is mostly concentrated in the period from 6:00 to 18:00 with hybrid mode (PV+WT) because there is energy available at that time with solar and wind energy. However, when dusk falls, the total amount of electricity produced from renewable energy sources depends on wind energy (WT) because wind is almost always present at all times of the day. Moreover, it can be seen that the total electricity output from renewable energy sources in hybrid mode (WT+PV) will be more in summer than in winter because there are more sunny hours in summer than in winter and wind is almost always present at all times of the day.

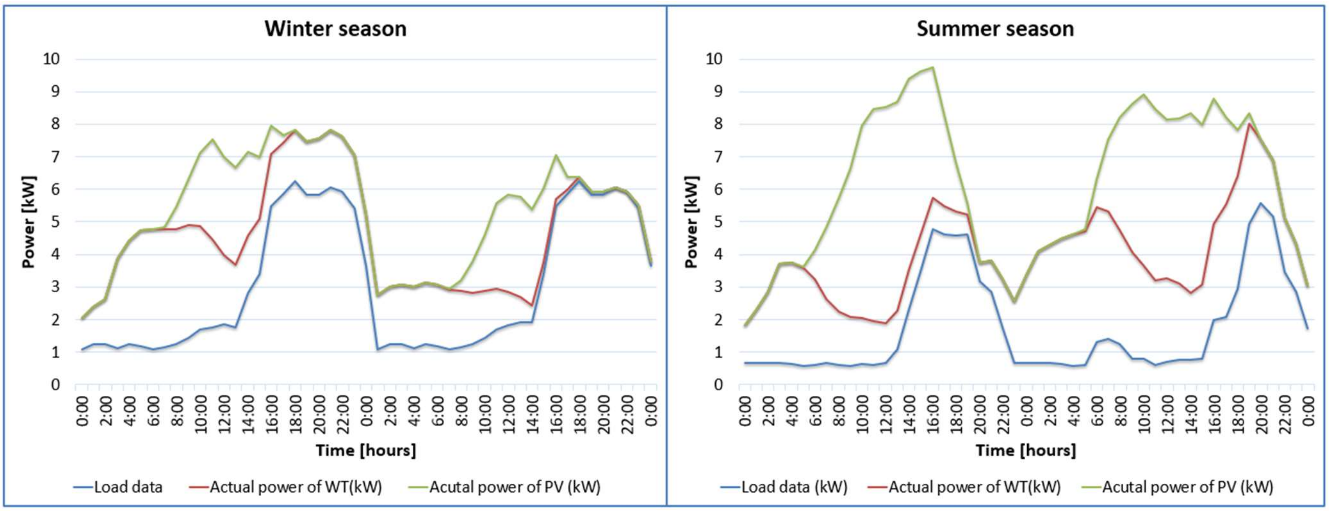


Figure 15. The Power from PV and WT separately with Load residential consumption at Load profile 1 in two typical days in Summer and Winter season with 48 hours

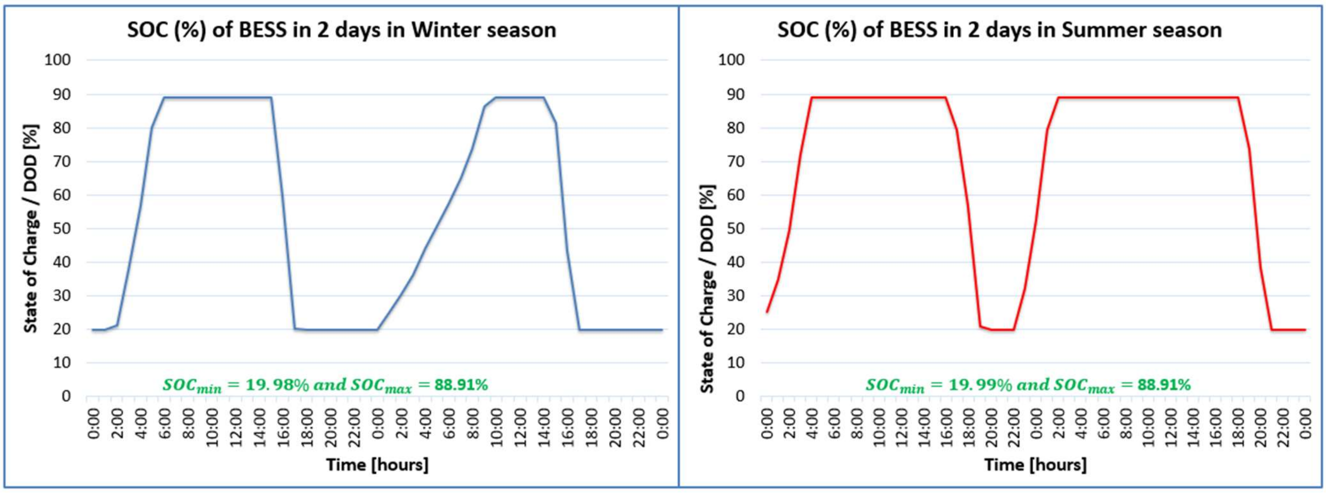


Figure 16. The State of Charge of BESS in two typical days in Summer and Winter season with 48 hours at load profile 1 with scenario 1.

Figure 15 provides a comprehensive representation of the power flow within the system, illustrating the individual contributions of photovoltaic (PV) power (depicted in green) and wind turbine (WT) power (depicted in red) over a period of 48 hours. On the other hand, Figure 16 presents the state of charge (SOC) of the battery energy storage system (BESS) within the same 48-hour frame.

According to the Figure 15 and Figure 16, with *the scenario 1 (load and battery will be considered simultaneously)* that the generated power from renewable resources (WT+PV) in daily (from 6:00 to 16:00) will be used to supply for load and BESS without importing from grid at sometimes it is possible to sell back to the national grid if the load demand at that time was not high and the battery is full (the BESS will be full at 10.24kWh) because at that time the total generated energy from hybrid mode system is highest. So, based on the storage energy from daily and during periods of high electricity demand in typical residential households (usually from 18:00 to 22:00), the amount of electricity imported from the grid system will be reduced because the BESS system and WT energy will support it to match the electricity consumption used in the home at that time, contributing to improving the cost of using electricity of a standard household, which will be presented in the following section.

Furthermore, according to the figure 16, the State of Charge (SOC) of Battery will present the status (charge or discharge) of battery. In there, when the battery is full the SOC will be nearly 88.91%, that means the energy in battery will be full at 88.91% of 10.24kWh. And when the battery is charging to lowest (around 19.98%) that mean the battery will be lowest at 19.98% of 10.24kWh. It can be easily to observe that, with the scenario 1, the power flow will be utilized for both load consumption and battery until the battery is full, and the peak hours in a day (from 16:00 to 22:00) the battery will discharge and combine with the grid as well as renewable energy sources to use for load consumption, reducing dependence on the grid to avoid putting pressure on the national electricity system during peak hours.

1.2. Scenario 2 with load profile 1 and logical flow chart 2

Figure 17 below depicts a comparison of the power flow with the total power generation of the hybrid system (PV+WT) (shown in green lines) and the amount of power stored for the BESS system in time (shown in along the purple line). Besides, with the amount of power load consumption in a certain period of time (shown in blue line), there will be the amount of power exported to the grid (shown in orange line) and the amount of power generated imported from the grid (represented by the red line) for different time periods.

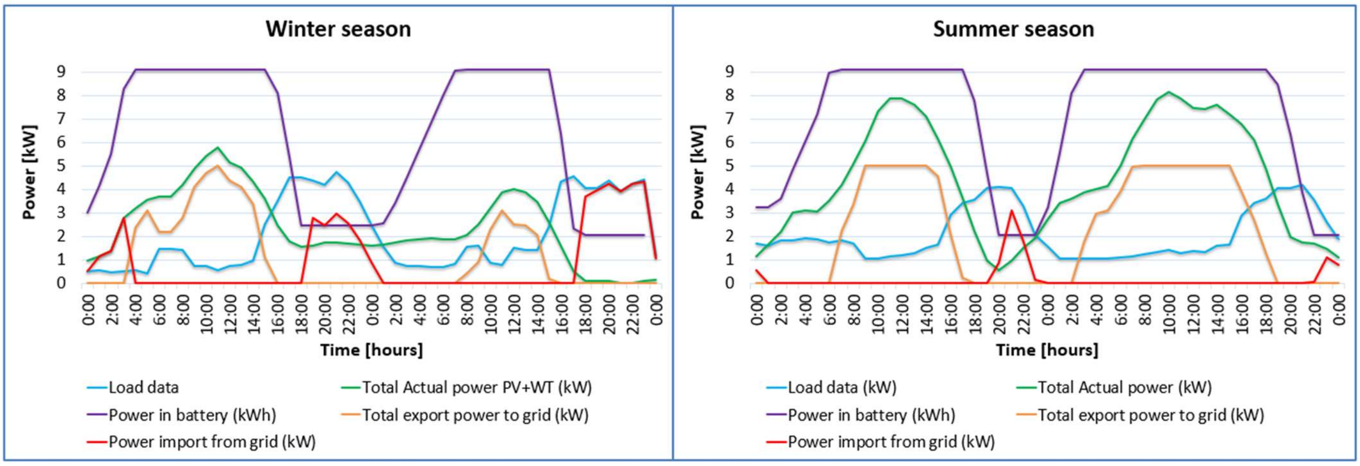


Figure 17. The comparison the power flow for load profile 2 with scenario 2 in two typical days in Summer and Winter season with 48 hours.

As shown in Figure 17, it can be easily observed that the load consumption is mostly concentrated in the time period from 15:00 to 22:00. This is natural in everyday life. In addition, the total electricity output produced from renewable energy sources is mostly concentrated in the period from 6:00 to 18:00 with hybrid mode (PV+WT) because there is energy available at that time with solar and wind energy. However, when dusk falls, the total amount of electricity produced from renewable energy sources depends on wind energy (WT) because wind is almost always present at all times of the day.

Moreover, it can be seen that the total electricity output from renewable energy sources in hybrid mode (WT+PV) will be more in summer than in winter because there are more sunny hours in summer than in winter and wind is almost always present at all times of the day.

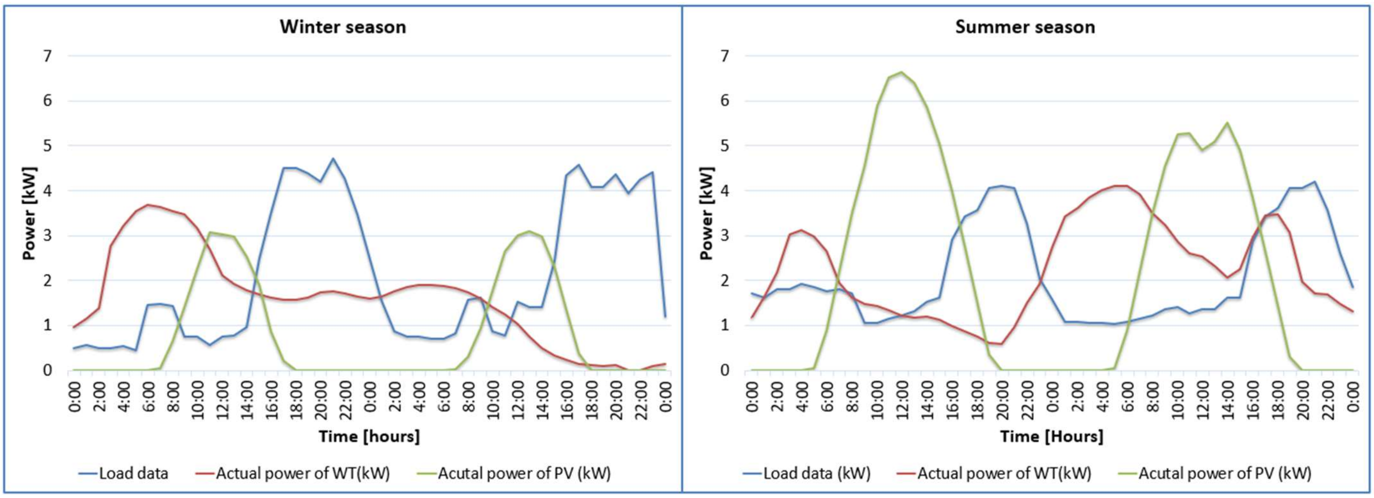


Figure 18. The Power from PV and WT separately with Load residential consumption at Load profile 2 in two typical days in Summer and Winter season with 48 hours.

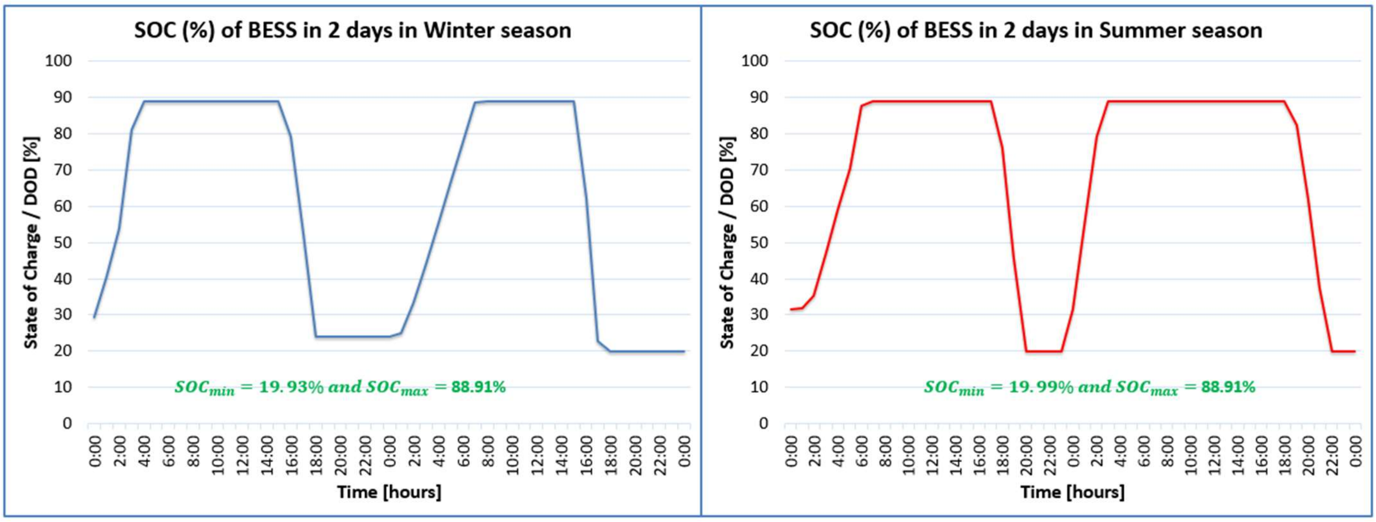


Figure 19. The State of Charge of BESS in two typical days in Summer and Winter season with 48 hours at load profile 1 with scenario 1.

Figure 18 provides a comprehensive representation of the power flow within the system, illustrating the individual contributions of photovoltaic (PV) power (depicted in green) and wind turbine (WT) power (depicted in red) over a period of 48 hours. On the other hand, Figure 19 presents the state of charge (SOC) of the battery energy storage system (BESS) within the same 48-hour frame.

According to the Figure 18 and Figure 19, with *the scenario 2 (battery will be only considered first)* that the generated power from renewable resources (WT+PV) in daily (from 6:00 to 16:00) will be used to supply for only BESS until it will be full (the BESS will be full at 10.24kWh), and while the charging for battery of hybrid sources (PV+WT). The load consumption will be consumed the energy from grid (import), and when the battery is full at that time, the excess energy from hybrid sources (PV+WT) will be exported to grid for selling.

Furthermore, the total generated energy from hybrid mode system is highest. So, based on the storage energy from daily and during periods of high electricity demand in typical residential households (usually from 18:00 to 22:00), the amount of electricity imported from the grid system will be reduced because the BESS system and WT energy will support it to match the electricity consumption used in the home at that time, contributing to improving the cost of using electricity of a standard household, which will be presented in the following section.

Furthermore, according to the figure 19, the State of Charge (SOC) of Battery will present the status (charge or discharge) of battery. In there, when the battery is full the SOC will be nearly 88.91%, that means the energy in battery will be full at 88.91% of 10.24kWh. And when the battery is charging to lowest (around 19.99%) that mean the battery will be lowest at 19.98% of 10.24kWh.

It can be easily to observe that, with the scenario 2, the power flow will be *only* utilized for battery until the battery is full, and the peak hours in a day (from 16:00 to 22:00) the battery will discharge and combine with the grid as well as renewable energy sources to use for load consumption, reducing dependence on the grid to avoid putting pressure on the national electricity system during peak hours. The cash flow will be analysed in next section in this Chapter.

2. Analysis the Cash flow

Table 4 presents the calculated capital cost of each component, taking into consideration the system parameters and actual market prices. One could argue that the capital cost of a photovoltaic (PV) system is greater than that of a wind turbine (WT) system by an estimated amount of 400 $/kWh. Furthermore, it should be noted that the battery is the highest cost component in both systems, amounting to 1034.08 $/kWh. So, the total investment cost for renewable system with hybrid mode is 18862.6 [$].

Table 4. The initial investment capital cost for PV, WT and BESS [40].

Separated RES	Currently market price [$]	Total price with required power [$]	Capital initial investment cost [$/kWh]
PV (5kW)	$280.20	$5,043.60	$1,008.72
WT (5kW)	$3,230	$3,230	$646
Battery (10.24kW)	$10,589	$10,589	$1,034.08

According to the Table 5, the cost for maintenance of the hybrid system and BESS is totally 477.4 $/year. Compare with the capital cost for system, Maintenance costs for the system account for about 2.53% of the initial investment cost.

Table 5. The cost for maintenance for system per year with ignoring the inflationary (without inflationary).

Separated RES	Maintenance cost [$/kWh/year]	Total price with required power [$/year]
PV (5kW)	$25	$125
WT (5kW)	$50	$250
Battery (10.24kW)	$10	$102.4

According to interest rate and investment loan of ANZ Bank 2023 [38], the deposit rate is 8% with the interest rate is 6.59% per year in 3 or 5- or 7-years duration with options.

With: Load for interest rate and investment [38]

- Interest rate: 6.59%/year => Paid interest rate/year $M_{interest}^{paid} = 1143.6$ [$/year]
- Deposit rate: 8% => get loan $M_{loan} = 17353.592$ [$]
- $NPC_C = \frac{\Sigma Price_{Res}}{No.of\ considered\ year} + \frac{M_{loan}}{No.of\ considered\ year} + \frac{M_{loan} * 6.59\%}{No.of\ considered\ year}$

In there:

$$NPC_C = \frac{18862.6}{3} + 18862.6\frac{8\%}{3} + \frac{18862.6}{3}.6.59\% = 7204.88[\$]$$

$$\boldsymbol{NPC_C = \frac{18862.6}{5} + 18862.6\frac{8\%}{5} + \frac{18862.6}{5}.6.59\% = 4322.93}[\$]$$

$$NPC_C = \frac{18862.6}{7} + 18862.6\frac{8\%}{7} + \frac{18862.6}{7}.6.59\% = 3087.8[\$]$$

With this hybrid system and BESS, the bank offered the loan investment package for energy is 5 years.

The aforementioned data will be integrated with the power flow analysis obtained from the simulation model in Simulink, as well as the material cost and electricity rate provided in Table 6 for load profile 1 with scenario 1 and Table 9 for load profile 2 with scenario 2. This integration will enable the determination of the annual Net Present Cost (NPC) of the system for each scenario.

Table 6. The Net Present Cost (NPC_G) for Components and for Grid reflections in Load profile 1

Load Profile 1	NPC_C capital investment		NPC_G /day ($)		NPC_G/ year ($)	
			Total TOU	Total FRP	FRP	TOU
PV-WT-BESS	19648.97$	Winter	20.17	20.17	4513.17	3332.5
		Summer	-1.91	-1.91		

Table 7. The Net Present Cost (NPC_G) for Components and for Grid reflections in Load profile 2

Load Profile 2	NPC_C capital investment		NPC_G /day ($)		NPC_G/ year ($)	
			Total TOU	Total FRP	FRP	TOU
PV-WT-BESS	19648.97$	Winter	11.16	11.82	3053.92	1688.4
		Summer	-1.90	-1.90		

According to the table 6 and table 7, the Feed Retail Price (FRP) refers to a financial incentive provided to individuals or entities for the surplus electricity they generate and supply to the grid, resulting in a credit being applied to their account. Commonly referred to as a buy-back rate, this charge is typically a fixed amount per kilowatt hour that is provided as a credit on the consumer's billing statement.

Time Of Use (TOU) rates are characterised by varying electricity pricing throughout different time intervals throughout the day. By comprehending these temporal intervals, individuals can make informed judgements regarding the optimal timing for power use, so strategically shifting their usage to hours when electricity can be procured from the grid at a lower cost. It is imperative for individuals subscribed to Time-of-Use (TOU) tariffs to possess knowledge regarding the specific time periods during which distinct peak, shoulder, and off-peak charges are applicable. There are 3 different ToU including: Peak, Off-Peak and Shoulder, which will be presented in Appendix C with detailed hours.

Thus, the total of NPC_C and NPC_G will be denoted as total NPC corresponding to Feed Retail (FR) and Time of Use (ToU).

Table 8. The summary of the NPC and COE of 2 load profiles with both scenarios in 5 years consideration

5 years	MWh	total NPC ($)		total COE (¢/kWh)	
		Feed Retail	TOU	Feed Retail	TOU
Load 1	17.97	8836.098	7655.42	49.17	42.60
Load 2	18.28	7376.853	6011.33	40.35	32.88

According to the Table 8 with summary, it can be easily to observe that with the scenario 1 at load profile 1, the ToU will be larger than the scenario 2 based on the logical mathematics power flow chart, because there is a difference between whether the power flow generated from the renewable energy source will simultaneously supply the load and charge the battery (according to scenario 1) or only charge the battery and the load will use electricity from the national grid. (According to scenario 2). Thus, the Time of Use at load 1 is larger than load 2, the same thing happens with FRP. However, the phenomenon of disparity. between the ToU and FRP of each scenario will be examined and it will be suggested which scenario will be considered in the next Chapter.

CHAPTER 5: DISCUSSION

In the discussion section, it is crucial to conduct a comprehensive analysis of the findings in relation to the project objectives that were outlined earlier in this investigation. The primary objective of this project is to utilize a hybrid system consisting of photovoltaic (PV) and wind turbine (WT) technologies, in conjunction with a battery energy storage system (BESS). This hybrid system will be powered by the energy generated by the PV and WT components, with the goal of reducing the cost of electricity (COE) compared to the current electricity rate. Based on the outcomes of the power flow analysis conducted in the previous section, as well as the computed cost of electricity (COE), the ensuing discussion section presents a comparative analysis of the two scenarios. Additionally, recommendations are provided to assist residents to reach a well-informed choice regarding the selection of the more favourable scenario for residential purposes. Furthermore, future research is also proposed in light of the project's limitations.

The summary of the power flow for each scenario will be illustrated as Figure 21. According to the Figure 21, the total generated power from hybrid sources (PV+WT) will present as blue colour, the energy with importation from grid and exportation to grid will be respectively presented as red colour and green colour. It can be easily to observe and understand that the total generated power from hybrid sources will be significantly equal due to the same weather data and components. However, as mentioned above, there is a difference between the power flow corresponding to each scenario.

For scenario 1, the electrical energy generated by each hybrid source will simultaneously supply the consuming load and charge the excess to the storage battery system. However, with scenario 2, the electrical energy generated from the hybrid source at the peak time of electricity production will only supply the storage battery system until the battery system is full. From that and combined with the observation in Figure 20, it can be discussed that, with scenario 1, the demand from the national grid to supply the load will be less than with scenario 2, particularly during the summer season, the utilisation of scenario 1 is expected to decrease. In the summer, the value is 5.6 times lower compared to scenario

2, while in the winter, it is 2.89 times lower. However, there will also be a disparity in the sale of electricity to the grid between the two scenarios, but a minimal and inconsequential one.

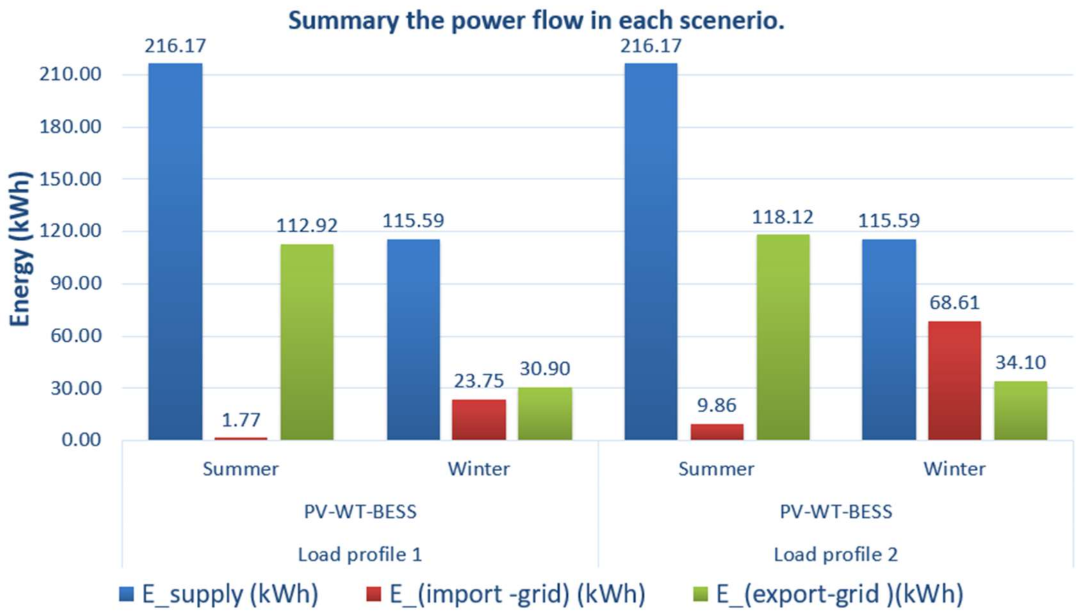


Figure 20. The summary of the power flow for each scenario.

Moreover, the Figure 21 will present the comparison of State of Charge (SOC) of BESS in each season with each scenario. According to the Figure 22, the SOC of scenario 1 will present as blue colour, and the SOC of scenario 2 will present as red colour. Based on the data presented in Figure 22, it can be observed that there is minimal variation in the State of Charge (SOC) levels across the different scenarios. In the summer season, the hybrid energy source presents a greater overall electricity , with the same peak hours (6:00 to 18:00) those observed during the winter season. This disparity can be attributed to the increased duration of sunshine hours in summer compared to winter, while wind availability remains consistent across all geographical locations. Combined with mathematical flow chart logical, with scenario 1, the battery will be fully charged faster in the summer than scenario 2.

In addition, according to the Appendix F, this pie chart in that appendix will present estimation for the summary power flow for each scenario in whole year.

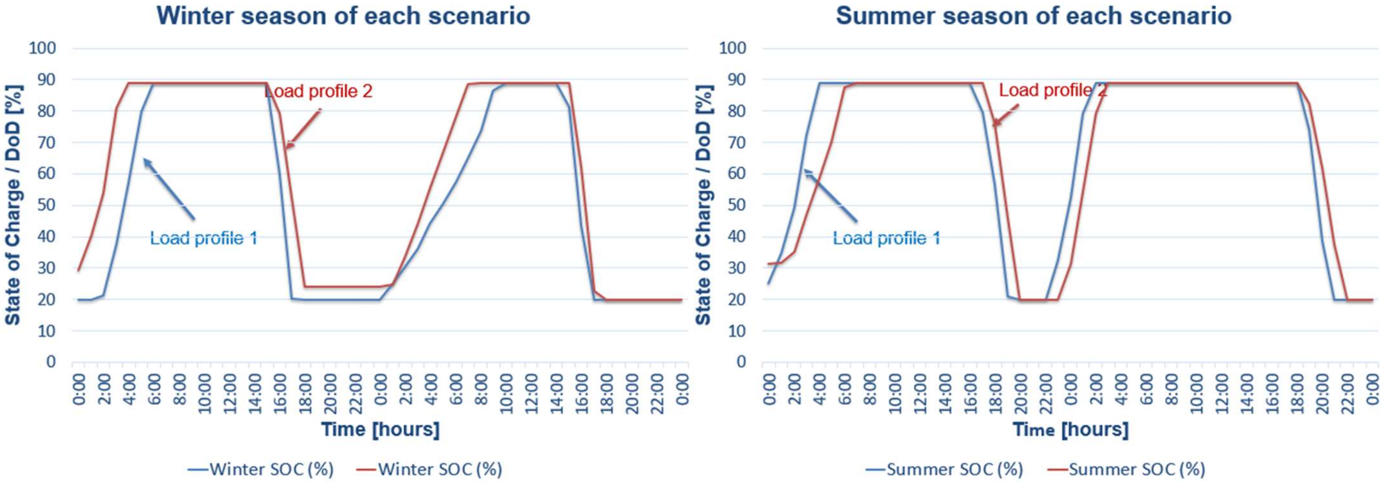


Figure 21. The comparison for SOC of BESS in each Season with each Scenario.

Upon analysis, it becomes evident that, with regards to the ***energy aspect***, scenario 1 exhibits better features compared to scenario 2 in terms of reliance on the national power grid. This means that scenario 1 involves a reduced dependence on the national grid as well as a negligible disparity in the electricity output sold to the grid.

When investigating the ***economic aspect***, it is evident from table 8 that the Time-of-Use (ToU) energy and Feed Retail Price in scenario 1 will be greater than those in scenario 2. This disparity can be attributed to the logical mathematical energy flow chart of each respective scenario, as previously discussed. However, it should be noted that the disparity between the Feed Retail Price and Time-of-Use (ToU) energy varies across the different scenarios. In particular, the discrepancy between the Feed Retail Price and ToU energy in scenario 1 is 6.57 (¢/kWh), whereas in scenario 2, it amounts to 7.47 (¢/kWh). From there, it shows that when considering the economic aspect, scenario 1 will be more beneficial than scenario 2.

Based on the aforementioned considerations regarding energy and financial aspects, it can be concluded that ***scenario 1***, which involves utilising energy from a hybrid system during peak hours of plentiful sunlight and wind production (6:00 a.m. to 6:00 p.m.) to supply the load consumption and charge the battery storage system simultaneously, ***is preferable, better, more beneficial and more effective to scenario 2***, which the energy is solely utilised for charging the storage battery system during the same time period.

Furthermore, consideration of the situation depending on the use of the national gridat certain times of the day will be discussed based on Figure 22 for scenario 1 and Figure 23 for scenario 2.

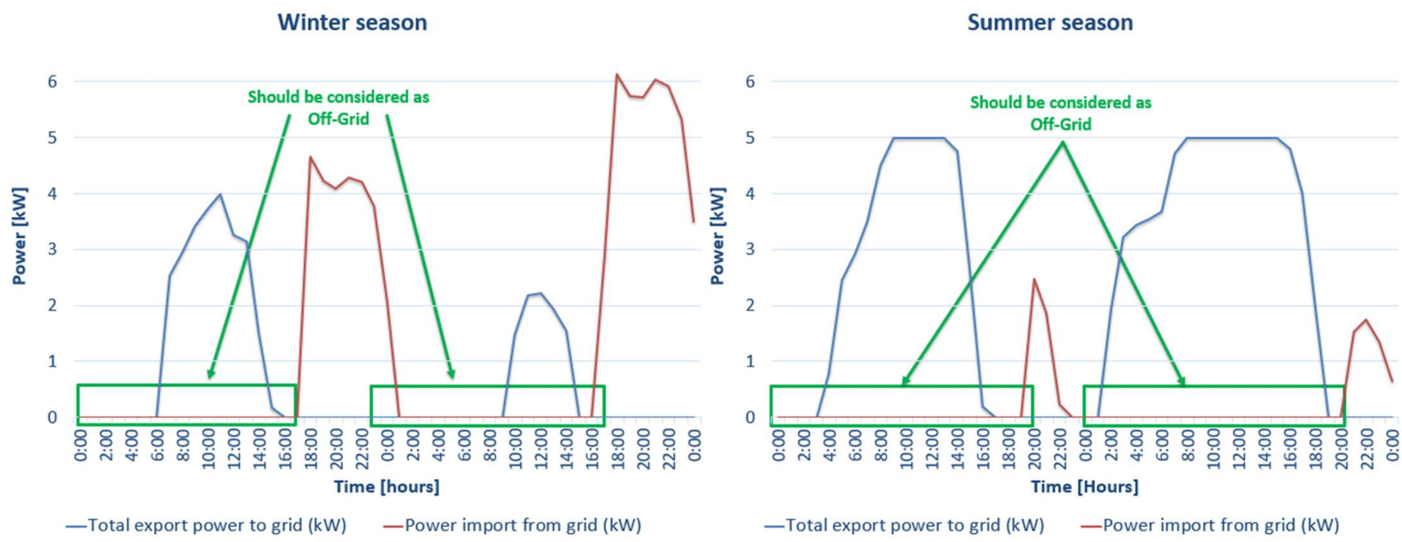


Figure 22. The recommendation for grid status (ON/ OFF grid) in scenario 1 in 2 typical days of each season

Figure 23. The recommendation for grid status (ON/ OFF grid) in scenario 2 in 2 typical days of each season

According to the Figure 22 and Figure 23, it shows the exporatation grid (as blue line) and importation grid (as red line). With the amount of electricity imported from the grid continuously being zero at some times of the day, people can consider going off-grid, meaning they can turn off the grid connection or not rely on electricity purchases from the national grid.

According to the Figure 22 and 23, at the same period time at Summer season, the total power exportation to grid is nearly equivalent, there is small differences. However, the total importation power from grid is quite different due to the difference in power flow in each scenario, therefore, it is easy to observe that in scenario 2, the power imported from the national grid will be much larger than scenario 1 (about 3.2kWh compared to 2.5kWh at peak times of the day), because in scenario 2, generated power from the hybrid source will prioritize fully charging the battery system first.

Furthermore, at the same period time at Winter season, the total power exportation to grid is nearly equivalent, there is small differences. However, the total importation power from grid is quite different due to the difference in power flow in each scenario, therefore, it is easy to observe that in scenario 2, the power imported from the national grid will be much larger than scenario 1 at peak times of the day, because in scenario 2, generated power from the hybrid source will prioritize fully charging the battery system first. Therefore, this can be considered a ***technical aspect.***

Thus, with the economic, technical and energy aspect, it will be perfectly concluded that the scenario 1 with the energy produced from the hybrid sources (PV+WT) is simultaneously supplied to the consuming load and charging the battery storage system, which will be more beneficial than scenario 2 which just only for charging the battery storage system.

In addition, according to the Appendix F for power flow in ***whole year***, it can be easily to observe that, the imported energy from grid in scenario 1 is less than one in scenario 2 (2.33 MWh > 3.07 MWh), an the exporte energy to grid in scenario 1 has a difference with scenario 2 but it is not significant (13.12 MWh versus 13.60 MWh).

As the results, the better scenario with power flow will be considered to select based on the advantages of three aspects above. However, there are minor limitations of this project such as:

- The project did not mention and take care about the lifecycle of renewable components: solar panels, wind turbines, battery system. This consideration is omitted in the mathematical conclusion.
- The size and utilized capacity of the components just based on the selection on market trade.

CHAPTER 6: CONCLUSION AND FUTURE WORKS

1. Conclusion

The effective energy management is crucial in reducing both residential energy usage and associated expenditures. The primary focus of this project was to establish an energy management system specifically designed for dwellings. The investigation will focus on the Hybrid mode, which incorporates solar photovoltaic (PV) systems, Wind turbines (WT), with the Battery Energy Storage System in order to storage the excess electricity generated from renewable energy sources (hybrid mode). From that, the study will be investigated based on the Hybrid mode including PV, WT and BESS. From that, there are two Scenarios with different power flow which established based on the basis configuration for residential households. In addition, the electricity tariff as well as the energy tariff will be considered in this article by determining the cost of energy for each scenario and the better selected scenario will be chosen based on the better Cost of Energy.

In conclusion, the economic efficiency will be better if the customers use the hybrid mode (PV+WT) with battery for storage with the power flow must be considered for both load consumption and battery status based on the Cost of Energy for whole year which has been proven above. Hence, this emphasises the significance of adopting clean energy sources as a viable alternative to traditional energy resources in the future era. Additionally, it serves to underscore the criticality of maintaining equilibrium in the national power transmission system during electricity generation in which the individual consumption patterns of each home constitute a significant factor to reduce overload on the national grid during peak hours. Subsequently, the prioritisation of across the nation development of renewable energy sources will lead to a decrease in annual maintenance operations for the national power system. This endeavour will contribute to the overall objective of mitigating greenhouse gas emissions and controlling environmental pollution. Moreover, at some times of the day, there may be no need to rely on the grid when the amount of electricity from the energy storage system as well as the energy system produced from solar panels and micro wind turbines is enough to supply the load (off-grid situation). Also, it shows that the advantages of investing in solar energy systems (from 5kW) as well as micro wind turbine systems (from 5kW) for households aim to encourage the use of clean energy in the future, and in order to avoid the dump power, it also shows that the importance of investing in a basic battery storage system for a household with that the initial investment cost for a 10.24kWh battery system can be considered acceptable. And, with the typical residential load, the Feed in Tariff will be tent to be same at for each kWh. However, the TOU of each configuration will be different due the power flow is different. *And from there with the **economic, technical and energy aspects**, these are finally proven that the flow scenario where power should be supplied simultaneously to the consuming load and the battery storage system will have more energy and economic benefits than the flow scenario power is only produced and supplied to the storage battery system.* Thus, the recommendation for SA house owners that if they are considering the hybrid mode with BESS, they should apply the power flow according to the scenario 1.

However, there are still many limitations in this project such as:

- State-scale assessments of consumption loads are difficult to implement due to uneven population distribution (between city and rural).
- Establish a residential load model in large area in one year is a difficult problem because it requires a good computer system.
- The frequency and voltage differences that can occur between on-grid and off-grid transitions can cause inertia risks in the power system.
- The initial cost of system investment.

2. Future works

Based on the above limitations, the author offers some future works for next generation such as:

- Develop the algorithm such as PSO, GA… and the actual control devices for switching the “on-off grid”
- Research plan to build a green energy system in remote areas independent of the national electricity system.
- Research and build software or applications capable of calculating, modelling, and predicting scenarios that may occur in the next 5-10 years at the most optimal cost.
- Developing systems/algorithms to reduce the possibility of power system inertia changes (keeping system frequency stable) for solar power systems and micro wind turbines. Reduce the risk of impact on the transmission grid.

BIBLIOGRAPHY

[1] Yan, Hui, Fang Zhuo, Nian Lv, Hao Yi, Zhenxiong Wang, and Cuicui Liu. "Model predictive control-based energy management of a household microgrid". In 2019 IEEE 10th International Symposium on Power Electronics for Distributed Generation Systems (PEDG), pp. 365-369. IEEE, 2019.

[2] Pamulapati, Trinadh, Muhammed Cavus, Ishioma Odigwe, Adib Allahham, Sara Walker, and Damian Giaouris. "A Review of Microgrid Energy Management Strategies from the Energy Trilemma Perspective". Energies 16, no. 1 (2022): 289.

[3] Grid System, Office of Electricity, viewed 2023, available on: www.energy.gov/oe/role-microgrids-helping-advance-nations-energy-system

[4] Zeinal-Kheiri, Sevda, Amin Mohammadpour Shotorbani, Amaiya Khardenavis, Behnam Mohammadi-Ivatloo, Rehan Sadiq, and Kasun Hewage. "An adaptive real-time energy management system for a renewable energy-based microgrid ". IET Renewable Power Generation 15, no. 13 (2021): 2918-2930.

[5] Anvari-Moghaddam, Amjad, Josep M. Guerrero, Juan C. Vasquez, Hassan Monsef, and Ashkan Rahimi-Kian. "Efficient energy management for a grid-tied residential microgrid ". IET Generation, Transmission & Distribution 11, no. 11 (2017): 2752-2761.

[6] Kumar, Abhishek, Yan Deng, Xiangning He, Praveen Kumar, and Ramesh C. Bansal. "Energy management system controller for a rural microgrid ". The Journal of Engineering 2017, no. 13 (2017): 834-839.

[7] Zhao Z. Operation Simulation and Economic Analysis of Household Hybrid PV and BESS Systems in the Improved TOU Mode. *Sustainability*. 2023; 15(11):8853. https://doi.org/10.3390/su15118853.

[8] Shakir, Majed, and Yevgen Biletskiy. "Forecasting and optimisation for microgrid in home energy management systems". IET Generation, Transmission & Distribution 14, no. 17 (2020): 3458-3468.
[9] Fouladi, Ehsan, Hamid Reza Baghaee, Mehdi Bagheri, and G. B. Gharehpetian. "Power management of microgrids including PHEVs based on maximum employment of renewable energy resources". IEEE Transactions on Industry Applications 56, no. 5 (2020): 5299-5307.

[10] Zeinal-Kheiri, Sevda, Saeid Ghassem-Zadeh, Amin Mohammadpour Shotorbani, and Behnam Mohammadi-Ivatloo. "Real-time energy management in a microgrid with renewable generation, energy storages, flexible loads and combined heat and power units using Lyapunov optimisation ". IET Renewable Power Generation 14, no. 4 (2020): 526-538.

[11] Yan, Hui, Nian Lv, Fang Zhuo, Hao Yi, and Zhenxionz Wang. "Energy Management of Household Microgrid with Multiple Energy Resources for Rural Area ". In 2019 10th International Conference on Power Electronics and ECCE Asia (ICPE 2019-ECCE Asia), pp. 1-6. IEEE, 2019.

[12] Khezri, Rahmat, Amin Mahmoudi, and Hirohisa Aki. "Optimal planning of renewable energy resources and battery storage system for an educational campus in South Australia

". In 2020 IEEE Energy Conversion Congress and Exposition (ECCE), pp. 3677-3683. IEEE, 2020.

[13] Zunnurain, Izaz, Md Nasimul Islam Maruf, Md Moktadir Rahman, and G. M. Shafiullah. "Implementation of advanced demand side management for microgrid incorporating demand response and home energy management system ". Infrastructures 3, no. 4 (2018): 50.

[14] Khezri, Rahmat, Amin Mahmoudi, and Hirohisa Aki. "Optimal planning of solar photovoltaic and battery storage systems for grid-connected residential sector: Review, challenges and new perspectives." Renewable and Sustainable Energy Reviews 153 (2022): 111763

[15] Slama, Sami Ben, Bassam Zafar, and Emad Shafie. "Green Hydrogen Microgrid: Household Energy Management System Dedicated to a Hydrogen Storage-based Renewable-Energy-System." 2022 International Conference on Electrical, Computer, Communications and Mechatronics Engineering (ICECCME). IEEE, 2022.

[16] Lei, Chen, and Niu Yugang. "Two-stage game framework for energy management in islanded multi-microgrid system." IET Generation, Transmission & Distribution 14.23 (2020): 5439-5446

[17] Carl Kitchen, Blaine Wang, "International electricity prices: How does Australia compare?", Energy Council, published on 03rd Feb 2022, viewed on 2023, available on: https://www.energycouncil.com.au/analysis/international-electricity-prices-how-does-australia-compare/

[18] Touma, Haider Jouma, et al. "Energy management system of microgrid: Control schemes, pricing techniques, and future horizons." International Journal of Energy Research 45.9 (2021): 12728-12739.

[19] Alipour, Manijeh, et al. "Microgrid energy management: how uncertainty modelling impacts economic performance." IET Generation, Transmission & Distribution 13.24 (2019): 5504-5510.

[20] Jafari, Amirreza, et al. "A fair electricity market strategy for energy management and reliability enhancement of islanded multi-microgrids." Applied Energy 270 (2020): 115170.

[21] Javeed, I., Khezri, R., Mahmoudi, A., Yazdani, A., & Shafiullah, G. M. (2021). Optimal sizing of rooftop PV and battery storage for grid-connected houses considering flat and time-of-use electricity rates. Energies, 14(12), 3520

[22] L. Zhou, Y. Zhang, K. Li and X. Xie, "Optimal Sizing of PV System and BESS for Smart Household under Stepwise Power Tariff," 2018 International Conference on Power System Technology (POWERCON), Guangzhou, China, 2018, pp. 1314-1319.

[23] Bartusch, Cajsa, and Karin Alvehag. "Further exploring the potential of residential demand response programs in electricity distribution." Applied Energy 125 (2014): 39-59.

[24] Li, Yang, et al. "Optimal scheduling of isolated microgrid with an electric vehicle battery swapping station in multi-stakeholder scenarios: A bi-level programming approach via real-time pricing." Applied energy 232 (2018): 54-68.

[25] Guo, Li-dong, et al. "Parameter optimization of operation strategy based on PSO for a Renewable Energy Microgrid." 2020 47th IEEE Photovoltaic Specialists Conference (PVSC). IEEE, 2020.

[26] Cai, Wenqi, Arash Bahari Kordabad, and Sébastien Gros. "Energy management in residential microgrid using model predictive control-based reinforcement learning and Shapley value ". Engineering Applications of Artificial Intelligence 119 (2023): 105793.

[27] Feng, Zhou, et al. "Electric energy management method based on binary genetic algorithm." 2020 IEEE 9th joint international information technology and artificial intelligence conference (ITAIC). Vol. 9. IEEE, 2020.

[28] Javaid, Nadeem, et al. "A survey of home energy management systems in future smart grid communications." 2013 eighth international conference on broadband and wireless computing, communication and applications. IEEE, 2013.

[29] Ramli, Makbul AM, H. R. E. H. Bouchekara, and Abdulsalam S. Alghamdi. "Optimal sizing of PV/wind/diesel hybrid microgrid system using multi-objective self-adaptive differential evolution algorithm." Renewable energy 121 (2018): 400-411.

[30] Mazzoni, Stefano, et al. "Energy storage technologies as techno-economic parameters for master-planning and optimal dispatch in smart multi energy systems." Applied Energy 254 (2019): 113682

[31] SA Power Networks, SA, Australia. [Online]. Available: Upcoming changes to small embedded generation connections (sapowernetworks.com.au), Accessed on: 14th April 2021

[32] GSES (2020) September. South Australia Regulations for New Solar Power System, Global Sustainable Energy Solutions, Australia. [Online]
Available: https://www.gses.com.au/south-australian-regulations-for-new-solar-power-systems/

[33] R. Khezri, A. Mahmoudi and M. H. Haque, "Optimal Capacity of PV and BES for Grid-connected Households in South Australia," 2019 IEEE Energy Conversion Congress and Exposition (ECCE), Baltimore, MD, USA, 2019, pp. 3483-3490, doi: 10.1109/ECCE.2019.8913055.

[34] Khezri, R., Mahmoudi, A., Haque, M.H. “Optimal capacity of solar PV and battery storage for australian grid-connected households”. IEEE Trans. Ind. Appl. 56(5), 5319–5329 (2020).

[35] K. Givaki, M. Parker and P. Jamieson, "Estimation of the power electronic converter lifetime in fully rated converter wind turbine for onshore and offshore wind farms," 7th IET International Conference on Power Electronics, Machines and Drives (PEMD 2014), Manchester, UK, 2014, pp. 1-6, doi: 10.1049/cp.2014.0301.

[36] Pan, X., Khezri, R., Mahmoudi, A., & Muyeen, S. M. "Optimal planning of solar PV and battery storage with energy management systems for Time-of-Use and flat electricity tariffs." IET Renewable Power Generation 16.6 (2022): 1206-1219.

[37] Electricity rate of Energy Australia in South Australia 2023. Available: https://wattever.com.au/compare-energy-locals-electricity-rates/

[38] https://www.anz.com.au/personal/home-loans/offers-and-rates/

[39] Bureau of Methodology (BoM) (2022), Report summary about the weather data in Adelaide, Available: http://www.bom.gov.au/climate/current/

[40] R. Khezri, A. Mahmoudi and M. H. Haque, "A Demand Side Management Approach For Optimal Sizing of Standalone Renewable-Battery Systems," in IEEE Transactions on Sustainable Energy, vol. 12, no. 4, pp. 2184-2194, Oct. 2021, doi: 10.1109/TSTE.2021.3084245.

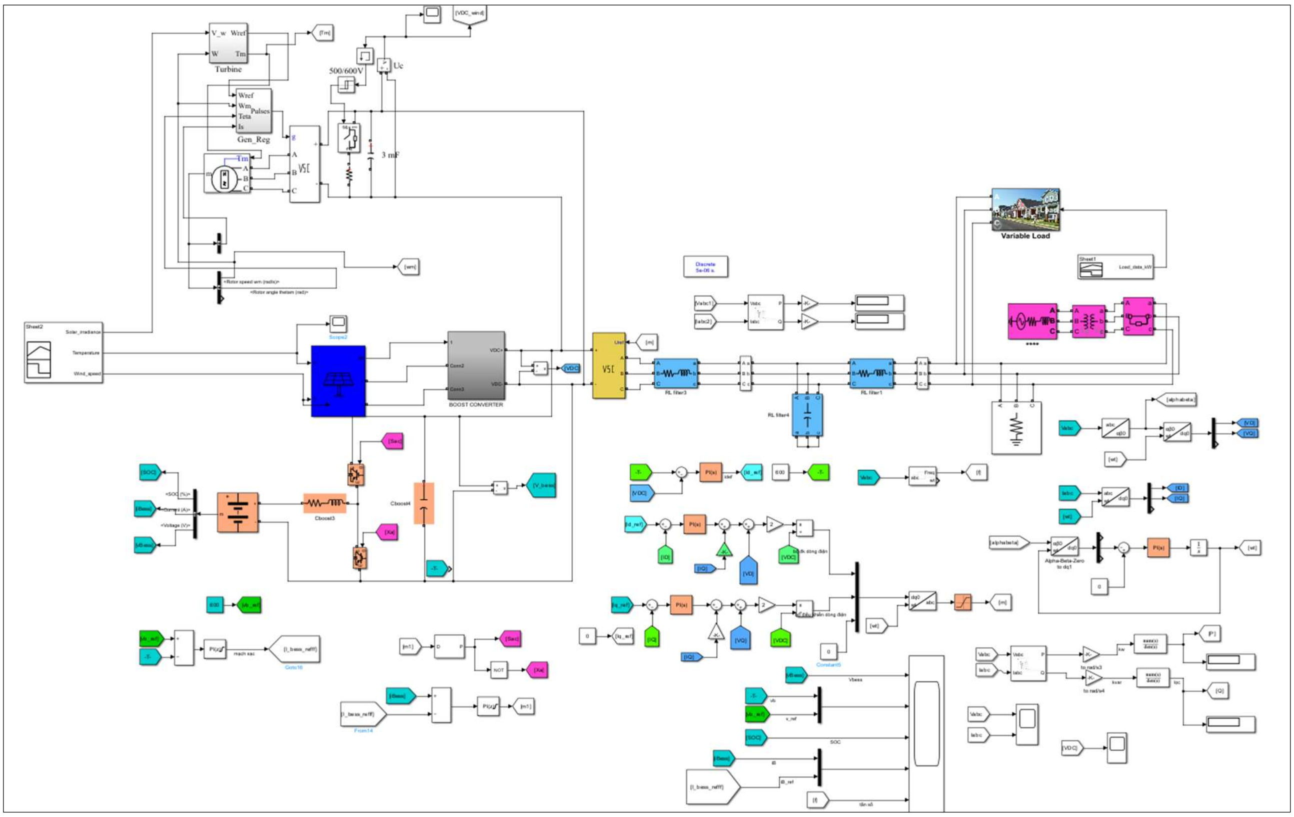
[41] Feed in Tariffs, Energy Australia, online, Available: https://www.energyaustralia.com.au/home/solar/feed-in-tariffs

[42] Magnum 5kW horizontal Wind Turbine, Tesup manufacturer website, Available: https://www.tesup.com.au/product-page/magnum5-wind-turbine-5kw-12v-24v-48v-Australia

[43] Growatt Battery Kit ARK 10.24kWh, Growatt manufacturer website, Available: https://growatt.tech/product/growatt-battery-kit-ark-10-24-kwh-for-xh/

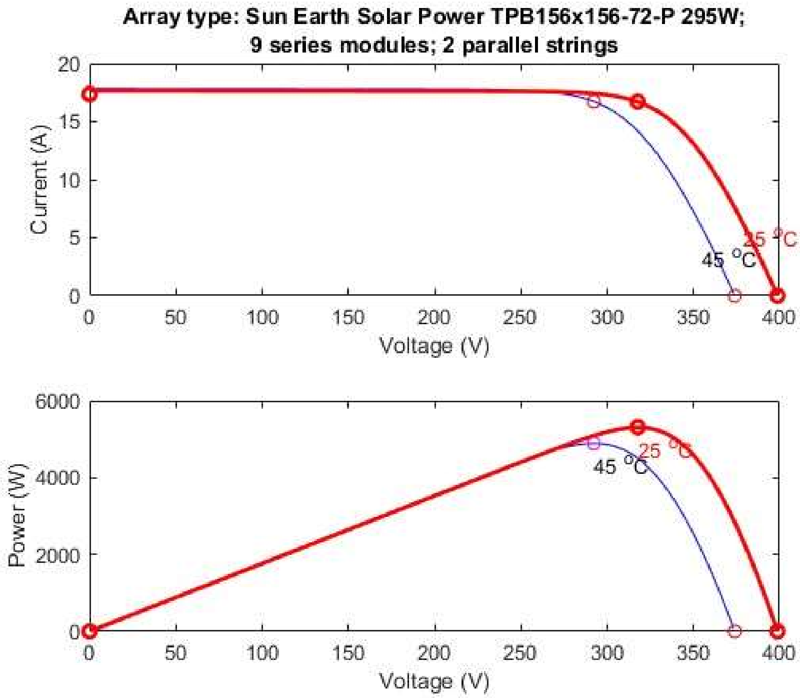
APPENDICES

Appendix A: The simulation model in Simulink with Hybrid mode (PV-WT) with BESS for residential load

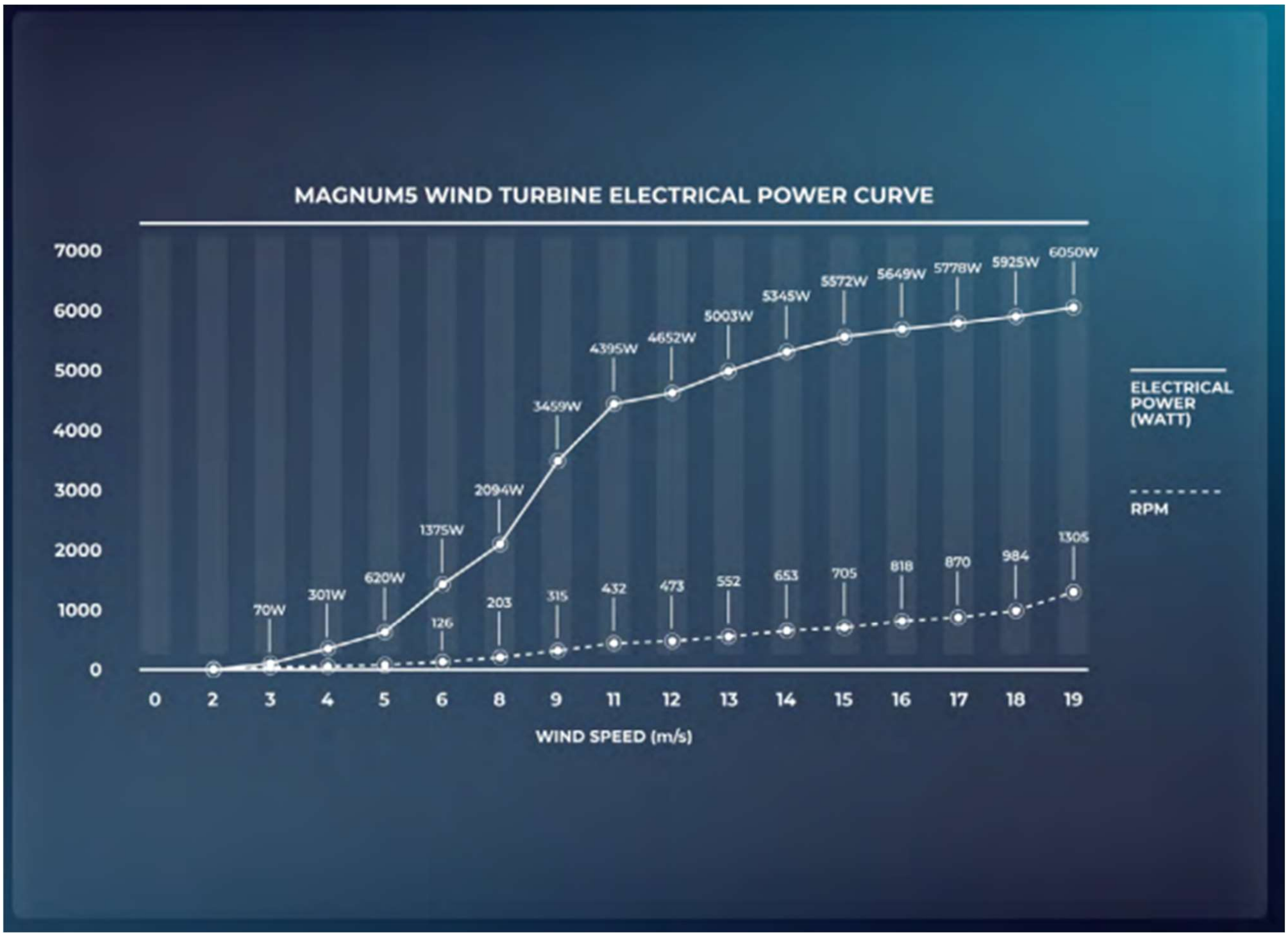


Appendix B: The specification of material with power curve

Solar panel with power curve and current curve



Mirco Wind Turbines: Tesup Magnum 5: [42]



Growatt Battery Kit ARK 10.24kWh: with basic datasheet [43]

Basic specifications of Growatt battery ARK 2.5H-A

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

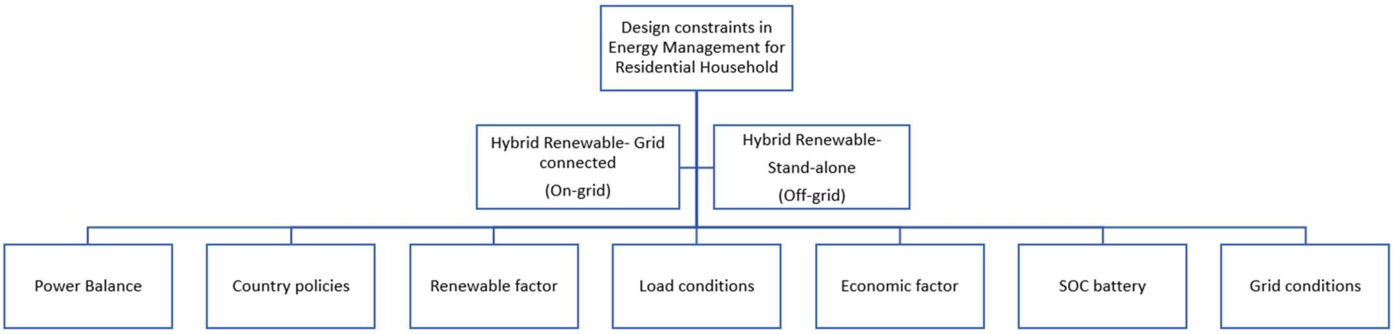
Appendix C: The detailed hours of Peak, Off-Peak and Shoulder

Time Of Use tariff (RTOU/RELE)

RTOU Tariff: Peak = 6am-10am and 3pm-1am, Shoulder = 1am-6am and Off-Peak = 10am-3pm

RELE (Electrify) Tariff: Peak = 5pm-9pm, Off-Peak = 10am-3pm, Shoulder = all other times

Appendix D: The design constraint of this project.



Appendix E: The summary main components for this system.

PV with solar panel spec.	
Number of Strings	2
Number of PV per series	9
Maximum power (W)	295.108
Working efficiency (^{0}C)	25-45
Rated power output (kW)	5.311
Area per solar panels (m^2)	1.72211
Efficiency (%)	0.2
Price in market ($/kWh)	1008.72 $
WT with micro wind turbine spec.	
Number of Turbine	1
Maximum power (kW)	5
Start of Charging to Maximum of Charging – Wind speed (m/s)	3-50
Diameter (m)	2.35
Weight (kg)	23
Price in market ($/kWh)	646 $
BESS with spec.	
Number of Battery	1
Number of Module	4
Energy Capacitor / Usable Capacity (kWh)	10.24 / 9.21
State of Charge (SOC%)	20-88
Price in market ($/kWh)	1034.08 $

Appendix F: The summary for the power flow of each scenario in whole year.