Final Year Research Project

A HYBRID SOLAR PV POWER SYSTEM WITH ISLANDED OPERATION CAPABILITY FOR CRITICAL LOADS

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A Hybrid Solar PV Power System with islanded operation capability for Critical Loads

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ABSTRACT

Design, simulation, and optimization of a Hybrid Solar PV system with the capability of achieving islanded operation mode was investigated in this study. The main objective of the project was to propose a Hybrid Solar PV system to a commercial load that could be utilized as a backup power system in the event of a power outage, as an alternative to fossil fuel-fired backup power sources. This study focuses on proposing a Hybrid Solar PV system for the University Hospital of Kotelawala Defence University, to meet the demand during a power outage with the integration of Solar PV generation to reduce expenses on the conventional usage of fossil fuel as an auxiliary energy source and reduce carbon footprint by implication. The architecture of the power system was designed to incorporate a Battery Energy Storage System (BESS) with a rooftop Solar Plant to an already existing diesel generator (DG) that can operate in both off-grid and grid-connected modes. The study investigates the most feasible and economical methods to supply the load during an outage. An analysis of energy economics utilizing Levelized Cost of Energy (LCOE) concludes that the Hybrid Solar PV system with a Li-ion BESS is more viable than using a DG to meet the load during islanded operation. The capability to perform peak shaving on normal days, export excess solar generation, and minimalized fuel costs impart high monetary benefits over the expected lifetime of the microgrid. Simulation using MATLAB Simulink and a techno-economic analysis using the HOMER Pro software was performed to investigate the performance and reliability of the design and to conclude upon characteristics of the optimum configuration of the proposed microgrid.

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We would like to express our heartiest gratitude and thanks to the supervisors of this study.

To Senior Professor J.P Karunadasa for his continuous support, invaluable time, advice, and immense knowledge and encouragement to conclude this study successfully.

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Finally, we convey our deepest gratitude towards our families and colleagues for their support and motivation provided till the end of the research.

DEDICATION

This thesis is gratefully dedicated to our supervisors Senior Professor J.P Karunadasa and Senior Professor Sisil Kumarawadu for their immense support and guidance that sustained throughout the study.

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LIST OF ABBREVIATIONS

LCOE	=	Levelized Cost of Electricity
BESS	=	Battery Energy Storage System
CEB	=	Ceylon Electricity Board
GDP	=	Gross Domestic Product
UPS	=	Uninterrupted Power Supply
DG	=	Diesel Generators
GHG	=	Greenhouse Gases
UHKDU	=	University Hospital of Kotelawala Defence University
DC	=	Direct Current
AC	=	Alternating Current
MPPT	=	Maximum Power Point Tracking
PV	=	Photovoltaic
ROI	=	Return On Investment
GHI	=	Global Horizontal Irradiance
MPP	=	Maximum Power Point
DOD	=	Depth Of Discharge
SOC	=	State Of Charge
EOL	=	End Of Life
CBI	=	Cost-Based Incentives
NPV	=	Net Present Value
IRR	=	Internal Rate of Return
CPI	=	Consumer Price Index
PWM	=	Pulse Width Modulation
COE	=	Cost of Energy

1 INTRODUCTION

1.1 Background

1.1.1 Energy Sector in Sri Lanka

The Ceylon Electricity Board plays a major role in the generation, transmission, and distribution of electricity in Sri Lanka. There are hydro,

coal, and thermal power stations in Sri Lanka which provided 2968MW to the national grid in the year 2020 [1] . There are other diesel power plants in the islands of the Jaffna peninsula.

Several other private power producers who are bound by agreements with the CEB, contribute to the energy portfolio of the country. Along with the development of the country and the increment in the demand for electricity number of Private power, suppliers have increased.

In the past, the field of electricity generation was dominated by hydropower plants. As a result, by 1996, the development of feasible hydro plants reached its saturation and thermal power plants were introduced to the country. Current thermal power plants contribute to 50 percent of the total generation of electricity.

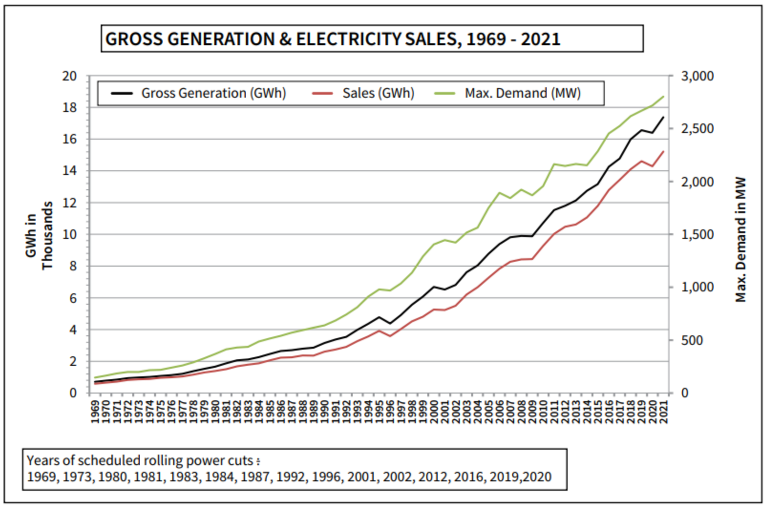

Figure 1.1: Gross Generation & Electricity Sales (1969-2021) [Source [2]]

1.1.1.1 Energy Demand

As the transmission and distribution sectors improved over the past years Sri Lanka was able to obtain complete electrification by providing electricity for all the citizens all over the island.

The peak demand has been increasing at a rate of 3.4 percent annually in the past years and it is expected to continue in the future. The demand profile of the island can be categorized into three sections Day peak, Night peak, and off-peak. At night peak, between (6.30-10.30), has the highest energy demand in the country. It is expected that the daytime demand will be prominent in the future. The installed capacity has two types of generation [2]. They are,

i. Dispatchable Generation

ii. Non-dispatchable Generation

Dispatchable generation is a source of electricity that could be programmed to supply deficit power on demand changes easily. In Sri Lanka, Hydro and thermal plants are maintained to operate as dispatchable power suppliers. It is very crucial to maintain adequate capacities of generation to supply sudden changes in demand and shortfalls of hydropower generation that occur during dry seasons.

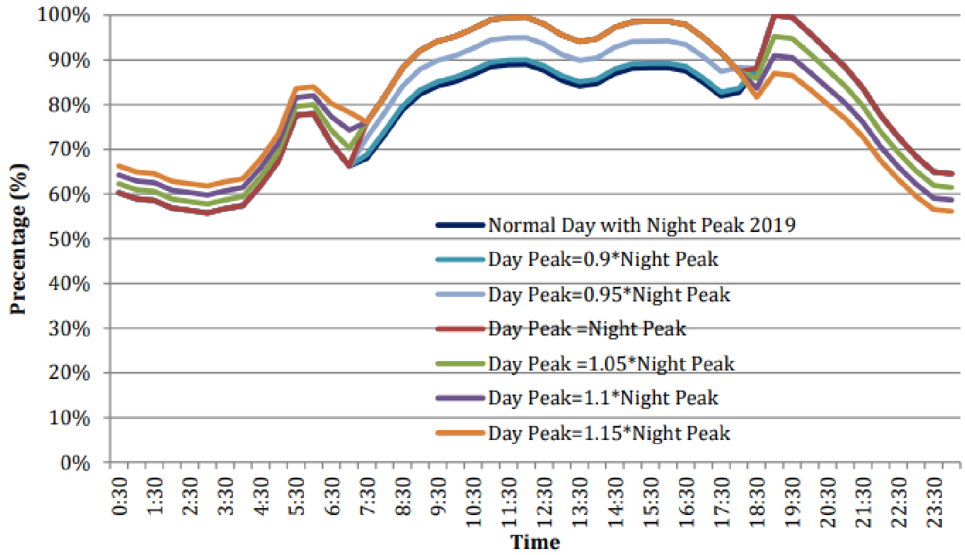

Figure 1.2: Load Profile Shape Forecast [Source [2]]

The demand sector or the electricity consumers have been cauterized as mentioned below by the CEB and unique tariff structures have been developed for each category following their level of consumption [3].

i. Commercial Sector (General Purpose, Hotel, and Government)

ii. Industrial Sector

iii. Domestic Sector

iv. Religious and Charitable Institutions

The combined consumption of the Commercial and industrial sectors is higher than the consumption of the domestic sector. This poses a favorable outlook on the economy and projects the growth of the Gross domestic product (GDP) of the country.

Yet because of the pandemic, the electricity consumption of commercial and industrial sectors reduced compared to domestic consumption due to lockdowns imposed in the country by the government.

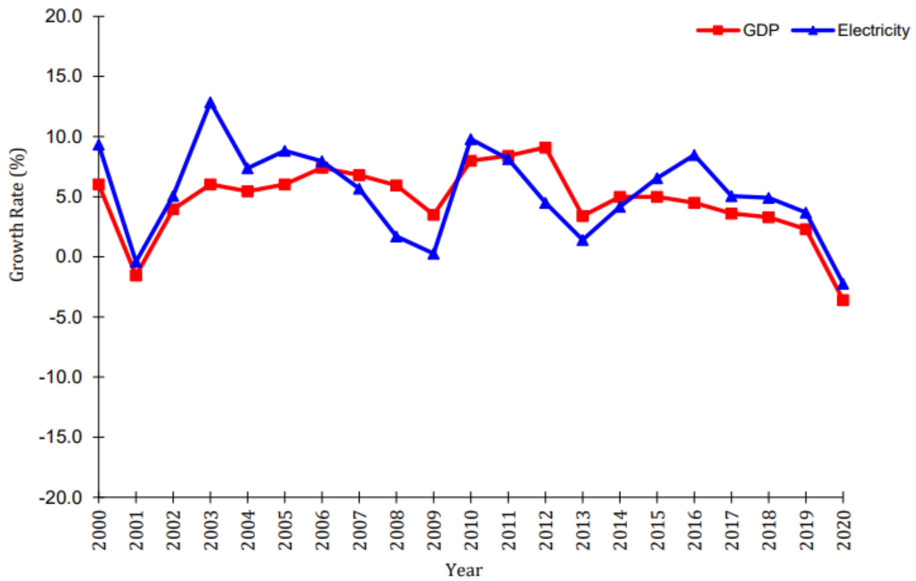

Figure 1.3: Growth rates of GDP and Electricity Sales [Source [2]]

1.1.1.2 Energy Supply

Until the mid-nineties, electricity generation was done by hydropower. With the growth of electricity demand and limitations of hydropower, the generation of electricity through thermal power was introduced. Due to hydrological variations and delayed implementations of other major power projects, oil and coal-based generation was added to the energy mix in Sri Lanka.

Depletion of fossil fuels resulted due to primary extraction and heavy consumption of fossil fuel resources. Thus, availability for the future has been limited. The rate of production of these fuels is slower than the rate of consumption by humans. Fossil fuel reserves are scarce. It has been predicted that the coal reserves will be over in another 150 years and oil & gas reserves will run out approximately in 50 years. Fossil fuels have inflicted risks on the environment [4]. Climate changes, pollution of the environment, and global warming have resulted due to extreme consumption over the past 200 years.

Sri Lanka imports fossil fuels due to the abundance of reserves in the country. This results in high import expenses and a negative impact on the country. The Lakvijaya Power plant is a coal-based plant with an installed capacity of 900MW. It contributes to almost 45% of the generation of the country. Bituminous coal is imported from countries such as South Africa. The Kelanithissa Power plant is a combined cycle power plant that uses diesel fuel as the primary source of fuel. Implementation of strategies to reduce importing fossil fuels will provide significant savings to the economy. Thus, the usage of renewable energy was included in the energy portfolio. By the year 2050, the Ceylon Electricity Board aims to generate power by solely using renewable energy sources. It will save expenses of 18-19 billion US dollars. Sri Lanka was able to achieve 37% of coal-based generation and 37% of generation from renewable energy in the year 2020 [5]. Currently, the types of fuel used to generate electricity in the country are shown in the figure1.4.

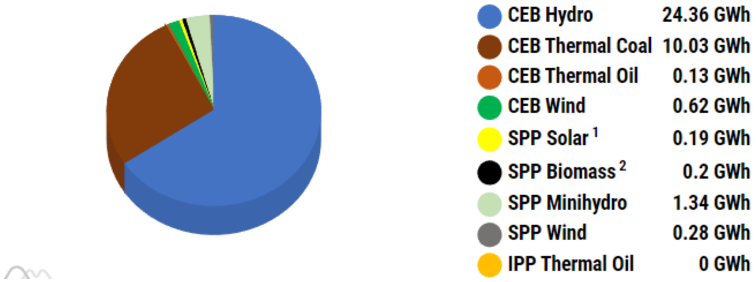

Figure 1.4: Current fuel consumption portfolio [Source [3]]

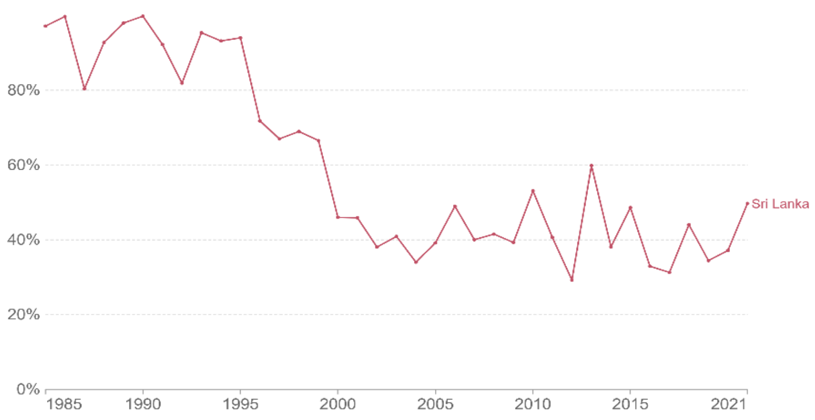

Figure 1.5: Share of Electricity Production from renewable energy sources [Source [6]]

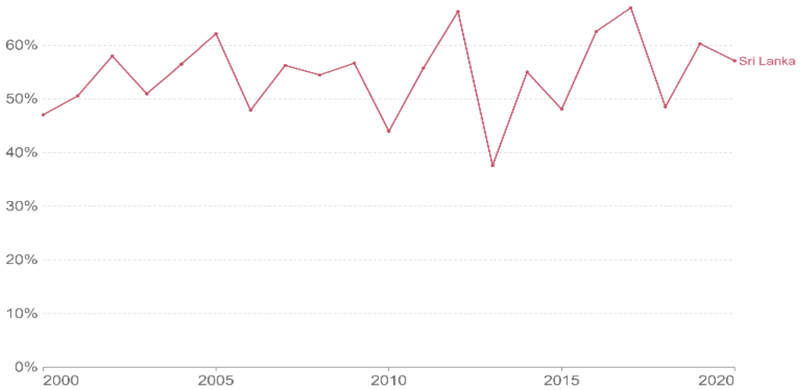

Figure 1.6: Share of Electricity Production from Fossil Fuels
[Source [6]]

The evolution of the usage of fossil fuels and Renewable energy is depicted figure1.5 and figure 1.6 [6].

1.1.1.3 Emissions of the energy mix

The CO_2 emission of Sri Lanka in 2020 was 0.23kg/kWh. The absolute emission levels as well as the per capita emission levels of Sri Lanka remain low compared to the overall global average and when compared to many regional countries, countries having similar economies [2]

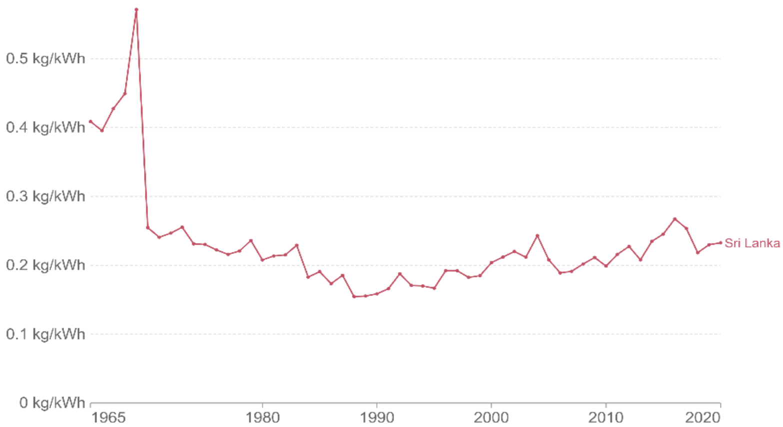

Figure 1.7: Carbon Intensity of energy production [Source [6]]

1.1.2 Renewable Energy

Fossil Fuel resources are scarce in the world and Sir Lanka lacks indigenous fossil fuel reserves. The dependence on these fuels will impose problems to supply to growing demand in the future. Additionally, due to the limited availability of these fuels, Sri Lanka must bear the significant expenses of importing them to the country. To secure the availability of electricity for the future the focus of electricity generation has shifted towards indigenous, renewable energy sources.

As a developing country, the growth of demand will increase in the future. Thus, it is imperative to develop and adopt methods to use renewable energy resources to meet the growing demand and allow significant savings on fuel expenses will have an immense impact on the economy and development o of the country. Additionally, it will enhance the renewable energy penetration and carbon footprint of the country and direct the country toward sustainability. The vulnerability to climate changes and intermittency of renewable energy sources challenges Sri Lanka in establishing clean energy generation. Thus, the government has introduced national policies & strategies to overcome the possible impacts and enhance the penetration of renewable energy sources.

Currently, the government has integrated Renewable energy such as Wind and Solar power along with existing Fossil fuel and hydro generation as a strategy. By 2014 the country was able to generate 10 percent of its electricity using renewable energy sources. Subsequently in the following years usage of fossil fuels reduces and the usage of Wind, Solar and large Hydro increased. In the 22nd UNFCCC Conference, under the Climate Vulnerable Forum, Sri Lanka pledged to generate electricity only by using renewable energy by the year 2050 [7].

In 2020, [1] states that renewable energy capacity has increased up to 49% of total installed capacity, which is a 3.2% increment compared to the previous year. To achieve complete renewable energy generation in the country development of peak demand management schemes is required. As of now, Sri Lanka uses Hydro Plants to balance the load fluctuations. However, the usage of energy sources such as solar and wind, which are intermittent, poses significant difficulties in peak demand management. Due to its availability Cost-effectiveness and efficiency, Solar PV power can be used to manage long-term energy crises.

According to the peak demand forecast by the year 2050 in figure 1.8, the peak demand will reach 12000MW. To achieve the generation of electricity using 100 percent of renewable energy, sufficient strategies and contingencies have to be implemented to avoid the unfavorable impacts caused by renewable energy sources.

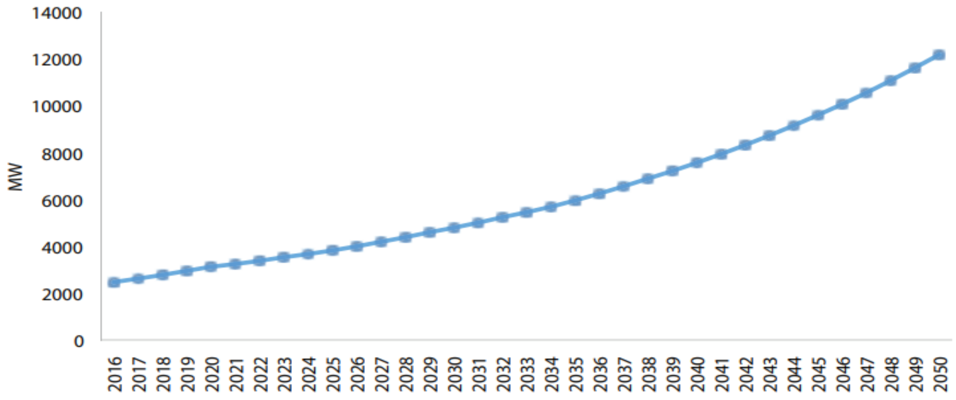

Figure 1.8: Peak demand Trajectory in Sri Lanka [Source [7]]

The Ceylon Electricity Board has devised a schedule to achieve 100 percent of renewable energy generation by the year 2050. Thus by 2030, the storage capacity of pump storage should be increased to meet the peak demand deficiency of 900MW as depicted in figure 1.9. It is also expected to enhance the usage of battery storage as the cost of batteries will reduce.

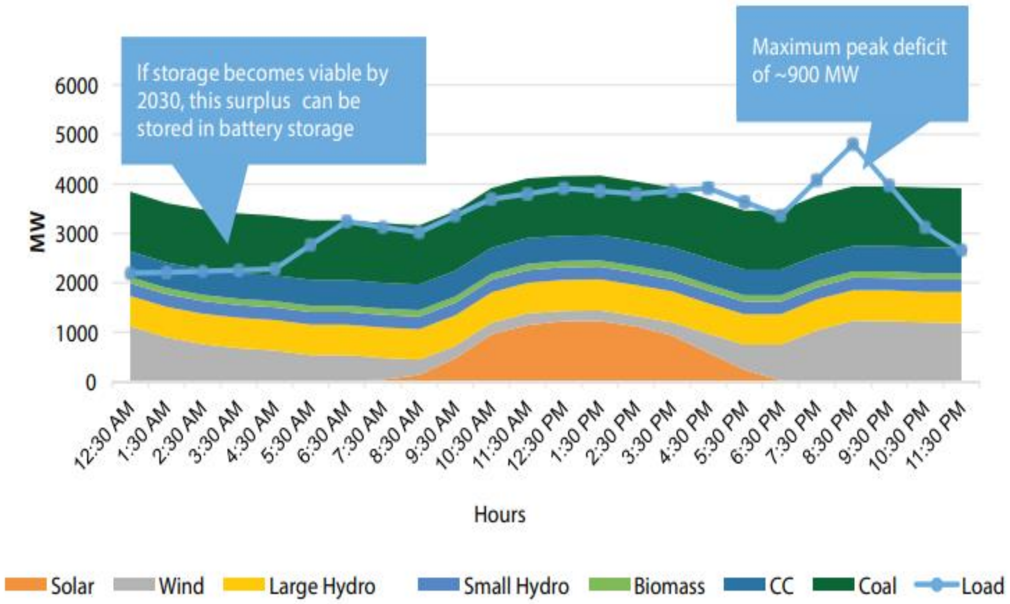

Figure 1.9: Daily Demand-Supply Scenario in the year 2030 [Source [7]]

The usage of Solar power will be increased to supply the deficit of expected retirement of coal bases and combine cycle generation in the year 2040 as depicted in figure 1.10. The night peak will be met using battery storage and the capacity will rise to 5000MWh.

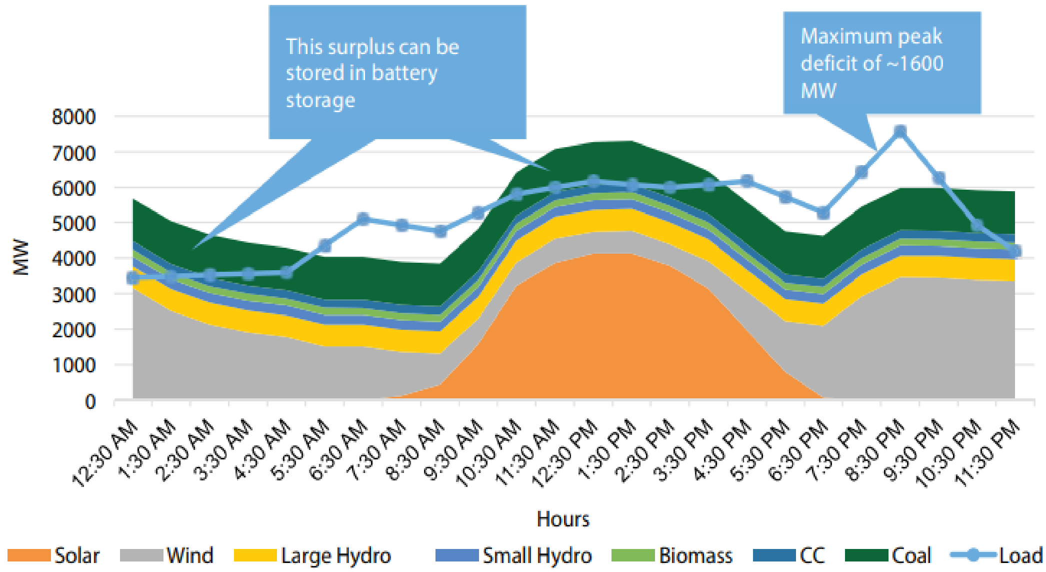

Figure 1.10: Daily Demand-Supply Scenario in the year 2040 [Source [7]]

By the year 2050, the complete usage of renewable energy to meet the demand will be accomplished as depicted in figure 1.11. The generated Solar PV power will be used solely to meet the demand during the day and the demand at nighttime will be obtained using storage technology

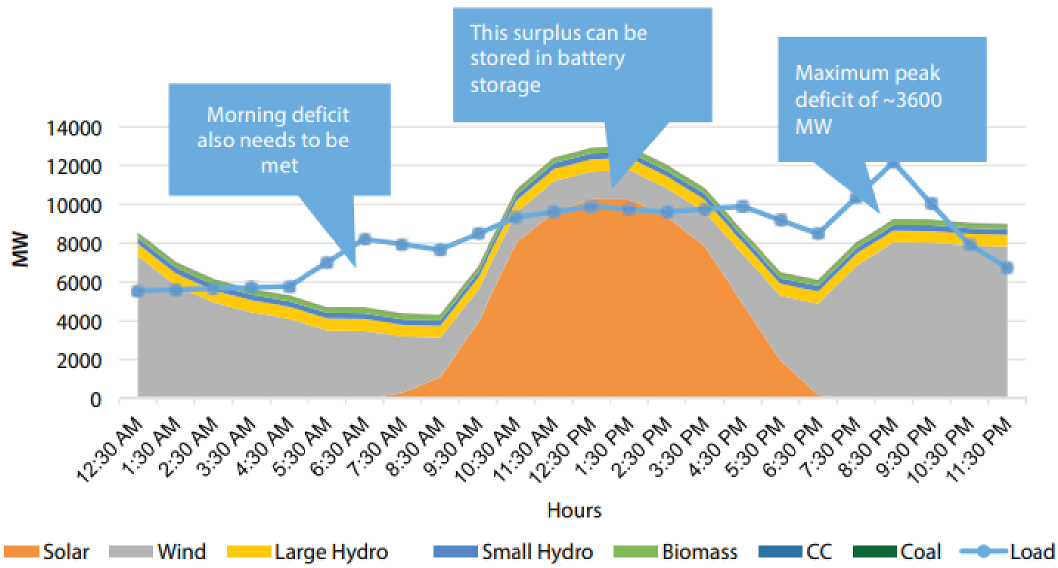

Figure 1.11:Daily Demand-Supply scenario in the year 2050 [Source [7]]

1.1.3 Hybrid Solar PV system

Generally, a combination of two-generation energy sources is usually referred to as a Hybrid System. Yet grid-tied systems powered by Solar PV generation and with battery storage are also called hybrid power systems. Such hybrid Solar PV systems can connect to the grid and reach islanded operation with the use of battery storage

Listed below are some of the advantages of hybrid systems.

- Reduces inconveniences caused by power outages
- Reduces economic losses
- Provides the capability to store PV energy during off-peak hours
- Allows to use the stored energy to engage in peak shaving
- Reduce power consumption from the grid.

Hybrid systems consist of several drawbacks. Some of these drawbacks can be listed below as follows,

- The higher installation cost of the system.
- The lifetime of the battery may be less than the payback period
- The number of loads that can be connected to the system may be limited

1.1.4 Power outages and existing backup power supply systems

Power outages that occur due to interruption of power in certain areas or blackouts have negative impacts on critical loads. In the year 2022, Sri Lanka was under wine daily power outages due to shortcomings of crude oil. To mitigate the risks of power outages and economic losses onsite backup power systems have been developed. The backup power systems can be interconnected with the grid or off-grid. These backup systems are designed according to their application

In Sri Lanka Stand by generators are used as backup power systems. The primary fuel of such generators is Natural gas, diesel, or propane. Lection of the type of generator should be done by considering the following factors [8].

1) Availability of fuel
2) Installation and running costs
3) Startup time of the generator
4) Environmental impacts

5) Type of application
6) Installation site
7) Generator ratings

Uninterrupted Power supply systems are also used in many instances. Even though generators supply power for a long period, due to the time taken to start up the generator and to supply the load after a power interruption, they may cause negative impacts on loads [9]. Thus, UPS systems are used as they can provide an uninterrupted power supply.

1.2 The Problem Statement

The occurrence of power outages could be due to unexpected disturbances in the grid or demand management (Load Shedding) done by the utility to maintain a stable power system in the country when there are only limited resources to produce electricity. Power interruptions cause significant negative impacts on critical loads which require a continuous supply of electricity. Therefore, it is vital to install a system that could provide continuity during the aforementioned circumstances.

Subsequently, backup power systems have been installed in residential, commercial, and industrial sectors of Sri Lanka, and due to ease of access and abundant availability of fuel in the market, most backup systems are diesel generators (DGs). The usage of diesel generators causes adverse effects on the environment such as global warming because of the emission of harmful greenhouse gases (GHG) into the environment.

Due to the current economic crisis (fuel price hike) in the country, bearing the operation and maintenance cost of DGs has been a challenging task for organizations having DGs as backup power resources despite their convenience. Almost every generator dissipates energy utilizing large noises due to their mechanical constraints which directly cause sound pollution. Thus, considering all the facts above, it is favorable to design backup power systems that not only have a less negative impact on the environment amidst the current transformation to contribute towards the efforts taken on creating a carbon-neutral world but also have a power system (microgrid) within an organization which includes renewable penetration for a profitable future. Even though the installation of rooftop Solar PV systems is a rising trend in Sri Lanka, the majority of the systems are grid-tie systems, whereas off-grid systems have been an emerging trend more recently. Therefore, we have found that a Hybrid Solar PV system with islanded operation is inclusive of both grid-tie and off-grid systems which provides many benefits to a commercial-scale organization.

1.3 Objectives of the Research

The overall aim of this study is to design, model, simulate, and control a Hybrid Solar PV Power System with islanded operation capability for identified critical loads, along with performing useful energy economic calculations. As a result, it is expected that critical loads will receive uninterrupted electricity regardless of power outages. Additionally, this system will reduce the carbon footprint which occurs due to the usage of fossil fuel-fired generators. The proposed system will optimize the usage of various sources of energy.

This study will be done considering the electricity demand of the UHKDU to eliminate the drawbacks of the current backup power system. The main goals of this research can be listed as follows.

- To decide the hybrid solar PV power system for a given critical load for several autonomous hours.

- Modelling and simulation of the islanded operation of a Hybrid Solar PV system in case of a grid power outage

- Compare and contrast lithium-ion battery storage against diesel generators as backup power sources.

- Perform energy economic calculations to recognize the potential benefits of the proposed system.

1.4 Thesis Structure

Chapter one of the thesis portrays the fields that will be explored in the rest of the study to provide an introduction. Chapter two focuses on an in-depth study of literature that discovers and identifies the existing studies of the field of renewable energy and Micro girds. The methodology of the study is elaborated in chapter three. The designed Hybrid Solar PV system with the capability of islanded operation is analyzed and discussed in chapter four. This final chapter concluded the performance of the study and its results.

2 LITERATURE REVIEW

2.1 Microgrid

A microgrid is an independent power system that uses various sources of energy along with energy storage systems and power control units to supply a given demand. The concept of microgrids was introduced to avoid the failures of the power grid and enhance the use of renewable energy sources.

Many studies have been done using various combinations of energy sources to supply power to many types of loads varying from domestic to industrial. The paper [10] discusses modeled microgrids which used Solar PV, Wind, and Diesel generators as Sources of power. A combination of Solar PV, wind, and battery to support the intermittent nature of the power supply was researched in a selected site in turkey [11]. A case study to develop a feasible and economical system was done in Pakistan to supply domestic loads using Wind turbines, Diesel generators, and batteries [12].

Microgrids can be divided into three types according to the types of connection; They are

1) Grid-tied systems
2) Standalone system
3) Hybrid Systems

In Grid-tied systems, the power supply relies on the grid. Standalone systems have the capability to supply power independently of the grid. This is also called an islanded operation. Hybrid systems can switch from islanded mode to grid-tied mode. The performance can be smoothed in hybrid systems while minimizing the disturbances that arise due to the intermittent nature of Renewable Energy.

The concept of microgrids and their sustainability has been studied over the past years due to the unique benefits we receive compared to the existing power grid. Microgrids create an opportunity to use zero-emission energy sources and thus reduce green gas emissions. Microgrids can balance the generation of power from renewable energy sources such as Solar, Wind, and Biogas and conventional energy sources such as diesel.

In the grid generation of the load is done to not only supply the loads but also to compensate for the losses that occur during transmission. Microgrids are established close to the clients which results in low loss of power in transmission lines. Microgrids can be designed to supply to remote areas where the supply from the national grid is ineffective

Microgrids can enhance the management of local power supply and demand by strategically utilizing existing renewable energy sources in certain areas. Such microgrids will maintain the electricity demand and reduce grid congestion and thus improving the reliability and efficiency of the grid. Additionally, it will also reduce costs invested in the infrastructure of the national grid for additional power generation. Micro Grids can enhance the resilience of the power supply in unavoidable events such as power outages.

Several studies have been conducted to develop suitable control strategies to optimize the performance of microgrids. Thus, many control mechanisms are developed by considering various components and expected features of the microgrids. In the paper [13] different control modes were further studied for DC microgrids.

2.2 Renewable Energy

Renewable energy is energy that is obtained from renewable resources on earth. It consists of sources such as sunlight, wind, water, and geothermal heat. Currently, fossil fuels such as coal, oil, and natural gas are used as sources of energy. These are called non-renewable energy sources due to their limited availability on earth. The rate of usage of fossil fuels is faster than its rate of production. Additionally, products that are produced due to the usage of fossil fuels are harmful to the environment. Over the next 20 years, the energy gap is expected to increase by a percentage of 33 & renewable energy can be used to bridge this energy gap [14].

2.3 Solar Photovoltaic Energy

The usage of Solar PV power has increased rapidly over the past years as it is an economical and feasible source of energy. Many studies have been conducted to enhance the performance and integration of PV systems.

The photovoltaic effect is a process that generates voltage or current in a photovoltaic cell during its exposure to sunlight. Solar cells consist of two types of semiconductors such as N-type and p-type. These layers are combined to create p-n junctions to create an electric field in the junction as electrons move from the positive p-side to holes on the negative n-side. Light consists of photons and when the light of a suitable wavelength is incident on the cell the energy from the photon is transferred to an electron of the semiconductor. This causes the electron to move to a higher energy state in the conduction band. In this excited state, the electron is free to move through the material and its motion created an electric current in the cell. Photovoltaic module technologies can be categorized into 3 types

1. Crystalline silicon cells
2. Thin film technologies
3. Emerging photovoltaics

Even though the usage of PV systems is economical and feasible there is a major drawback that occurs due to their intermittent nature. The output of the Solar PV panels depends on the solar irradiance and the ambient temperature. The cloud cover and the position of the sun during the day affect the intermittency of the output solar power. Thus, loads cannot be directly connected to the Solar PV panels.

Thus, in recent years, several studies have been done to propose algorithms to track the Voltage (*Vmpp*) or Current (*Impp*) at which the PV array will operate to supply maximum power output under a given temperature and irradiance. These algorithms vary in aspects such as range of effectiveness, complexity, convergence speed, cost, implementation hardware & sensors required [15]. Most of the techniques in studies are sensitive to changes in both irradiance and temperate while some are specifically designed to temperature be approximately constant. Some of the MPPT techniques studied in literature are

1. Perturbation and observation technique
2. The incremental conductance technique
3. Ripple correlation technique
4. Short circuit current technique
5. Open circuit voltage technique

Inverters have been developed to perform as an interface between Solar PV and the load. These are also called power conditioning units in the study [16] The topology of the PCU is determined based on the application of the PV system.

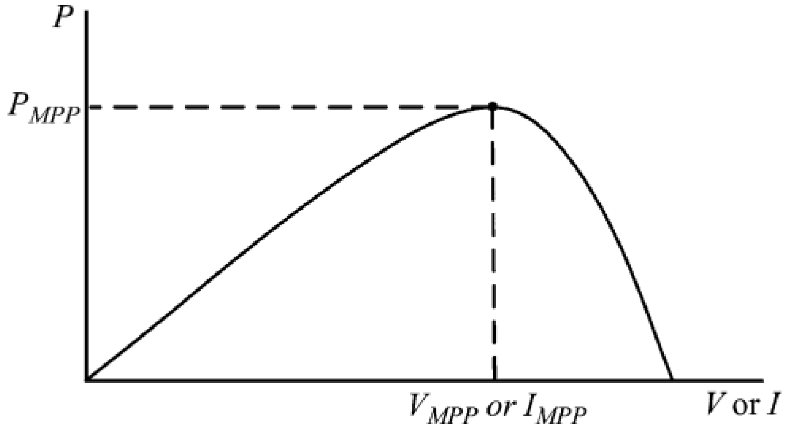

Figure 2.1: Characteristic PV array power curve. [Source [17]]

2.4 Hybrid Solar PV Systems

Intensive research has been done in the field of microgrids with Solar PV generation. These studies have been conducted to develop feasible systems using computer modeling & control strategies to suit numerous applications around the world. There are two types of PV systems. They are Grid connected and standalone PV systems. Grid-connected systems operate with the national grid. On sunny days, the generation of solar power is high and the demand will be met and a surplus will remain. This power can be exported to the national grid, under an agreement with the electricity supplier in a country. In Sri Lanka, the Ceylon electricity board follows 3 tariff schemes Net metering, Net Accounting, and Net Plus. Yet research has been done involving battery storage or other types of energy generators to enhance the reliability of the system, especially in an event of a power outage. In an event of power outage grid ties Solar PV systems will not be able to supply the required demand. Thus, research has been done involving battery storage or other types of energy generators to enhance the reliability of these systems.

The standalone PV systems are developed to solely supply power by its generation to selected loads. During the islanded mode when the load is greater than the generation, load shedding is performed. However critical loads should be supplied with a continuous supply. The study in the paper [18] discusses the use of a pump storage station to maintain the critical loads in such scenarios. In this study these pumps perform in the motor mode when the system is connected to the grid. There are three types of stand-alone PV systems according to the study in [19].

They are PV-powered water pumping systems, Remote residential PV systems, and PV-powered lighting systems. A proposed PV-diesel hybrid power system with battery storage to meet the residential loads in Dhaka city was designed to reduce the usage of the available Diesel generators [20] Even though studies from [21]- [22] show significant advantages of installing a standalone, they have drawbacks such as high installation cost and limited energy storage capacity. Thus, the application of standalone PV systems is limited to minimal demand requirements. Controlled islanded can improve the reliability of Grid-tied and Standalone microgrids. Additionally in a system with various energy generators. Several studies have been conducted on hybrid Solar PV power systems which can switch from Grid tied to the islanded operation mode.

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2.5 Inverter

The inverter plays a key role in microgrids. It is used to convert DC power to AC power & vice versa. Inverters can be categorized into three types based on their mode of control.

1. Micro inverter: Micro Inverters are connected to each PV panel or module.
2. String inverter: String Inverters are connected to a string of PV modules wired in series
3. Central inverter: Central Inverters are connected to an array of PV strings wired in parallel.

The amount of Solar PV systems that can be installed depends on the costs of the components of the systems. Thus, the sizing of components should be done to obtain results with maximum efficiency for the lowest cost. The ratio between the rated power of solar panel arrays to the rated power of the inverter should be maintained at 1 to obtain maximum output from the power system. Inverters are categorized into three types based on their mode of operation.

1. Off-grid solar inverters: Off-grid Solar Inverters perform the voltage source operation during the islanded mode. It produces a voltage waveform of frequency 50 Hz.

2. On-grid solar inverters: These are current source inverters that produce a sinusoidal current waveform. During the grid-tied operation, the voltage of the system is maintained by the grid voltage and thus the utility sever will only observe the current waveform while exporting generated solar power to the grid. Anti-islanding protection is operated to shut down the inverter automatically during maintenance of the power line to ensure the safety of the maintenance team. shuts down the grid-tie inverter automatically during grid power. In Sri Lanka, the grid-tie inverters must satisfy the power quality and safety regulations imposed by the grid utility.

3. Hybrid Inverters: Hybrid inverters can combine Solar PV systems, AC utility, and Battery storage to supply uninterrupted power and seamless switching between two modes of operation of the hybrid Solar PV system. These inverters can supply power to loads directly, export power to the grid, and store the generated Solar power and

grid power in batteries. As soon as the inverter detects the occurrence of islanding it changes to voltage source operation from current source operation. It provides constant current to the grid during current source operation [24]. Several studies have proposed load-shedding algorithms for intended islanding and synchronization algorithms for grid connection. Droop schemes have been introduced for the operation of inverters in a grid-connected and islanded mode in certain studies. These schemas are P-Q strategies to share power supplied to loads. In studies [25] & [26] inverters are operated according to droop schemes in both modes of operation.

Hybrid Inverters are of four types [27]:

- *Hybrid Inverter with no backup Power*

These simple Hybrid inverters work as grid-feed solar inverters and provide the capability to store solar energy in batteries. Yet the inverters cannot perform grid isolation thus they aren't useful for an application with constant power outages.

- *Hybrid Inverter with backup power*

These are advanced inverters that have a backup power capability. Under normal conditions, it can supply power to loads and batteries and export excess solar power to the grid. During a power outage, it can switch to perform independently from the grid and supply power through the batteries.

- *All-in-one battery energy storage systems (BESS)*

These are hybrid inverters incorporated with BESS. There are two types, such as AC coupled and DC coupled. Tesla Powerwall 2 and Sonnen ECO are types of AC-coupled BESS.

- *Advanced AC-coupled systems (off-grid or hybrid)*

These inverters behave as an inverter and batteries perform energy management. They are capable of supplying power similar to off-grid inverters, automatically initiating a backup generator, and exporting & import power from the grid.

2.6 Battery Storage System

Energy storage systems are used to store power generated from the microgrid or power utilized from the grid. With the development of BESS, studies were done to incorporate batteries into microgrids to enhance their performance.

Battery Storage Advantages

- Gives the user more storage capacity solar for a much lower price point
- Allows peak shaving ability which is also known as the usage of solar power at peak evening times.
- Decrease the use of power from the grid
- Gives access to advanced energy management peak shaving)

Battery Storage Disadvantages

- With the increased price of batteries, the cost of battery storage will be high.
- Return on investment (ROI) will be longer.
- Due to the high complexity of the installation process, more space will be required along with a high installation cost.
- The life expectancy of batteries would be from 7 - 15 years.
- The number of appliances that could be used at a particular time may be limited due to backup power. (Type of hybrid inverter and its capabilities will be a deciding cause for this)

These battery storage systems are mainly used for the following occasions in microgrids.

1. Usage of batteries in off-grid systems.

Battery storage is commonly used in many standalone microgrids to store generated energy and supply during periods of low generation. Even though Diesel generators are a viable option, the usage of diesel affects the environment negatively. Thus, many studies have been done to incorporate battery storage into microgrids to reduce the carbon footprint. A Hybrid

Solar PV-Fuel Cell power system was proposed to supply power for a residential community with 150 houses in a study. Their main objective was to develop a power system that meets the required load while maintaining high penetration of renewable energy sources in the energy mix, low cost for energy, and low emissions of greenhouse gases. The proposed system in this paper offered good penetration of renewable energy sources (renewable fraction f_{ren}=40.2%), low cost of energy, low excess power (18%), and produced zero carbon dioxide emissions during the generation of energy [28]. Likewise, studies have proved that usage of battery storage is a better solution compared to the usage of diesel generators.

2. Usage of Batteries for better reliability in grid-tied Systems

Battery storage has been introduced for grid-connected systems to feed power to the loads during a power outage. Thus, batteries are used to enhance the reliability of grid-connected microgrids. Many studies have been conducted to develop suitable control strategies and enhance the performance of such systems. The study in [29] proposes a system with a hybrid PV-battery system to supply the loads during a blackout. This paper studies the benefits of applying economic model predictive control to optimize this system given that the lifetime of battery storage will be shortened if it is not properly operated.

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3. Perform Peak shaving

In Sri Lanka, expensive modes of power generation are used to meet the peak demand. As an economical alternative, batteries can be used to meet the peak demand. These batteries can be charged by the grid or renewable energy generation sources during off-peak times. Many studies have been done to propose control strategies and optimize battery storage systems to perform peak shaving and thereby improve electricity bill savings. A study was done for a residential community in South Africa where a grid-connected Hybrid Solar PV-battery system was proposed. This battery system was designed to supply the demand along with Solar

PV power and supply the load during peak hours if excess energy is available during peak hours [30]. Peak shaving using battery storage is proven to be economical on an industrial scale because the consumer is charged with a time-of-use tariff. (LKR/kWh charge during different time periods of the day). An optimized battery storage system can provide additional energy required to supply the demand during peak hours and when there is no generation done by renewable energy sources.

4. Mitigate intermittency and fluctuations.

As the penetration of renewable energy in the grid enhances, the grid has inherent unfavorable effects due to the intermittency of renewable energy sources. This intermittent nature can be caused due to variable cloud cover, different positions of the Sun during the day, wind speeds, and weather. Thus, the greater the usage of renewable energy sources, the greater the reliance on the grid in weather conditions. This results in fluctuations of powers at generating units. In microgrids with the islanded operation, such variations of power result in changes in the frequency and voltage stability of the system. Installed generators can be used to negate the fast changes in power output. Yet this may result in wear and tear of the governor system of the generator in the long run due to quick variation of power output. Thus, to mitigate these power variations and to quickly supply the deficit, battery energy storage systems are developed. Many studies have been done to explore BESS to mitigate the inherent intermittencies of Solar power on the grid [31]- [32]. Several studies have proposed Hybrid energy Storage systems with Solar PV to mitigate Solar power fluctuations [33]. In the paper [34] the authors propose a super capacity bank with Vanadium Red-Oxide Battery as BESS to smooth the solar output power. The services provided by battery storage systems range from fast frequency support to arbitrage of energy for economic dispatch to ancillary services of renewable energy integration. Compared to other batteries such as Sodium Sulphur batteries, Flow batteries & Lead-based batteries, Lithium-ion batteries have a wide market. It is crucial to conduct a techno-economic analysis to identify the type of battery storage and technology to be used in a given project to establish effective storage methods.

2.7 Generator

Diesel power, renewable energy, and battery storage are the most used methods by microgrids to deliver electricity to remote locations. The important feature of diesel power is that it provides stability and reliability that renewable energy and accumulators fail to provide. Requirement of a backup power source will be needed in almost all systems as there can be situations where a continuous supply of power is required. Hence most microgrids consider an internal combustion engine as a necessary component to provide undisrupted power for a longer time.

As of now most micro gird or back power systems consists of diesel generators from the domestic to industrial scale. When compared to a microgrid that is designed from the initial stage, designing a hybrid solar PV system in a site with backup generators will provide economic benefits. Thus, such factors should be considered while proposing a microgrid.

The usage of generators imposes a major drawback. The source of energy used for generators is diesel and as a result the emission of CO2 increases. Several studies have been conducted to explore solutions to reduce carbon footprint and as a result battery storage systems were introduced to the microgrids.

3 METHODOLOGY

3.1 Identification of a critical load

3.1.1 Introduction to critical loads

The Ceylon Electricity Board has categorized the electricity consumers according to the tariff schemes imposed on them. Yet these consumers can also be categorized according to the level of demand they consume. The consumers that utilize demand less than 42kVA are called Domestic consumers. On the other hand, consumers who utilize demand more than 42kVA are known as Bulk Consumers. The Industrial, Commercial and Religious sectors mostly fall under bulk customers.

Each of these customers acquires critical and non-critical loads. The critical loads are electrical equipment that requires a continuous supply of power throughout their period of operation as their performance is critical. The non-critical loads do not require power continuously and their operation can be halted during a power interruption.

Consequently, backup power systems have been designed to cater to the critical loads of the electricity consumer. Categorization of these critical loads can be done concerning their performance at a certain site and dependency of other equipment on its operation. At the domestic level, equipment such as refrigerators, security systems, certain lights, and fans can be contemplated as critical loads. Loads such as equipment in the control room, motors, ventilation, and air conditioning systems can be considered critical loads in a power plant. Hence it is vital to assess all the essential loads before designing a backup power system.

Overestimation and underestimation of load consumption may result in unfavorable outcomes to the performance and economy of the system. Strategic decisions should be implemented to determine the sufficient loads for the system with expected expansions in the future.

3.1.2 Survey of critical loads

Preceding the selection of the critical load a study was done to identify the most appropriate critical load for the proposed design. The benefits received by the selected site from this proposed design and the availability of required conditions to design the Hybris Solar PV system were taken into consideration.

The demand requirements of the health sector are progressing rapidly. Island wide, the health sector experienced challenges due to the COVID-19 pandemic. Subsequently, the energy requirements were increased which expanded the energy demand and emissions as well.

An unhindered power supply is obligatory for healthcare facilities to operate a vast range of equipment which extends from life monitoring & complex diagnostic machinery to long-hour surgeries that requires a continuous flow of power. Hospitals have invested in Diesel generators as backup power systems to maintain a fail-safe environment. Such dependency on non-renewable energy sources causes adverse effects on the environment and high expenses in maintaining the system.

The usage of clean energy as an alternative to a backup power system that could step up in an event of a power outage may arise many benefits to the health sector and its development. Even though the usage of wind, hydro, and other clean energy farms are not practical, most hospitals have sufficient space for the installation of Solar panels. Adapting Solar PV systems to cater to the load during power outages not only provides fewer expenses but also lays a foundation for the transformation of buildings to green buildings. These power systems provide beneficial economic propositions because their life expectancy expands over 25 years.

3.1.3 University Hospital KDU

After the study of critical loads, the University Hospital KDU was chosen as the site for the proposed Hybrid solar PV system. A thorough Site survey was conducted before the confirmation of the site. Hence, an investigation of the availability of sufficient space, climate, irradiance, and load demand was conducted.

The University Hospital KDU which is situated in Werahara is a leading primary health care provider in Sri Lanka. The Hospital provides many facilities for its patients and aims to further develop into a 704-bed hospital with cutting-edge technology to provide a great service around the clock in the future.

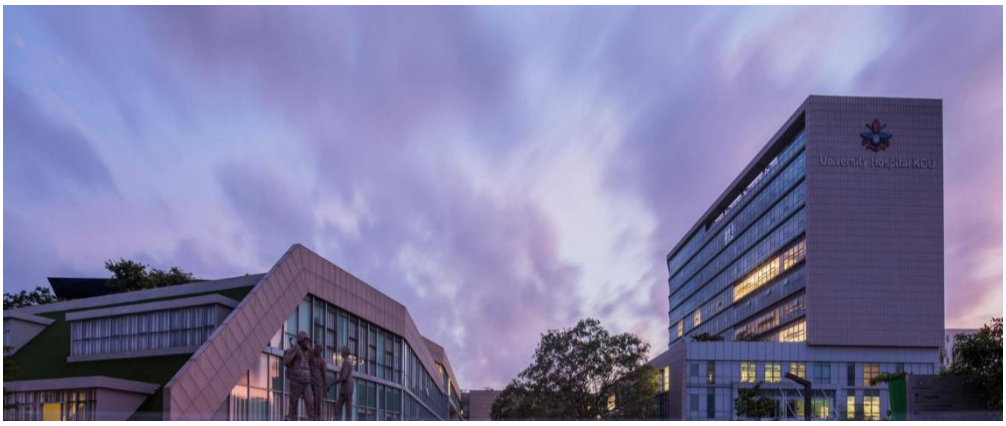


Figure 3.1: University Hospital KDU

3.1.3.1 Analysis of Solar GHI level and Temperature of the site

<u>Analysis of the GHI level of the site</u>

The primary source of energy of the earth is the radiant energy received from the sun. The amount of this energy directed over a square meter of the earth's surface each second is termed Solar Irradiance. It can be categorized as extraterrestrial radiation and global radiation depending on the way that radiation reaches earth. Radiation that occurs beyond the atmosphere of earth is known as extraterrestrial radiation. The portion of the radiation that reaches the surface of the earth horizontally is known as global radiation. Parameters such as air density, weather, latitude, seasons, and time of the day affect the shortwave received on the ground. These can be categorized into two types of radiation as mentioned below,

1) Direct radiation
2) Diffuse Radiation

The portion of radiation which reaches the earth's surface directly is known as direct radiation and the portion reaching the surface having been through scattering factoring such as particulates of air and molecules are known as diffused radiation. Factors that influence the amount of solar radiance received by the surface are as follows.

1. Geographical location

The tilt of the earth results in various distances from the surface to the sun around the earth. Thus, certain geographic locations could have higher radiation from the sun than other locations on the earth

2. Time of the day

The rotation of the earth varies the relative position of the earth throughout the day. The maximum radiation of solar energy can be obtained when the light waves reach the earth at a 900 angle. This angle between the PV array and the sun affects the efficiency of solar power generation.

3. Weather and other environmental conditions

The atmosphere which covers the earth may have varying weather conditions which will affect the incoming rays of sunlight. Cloud coverage could result in low power generation over a significant period. Additionally, factors such as water which has low reflectivity, and cloud which has high reflectivity results in less solar irradiance. In Sri Lanka, the climate is dominated by two major monsoon seasons which affect Solar irradiation. They are as follows,

1) Southwest monsoon season
2) Northeast monsoon season

The climate throughout the year on the island is categorized as follows by the department of meteorology [35].

1) First Inter monsoon season from March to April
2) Southwest monsoon season from May to September
3) Second Inter monsoon season from October to November
4) Northeast monsoon season from December to February

4. Landscape of earth

The nature of the landscape of the site may affect the solar irradiance through the atmospheric condition over the location and other external factors such as shading. A quantitative analysis of shading by trees, chimneys, antennas, buildings, and power lines must be used to determine the maximum amount of energy the arrays could produce [36].

Thus, the variations of solar irradiance over time in a selected location should be adequately analyzed before designing a Solar PV system. The required periodic GHI data, historic or forecasted, could be obtained through various methods for a particular period of time. The forecasted data with a 50% probability of exceedance and historic data were obtained from [37] and [38] and were averaged concerning different periods to proceed with the site survey.

Forecasted data of daily GHI over 12 months of a year was categorized monthly and hourly respectively. The hourly data of a month were then organized according to the days of the respective month. Then and a total sum of the average solar GHI for an average day of a particular month is obtained by the addition of average hourly solar GHI calculated. The Average sum of daily solar GHI for a given month can be calculated by equation 3.1. The calculated data of each month were observed through pictorial representations and it was perceived that quantitative generation of Solar power could be obtained during 08:30hrs – 15:30hrs at the Werahara area.

$$Average\ sum\ of\ daily\ solar\ GHI\ for\ a\ month = \frac{Sum\ of\ average\ hourly\ GHI\ for\ a\ day}{24} \quad (3.1)$$

The plotted graphs of variations of irradiance level on an average day of each month depicted variations that resulted due to seasonal and weather changes in the country. The solar irradiance was comparatively high in the months from January to April, where March had the highest Average Daily GHI of 6.21 kWh/m2/day as shown in figure 3.3. Figure 3.4 and Figure 3.5 depicts the average daily GHI variation in the months of July and December which is comparatively low from the rest of the months.

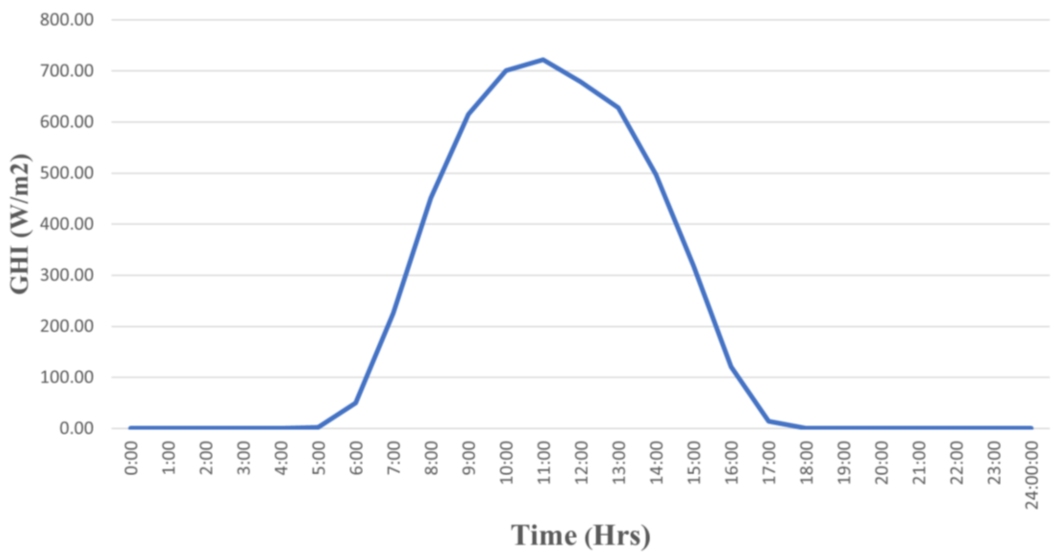


Figure 3.2: Average Sum of daily Solar GHI for the month of January

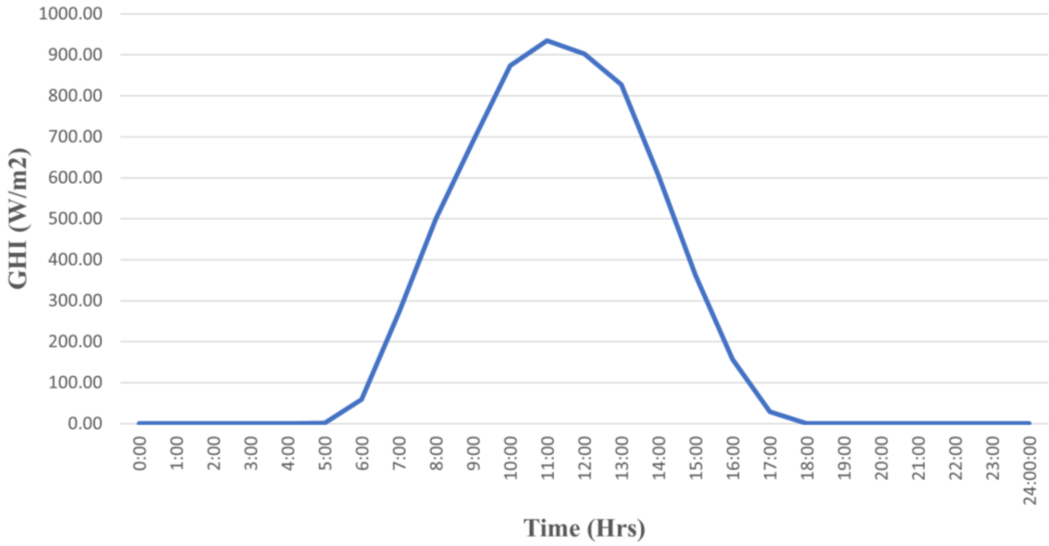


Figure 3.3: Average Sum of daily Solar GHI for the month of March

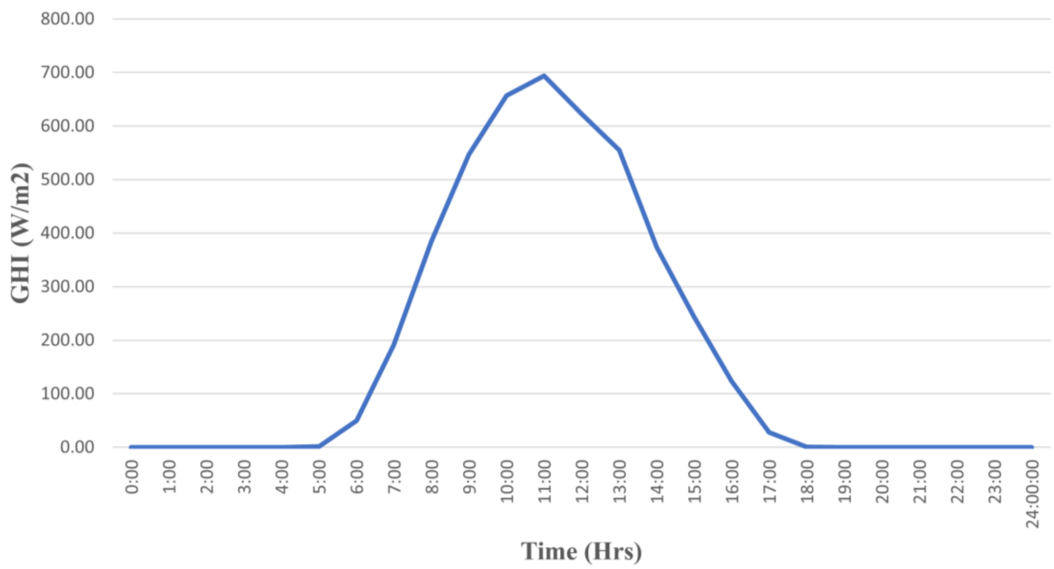


Figure 3.4: Average Sum of daily Solar GHI for the month of July

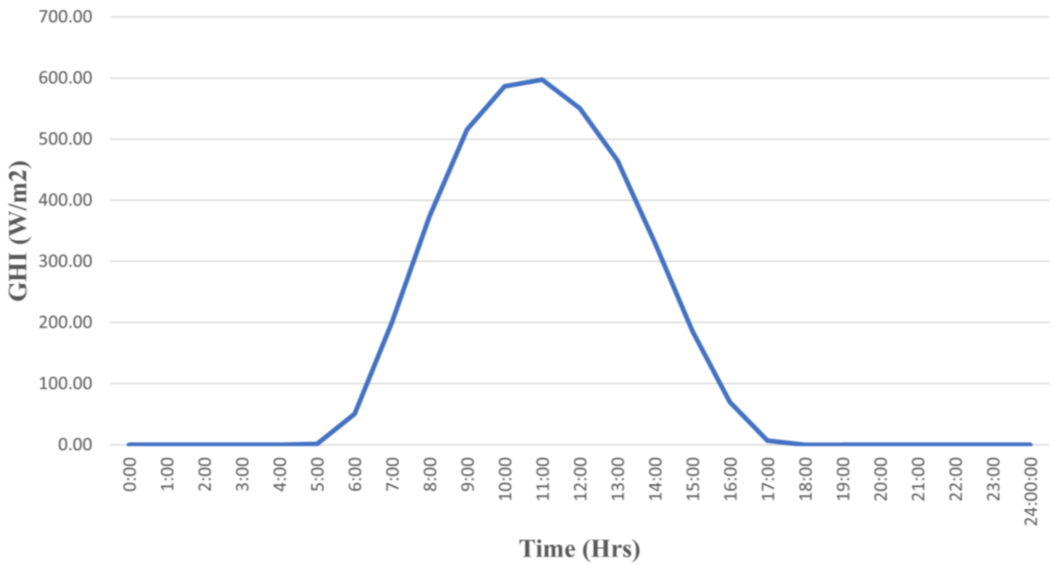


Figure 3.5: Average Sum of daily Solar GHI for the month of December

The average sum of the Solar GHI of an average day for each month was then organized as shown in table 3.1 and an average value was obtained for the sum of GHI received for a given year. The average sum of daily solar GHI for a given year can be calculated from equation 3.2.

$$Average\ sum\ of\ daily\ solar\ GHI\ for\ a\ year = \frac{Sum\ of\ average\ hourly\ GHI\ for\ a\ month}{12} \tag{3.2}$$

Table 3.1: Calculation of the sum of average daily Solar GHI for a given year

Month	**GHI Daily (kWh/m2/day)**
January	5.02
February	5.61
March	6.21
April	5.33
May	4.50
June	4.59
July	4.47
August	4.49
September	4.86
October	4.50
November	4.34
December	3.93

The computation of organized data in table 3.1 provides the following result.

Sum of average daily Solar GHI for a given year at Werahara area	= 4.82 (kWh/m2/day)

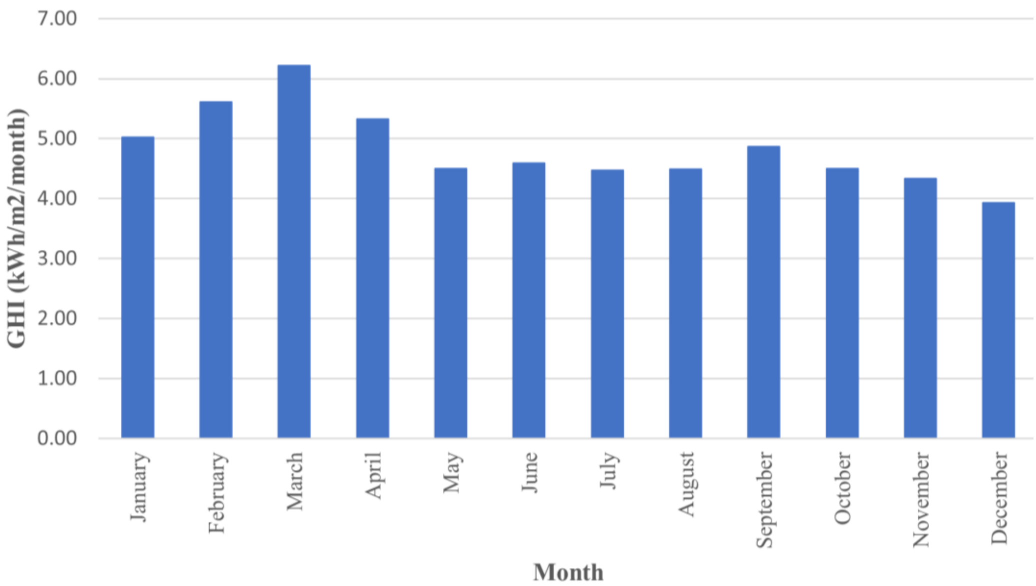


Figure 3.6:Monthly average distribution of GHI

Analysis of Temperature variations of the site

The air temperature differences in regions of Sri Lanka are dependent on the attitude of the region. The average temperature on monthly basis varies as it is influenced by the seasonal variations of sun and rainfall in the country. The data of monthly averaged air temperature of the Werahara area was obtained through the HOMER software from NASA Prediction of Worldwide Energy Resource Database. An annual average of air temperature was computed as 26.88 ℃.

Table 3.2: Monthly average Air Temperature data of Werahara

Month	Daily Temperature (°C)
January	26.22
February	26.84
March	27.73
April	27.89
May	27.8
June	27
July	26.49
August	26.41
September	26.63
October	26.58
November	26.59
December	26.36

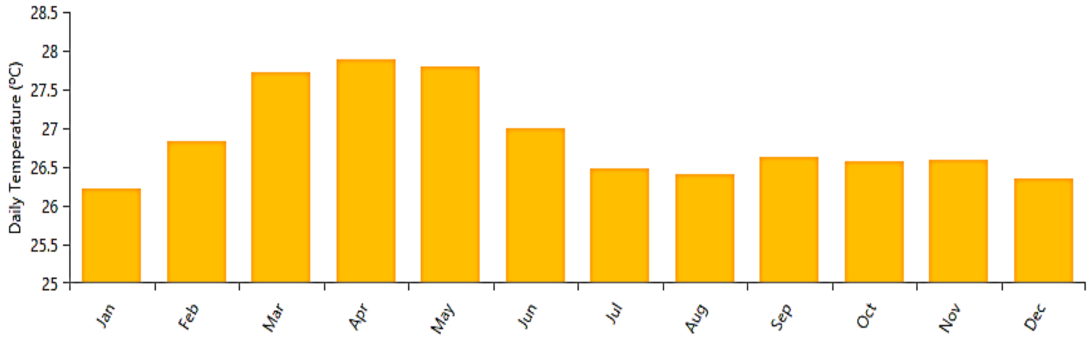


Figure 3.7: Variation of monthly average air temperature in the Werahara area

3.1.3.2 Identification of the maximum Solar PV installation Capacity of the hospital

The capacity of the area suitable for solar installation should accommodate the relevant aspects such as Accessibility, Roof Configuration, Shading, Aesthetics & Roof Materials, and Structure. The area of installation should be, easily accessible for installation, monitoring, and maintenance purposes. The rooftop areas of several buildings were identified to provide the required rooftop space to obtain the maximum possible solar power that could be generated on the site. This installation space was assessed by considering the heights, slopes, additional structures present on the roof, shading factors, and aesthetics of the site.

Table 3.3: Feasible installation capacity of Solar PV system at UHKDU

Building Name	Building Sub Sections	Width (m)	Length (m)	Area of Subsection (m2)	Roof Top Area (m2)
3.1 Building	FAHS	9	23	207	387
	Badminton Court	9	20	180	
3.2 Building		14	15	210	210
3.3 Male Building	3.3 Male Building (1)	-	-	189	351
	3.3 Male Building (2)	-	-	162	
3.3 Female Building	3.3 Female Building (1)	-	-	189	351
	3.3 Female Building (2)	-	-	162	
Hospital Tower Building		14	36	504	504
Hospital Building AHU Roof Top		19	63	1197	1197
Hospital Building Auditorium		42	42	1764	1764
6.1 Building		14	28	392	392
6.2 Male Building		5	48	240	240
6.2 Female Building		5	28	140	140
6.5 Building	6.5 Building 1	10	33	330	660
	6.5 Building 2	10	33	330	
6.10 Building		15	28	420	420
Service Building	Service Building 1	23	23	529	1058
	Service Building 2	23	23	529	
6.8 A Building	6.8 A Building 1	9	39	351	550
	6.8 A Building 2	11	6.5	71.5	
	6.8 A Building 3	8.5	15	127.5	
6.11 Building				142	142
6.9 Building		11	18	198	198
6.8 B Building	B Building 1	7	15	105	385
	B Building 2	8	35	280	
‘A’ Substation		18	32	576	576
‘F’ Substation		8.5	15	127.5	127.5
6.3 Building		7	30	210	210
Total Rooftop area					**9862.5**

The selected rooftop areas of the hospital, which are shown in table 3.3, are flat surfaces with minimum shading and availability of space for ancillary components of the system. Thus, the available capacity for the installation of Solar PV panels was identified as follows.

Total feasible capacity for installation of Solar PV panels in the hospital (Rooftop Area) = 9862 m^2

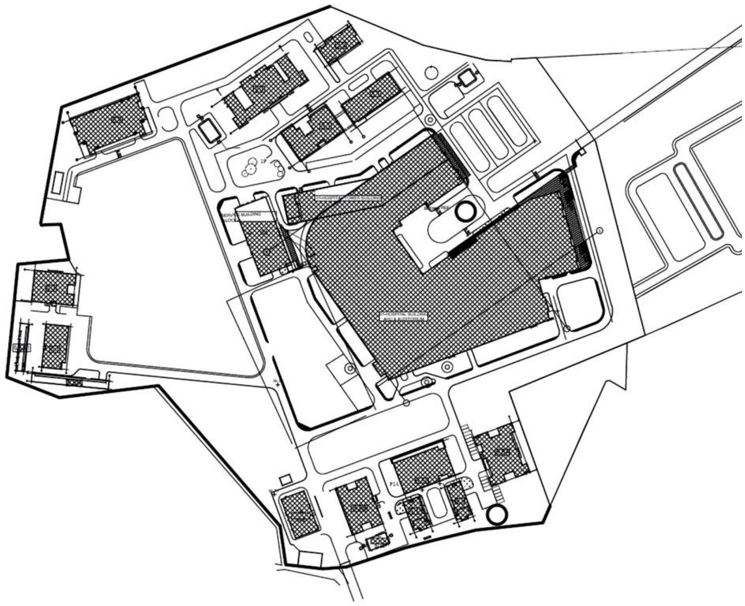


Figure 3.8:Master Plan of UHKDU

3.1.3.3 Investigation of Load Requirement of the Hospital

The design of the microgrid depends on the load requirement characteristics which in turn could vary the control strategies and management of energy supply according to the tiers of loads used in the facility. A comprehensive analysis of load consumption is thereby required during the initial phase of the project. Identifying the demand of the proposed facility will require proper defining of loads of the site.

A thorough assessment of the site influenced to identification of inclusive loads of the hospital as the demand requirement of the project since a hospital itself could be acknowledged as a critical load. To appraise the collected data of load consumption through electric bills and requested data from the Ceylon Electricity Board, the following factors were computed.

1. Average Annual Electricity consumption
2. Load profiles of the facility on weekdays and weekends
3. Peak demand

Average Annual Electricity consumption

The most convenient method of analyzing the monthly energy consumption is from the electricity bills of the facility. Before obtaining the average, the monthly energy consumption values were analyzed for the past year/s and the average was taken afterward from equation 3.3. Units consumed were graphically plotted for the selected months to provide the customer with a convenient representation of variations throughout the year/s. This was compared against the monthly average solar GHI in the particular area to determine the requirements of solar PV plant capacity and means of meeting the monthly consumption. Monthly average energy consumption was calculated from equation 3.3

$$Monthly\ avg.\ Energy\ Consumption = \frac{Total\ sum\ of\ monthly\ energy\ consumed}{No.\ of\ months\ during\ the\ analyzed\ period} \tag{3.3}$$

Further, annual energy consumption can be calculated from the following formula.

$$Annual\ Energy\ Consumption = Monthly\ avg.\ Energy\ Consumption \times 12 \tag{3.4}$$

This data is vital in the forecasting, planning, and decision-making process as well as in determining means to incorporate mitigation of excess energy consumption and increase savings.

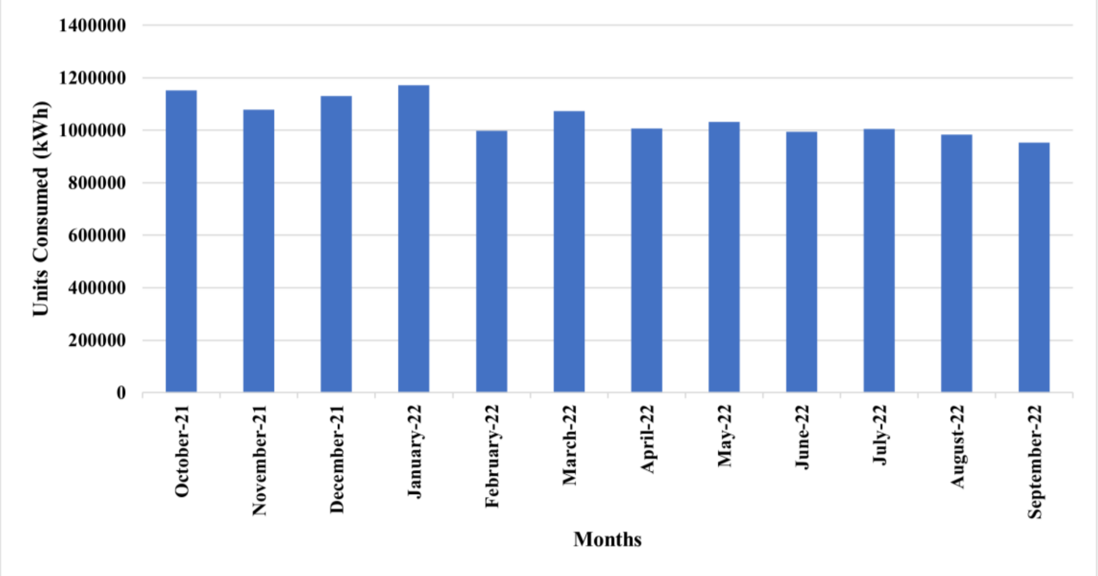


Figure 3.9: Monthly Averaged Electricity Consumption (Oct. 2021 - Sep. 2022) - UHKDU

Load profiles of the facility on weekdays and weekends

Assessment of daily load profiles of the facility is crucial for the designing of components of the proposed system suitable for an islanded operation. During an islanded operation the load will be supplied through various combinations between solar power, battery storage, and diesel generator. The combination of loads among the sources of energy depends on the consumption of electricity during the affected period of time of the day. Thus, a detailed analysis of load variations during weekdays and weekends, during 24 hours of an average day & maximum load consumption of an average day is significant.

Hourly load consumption data for five days was obtained through the Ceylon Electricity board. This data was plotted as shown in Figure 3.8 to observe the variation margins of different days of the week. Figure 3.8 depicts the active power consumption of UHKDU during five different days of the week. The system peaks usually occur in the afternoon from 12.00 to 2.00 pm and 8.30 to 9.30 in the morning. The overall energy consumption is highest on Monday and lowest on Sunday.

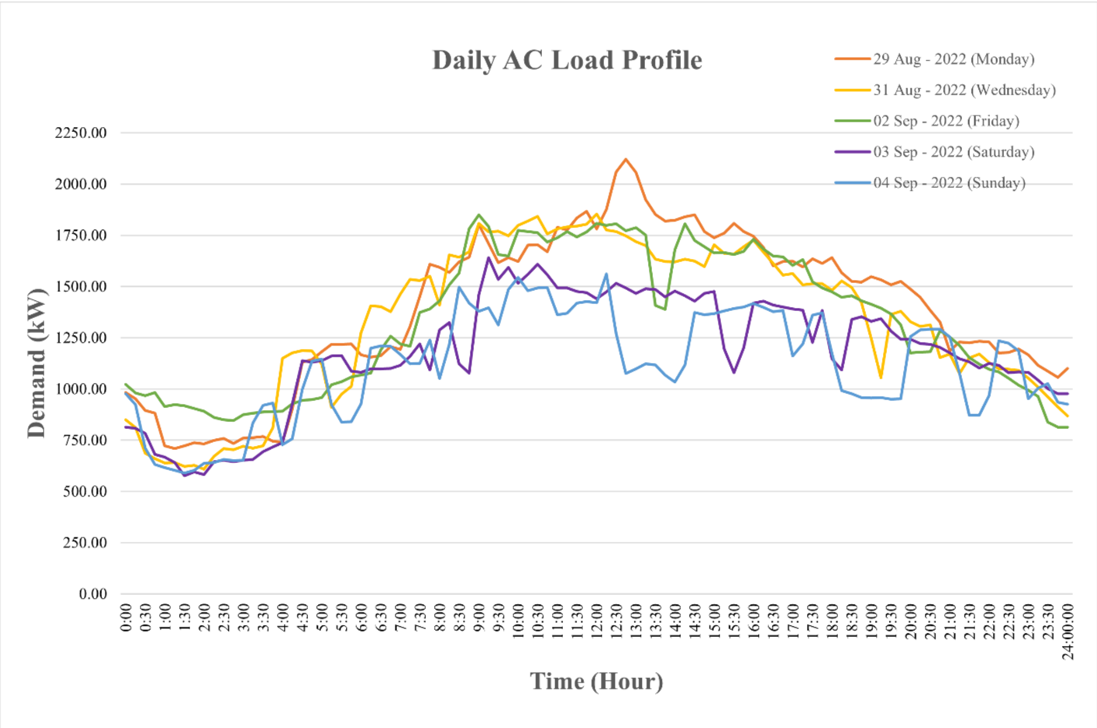


Figure 3.10: Daily AC Load Profile on Monday, Wednesday, Friday, Saturday & Sunday

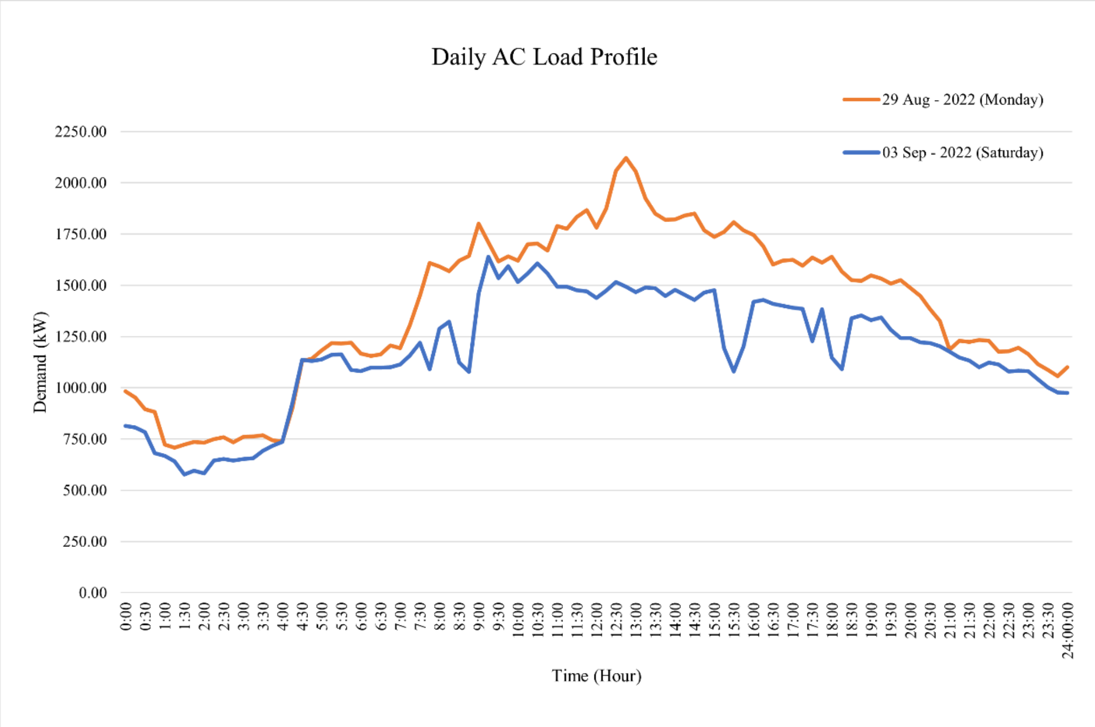


Figure 3.11:Variation of Daily AC Load profiles between a Weekday and Weekend

Figure 3.9 consists of the active power variation to compare the variation during weekends and weekdays by plotting the day which has the highest power consumption among weekdays and weekends. The maximum active power consumed on Monday is approximately 2MW and the Maximum active power consumed on Sunday is approximately close to 1. 5MW. Thereby it should be acknowledged that there is a significant margin between load demand between the weekdays and weekends. These relationships were thoroughly noted as there could be a surplus of Solar power generation during the weekend compared to the weekdays, which in turn could be converted to an economical benefit.

Subsequently, an averaged AC load profile was plotted considering the average units consumed per day. With known hourly data equation 3.5 can be used to compute the required average consumption units per selected time interval (Δt_i). The trapezoidal method or any other convenient method could be used to justify the computed results.

$$Average\ units\ consumed\ = \sum_{i=1}^{n} \frac{(P_i + P_{i+1}) \times \Delta t_i}{120} \tag{3.5}$$

n	=	no. of time intervals in the load profile
i	=	i^{th} recorded data
P_i	=	Load demand for the i^{th} recorded data (kW)

P_{i+1} = Load demand for the (i+1) recorded data (kW)

Δt_i = the time interval between i^{th} recorded data and $(i+1)^{the}$ recorded data (minutes)

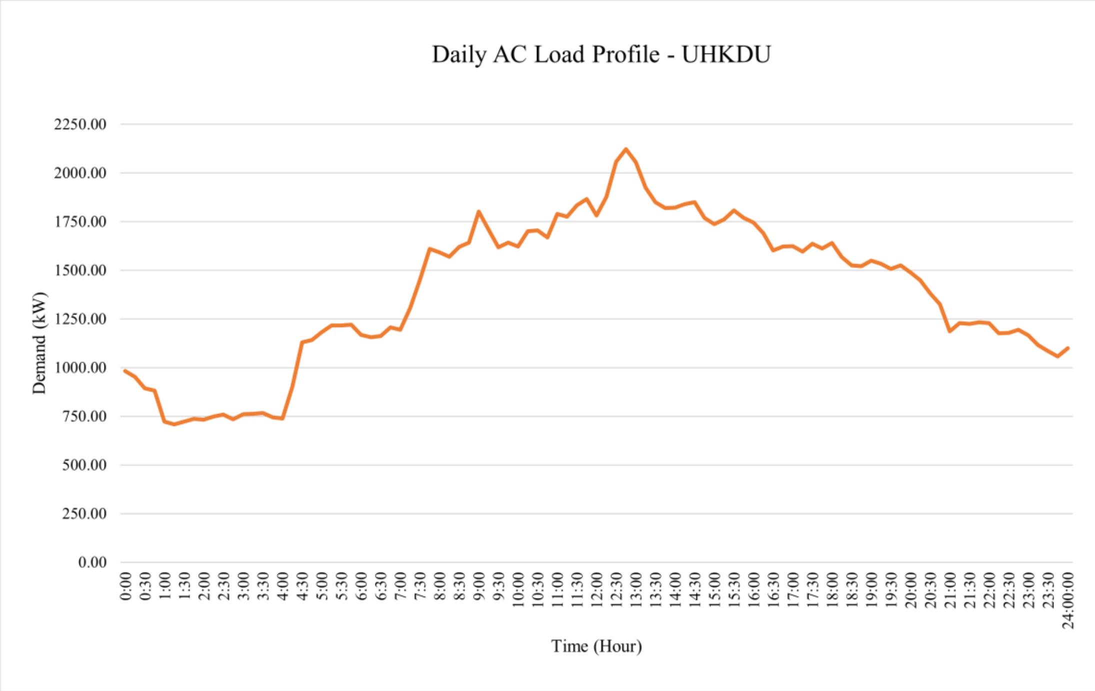


Figure 3.12: Daily AC Load Profile of UHKDU (Δti=15 mins)

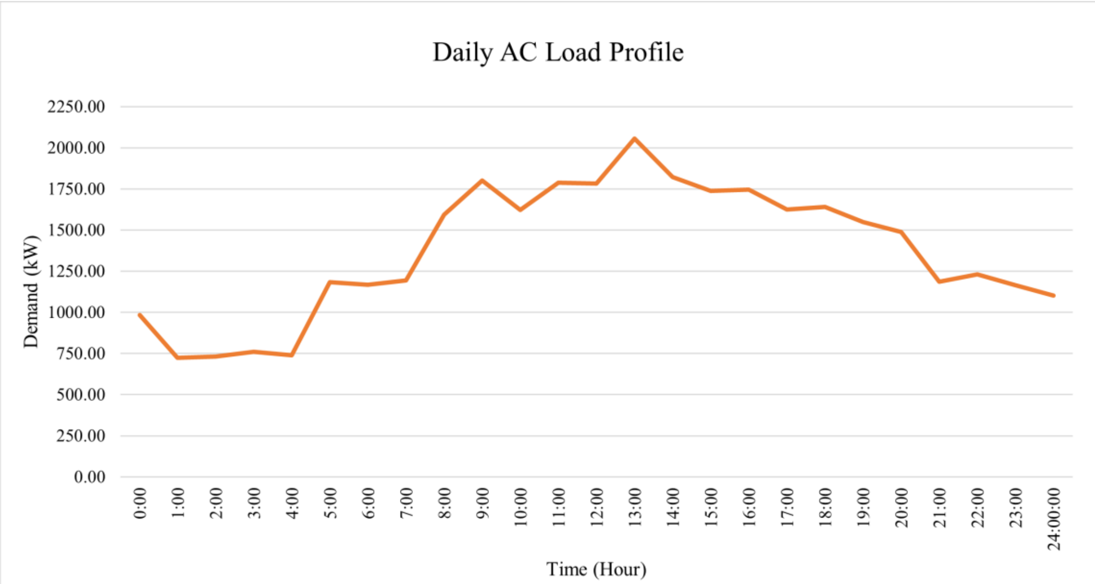


Figure 3.13: Daily AC Load Profile of UHKDU (Δti= 1 hour)

Figure 3.10 and Figure 3.11 depicts an average variation of daily Active power on time intervals of 15 minutes and 1 hour respectively. During the Day peak((05:30 – 18:30) the consumed units are 21542.51 kWh and during the Night peak(18:30 – 22:30) the consumed units are 5477.47 kWh.

Determination of average sun peak hours is required to identify,

1. Identify the energy generation from the solar PV array
2. Identify the energy required to meet the load during the solar PV generation
3. Determine utilization/compensation of excess/required energy

As a rule of thumb, daily average sun peak hours were considered to be between 08:30 hrs. to 15:30 hrs. after analyzing forecasted and historic solar GHI incidence in Werahera, Sri Lanka. It was justified by considering the hours where solar GHI levels are greater than 500 Wh/m^2 as an index.

The energy generation during sun peak hours can be calculated from equation 3.5 where.

$i = 1$: first data recorded during the beginning of sun peak hours

$i = n$: final data recorded at the end of sun peak hours

Thus, according to figure 3.10, a total of 12498.13kWh was consumed during the sun peak hours (08:00 - 15:00).

Peak Demand

The Peak demand of the hospital is a crucial parameter to observe as the required peak kVA rating that needs to be supplied during an outage or an islanded mode from an auxiliary power source is influenced by it. Figure 3.31 depicts the variation of peak demand of the hospital over 12 months initiating from October 2021 to September 2022.

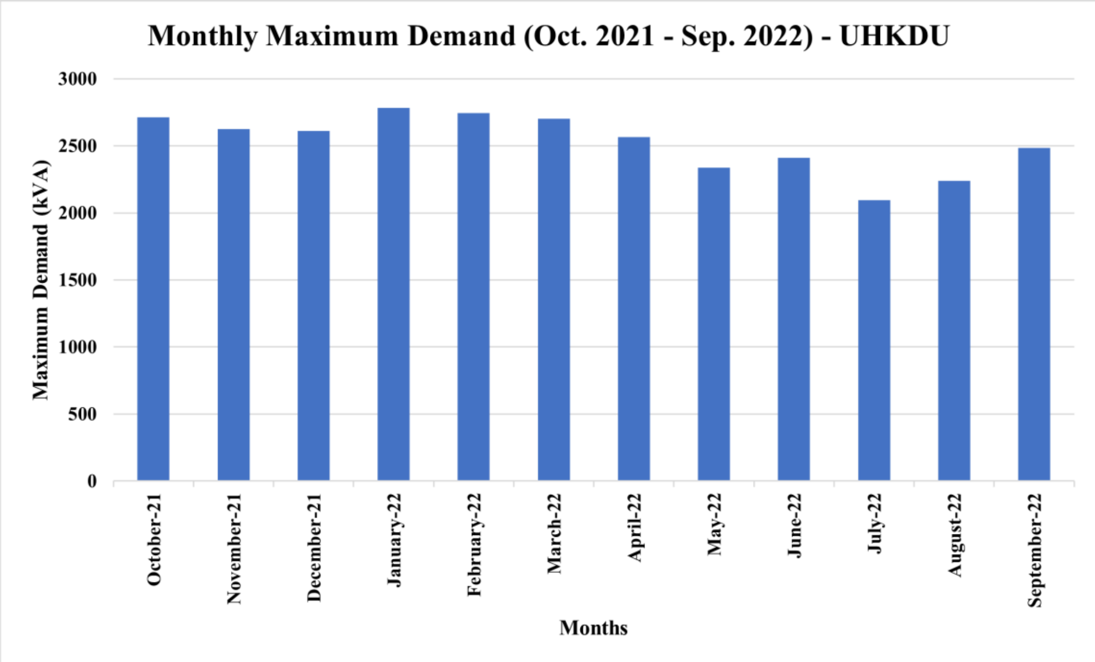


Figure 3.14:Monthly Maximum Demand (Oct. 2021 - Sep. 2022) - UHKDU

3.2 Identification of the main components of the Hybrid Solar PV System

The design of a Hybrid Solar PV system with the capability of obtaining seamless transfer between grid-tied mode and islanded operation aims to replace the existing backup power system by providing favorable economic and environmental benefits. The rise of penetration of renewable energy into microgrids has created alternative solutions to achieve the prior mentioned goals of society. Due to the presence of solar irradiance throughout the year, it is beneficial to integrate Solar Power generation into the system. This generation could be utilized to reduce the use of grid power, provide monetary benefits through the export of power to the grid or charge energy storage systems for later use. The integration of energy storage systems that allow effective manipulation of active power is crucial for this design. It is necessary to identify the most economical and efficient capacity of battery storage through a thorough techno-economic analysis. The UHKDU currently possesses an installed capacity of 7200kW to supply the load requirements during a power outage. Both battery storage and Diesel generator can be utilized to supply power during insufficient solar power generation. Thereby proposed system was modified to integrate less power generated through the diesel generator and more from clean energy. Following the Site assessment, identification of available GHI of the site, and load requirement characteristics, the components of the Hybrid Solar PV system were identified as follows.

1. Solar Photovoltaic (PV) system
2. Energy storage system
3. Inverter
4. Diesel Generator
5. National Grid

3.3 Analysis of capacities of components of the proposed system

The proposed systems consist of Solar PV arrays, Batteries, and inverters that should be designed to cater to the aim of the proposed system. The proposed system aims to develop a Hybrid Solar PV system that could transfer to islanded operation mode and supply the loads during a power outage through integrated solar power and stored energy. Thereby optimal sizing of the components of the proposed system was done by considering the unique characteristics and performance of each component.

3.3.1 Estimation of demand of the hospital

3.3.1.1 Total load requirements per average day

The assessed monthly average consumption of UHKDU, as depicted in table 3.4, provides the total annual consumption of the facility throughout the year. Thereby a total consumption of 12580493 kWh units is consumed annually.

Thereby an average daily unit consumed in the facility was obtained as 33468.95 kWh using equation 3.5.

$$Averaged\ \ units\ consumers\ per\ day = \frac{Total\ Annual\ Consumption\ of\ the\ facility}{365} \tag{3.5}$$

Table 3.4: Monthly Electricity Consumption of UHKDU

Month	Consumption(kWh)
October-21	1151333
November-21	1078602
December-21	1131210
January-22	1171325
February-22	997507
March-22	1073623
April-22	1006000
May-22	1032656
June-22	994928
July-22	1005127
August-22	984436
September-22	953746
Total Annual Consumption of the facility	12580493

The load consumption of the proposed design can be summarized as follows,

Average units consumed per day	=	33,468.95	kWh
Units consumed during day peak hours (05:30 – 18:30)	=	21542.51	kWh
Units consumed during night peak hours (18:30 – 22:30)	=	5477.47	kWh
Units consumed during off-peak hours (22:30 - 05:30)	=	6448.97	kWh
Units consumed during sun peak hours (08:00 - 15:00)	=	12498.13	kWh
Maximum consumption during power outage hours (08:00 - 15:00)	=	3881.91	kWh

3.3.2 Identification of the capacity of Solar PV generation

3.3.2.1 Determination of the size of Solar Array

An interconnection of solar cells is referred to as a solar module and the combination of such solar modules or panels is termed a solar array. The performance of a Solar array can be studied through basic characteristics such as efficiency, Maximum Power Point (MPP) Voltage, Open Circuit Voltage (V_{oc}), Short Circuit Current (I_{sc}), Current (V_{mpp}), and (I_{mpp}) of Solar modules. A Current -Voltage characteristic is plotted for solar modules to further examine the voltage and cooperating current variations at different operating conditions. The Short circuit condition portrays the maximum current condition and the open circuit condition defines the maximum voltage occurrence of the solar module. The I-V characteristic initiates at conditions open circuit condition and with the increment of applied load the current increases while decreasing the voltage resulting in a short circuit condition at the end. The knee of the curve in Figure 3.14 denotes the operating condition where the current and voltage allows the MPP.

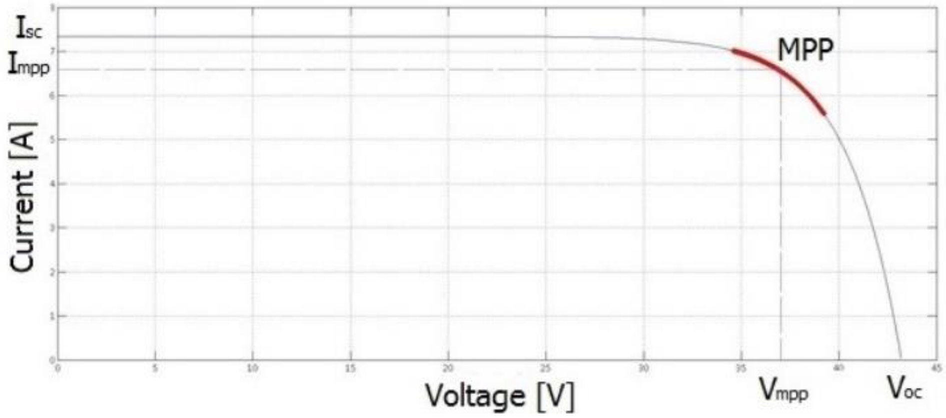


Figure 3.15: The I-V curve of the PV module [Source [39]]

The sized arrays should be able to meet the highest possible daily load requirements during the season of the year with the lowest ratio of daily insolation to daily load. Higher probability of higher generation with a higher size of solar panels and storage capacities Identification of the optimal sizing of the solar panel for this project was influenced by the requirement of obtaining the maximum possible power generation from the available space of the hospital and solar insolation. Thus, by comparison between various solar panels in the market, the panel providing the most efficient and effective generation of power was chosen. Thus, a panel of a 545 Wp rating was chosen as the most suitable for this proposed Hybrid Solar PV system.

3.3.2.2 Determination of capacity of Solar plant

It is significant to identify the capacity of the Solar plant that could be installed with maximum utilization of the available rooftop area of the proposed system.

The feasible rooftop capacity available for panel installation at the hospital is 9862 m2. The selected 540 wp Solar panel has an area of 2.5764 m^2 where the width is 1.13 & the length is 2.28 m. Thus, the area of coverage of solar panels can be obtained as in table 3.5.

Table 3.5: Installation capacities of Solar panels at UHKDU

Building Name	**Building Sub Sections**	**Roof Top Area (m2)**	**Area Covered By the panels in a given rooftop (m2)**
3.1 Building	FAHS	387	154.58
	Badminton Court		131.39
3.2 Building		210	100.47
3.3 Male Building	3.3 Male Building (1)	351	152.00
	3.3 Male Building (2)		190.65
3.3 Female Building	3.3 Female Building (1)	351	152.00
	3.3 Female Building (2)		190.65
Hospital Tower Building		504	479.21
Hospital Building AHU Roof Top		1197	1133.61
Hospital Building Auditorium		1764	1715.88
6.1 Building		392	371.00
6.2 Male Building		240	216.41
6.2 Female Building		140	123.66
6.5 Building	6.5 Building 1	660	267.94
	6.5 Building 2		267.94
6.10 Building		420	401.91
Service Building	Service Building 1	1058	515.28
	Service Building 2		515.28
6.8 A Building	6.8 A Building 1	550	306.59
	6.8 A Building 2		46.37
	6.8 A Building 3		108.20
6.11 Building		142	113.36
6.9 Building		198	162.31
6.8 B Building	B Building 1	385	92.75
	B Building 2		270.5
‘A’ Substation		576	541.04
‘F’ Substation		127.5	108.20
6.3 Building		210	200.95

In conclusion, it can be stated that,

Total available capacity for installation of panels = 9862.5 (m2)

The total area covered by installed Solar Panels = 9030.282 (m2)

Identification of the maximum rooftop Solar PV installation capacity requires computations using equation 3.6.

$$C_{PV} = \frac{C_{module}}{1000} \times \left(\frac{R \times A_{roof}}{A_{module}}\right) \tag{3.6}$$

C_{PV}	=	Potential Solar PV installation capacity (kW_p)
C_{module}	=	The individual module rated capacity (W_p)
R	=	The roof cover ratio, which is the fraction of roof area that the modules will cover
A_{roof}	=	The total roof area available for installation of solar modules (m^2)
A_{module}	=	the area of one module (m^2)

The roof area (A_{roof}) denotes the total available space for the installation of panels excluding the obstructions that could hinder the power generation of panels such as shading obstacles and obstructions on the roof, such as helipads, water tanks, utility rooms, communication towers, and air conditioning units. The roof cover ratio ranged from 0.85-0.9, leaving a clearance margin of 10-15% clear for module spacing and obstruction-free use. Thus,

Potential installation capacity of the rooftop Solar PV plant = 1878 kW_p

It can be concluded that the capacity of the Solar plant of the proposed system at UHKDU is 1. 9MW with 3487 numbers of Solar obtained using equation 3.7.

$$No.of\ Solar\ PV\ panels\ required = \frac{Capacity\ of\ proposed\ plant}{Rating\ of\ a\ single\ module} \tag{3.7}$$

Through the site survey and computations, it can be established that due to the limitation of the capacity available for the installation of solar panels, the total demand of the hospital cannot solely be met by solar power generation. Thus the 1.9MW solar plant will only supply a portion of the total demand during the islanded operation mode.

3.3.2.3 Computation of total Solar generation for an average day

The total solar power generated on an average day was obtained through equation 3.8.

$$Total\ Solar\ Power\ generated\ on\ an\ average\ day = \frac{G \times A \times i \times (1 - L)}{10^4} \tag{3.8}$$

i	:	The efficiency of a Panel
L	:	Losses of the system
A	:	Total Rooftop Area that can be occupied for installation of Solar PV array
G	:	Daily average summation of solar GHI at the selected site

Considering that the power outage occurs during the day peak which has the maximum demand of the hospital, the plant could supply a generation of 3429.59 kWh to the system.

3.3.3 Investigation of the capacity of the Battery Storage system

Currently, Batteries are the most commonly used energy storage technology due to their ease of availability and use and attractive monetary value. The high energy density of a battery depicts the amount of energy that can be obtained from the cells and the lower power density depicts the limitations on the speed of providing the energy to the load. The power density depends on the internal resistance and time obtained to undergo electrochemical reactions. A battery consists of positive and negative electrodes known as the anode and cathode respectively, electrolyte & separator.

Several parameters that acknowledge the performance of the battery are as follows,

1. Charge and Discharge Current:

The current is flown from the anode to the cathode during the discharging process where the electrolyte enables the complete path for the circuit. During the charging process, oxidation occurs in the positive electrode and reduction occurs negative electrode due to the externally supplied current. Depending on the battery technology, different methods are used to estimate this value.

2. State of Charge:

State of charge means the energy stored in the battery relative to the total energy stored in the capacity of the battery. In simple terms, it can be defined as the remaining charge of the battery.

3. Depth of Discharge

Depth of discharge is known as battery capacity that has been discharged compared to the rated capacity. Higher periods of autonomy increase the size and availability of the battery while reducing the depth of discharge. Greater DOD allows higher availability at the expense of the lifetime of the battery.

4. Cycle Life:

The cycle life determines the number of charging and discharging cycles the battery can undergo to reach its rated capacity.

The Battery Storage system is the key component that provides the islanded mode operation capability. In the development of a battery storage system for a hybrid system, the most vital step is to identify the type of battery suitable for the design. For this proposed system design and analysis are done by considering the Li-ion battery storage. The Li-ion batteries consist of several benefits as mentioned below.

1. High energy density
2. Higher power density
3. Excellent efficiency
4. Good Cycle of life
5. Fast charging

Due to exacerbation by limited lithium resources, these batteries tend to have a high initial cost and economical disadvantages compared to Lead-acid batteries.

The capacity of the battery storage system can be affected by the temperature, discharge rate, and lifetime of the battery. Additionally, the identified autonomy and maximum allowable discharge rate influence the ratings of the batteries as with higher DOD, higher power availably is allowed and higher expenses are incurred.

The basic factors that influence the sizing of the Battery Energy Storage System are as follows:

- Autonomous days or hours of the storage system
- Frequency of occurrence of outage in the selected area.
- Duration of an average outage.
- Budget constraints & economic viability storage system.
- Capability to Peak shaving.
- Daily solar production and its contribution to an outage occurred during the daytime.

- Charging and discharge rates of the batteries in worst-case scenarios such as an occurrence of sudden voltage dip in the solar PV system due to cloud cover while supplying the load during an outage in daytime

The calculations of battery capacity were done considering the several cases that could occur due to the worst-case scenarios that could occur in the system. An outage could occur during sun peak hours or off-sun peak hours. Thus, the battery capacity should be sufficient to hold the required load during an outage at any time of the day. The development of a battery storage system by considering a specific period of time of the day may not provide the most economical and effective design. Thus, the following cases were identified and computation of battery capacities was done for each of the scenarios.

Case study 1

An outage of 2 hours during the daytime (during sun peak hours) was considered under case study 1. It was assumed that the outage occurred from 11:30 – 13:30 hours as the maximum demand of the daily load profile of UHKDU was obtained in the daytime. During the daytime, the installed solar plant can be utilized to supply power. During the site survey, it was noticed that the hospital has standby backup diesel generators to compensate for the loss of power during an outage. Thus, subcases of Case study 1 were identified as follows by taking the existing diesel generator and Solar PV generation into consideration.

Sub Case A: Compensation of load is achieved with Solar PV generation & Battery Energy under this subcase. The remainder of solar generation will be exported when the outage is restored.

Sub Case B: The load is compensated with Solar PV generation & Diesel Generator under this subcase. The remainder of solar generation will be exported when the outage is restored.

Sub Case C: The load is compensated with Solar PV generation & partial Battery Energy and partial Diesel Generator. The remainder of solar generation will be exported when the outage is restored.

Case study 2

An outage of 1 hour during the remainder of the day (excluding sun peak hours) is considered under this case. The outage was selected to be from 15:30 – 16:30 hours, which was obtained from the daily load profile where the demand is maximum during the remainder of the day (excluding the period considered in Case study 1).

Sub Case A: The load is compensated with only the Battery Energy storage system. The remainder of solar generation will be exported when the outage is restored.

Sub Case B: The Load is compensated with only Diesel Generator. The remainder of solar generation will be exported when the outage is restored.

Sub Case C: The Load is compensated with partial Battery Energy and partial Diesel Generator. The remainder of solar generation will be exported when the outage is restored.

If the outage is considered to be longer than the stipulated periods in the above cases, the conventional approach of powering up the Diesel generator to meet the load will be assumed.

Even though subcase B of each case is not affected by the battery storage system and studies the use of existing generators, it was identified to establish economically beneficial decisions.

The rated capacity of the battery was selected as 400Ah. The total energy required by the battery is taken to be the highest value of the peak shaving requirement and the total load compensation requirement because if the battery is sized according to the highest value (worst case) it will be eligible for the case of supplying a lower value.

A worst-case scenario of 90% of peak instantaneous power fluctuation of solar PV is considered due to the formation of clouds for a period of 5 mins within the 2-hour outage duration. Therefore, the battery discharge rate during that time is fixed to compensate for the relevant voltage ramps.

Peak shaving is only done on the days when an outage would not occur. The battery is charged during the off-peak time from the grid. Peak shaving duration is considered as 18:30 -19:00 where the load demand is high, in the peak time region categorized by the electricity provider (CEB) where the tariff rates are high during the day. The sizing of battery capacity for optimal performance under Case 1 was done by utilizing equations 3.9-3.12.

$$Current\ required\ to\ compensate\ the\ voltage\ dip = \frac{Total\ Load\ to\ be\ met\ during\ a\ voltage\ dip}{Nominal\ Voltage\ of\ battery} \quad (3.9)$$

$$Discharge\ C\ rate\ of\ a\ battery\ during\ a\ voltage\ dip = \frac{Current\ required\ to\ compensate\ the\ dip}{Current\ @\ 1C\ discharge\ rate\ of\ a\ batt.} \quad (3.10)$$

$$Battery\ Capacity\ Required\ (kWh) = \frac{Q \times \alpha \times \gamma}{DOD} \quad (3.11)$$

$$No.\,of\ Batteries\ required = \frac{Battery\ capacity\ required\ (kWh)}{Nominal\ voltage\ \times capacity\ of\ a\ battery\ (Ah)} \quad (3.12)$$

Where,

Q	=	Required Capacity (kWh)
α	=	Temperature correction factor
γ	=	Design margin
DOD	=	Depth Of Discharge

Case study 1

The identified scenario assumes an outage of 2 hours during the daytime (during sun peak hours). between 11:30 – 13:30 hours. Computation of battery capacities to peak shave and supply and outage was done by considering the total load to be met during the outage, excess Energy requirement to meet the load compensating for voltage dips during a 2-hour outage, and the maximum demand during selected peak time. as the load required peak shave is higher than the summation of demand required to meet the load and compensate voltage dips during an outage, Load requirement to peak shave was considered as the energy required to be met by the battery. Therefore, such calculations were conducted under subcase A. Peak shaving capability was neglected under subcase C in order to perform a precise energy economic comparison.

Sub Case A: The Load is compensated with Solar PV generation & Battery Energy.

Table 3.6: Battery Sizing: Case study 1 -Subcase A

Case study 1 – Sub Case A				
	Peak shave & Outage		***Only outage***	
Load to be met by a battery	451.60	kWh	451.60	kWh
Load to be met during Peak Shaving (18:30-19:00 hours)	764.63	kWh	0.00	kWh
Total Load to be met during one discharging cycle	1216.23	kWh	451.60	kWh
Nominal Voltage of a battery	48	V	48	V
Rated capacity of a battery	400	Ah	400	Ah
Design Criteria considering discharge rate				
Peak average solar GHI	722.82	W/m2	722.82	W/m2
Total peak solar output power	1239.49	kW	1239.49	kW
Maximum considerable output solar power fluctuation during peak solar output (90% dip)	1115.541	kW	1115.541	kW
Peak Load Demand	2121.56	kW	2121.56	kW
Total peak load to be met by the battery during a worst-case scenario voltage dip	1997.61	kW	1997.61	kW
The total current required to compensate for the voltage dip	41616.87	A	41616.87	A
The total current that can be discharged from the battery bank at 1C	24800	A	18000	A
The discharge rate of a Battery during a voltage dip	1.68	C	2.31	C
Total time the battery will be discharged at the above C rate	5	mins	5	mins
The excess Energy requirement to meet the load compensating for voltage dips during 2-hour outage	92.96	kWh	92.96	kWh

Table 3.7:Continued

The total energy required by ESS during the daytime outage	**764.63**	**kWh**	**544.56**	**kWh**
<u>Design Criteria considering energy requirement</u>				
DOD (Depth of Discharge)	80	%	80	%
Battery Capacity adjusted for DOD	955.79	kWh	680.70	kWh
Capacity at EOL (End of Life)	80	%	80	%
Battery Capacity adjusted for EOL	955.79	kWh	680.70	kWh
Battery Capacity after adjusting	955.79	kWh	680.70	kWh
associated temperature correction factor (based on curves in IEEE 1635)	1.13		1.13	
Battery capacity adjusted for temperature	1080.05	kWh	769.19	kWh
Design Margin factor (≥ 1)	1.1		1.1	
Battery Capacity required	1188.05	kWh	846.11	kWh
Battery Capacity in Ah	24751.05	Ah	17627.29	Ah
No. of batteries needed	62		45	
Upper SOC	95	%	95	%
Lower SOC	20	%	20	%

Sub Case C: The load is compensated with Solar PV generation & partial Battery Energy and partial Diesel Generator. Peak shaving is neglected.

Table 3.8: Battery Sizing: Case study 1-Subcase C

Case study 1 – Sub Case C		
	Only Outage	
Load to be met by a battery	225.80	kWh
Load to be met during Peak Shaving (18:30-19:00 hours)	0.00	kWh
Total Load to be met during one discharging cycle	225.80	kWh
Nominal Voltage of a battery	48	V
Rated capacity of a battery	400	Ah

Table 3.7: Continued

Design Criteria considering discharge rate		
Peak average GHI	722.82	W/m2
Total peak solar output power	1239.49	kW
Maximum considerable output solar power fluctuation during peak solar output (90% dip)	1115.541	kW
Peak Load Demand	1232.47	kW
Total peak load to be met by the battery during a worst-case scenario voltage dip	1108.52	kW
The total current required to compensate for the voltage dip	23094.19	A
The total current that can be discharged from the battery bank at 1C	5200	A
The discharge rate of a Battery during a voltage dip	4.44	C
Total time the battery will be discharged at the above C rate	5	mins
The excess energy required to meet the load compensating for voltage dips during a 2-hour outage	92.96	kWh
The total energy required during a daytime outage	**318.76**	**kWh**
Design Criteria considering energy requirement		
DOD (Depth of Discharge)	80	%
Battery Capacity adjusted for DOD	398.45	kWh
Capacity at EOL (End of Life)	80	%
Battery Capacity adjusted for EOL	398.45	kWh
Battery Capacity after adjusting	398.45	kWh
associated temperature correction factor (based on curves in IEEE 1635)	1.13	
Battery capacity adjusted for temperature	450.25	kWh
Design Margin factor (≥ 1)	1.1	
Battery Capacity required	495.27	kWh
Battery Capacity in Ah	10318.22	Ah

Table 3.7: Continued

No. of batteries needed	26
Upper SOC	95 %
Lower SOC	20 %

Case study 2

An outage of 1 hour during the remainder of the day (excluding sun peak hours) between 15:30 – 16:30 hour is considered in this scenario. The load to be compensated during off-sun peak hours in an outage & excess Energy requirement to meet the load compensating for average peak demand during the outage is considered as the energy requirement of the battery as its summation is greater than the demand required to perform peak shaving.

Sub Case A: Load is compensated with only Battery Energy.

Table 3.9: Battery Sizing: Case 2-Subcase A

Case Study 2 – Sub Case A		
	Outage Only (Peak shave considered)	
Load to be met by battery (1hr)	1727.36	kWh
Load to be met during Peak Shaving (18:30-19:00)	764.63	kWh
Total Load to be met during one discharging cycle	2491.99	kWh
Nominal Voltage of a battery	48	V
Rated capacity of a battery	400	Ah
Design Criteria considering discharge rate		
average Peak Load Demand	1753.10	kW
Total time the battery will be discharged at the required C rate	1	hrs
Total Energy required to discharge	1753.10	kWh
The total current required to compensate for the average peak demand	36522.85	A
The total current that can be discharged from the battery bank at 1C	28400	A

Table 3.8: Continued

The discharge rate of a Battery	1.29	C
The excess energy requirement to meet the load compensating for avg. peak demand during a 2hour outage	25.74	kWh
The total energy required during an outage	**1753.10**	**kWh**
<u>**Design Criteria considering energy requirement**</u>		
DOD (Depth of Discharge)	80	%
Battery Capacity adjusted for DOD	2191.37	kWh
Capacity at EOL (End of Life)	80	%
Battery Capacity adjusted for EOL	2191.37	kWh
Battery Capacity after adjusting	2191.37	kWh
associated temperature correction factor (based on curves in IEEE 1635)	1.13	
Battery capacity adjusted for temperature	2476.25	kWh
Design Margin factor (≥ 1)	1.1	
Battery Capacity required	2723.87	kWh
Battery Capacity in Ah	56747.3805	Ah
No. of batteries needed	142	
Upper SOC	95	%
Lower SOC	20	%

Sub Case C: The load is compensated with partial Battery Energy and partial Diesel Generator.

Table 3.10: Battery Sizing: Case 2-Subcase C

CASE 2 – Sub Case C		
	Outage Only (Peak shave considered)	
Load to be met by battery (0.5 hours)	886.37	kWh
Load to be met during Peak Shaving (18:30-19:00)	764.63	kWh
Total Load to be met during one discharging cycle	1651.01	kWh
Nominal Voltage of a battery	48	V

Table 3.9: Continued

Rated capacity of a battery	400	Ah
Design Criteria considering discharge rate		
average Peak Load Demand	1788.32	kW
Total time the battery will be discharged at the above C rate	0.5	hours
Total Energy required to discharge	894.16	kWh
The total current required to compensate for the average peak demand	37256.62	A
The total current that can be discharged from the battery bank at 1C	14600	A
The discharge rate of a Battery	2.55	C
The excess energy required to meet the load compensating for average peak demand during a 2-hour outage	7.79	kWh
The total energy required during an outage	**894.16**	**kWh**
Design Criteria considering energy requirement		
DOD (Depth of Discharge)	80	%
Battery Capacity adjusted for DOD	1117.70	kWh
Capacity at EOL (End of Life)	80	%
Battery Capacity adjusted for EOL	1117.70	kWh
Battery Capacity after adjusting	1117.70	kWh
associated temperature correction factor (based on curves in IEEE 1635)	1.13	
Battery capacity adjusted for temperature	1263.00	kWh
Design Margin factor (≥ 1)	1.1	
Battery Capacity required	1389.30	kWh
Battery Capacity in Ah	28943.734	Ah
No. of batteries needed	73	
Upper SOC	95	%
Lower SOC	20	%

3.3.4 Investigation of the Inverter capacity of the system

A hybrid Solar inverter compromises a solar inverter and a battery inverter which manages the power from the Solar plant, batteries, and the grid. The capacity of such an inverter should be measured from the maximum continuous output in Watts. This rating should be larger than the total power of connected alternating current loads.

Computation of the capacity of the inverter was conducted by considering 25-30% higher than the maximum power consumed by the load. The Peak demand obtained from the load profile is 2121.56 kW. Thus, with an inverter design margin of 25% & using equation 3.13 required inverter capacity was found to be 2651.95kW.

$$Required\ inverter\ capacity = Peak\ demand \times (1 + inverter\ design\ margin) \tag{3.13}$$

By considering factors such as cost, efficiency, and practicality the selected rating for the inverter in the proposed design was 150kW.This number of inverters required to supply the demand was obtained using equation 3.14 as 18.

$$No.\,of\ inverters\ required\ to\ supply\ the\ demand = \frac{Required\ inverter\ capacity}{Rating\ of\ a\ single\ inverter} \tag{3.14}$$

3.4 Modeling and Simulation

A sample model of the proposed Hybrid Solar PV system was designed using MATLAB Simulink software to observe the performance of a concept system in a virtual platform. A Single-Phase Solar PV system with a Li-ion Battery Energy Storage System (BESS) that can be operated in islanded as well as grid-connected modes were designed and the performance was observed via the simulation results. Solar PV array, AC-DC bi-directional converter, Load and Grid, and Li-ion BESS stand out as some of the main components that were modeled during the course. Some of the auxiliary components such as MPPT algorithm, Voltage controller, Inverter control for grid connected and islanded modes were necessary for the smooth operation of the system. Two modes (grid-connected or islanded operation) can be toggled by setting an input to the system to observe the dynamic performance.

3.4.1 Solar PV Array

Solar PV array is one of the main components of a Hybrid Solar PV system that extracts the solar irradiance and outputs electricity. PV Array block in MATLAB Simulink allows user to customize a Solar Photovoltaic system with user preferred PV modules that is included in the module database, as well as set parameters such as no. of parallel strings and no. of series connected modules per string to obtain the required capacity of the solar PV system. Since the output voltage of panels are DC voltages of lower order, DC-DC boost converter along with an MPPT algorithm is used to boost the voltage to higher DC value and extract the maximum power for a given condition of irradiance and temperature.

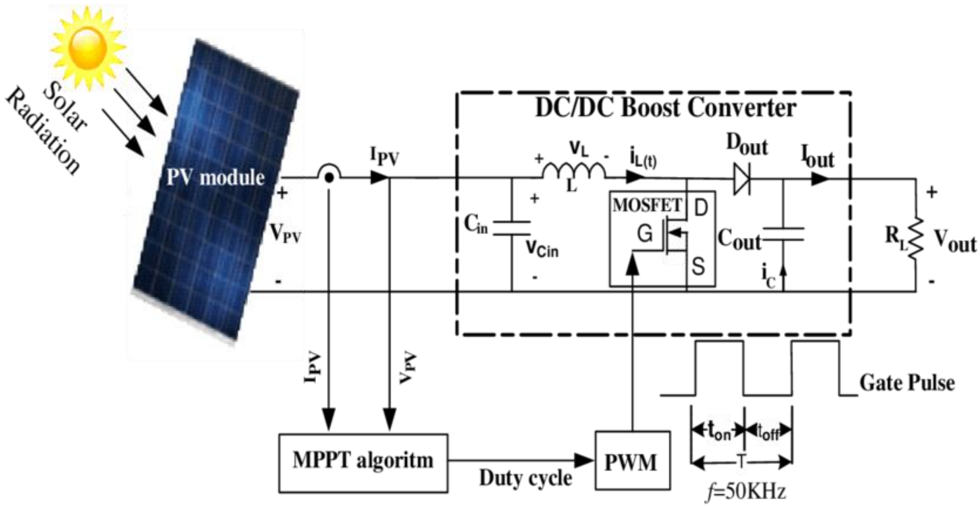


Figure 3.16: Schematic of a Solar PV array configuration with a boost converter and an MPPT algorithm

Solar PV array could not only be included from the Simscape library in Simulink but also can be modelled according to user preferences considering the following equations and procedure.

Much research have been conducted to study PV cells, including improvements to increase the efficiency of a cell, etc. Some of the basic equations of modelling a solar PV module can be recognized as follows.

Output current (I) of a practical cell,

$$I = I_{PV} - I_o\left[exp\left(\frac{V + R_s I}{V_t a}\right) - 1\right] - \left(\frac{V + R_s I}{R_{sh}}\right) \tag{3.15}$$

Where,

$$I_d = I_o\left[exp\left(\frac{V + R_s I}{V_t a}\right) - 1\right] \tag{3.16}$$

$$V_t = \frac{N_s k T}{q} \tag{3.17}$$

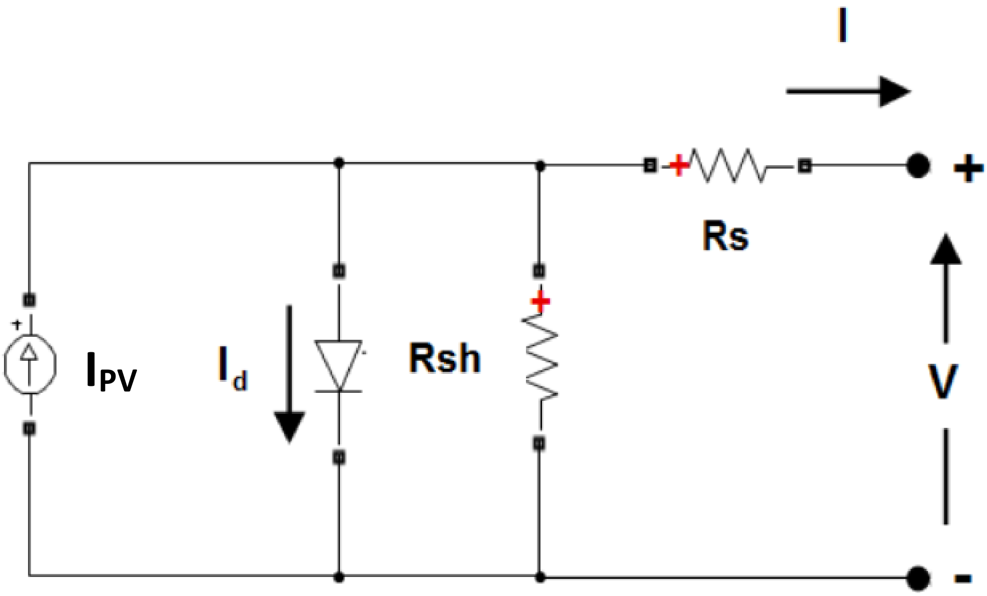


Figure 3.17: Equivalent circuit of PV cell [Source [[44] [44]]

Photovoltaic current (I_{PV}) can be calculated as follows,

$$I_{PV} = \left(I_{PV,n} + K_I(T - T_n)\right)\frac{G}{G_n} \tag{3.18}$$

$I_{SC} \approx I_{PV}$ is assumed in most practical cases.

$$I_o = I_{o,n}\left(\frac{T_n}{T}\right)^3 exp\left[\frac{qE_g}{ak}\left(\frac{1}{T_n} - \frac{1}{T}\right)\right] \tag{3.19}$$

And,

$$I_{o,n} = \frac{I_{SC,n}}{exp\left(V_{OC,n}/aV_{t,n}\right) - 1} \tag{3.20}$$

$$V_{t,n} = \frac{N_s k T_n}{q} \tag{3.21}$$

I	=	The net cell current
I_{PV}	=	Light-generated current/photovoltaic current
I_o	=	Saturation current
V	=	Cell output voltage
V_t	=	Thermal voltage of the array
R_s	=	Series resistance of a practical PV cell
R_{sh}	=	Shunt resistance of a practical PV cell
a	=	Diode constant
I_d	=	Diode current
$I_{PV,n}$	=	Photovoltaic current at STC
K_I	=	Short-circuit current/temperature coefficient
T	=	Actual temperature
T_n	=	Nominal temperature
G	=	Irradiation on the device surface
G_n	=	Nominal irradiation
$I_{o,n}$	=	Nominal saturation current
q	=	Electron charge (1.602176×10^{-19} C)
E_g	=	Bandgap energy of the semiconductor
k	=	Boltzmann constant ($1.3806503 \times 10^{-23}$ J/K)
I_{SC}	=	Short circuit current
$I_{SC,n}$	=	Nominal short circuit current
$V_{OC,n}$	=	Nominal Open circuit voltage
$V_{t,n}$	=	Thermal voltage at nominal temperature
N_s	=	Series-connected cells

Apart from the conventional method of modelling, it is more convenient to utilize the given model (in-built models in the simscape library) block of solar PV array in Simulink to fulfill the purpose of modelling a Hybrid Solar PV system. Parameters (Module brand and rating, No. of series connected modules per string, No. of parallel strings, etc.) can be set according to the user preference such that required plant capacity can be modeled. Then, P-V and I-V graphs of the modeled array can be obtained to observe the variance of maximum power and maximum current for difference irradiance levels at 25 °C. Following are I-V and P-V characteristics of the PV array modeled in the current study.

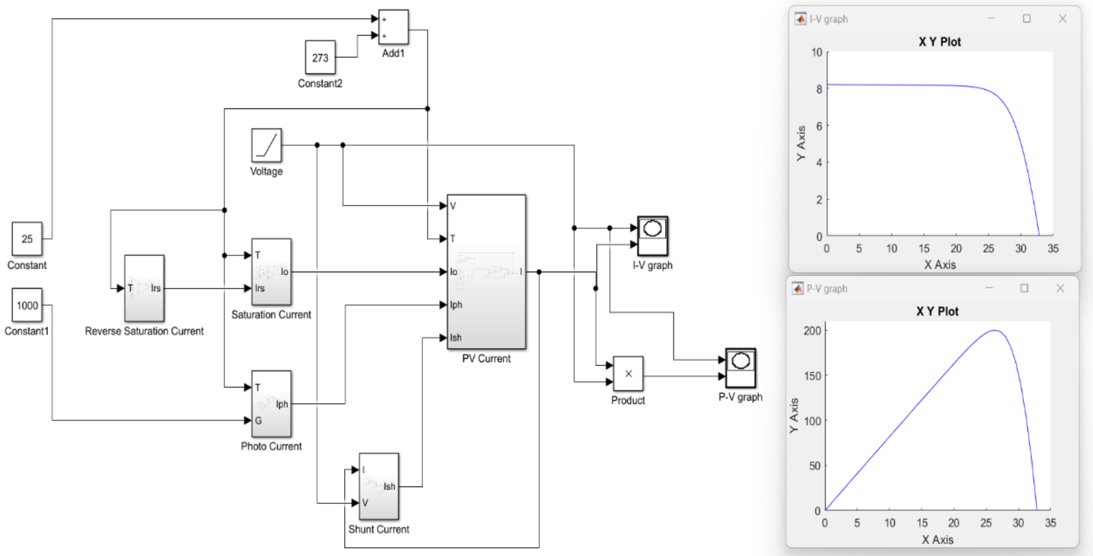


Figure 3.18: PV Cell Simulink model for STC and output graphs

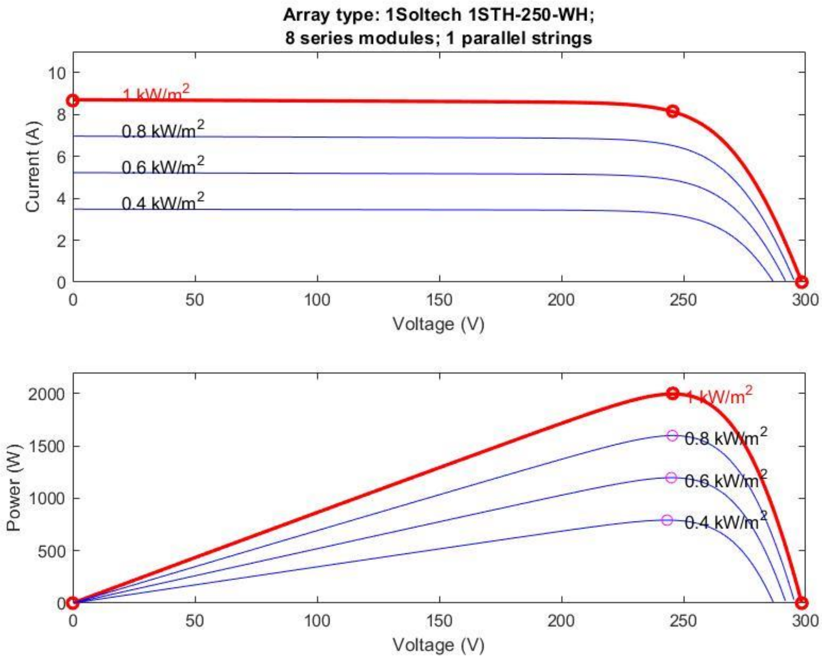


Figure 3.19: I-V and P-V characteristics at 25°C of the PV array modeled

[Source [44]]

3.4.1.1 Boost Converter

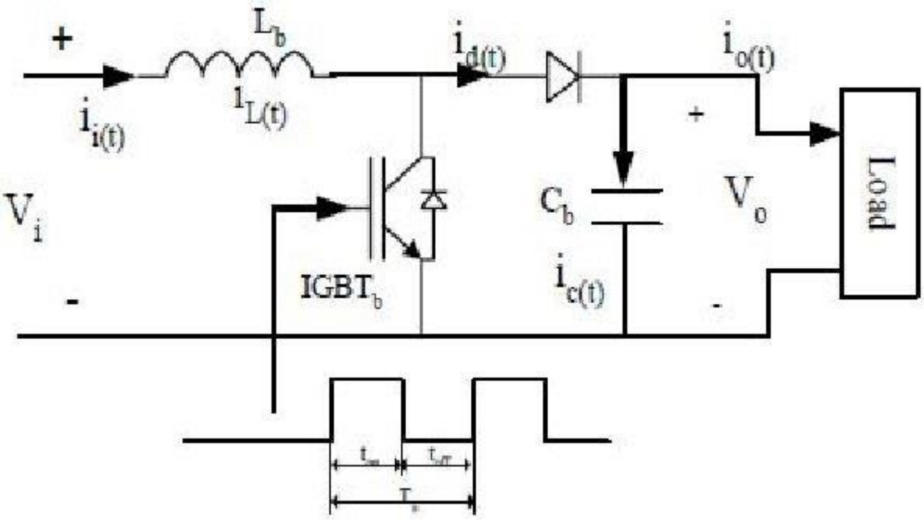


Figure 3.20: Schematic of a DC-DC boost converter

Boost converter produces an output voltage which is always greater than input voltage. This converter is also known as “step-up” converter. Main function of the circuit is to increase the DC voltage to a higher level suitable for the subsequent inverter stage. MPPT algorithm too is implemented within this stage.

When rated power output, input voltage, output voltage, and switching frequency of IGBTs/MOSFETs are known, design parameters such as Duty factor, suitable inductance and capacitance values can be calculated using the following equations. Keeping the ripple output voltage 0.01 of total output voltage and ripple inductor current 0.01 of total input current,

$$\Delta V_o = 0.01 V_o \tag{3.22}$$

$$\Delta I_L = 0.01 \frac{P}{V_d} \tag{3.23}$$

Passive elements L, R, C, and the duty factor can be calculated as follows,

$$D = 1 - \left(\frac{V_d}{V_o}\right) \tag{3.24}$$

$$L = \frac{V_d (V_o - V_d)}{\Delta I_L f_s V_o} \tag{3.25}$$

$$C = \frac{DP}{V_o f_s \Delta V_o} \tag{3.26}$$

$$R = \frac{V_o^2}{P} \tag{3.27}$$

Calculations that were done in the model to obtain design parameters. Desired output performance values are as follows

1. P = 2000 W
2. V_d = 245.6 V
3. V_o = 400 V
4. f_s = 1 kHz.

$$\Delta V_o = 0.01V_o = 0.01 \times 400 = 4\ V \tag{3.28}$$

$$\Delta I_L = 0.01\frac{P}{V_d} = \frac{0.01 \times 2000}{400} = 0.05\ A \tag{3.29}$$

$$D = 1 - \left(\frac{V_d}{V_o}\right) = 1 - \left(\frac{245.6}{400}\right) = 0.3860 \tag{3.30}$$

$$L = \frac{V_d(V_o - V_d)}{\Delta I_L f_s V_o} = \frac{245.6(400 - 245.6)}{0.05 \times 10^3 \times 400} = 0.1164\ H \tag{3.31}$$

$$C = \frac{DP}{V_o f_s \Delta V_o} = \frac{0.386 \times 2000}{400 \times 10^3 \times 4} = 4.827 \times 10^{-5}\ C \tag{3.32}$$

$$R = \frac{400^2}{2000} = 80\ \Omega \tag{3.33}$$

Where,

P	=	Power generated from Solar PV
V_d	=	Input Voltage to the Boost Converter

V_o = Output Voltage of the Boost Converter

f_s = Switching frequency

D = Duty Factor

L = Inductance

C = Smoothing Capacitance

R = Resistance

ΔV_o = Output ripple voltage

ΔI_L = Input ripple current

3.4.1.2 MPPT algorithm

From the literal meaning of the word Maximum Power Point Tracking (MPPT) several techniques are being used to increase the efficiency of solar panels and produce the maximum efficiency to the system. Out of many studies that have been published [40] shows the importance of incremental conductance MPPT algorithm for its higher accuracy and environmental versatility as a solar tracking algorithm.

According to the research conducted by [41], an improved version of Incremental Conductance (InC) MPPT technique has been contrasted with the conventional operation of InC MPPT algorithm. The flow chart in figure 3.20 depicts a basic understanding of the principal operation of InC MPPT. Incremental Conductance MPPT algorithm model used in the simulation of the main system, i.e. Hybrid Solar PV system is shown in the figure 3. 21.

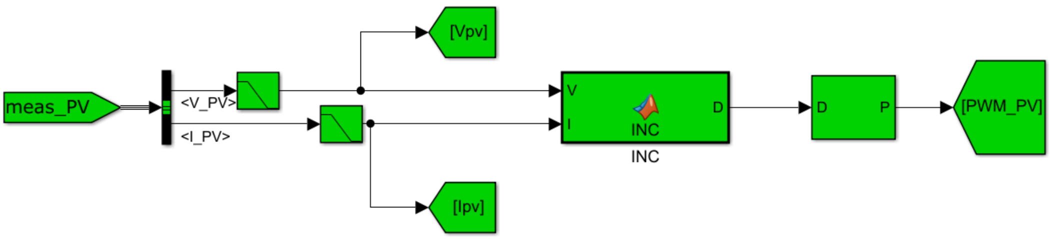


Figure 3.21:Incremental Conductance MPPT model

p

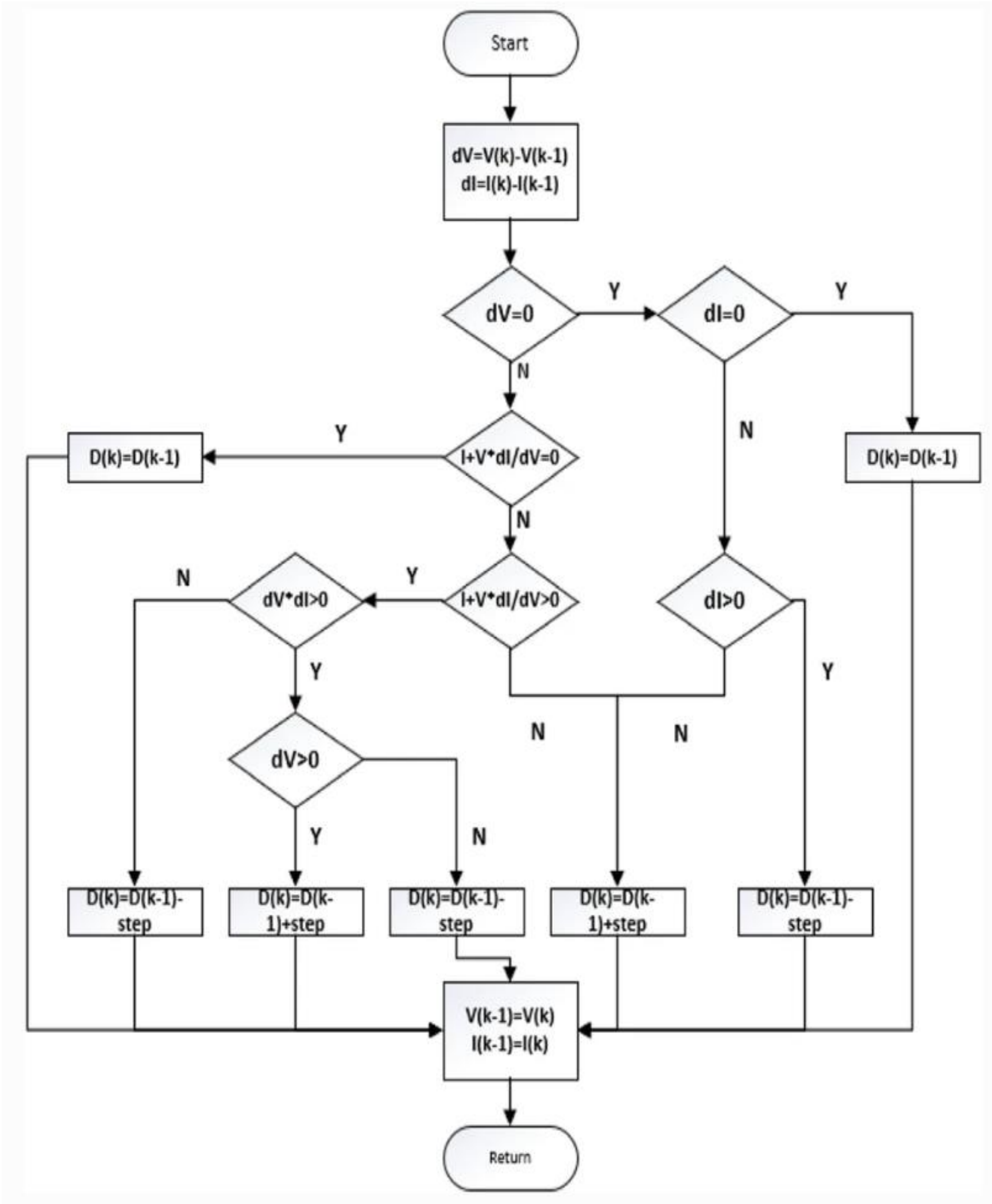


Figure 3.22:: Flowchart of Incremental Cost algorithm [source [40]]

3.4.1.3 Solar PV array system Model

Combining all above subcomponents, a subsystem for Solar PV array was able to model using MATLAB Simulink.

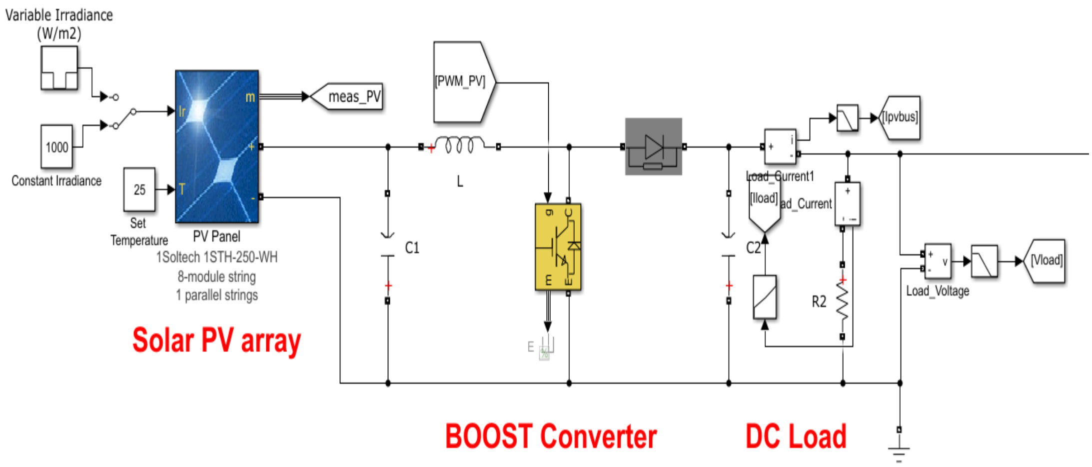


Figure 3.23: Simulink model of a Solar PV array configuration with a boost converter and an MPPT algorithm

3.4.2 AC-DC Bi-directional converter

Bi-directional AC-DC/DC-AC converter is used to control the active power transferred from the AC bus to DC bus and vice versa at unity power factor. These bi-directional converters are vital components of the network architecture as they support in maintaining the power quality of the system a reducing system instability. This converter compromises of converter, islanded mode controller circuit, grid-connected mode controller circuit, and LCL filter circuit.

The converter consist of $ IGBTs. A PWM switching signal is generated on control circuits of both modes (islanded mode and grid tied mode) to be in charge of the direction of power flow of the network.

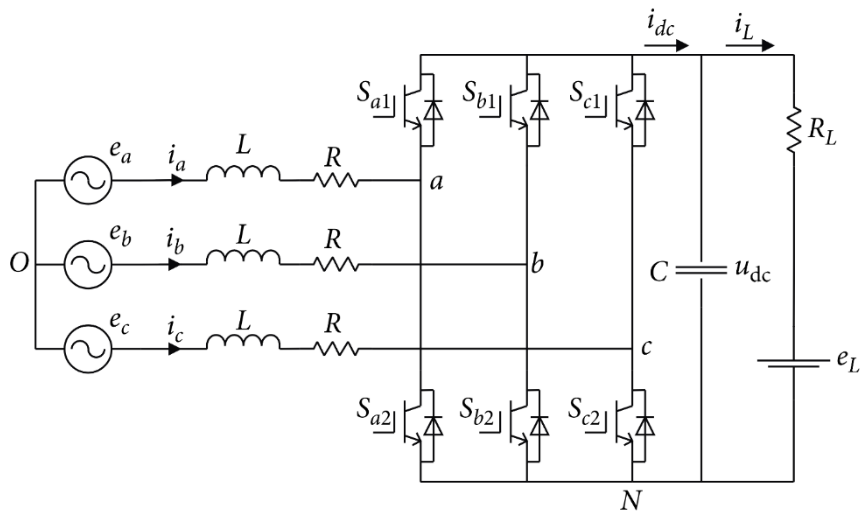


Figure 3.24:Schematic of a 3 phase AC-DC Bidirectional Converter

3.4.2.1 Islanded Mode

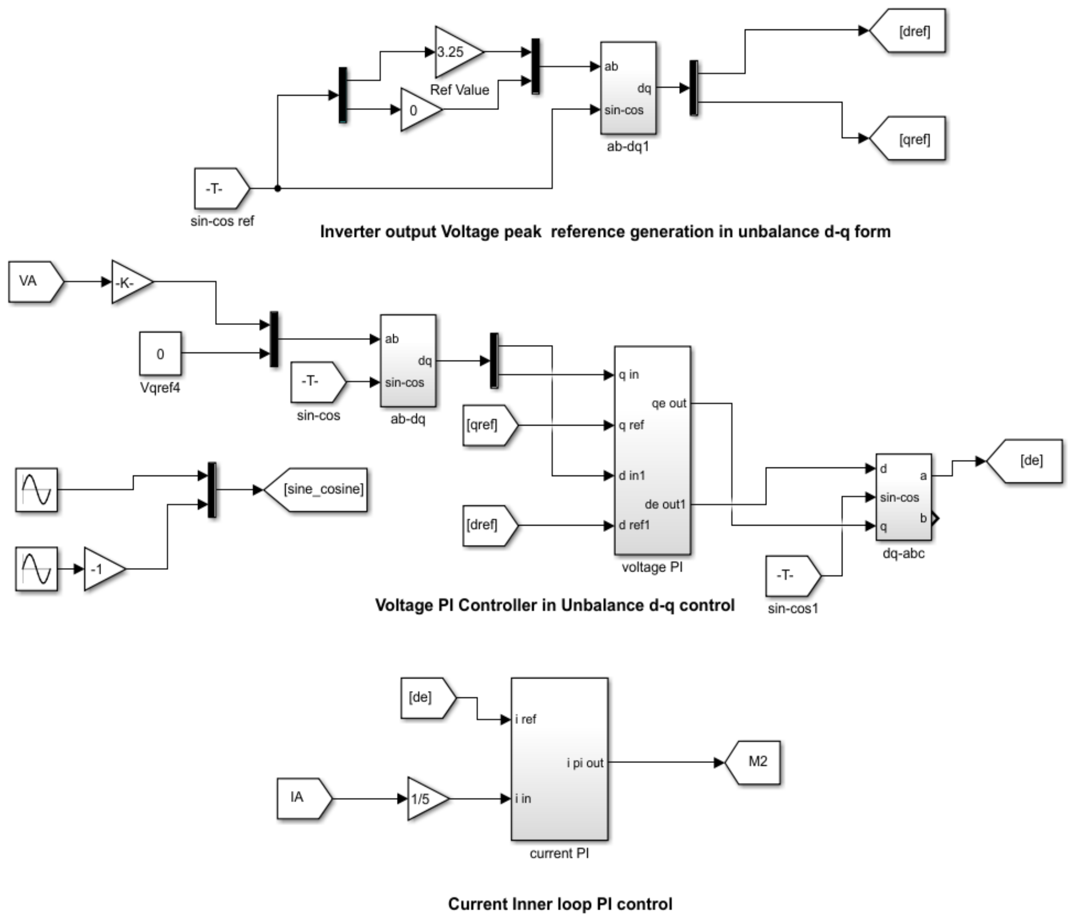


Figure 3.25:Inverter Control of Islanded Mode

Firstly, the sine and cosine waveforms need to be generated which would be an input to the ab-dq transformation (Park's transformation). This signal is used in both inverter output voltage peak reference generation and in the voltage PI controller. A reference phase voltage (load voltage) from the grid side is fed into the ab-dq transformation block in the voltage controller where the output is compared with the dq signals generated from the inverter output voltage peak generator. Then it is possible to obtain two output control signals in the form of d-axis and q-axis components. These control signals will be converted back to the phase components form via ab-dq transformation block. Control output signal will be fed into the current PI controller along with the grid side phase current (load current) as a second input reference. An output modulating signal can be obtained which is fed to the PWM generator to generate relevant switching signals for the converter islanded operation control mode.

3.4.2.2 Grid-connected mode

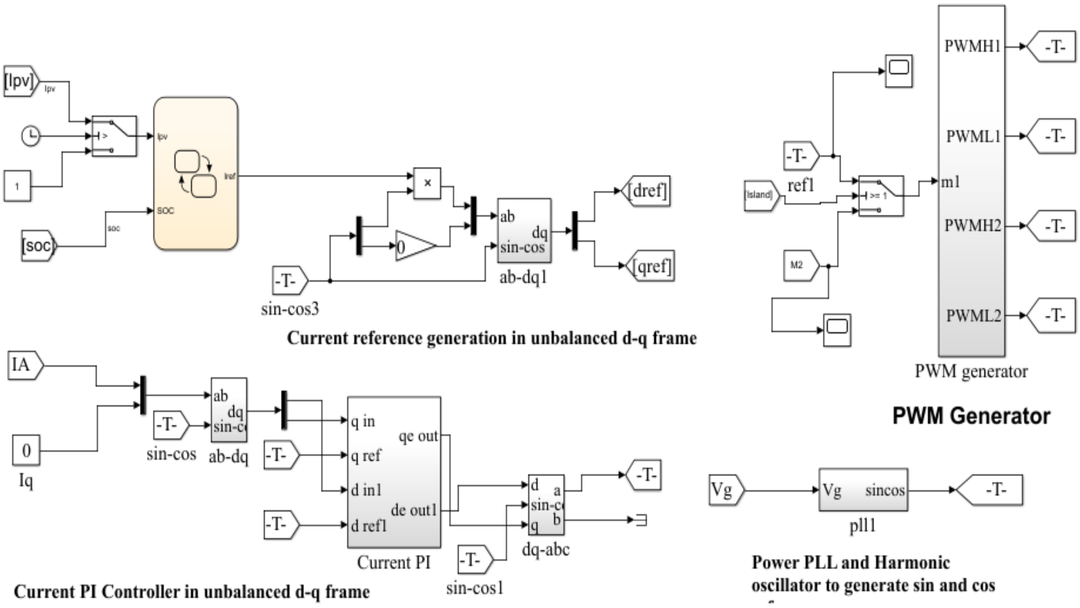


Figure 3.26: Inverter control of grid-connected mode

A State flow block in Simulink with PV output current and battery SOC as input criteria (states) is used to differentiate and determine the direction of power flow in the system during grid-connected mode.

Condition 1: IPV<0.5 AND SOC<10 – Power flow from the grid to the system

Condition 2: IPV>0.5 AND SOC>10 – Power flow from the system to the grid

In the case study model, it is programmed that if condition 1 is fulfilled, current with a magnitude of 10 will be flowing to the system from the grid (absorbing power). And if condition 2 is fulfilled, current with a magnitude of 2 will be flowing out of the system to the grid (injecting power).

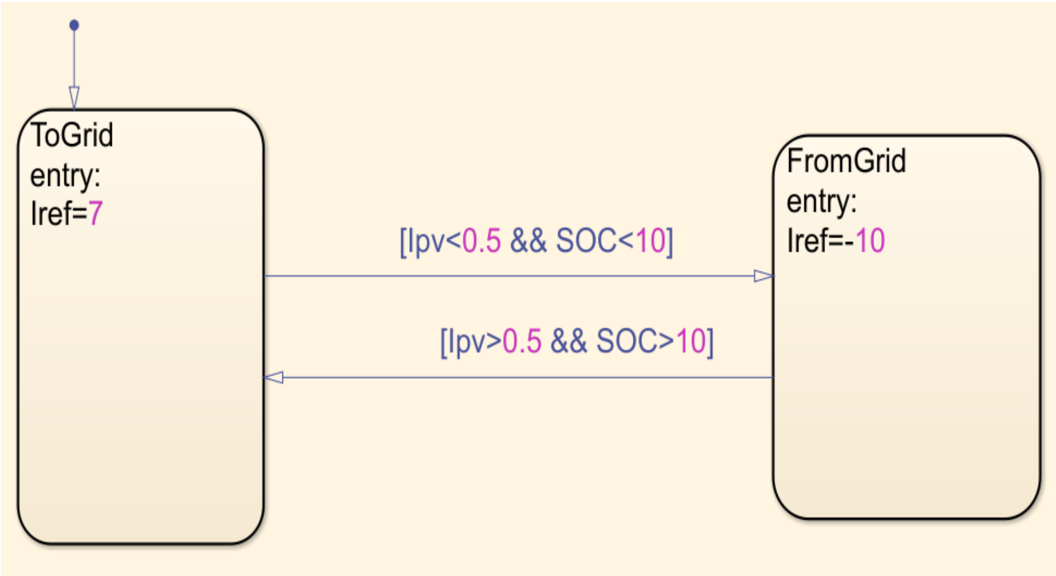


Figure 3.27: State flow diagram of system-grid power exchanging criteria

The output reference current magnitude needs to be converted to the sinusoidal form before inserting to the ab-dq transform of the current reference generator. Therefore, using a PLL block the grid voltage is converted to obtain “wt” component required for the sine and cosine waveforms. These sinusoidal waveforms are multiplied with output reference current magnitude that is to be fed into the ab-dq converter block in the current reference generator. The output values of reference dq components are used as inputs in the current PI controller along with the two other dq inputs obtained from the conversion of grid current (load current) to dq form. Then it is possible to obtain two output control signals in the form of d-axis and q-axis components from the PI controller. These control signals will be converted back to the phase components form via ab-dq transformation block. An output modulating signal can be obtained which is fed to the PWM generator to generate relevant switching signals for the converter grid-connected control mode.

3.4.2.3 LCL filter circuit

Harmonics results in decay of system voltage and reduction of the quality of power and performance of the system. These Harmonics are more likely to be created by the output waveforms of the inverter. Therefore LCL filters are used to reduce the effects of harmonics at the inverter.

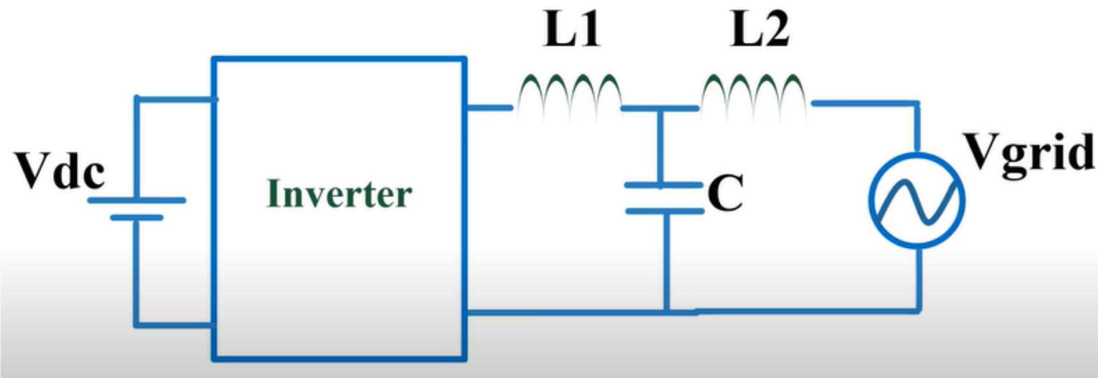


Figure 3.28: Inverter and LCL filter connection to the grid

The capacitor as in equation 3.33 was designed based on the reactive power absorbed at rated conditions. Reactive power absorbed by the capacitor is limited to 5% of rated power.

$$C = \frac{0.05S}{2\pi f V_{ac}^2} \tag{3.33}$$

The value of the inverter side inductor (L1) as in equation 3.34 was selected based on the maximum permissible ripple current. The current ripple should be limited to 20% of the rated current.

$$L_1 = \frac{V_{DC}}{4F_{sw}\Delta I_{ppmax}} \tag{3.34}$$

$$\Delta I_{ppmax} = \frac{0.15S}{V_{ac}} \tag{3.35}$$

$$L_2 = \frac{0.1V_{ac}^2}{2\pi f S} - L_1 \tag{3.36}$$

The total inductance (L1+L2) is selected based on the maximum voltage drop across the inductor. Maximum voltage drop is limited to 10% of the rated voltage

Design parameters then need to be verified by calculating the resonance frequency (Fres). It should satisfy 10f < Fres < 0.5Fsw.

$$F_{res} = \frac{1}{2\pi}\sqrt{\frac{L_1 + L_2}{L_1 L_2 C}} \tag{3.37}$$

Where,

C	=	Capacitance (μF)
L1	=	Grid side inductance (mH)
L2	=	Inverter side inductance (mH)
Fsw	=	Switching frequency (Hz)
Vac	=	Grid phase voltage (V)
f	=	Grid frequency (Hz)
S	=	Rated power (W)
ΔI_{ppmax}	=	Maximum permissible ripple current (A)
V_{DC}	=	DC bus voltage (V)
Fres	=	Resonance frequency (Hz)

The parameters of the developed model were computed using equations 3.33-3.37 using the below-mentioned data of the system.

Fsw	=	10000 Hz
Vac	=	230 V
f	=	50 Hz
S	=	2000 W
V_{DC}	=	400 V

The computer the resonance frequency of 3738 Hz value satisfy the condition of 10f < Fres < 0.5Fsw .Thus it was concluded that the chosen values are applicable to the design.

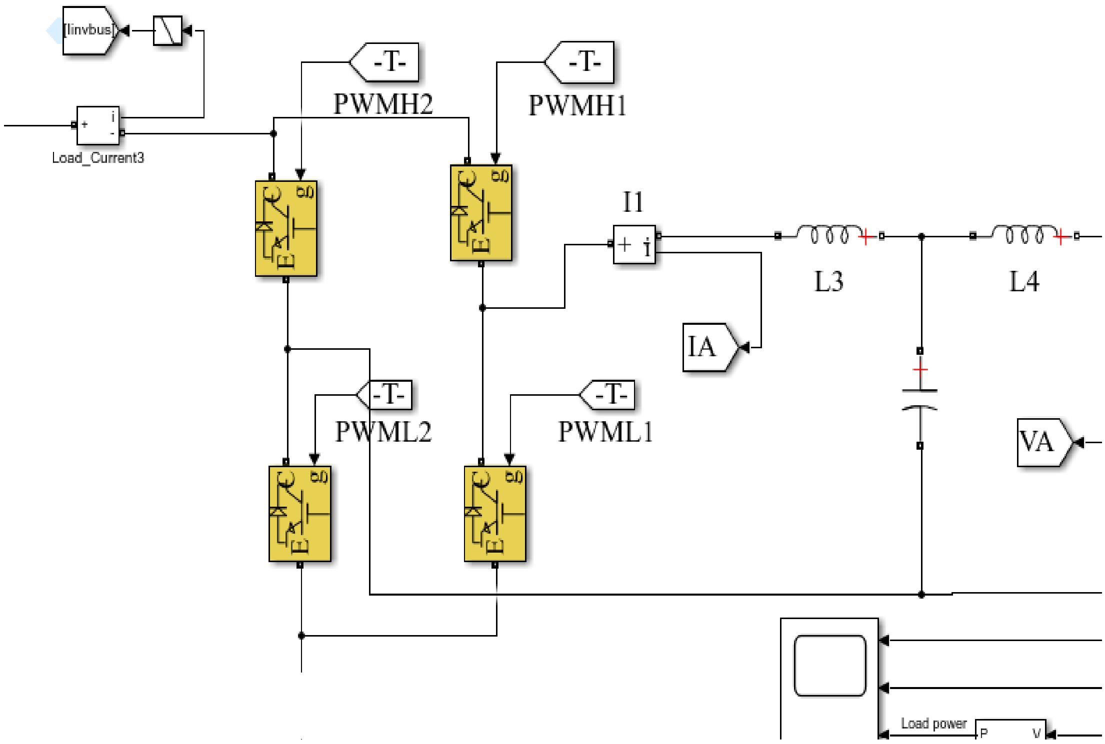


Figure 3.29: AC-DC bi-directional converter subsystem

3.4.3 Li-ion BESS

Lithium batteries are made up of positive and negative electrodes which are lithium cathode and carbon anode respectively. The energizing the rundown of these batteries happen through a series of chemical reactions that allow the energy to be gathered and stored. In this particular scenario this energy is created by reusable power sources. High discharging and charging efficiency which exceeds 90% on unit module level, modularity and high energy density are some of the most important technological features that the lithium cells consists for various energy related purposes.

Simulink library which consists of various popular generic battery models is the most appropriate method of modeling battery storage as it consists of inbuilt battery blocks. For Lithium-ion battery types features like aging due to cycling and temperature can be specified. A DC-DC two-way converter is connecting the BESS to the DC Bus. This converter is separately controlled by a voltage controller to satisfy the requirement of charging and discharging at the time of need

3.4.3.1 BESS

The parameters of the battery were fixed according to the used preference.

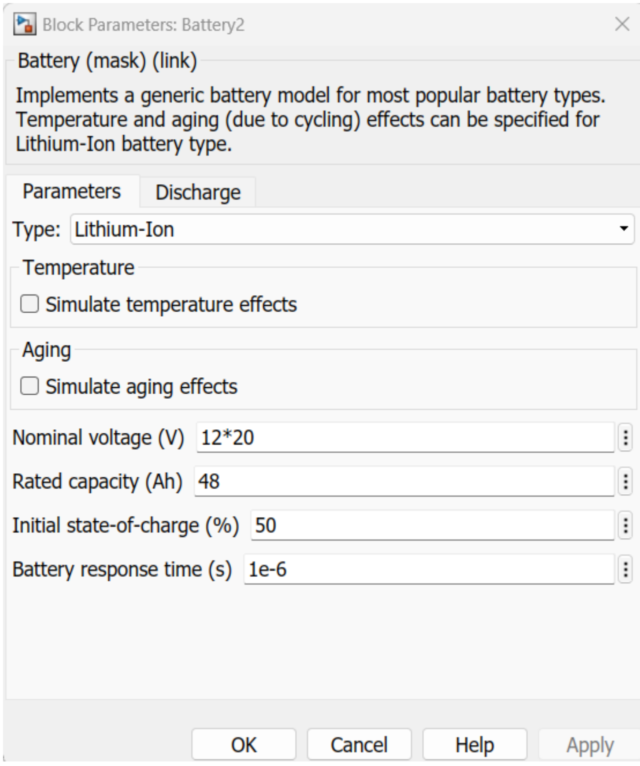


Figure 3.30: Parameter window of the battery block in Matlab Simulink

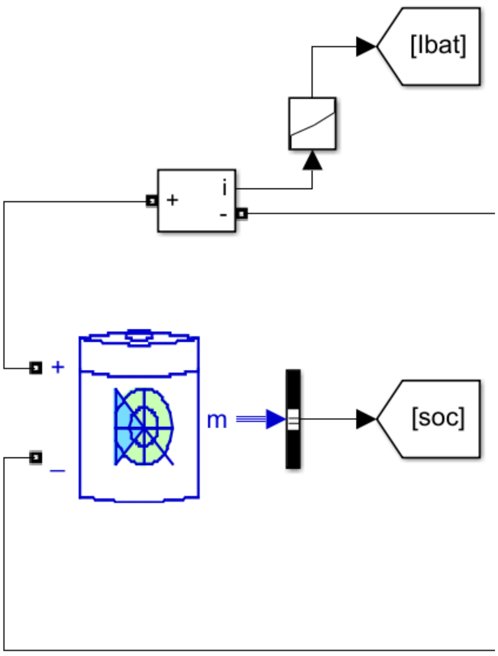


Figure 3.31: Model of BESS

3.4.3.2 DC-DC bi-directional converter

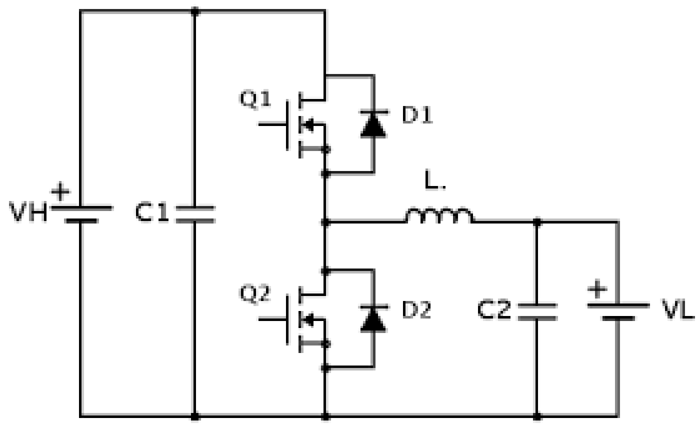


Figure 3.32: DC-DC bi-directional converter

Figure 3.31 portrays a circuit which performs bidirectional operation via switching between two MOSFETS Q1 and Q2 and anti-parallel diodes D1 and D2. The diodes behave as freewheeling diodes in the circuits resulting in step up and down of voltage across them. The performance of this circuit can be categorized into two modes.

<u>Mode 1</u>

This mode can be considered as the boost mode where Q2 and DI initiated conduction in according to a duty cycle. According to the conduction of the switch the mode can be divided into two intervals.

Interval 1(Q2-on, D2-off; Q1-off, D2-Off): When the switch Q2 is on it can be considered as short circuited. Therefore, the voltage reduces and battery charges the inductor and thereby the current increases till the gate pulse is separated from Q2. As D1 is reversed biased and Q1 is off, current does not flow through Q1.

Interval 2 (Q1-off, D1-off; Q2-off, D2-on): The circuit can be considered as an open circuit since both Q1 and Q2 are off. The polarity of the voltage across the inductor reverses as the current is flowing into the inductor doesn't vary quickly. Thus, it acts in series with input voltage and thus D1 is forward biases. The inductor charges the capacitor C2 resulting a voltage boost.

Mode 2

This mode can be referred as buck mode. The switch Q1 and D2 conduction depends on the duty cycle and Q2 and D1 are off throughout the time. There are two intervals of conductance.

Interval 1 (Q2-on, D2-off; Q1-off, D2-Off): The higher voltage battery will charge the inductor and capacitor as Q1 and Q2 are off.

Interval 2 (Q1-off, D1-off; Q2-off, D2-on): Q1and Q2 are switched off and the inductor current is discharged via the diode D2 as it does not change quickly. The voltage across the load is reduced.

$$\Delta V_o = 0.01 V_o \tag{3.38}$$

$$\Delta I_L = 0.01 \frac{P}{V_d} \tag{3.39}$$

$$D = 1 - \left(\frac{V_d}{V_o}\right) \tag{3.40}$$

$$L = \frac{V_d (V_o - V_d)}{\Delta I_L f_s V_o} \tag{3.41}$$

$$C = \frac{DP}{V_o f_s \Delta V_o} \tag{3.42}$$

Where,

P	=	Power generated from Solar PV
V_d	=	Input Voltage to the Boost Converter
V_o	=	Output Voltage of the Boost Converter
f_s	=	Switching frequency
D	=	Duty Factor
L	=	Inductance
C	=	Smoothing Capacitance
ΔV_o	=	Output ripple voltage
ΔI_L	=	Input ripple current

Using equations 3.38-3.42 the computation of the design parameters of a DC-DC bi-directional converter was done.

3.4.3.3 Voltage Controller

This compares the DC bus voltage with the reference voltage, and it generates a duty cycle via the PI controller. The duty cycle is then used to generate the PWM switching signal to be fed to the IGBTs in the DC-DC bi-directional converter.

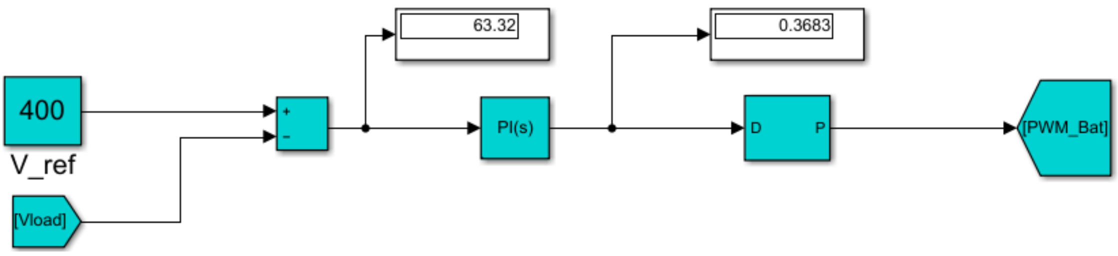


Figure 3.33: Voltage controller for DC-DC Bi-directional converter model

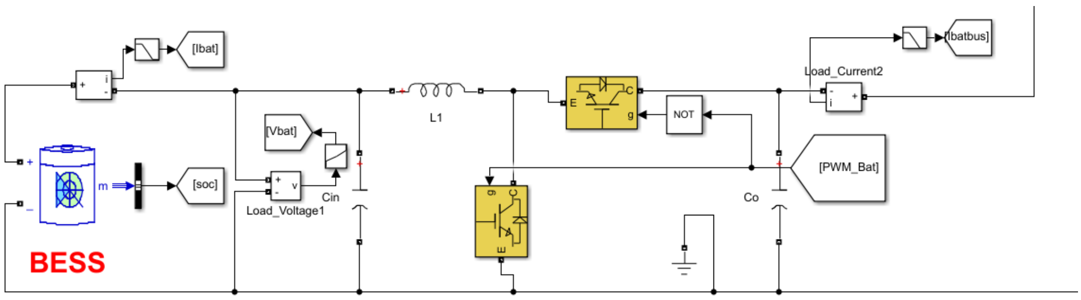
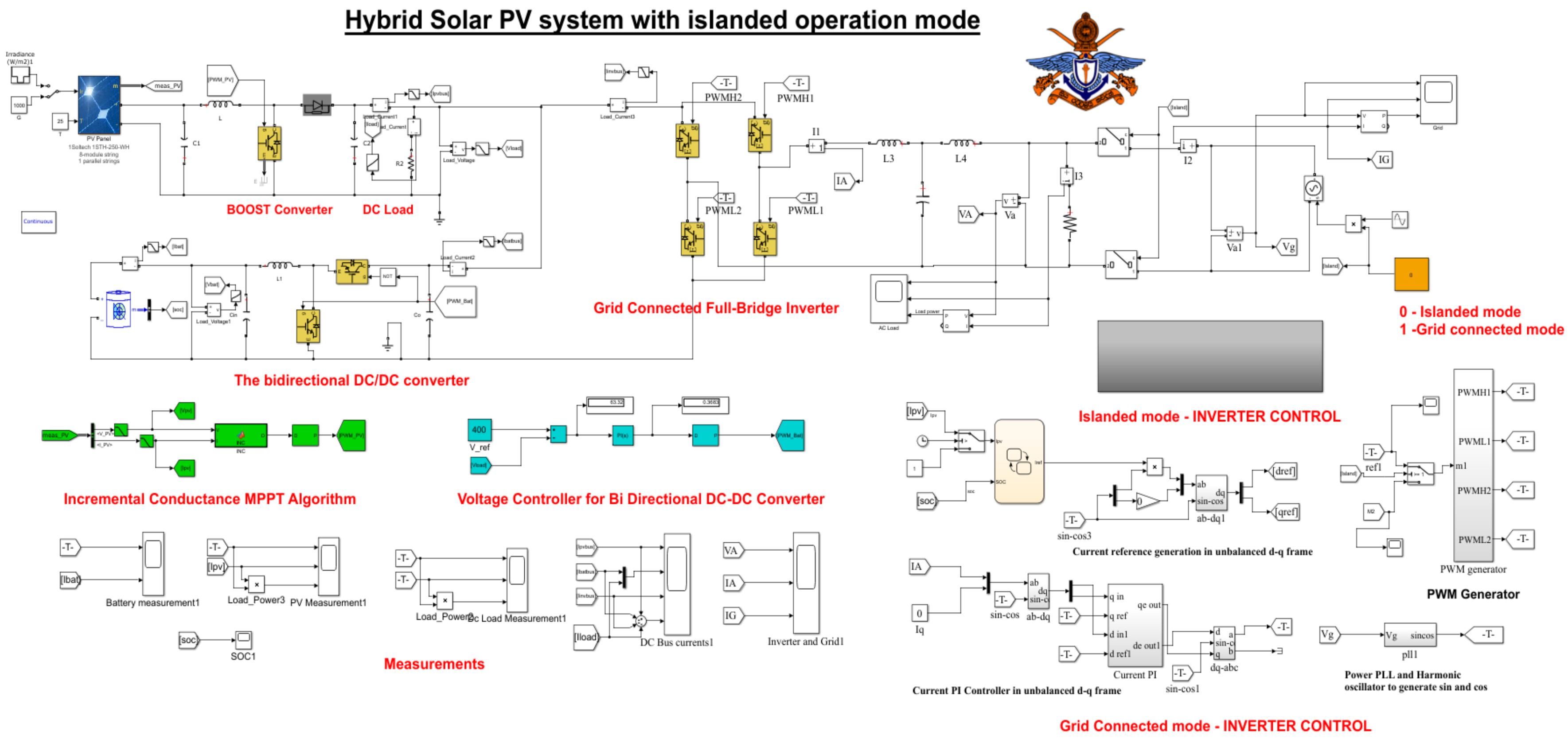


Figure 3.34: BESS with DC-DC bi-directional converter subsystem

3.5 Model of Hybrid Solar PV system with the capability of islanded operation

Once the subsystems were combined, the model shown in figure 3.34 was obtained. Grid-connected mode and the islanded mode can be toggled by changing the constant value to '1' and '0' respectively to operate the switchgear accordingly.

Figure 3.35 : Model of the proposed system in Matlab Simulink



3.6 Analysis of Energy Economics

The study to identify the feasibility and practicality of the proposed Hybrid Solar PV system with the capability of achieving the islanded operation mode during a power outage is required to establish the significance of this system compared to the already installed system. Thus, energy economic analyses were conducted to analyze the monetary benefits of the proposed system while achieving the main objective of ensuring a continuous supply of electricity during outages. A constructive analysis is necessary to identify the distinct impacts made by incorporating battery energy systems along with a solar plant in place of commonly used diesel generators.

Essentially this analysis is based on a computation of cost, gains, and benefits obtained over years in monetary terms. Subsequently, a comprehensive comparison between the gains and the costs will acknowledge the appropriateness of the proposed design.

The components of the design were computed according to two cases which were identified through the worst-case scenarios that could occur in the power system. The analysis of energy economics was done per these case studies to maintain the efficiency and reliability of the system. Peak shaving is considered in some scenarios to determine the profitability compared to just utilizing the batteries for outages

3.6.1 Estimation of Capital costs

The investment cost or the capital cost which means the initial expenses of the design, engineering, purchases, construction, and installation exclusive of the sunk costs of the proposed design under each case study were computed using the existing prices of the components in the market. The total cost of investment comprises the following key expenses.

1. Component costs
2. Shipping costs & taxes
3. Installation costs
4. Replacement costs

The capital cost calculation was conducted by considering the following estimations.

- 10% of Solar & Inverter component costs and 15% of the battery component costs are considered Shipping costs
- 15% of the total component cost is considered the installation cost of the system
- The replacement cost for each component is considered 25% of their component cost.

3.6.1.1 Analysis of Capital cost of Cases study 1

Case study 1 analyzes the capacities of components required to compensate for the power supply during a 2-hour power outage during sun peak hours. Subcase A analyzes the capital cost of the proposed system which can compensate for the load with Solar PV generation and battery. The remainder of Solar power is assumed to be exported to the grid. Subcase B analyzes the compensation of load solely by the existing diesel generation thus subcase B does not incur a capital cost for the generator. Subcase C investigates the capital cost incurred in meeting the load partially by battery and diesel generator. Computed capital costs in Table 3.10 and Table 3.11 depicts that subcase A requires a higher investment than subcase C as the batteries solely meet the required demand.

Table 3.11: Capital Cost analysis of Case study 1- Subcase A & B

Capital Costs for Case 1	**Sub Cases A & B**					
1. System Components cost	**Outage + peak shaving**			**Only outage**		
Solar PV panels	3487	$114.45	$399,087.15	3487	$114.45	$399,087.15
Battery	62	$2,800.00	$173,600.00	45	$2,800.00	$126,000.00
Inverter	18	$20,400.00	$367,200.00	18	$20,400.00	$367,200.00
Total Component Cost			$939,887.15			$892,287.15
2. Shipping Cost (10% and 15% from batt)			$102,668.72			$95,528.72
3. Installation Cost (15%)			$140,983.07			$133,843.07
4. Replacement Cost (25% battery + 25% other components)			$234,971.79			$223,071.79
Total Investment Cost			**$1,418,511.00**			**$1,344,731.00**

Table 3.12: Cost Analysis of Case study 1-Subcase C

Capital Costs for Case 1	**Sub Case C**		
1. System Components cost	**Only Outage**		
Solar PV panels	3487	$114.45	$399,087.15
Battery	26	$2,800.00	$72,800.00
Inverter	18	$20,400.00	$367,200.00
Total Component Cost			$839,087.15
2. Shipping Cost (10% and 15% from batt)			$83,908.72
3. Installation Cost (15%)			$125,863.07
4. Replacement Cost (25% battery + 25% other components)			$209,771.79
Total Investment Cost			**$1,258,631.00**

3.6.1.2 Analysis of Capital cost of Cases study 2

Case Study 2 investigates the compensation of load during an outage in off-sun peak hours. The computed Cost summaries are depicted in table 3.12.

Table 3.13: Cost Analysis of Case study 2

Capital Costs for Case 2	**Sub Cases A & B**			**Sub Case C**		
1. System Components cost	**Only Outage (peak shave included)**			**Only Outage**		
Solar PV panels	3487	$114.45	$399,087.15	3487	$114.45	$399,087.15
Battery	142	$2,800.00	$397,600.00	73	$2,800.00	$204,400.00
Inverter	18	$20,400.00	$367,200.00	18	$20,400.00	$367,200.00
Total Component Cost			$1,163,887.15			$970,687.15
2. Shipping Cost (10% and 15% from batt)			$136,268.72			$97,068.72
3. Installation Cost (15%)			$174,583.07			$145,603.07
4. Replacement Cost (25% battery + 25% other components)			$290,971.79			$242,671.79
Total Investment Cost			**$1,765,711.00**			**$1,456,031.00**

3.6.2 Fuel consumption rates for Diesel Generators

Regardless of the ease of installation and usage of diesel generators which has brought higher demand as a source of standby power supply, the expensive fuel costs and adverse effects on the environment make it unsuitable for continual usage. Even though renewable energy alternative systems can be introduced as environmentally friendly power generators, the economic viability of such systems compared to diesel generators is quite impactful in establishing clean energy power systems.

The installation of the proposed Hybrid solar PV system for UHKDU should be an economical alternative to the already installed diesel generator for this design to be a success. Thus, an economic comparison with the Li-ion battery storage was done using the Levelized cost of energy. To calculate the LCOE of generator output it is necessary to identify the performance of the existing diesel generator in the facility.

The manufacturing data sheet was analyzed and the fuel consumption rates of various loadings were found with respective efficiencies. Under different loadings, the efficiency of the generator tends to vary proving and proportional relation between loading and efficiency.

UHKDU consists of four 1800kW installed units. Thus, the shared loading conditions during an outage were investigated. It was identified that 2 Diesel generators are operational during islanded operation whereas 2 Diesel generators are on standby. The 2 operating Diesel generators are programmed such that only 1 Diesel generator will start serving the load until 30% of its rated capacity is exceeded and then the 2nd generator will start to share the load. Thus, when the load serving is greater than the 540 kW (1800 x 30%) a 2nd generator is energized to share the load.

The characteristics of fuel consumption of the site were determined by plotting a graph and data was obtained by analyzing the graph. Figure 3.35 depicts the characteristic curve of fuel consumption of generators at UHKDU. Even though the curve is portrayed as a straight line, it is a polynomial trendline that suits best under precise observation. Therefore, the trendline equation for fuel consumption rate can be considered as in equation 3.43,

$$Fuel\ Consumed\ (L/hr) = 0.0000281x^2 + 0.193x + 56.5 \qquad (3.43)$$

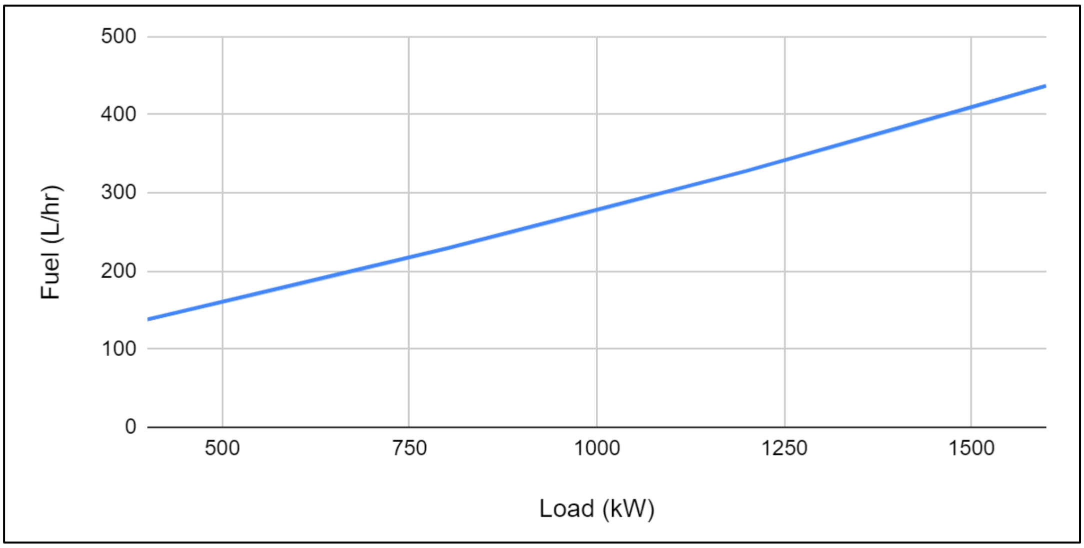


Figure 3.36: Fuel Consumption Rate

3.6.3 Tariffs

The renewable energy producers are paid for each energy unit injected into the grid under the Feed-in-tariffs. Different rates may be applied under different tariff schemes depending on the size of the system. For certain electricity providers a process called "Competitive bidding "is carried out to determine an offer for the excess generation that will be exported to the grid.

OTHER CONSUMER CATEGORIES			Industrial		General Purpose / Hotel / Government	
			IP 1-1	IP 1-2	GP 1-1 / H 1-1 / GV 1-1	GP 1-2 / H 1-2 / GV 1-2
Rate 1 Supply at 400/230V Contract demand <= 42kVA	Volume differentiated monthly consumption		*For ≤ 300 kWh/ month*	*For > 300 kWh/month*	*For ≤ 180 kWh/ month*	*For > 180 kWh/ month*
	Energy Charge (Rs. /kWh)		20.00	20.00	25.00	32.00
	Fixed Charge (Rs. /Month)		960.00	1500.00	360.00	1500.00
Rate 2 Supply at 400/230V Contract demand > 42 kVA	Energy Charge (Rs. /kWh)	Day (05:30 – 18:30 hrs)	29.00			
		Peak (18:30 – 22:30 hrs)	34.50			
		Off Peak (22:30 – 05:30 hrs)	15.00			
	Demand Charge (Rs. /kVA)		1500.00			
	Fixed Charge (Rs. /Month)		4000.00			
Rate 3 Supply at 11 kV & above	Energy Charge (Rs. /kWh)	Day (05:30 – 18:30 hrs)	28.00			
		Peak (18:30 – 22:30 hrs)	34.00			
		Off Peak (22:30 – 05:30 hrs)	14.00			
	Demand Charge (Rs. /kVA)		1400.00			
	Fixed Charge (Rs. /Month)		4000.00			
STREET LIGHTING (Rs. /kWh)			22.00			

Figure 3.37:Tariff Structure in Sri Lanka [Source [3]]

3.6.4 LCOE (Levelized Cost of Energy)

The Levelized Cost of energy or levelized energy cost is a measurement used to analyze and compare the methods of energy production. The LOCE of an energy source can be studied as a summation of expenses of installing and operating the source per unit of the total energy produced over an estimated lifetime. Subsequently, the LCOE can be referred to as the average minimum cost where the electricity produced is required to be sold to compensate for the total cost of production during its lifetime. Thus, the summarized LCOE of each case study of the proposed system will determine the suitable system which will be the most worthwhile venture. This can be considered as a metric that will determine if the proposed system will be profitable or reach the breakeven point.

Equation 3.44 shows the fundamental formula to calculate the LCOE. Yet the simplified equations 3.45 -3.46 could be used to calculate the LCOE of each component.

$$Levelized\ Cost\ Of\ Energy = \frac{Present\ Value\ of\ total\ cost\ over\ the\ project\ lifetime}{Present\ Value\ of\ total\ electricity\ produced\ over\ the\ project\ lifetime} \tag{3.44}$$

$$LCOE\ of\ solar\ PV\ system = \frac{PC - CBI + \sum_{j=1}^{n}\left(\frac{\left(M(1+r)^j + F\right)\times(1+i)^j}{(1+d)^j}\right)}{\sum_{j=1}^{n}\left(\frac{(1+i)^j}{(1+d)^j}\times Q_o(1-\delta)^j\right)} \tag{3.45}$$

$$LCOE\ of\ Battery\ or\ DG = \frac{PC - CBI + \sum_{j=1}^{n}\left(\frac{\left(M(1+r)^j + F\right)\times(1+i)^j}{(1+d)^j}\right)}{\sum_{j=1}^{n}\left(\frac{(1+i)^j}{(1+d)^j}\times Q_o\right)} \tag{3.46}$$

Where,

M	=	Operation & Maintenance Cost ($)
F	=	Fuel Consumption cost ($/L)
r	=	Growth rate (%)
d	=	Discount rate (%)
i	=	Inflation rate (%)

j	=	Year
n	=	Project lifetime (years)
Q_o	=	Initial annual electricity output (kWh)
δ	=	Duration rate (%)
PC	=	Project Cost ($)
CBI	=	Cost-Based Incentives ($)

Computation of LCOE was conducted in accordance with each case study for a lifetime of 25 years using constants mentioned below,

r	=	2 %
d	=	8 %
i	=	3 %
n	=	25 years
δ	=	0.55%
CBI	=	0

<u>Case study 1</u>

An outage of 2 hours during the daytime (during sun peak hours). 2 hours is considered to be 11:30 – 13:30 hours, which was obtained from the daily load profile where the demand is maximum during the day.

Considering scenarios where not only the demand is met during an outage but also peak shaving is performed on normal days

I. **Sub Case A:** LCOE for Battery

Load is compensated with Solar PV generation & Battery Energy. Peak shaving is performed on normal days without power outages.

PC	=	$260,000
F	=	$0
M	=	$694.40
Q_o	=	325228.80 kWh

From equation 3.46,

NPV of total costs = $271,638.33

NPV of total energy output = 4651416.16 kWh

Levelized Cost of Energy for Sub Case A= 0.058 $/kWh

Considerations:

- Total replacement & installation cost = 50% of component cost
- O&M cost is considered as 10% of investment cost due to continuous cooling and operational conditions
- Assuming there is no O&M cost during the first year

II. **Sub Case B:** LCOE for Diesel Generator

Load is compensated with Solar PV generation & Diesel Generator. The remainder of solar generation will be exported when the outage is restored.

PC	=	$0
F	=	$218666.44
M	=	$2000.00
Q_o	=	325228.80 kWh

From equation 3.46,

NPV of total costs = $3,162,286.58

NPV of total energy output = 4651416.16 kWh

Levelized Cost of Energy for Sub Case B = 0.680 $/kWh

The fuel consumption calculations were conducted using equation 3.43 considering whether the maximum load demand is less than or greater than 540 kW. In this subcase since the peak load demand is less than 540 kW, the load is not being shared by the two operating units. Therefore, the total fuel consumption was computed as 502 liters.

Considering the Subcases which only compensate for the demand during a power outage.

I. **Sub Case A:** LCOE for Battery

Load is compensated with Solar PV generation & Battery Energy. Peak shaving is not performed on normal days.

PC	=	\$115,750.00
F	=	\$0
M	=	\$124.60
Q_o	=	22844.97 kWh

From equations 3.46,

NPV of total costs = \$157,766.56

NPV of total energy output = 326728.29 kWh

Levelized Cost of Energy for Sub Case A (Power Outage Only) = 0.483 \$/kWh

Considerations:

- Total replacement & installation cost = 25% of component cost
- O&M cost is 2% of the Investment cost
- Assuming there is no O&M cost during the first year

II. **Sub Case B:** LCOE for DG

Load is compensated with Solar PV generation & Diesel Generator. The remainder of solar generation will be exported when the outage is restored. The computed total fuel consumption of subcase B is 340 Liters.

PC	=	\$0
F	=	\$14,614.24
M	=	\$400.00
Q_o	=	19604.15 kWh

From equation 3.46,

NPV of total costs = \$215,997.18

NPV of total energy output = 280378.26 kWh

Levelized Cost of Energy for Sub Case B (Power Outage Only) = 0.770 $/kWh

III. **Sub Case C:** LCOE for Battery & Diesel Generator

Load is compensated with Solar PV generation & partial Battery Energy and partial Diesel Generator. The remainder of solar generation will be exported when the outage is restored. The computed total fuel consumption is 192 Liters.

PC	=	\$91,000.00
F	=	\$8272.58
M	=	\$582.00
Q_o	=	23174.49 kWh

From equation 3.46,

NPV of total costs = \$219,476.92

NPV of total energy output = 283783.30 kWh

Levelized Cost of Energy for Sub Case C (Power Outage Only) = 0.773 $/kWh

<u>Case study 2</u>

An outage of 1 hour during the remainder of the day (excluding sun peak hours). 1 hour is considered to be 15:30 – 16:30 hours, which was obtained from the daily load profile where the demand is maximum during the remainder of the day (excluding the period considered in case study 1).

I. **Sub Case A:** LCOE for Battery

Load is compensated with only Battery Energy. The remainder of solar generation will be exported when the outage is restored.

PC	=	\$596,400.00
F	=	\$0

M	=	$2385.60
Q_o	=	745660.58 kWh

From equation 3.46,

NPV of total costs = $596,400.00

NPV of total energy output = 10664423.60 kWh

Levelized Cost of Energy for Sub Case A = 0.057 $/kWh

Considerations:

- Battery sized for an outage is sufficient for peak shaving and it is assumed to peak shaving is done on the day outages don't occur.
- Total replacement & installation cost = 50% of component cost
- O&M cost is considered as 10% of investment cost due to continuous cooling and operational conditions
- Assuming there is no O&M cost during the first year

II. **Sub Case B:** LCOE for DG

Load is compensated with only Diesel Generator. The remainder of solar generation will be exported when the outage is restored. The total fuel consumed is 477 Liters.

PC	=	$0
F	=	$20,526.60
M	=	$1200.00
Q_o	=	63111.49 kWh

From equation 3.46,

NPV of total costs = $327,731.34

NPV of total energy output = 902619.31 kWh

Levelized Cost of Energy for Sub Case B= 0.363 $/kWh

III. **Sub Case C:** LCOE for Battery & Diesel Generator

The load is compensated with partial Battery Energy and partial Diesel Generator. The remainder of solar generation will be exported when the outage is restored. The total fuel consumed is 477 Liters.

PC = \$255,500.00

F = \$20,526.60

M = \$711.00

Q_o = 396415.52 kWh

From equation 3.46,

NPV of total costs = \$559,356.76

NPV of total energy output = 5669527.37 kWh

Levelized Cost of Energy for Sub Case C= 0.099 $/kWh

The levelized Cost of Energy for Solar PV was computed using equation 3.45.

PC = \$698,402.51

F = \$0

M = \$4190.42

Q_o = 3018269.00 kWh

Therefore,

NPV of total costs = \$766,211.16

NPV of total energy output = 42939442.26 kWh

Levelized Cost of Energy for Solar PV = 0.018 $/kWh

3.6.5 Cost Analysis

The performance of cost analysis consists of the conclusion of the economic analysis with comparisons of LCOE for battery storage and DG output for several scenarios analyzed previously. Thus, acknowledgment of the optimum battery storage capacity, its monetary benefits, and thereby the feasibility of the proposed hybrid Solar PV system will be done.

The cost analysis was conducted for each case where each LCOE was compared against the net cost incurred per month, net income, savings, the payback period for the project investment, and profits gained over the project lifespan after the break-even margin. The monthly energy consumption, costs incurred during an outage day, costs incurred during a normal day, and total income obtained exporting solar PV generation were calculated before computing the aforementioned criteria.

The monthly electricity charges were computed using equation 3.47. Thus, expense consists of the unit charges of consumed electricity from the grid, the Maximum demand charges of the customer, and the fixed charges per consumed unit of electricity. The unit charges were calculated using equation 3.48, separately for outage days and normal days, and the summation to obtain the total monthly unit consumption charges was investigated.

The net cost incurred per month, as in equation 3.48, is comprised of total cost per day on both normal and on a day with an outage, fixed charges, and maximum demand charges. The net income of each subcase as shown in equation 3.49 were then computed using the total Solar power exported under feed-in-tariff of 0.096$/kWh.

Parameters such as inflation rate, discount rate, and operational and maintenance cost rate were considered as 3%,8%, and 2% respectively. The inflation rate is the rise of costs of components and 3% was considered as it is considered to result in economic growth in accordance with Consumer Price Index (CPI). The discount rate is used to identify the future cash flows regarding the current capital cost of the investment and 8% is considered a nominal rate [42]. The operational and maintenance cost rate usually may vary to 10% but 2% was considered according to the Homer software. It was assumed that there is no O&M cost for the first year of battery.

$$Monthly\ Electricity\ Charges = Unit\ charges + Max.Demand\ charges + Fixed\ charges \tag{3.47}$$

$$UC = \Big(\big(P_{o1} + P_{battery}\big)T_{op} + P_{o2}T_d + P_{o3}T_p\Big)n + \Big(\big(P_{n1} + P_{battery}\big)T_{op} + P_{n2}T_d + P_{o3}T_p\Big)(30 - n) \tag{3.48}$$

$$Nett\ Cost\ estimated\ per\ month = (LCOE_{PV}P_{PV} + LCOE_{batt}P_{batt} + LCOE_{DG}P_{DG}) + EC \tag{3.49}$$

$$Nett\ Income\ per\ month = (P_{PV} - P_{PVused})T_{PV} \tag{3.50}$$

$$Savings\ per\ month = Usual\ Cost - Nett\ Estimated\ Cost + Nett\ Income \tag{3.51}$$

$$Payback\ Period = \frac{Total\ Investment\ Cost}{(Savings\ per\ year)} \tag{3.52}$$

$$Profits\ over\ the\ project\ lifespan = (Project\ lifespan - Payback\ period) \times Savings\ per\ year \tag{3.54}$$

EC	=	Electricity Charge
UC	=	Unit Consumption Charge
Pmax	=	Maximum Demand (kVA)
D	=	Demand Charge ($/kVA)
FC	=	Fixed Charges
Po1	=	Off-peak units consumed during an outage day
Po2	=	Daytime units consumed during an outage day
Po3	=	Peak units consumed during an outage day
Pbatt	=	Units consumed to charge the battery
Pn1		Off-peak units consumed during a normal day
Pn2		Daytime units consumed during a normal day

Pop	Average off-peak unit consumption
Pd	Average daytime unit consumption
Pp	Average peak unit consumption
Ppv	Units generated by the solar PV array
Top	Off-peak tariff rate
Td	Daytime tariff rate
Tp	Peak tariff rate
N	Outage occurrence (days)
Tpv	Feed-in-tariff

3.7 Optimization of design configurations for the Hybrid Solar PV system

3.7.1 Introduction to Techno-Economic Analysis

The economic analysis is done both manually and by use of computerized software. On further research Homer pro Software has taken its place to give the most feasible economic outputs of a Hybrid solar PV system. With these facts meeting an outcome, HOMER Pro software is selected for the project to carry out the economic analysis automatedly.

Homer Pro software is used to perform various functions such as simulation, optimization, net present cost (NPC), loss of power supply probability (LPSL), and sensitivity analysis all automatedly with the HOMER optimization.

Here by using the HOMER pro software for the economic analysis the foremost factors which contribute to an optimum economical outcome are outlined. The generation of the reports with regard to different combinations of the Hybrid solar PV system and obtained optimum economically feasible system on the basis of minimum net present cost (NPC), the design cost of the hybrid system included the costs for initial capital, replacement, Operation and Maintenance costs, salvage and interest spent on project lifetime. With all the factors into consideration, it can be established that the most economical and feasible hybrid system can be installed to get the maximum optimum results possible.

3.7.2 Introduction to HOMER Pro Software

The HOMER Pro software by Homer energy is the global standard for optimizing microgrid design in all energy sectors. From residential houses and island utilities to grid-connected campuses and military bases the designing and optimization using HOMER Pro software can be done. Homer Pro or HOMER (Hybrid Optimization of Multiple Electric Renewables) simplifies the tasks of evaluating designs for both off-grid and grid-connected power systems.

When designing the power system, one must make many decisions and configurations with regard to the whole power system such as

- Choosing The best components that suit best for the system
- Identifying and having a count on the number of components needed and the sizing of the components which is the most efficient has to be identified independently.

A large number of technological options, different variations in costs, and the availability of energy resources make these decisions difficult. Therefore, if these criteria can be done automatedly, various tasks can be completed in very less time and with more efficiency.

3.7.2.1 Operation of Homer Software

Homer pro software simulates power systems, shows system configurations optimized by costs, and provides accurate sensitive analysis according to the inputs given by the user. Below are the basic main components of the interface of the homer pro software

1. Simulation

The simulation process carried out by Homer pro software is done by performing energy balancing calculations for each time step of the year. Homer identifies the energy flow to and out of the system components for each time step criterion by comparing the electrical and thermal demand. In systems with gasoline/fuel-powered generators or batteries, the built-in Simulation capability of HOMER can determine how to run and what time period the generators should run, also it can determine when to charge the battery and when it should be discharged. Here Homer itself has a built-in Algorithm for this process such that the task can be done in the most efficient way. The battery or generator needs to be powered up by the use of setting a control strategy.

For each system configuration that is taken into consideration, HOMER itself simulates the specified inputs given by the user. Here Homer gives a set of various outputs for different configuration levels based on the cost of installing and maintaining the project to the specified lifespan. Here the costs include Capital costs, Replacement costs, Operation and Maintenance costs, Fuel costs, and the interest and inflation rates are taken in the system cost calculations

2. Optimization

In HOMER Pro software, there are 2 types of optimization algorithms. By using the original grid search techniques all of the conceivable systems configurations are specified by the search space. To find the least expensive system, which Homer itself gives it in its configurations. Following with regard to that Homer presents a list of configurations that the user can use to contrast different system design possibilities, organized by net present cost (This is also called Cycle cost)

3. Sensitivity Analysis

HOMER continues the optimization procedure for each sensitivity variable that the user defines sensitivity variables as input. For instance, HOMER replicates system configurations for the range of wind speeds that can be selected if the wind speed as a sensitivity variable is included.

4. HOMER Pro Software Design Interface

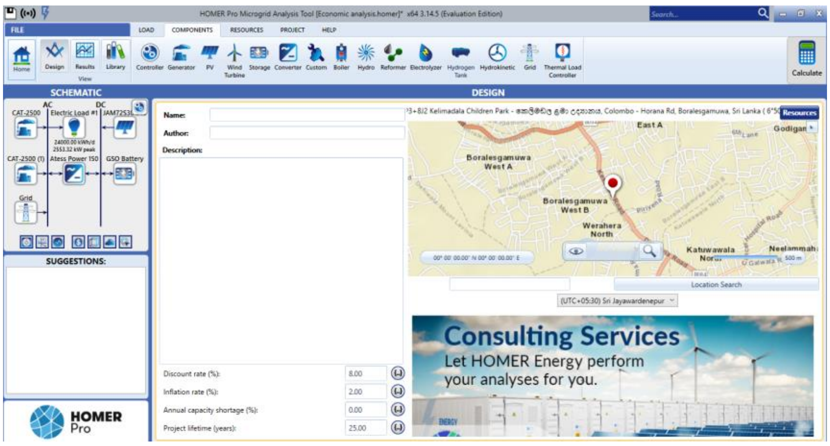


Figure 3.38:User Interface of HOMER Pro software

Figure 3.38 is the home page of the HOMER PRO software, more information regarding how to use the software can be learned from the Homer Pro User manual [43]. Access to the user

Manuel can be granted via the Help tab in the software, or through the HOMER official site help center.

3.7.3 Using HOMER Pro for Optimzation

The Hybrid system model designed in Homer pro for simulation purposes is given in below fig. Here Hybrid solar PV system consists of solar panels, a battery energy storage system 2 Diesel generators, and a convertor as per the energy demand of the institution. The annual average energy demand is 33,500.00 kWh/day, and the peak demand is 2500 kW.

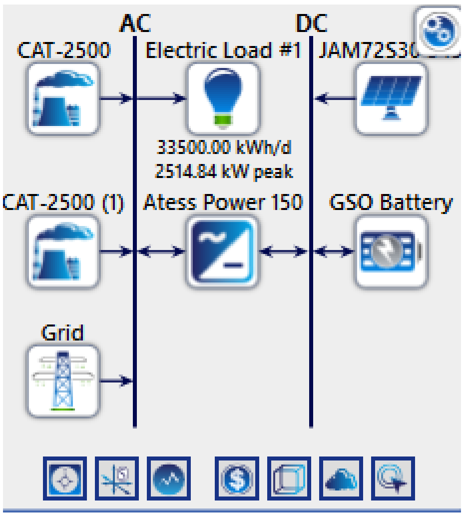


Figure 3.39:Hybrid Solar Model designed in Homer Pro

For the selection of the necessary components for the system, the components are selected based on the availability and supplier capability to deliver the components to Sri Lanka. With regard to these factors as shown in table 3.14, brands relevant to its specifications are used as the inputs of the Software.

Table 3.14:Specifications of components used as input data

Component	**Brand and Type**
Investors	Atess Power 150kw Hybrid Invertor
Solar Panels	JA solar JAM72S30 545W Solar Panels
Batteries	GSO battery 200AH Lifepo4 batteries
Generator	CAT 2500kw Diesel Generator (Already available in UHKDU)

The components in table 3.14 for the specific brands were selected by comparing with several other brands and selecting the best based on the Efficiency and Cost of the product.

The Cost calculations of the generator were not added to the cost analysis since its already available in UHKDU. The generator was added for the correct simulation purpose.

3.7.3.1 *Identification of location*

The site location of UHKDU is given to Homer Pro software as shown in figure 3.40, from the software the simulation is located at 6°49.6′ N latitude and 79°54.4′ E longitude. The solar, wind and temperature as per the area is calculated by the software's internal calculations as per the NASAs Prediction. Thus, precise values with regard to Global horizontal Irradiance (GHI) and Temperature indexes and values were obtained.

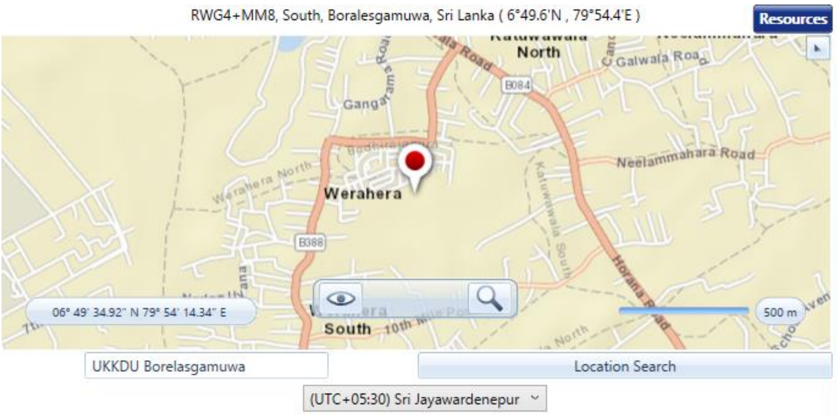


Figure 3.40:Site identification of HOMER Software

The Annual average horizontal solar radiation of the hospital's location is 5.59kWh/m2/day. The monthly average global horizontal radiation is in the range of 4.930 to 6.670.

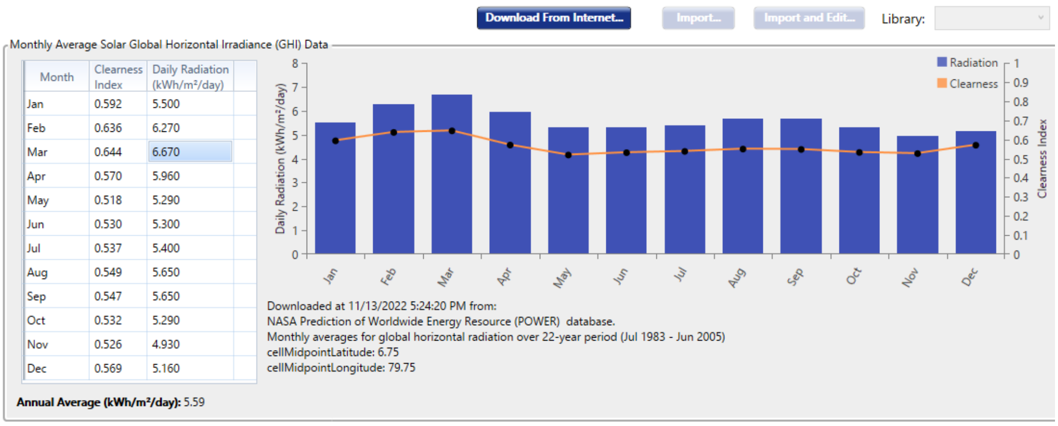


Figure 3.41:Monthly average Solar GHI data from HOMER Software

kWh/m2/day. Also, the annual average temperature value is 26.88C, the temperature ranges from 26.41C to 27.89C to a daily average for a certain month. With addition to this Wind data is also calculated through Homer. The values are set into the software according to the data of NASAs initiatives.

3.7.3.2 Load Demand Profile

The average load demand pattern for the institute was taken from the CEB under a special request from the institute. The load demand profiles presented load for a complete year which is categorized hourly and 15min intervals for a single day. With the data that was given from CEB the average daily based annual energy demand is 33,500.00kWh/day, which a total annual demand is 12227000kWh/year and which approached a maximum peak demand value of 2514.84kW.

Below Figures depicts the daily load profile, monthly load profile, seasonal profile, and yearly load profile according to the Homers internal simulations when the necessary data are given as an input

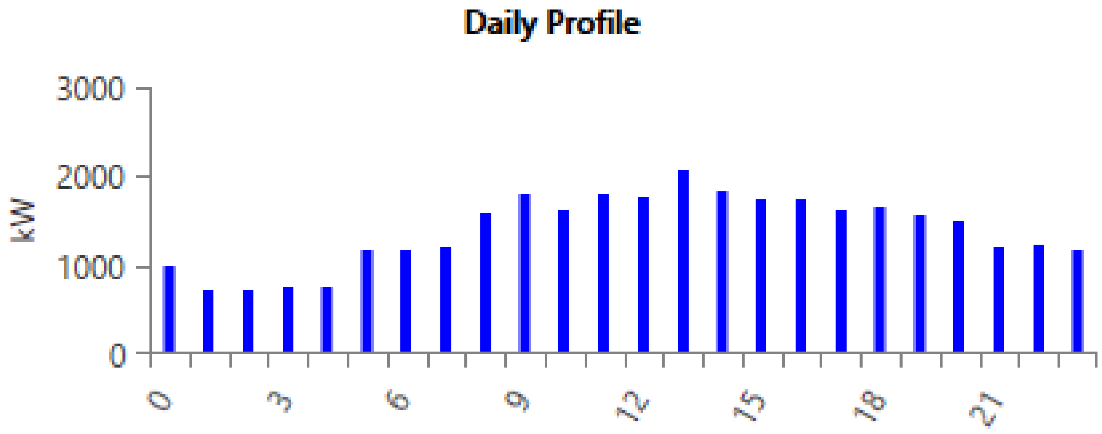


Figure 3.42:Daily profile from HOMER Software

Figure 3.43:Scaled data of Daily profile

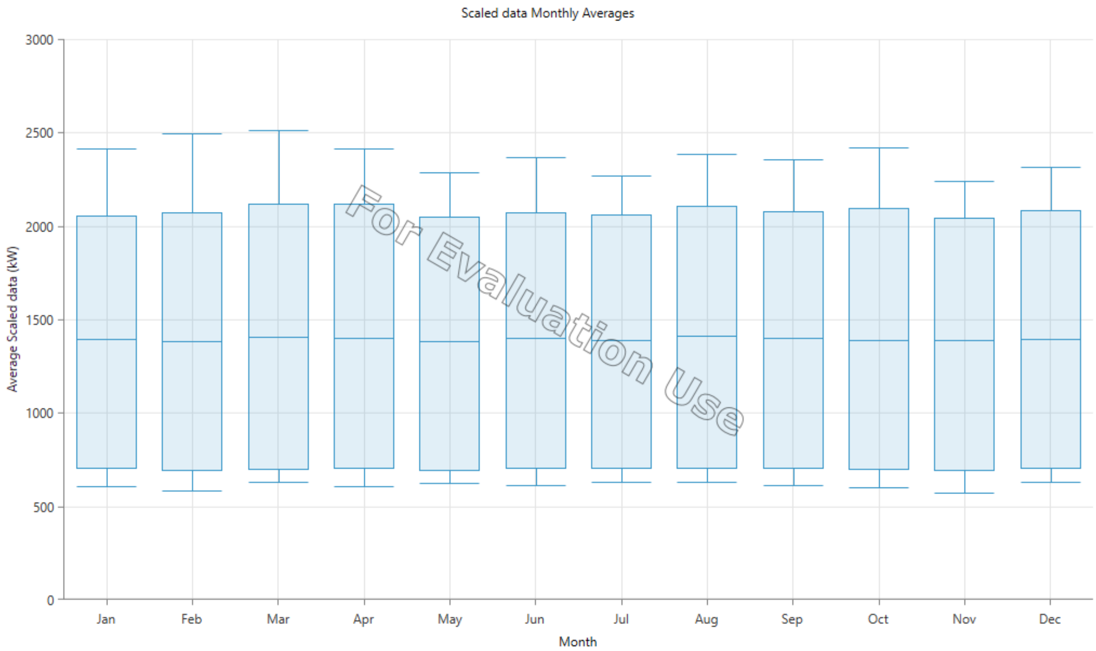


Figure 3.44: Scaled data monthly average

3.7.3.3 Grid Rates

Based on the latest Sri Lankan electricity demand rates the rates are divided into peak, day, and off-peak respectively. The suitable rates fall under GV category. The charge under rate 3 as shown in figure 3.37 was applied in the HOMERs Scheduled rates under the Advanced Grid Tab.

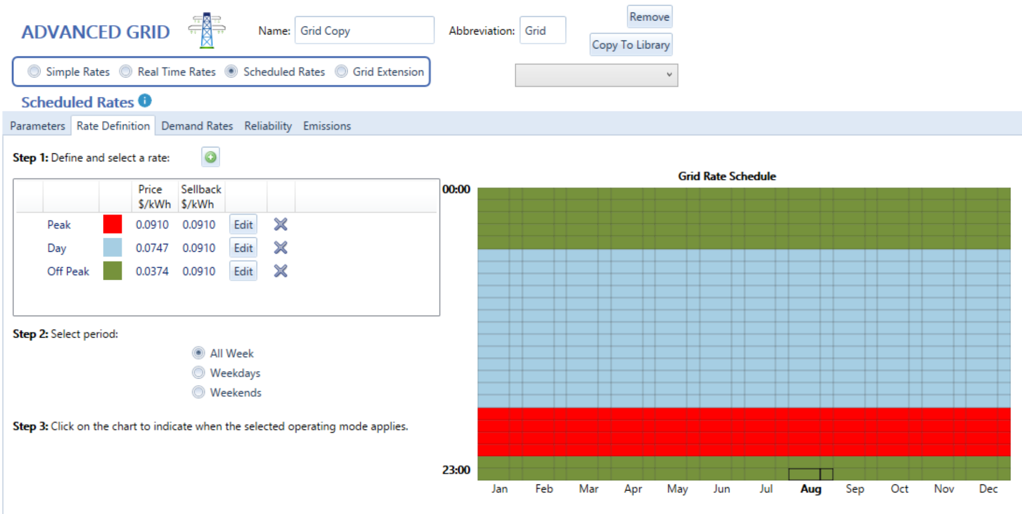


Figure 3.45: Grid rates

3.7.3.4 Outages

The frequency of outages is selected as 36 per year with a repair time of 1h for each outage.

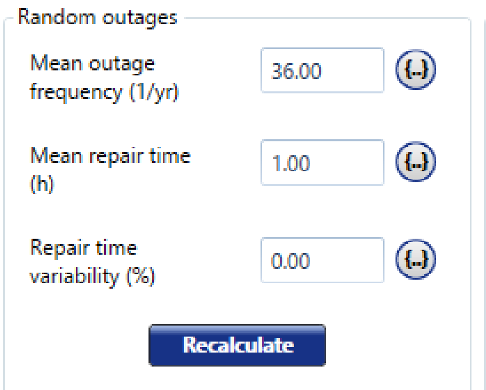


Figure 3.46: Outage inputs

3.7.3.5 Components of the Hybrid Solar PV system

Once the geographical data is given to HOMER Pro software the GHI, Temperature, and wind factors are determined by the Homer software. When it comes to components of the solar Hybrid system, pricing and selection of the right components and optimum sizing have to be done by the designer by identifying the suitable combination of renewable energy system components consisting of a solar, battery, diesel generator, and convertor. Also, the designer has to input the necessary inputs such as capacity, quantity, lifetime, efficiency, average energy, peak load, average load, and cost required for the capital, Replacement, operation, maintenance, etc. in the HOMER Pro software. Once these values are set HOMER will simulate the results to our required budget plan and criteria.

When adding a component to the homer pro software, it consists of a list of components in its default catalog itself, if an additional component from another brand and type is needed to be added, the procedure can be completed via the add from the library in which a custom component can be added with its relevant specifications and its distinctive data.

According to the sizing calculations with regard to the rooftop area availability and the capacity that can be implemented, the homer pro software is fed with component capacities as shown in table 3.15.

Table 3.15:Input data of the component

Components	Sizing	Quantity	Price of a single component	Cost
Solar PV array	1900kW (545Wp*3487)	3487	$114.45	$399,087.15
3 Phase invertors	2651.949kW (150kw*18)	18	$20,400	$367,200.00
Battery Storage	56747.38045Ah	284	$1,400	$397,600.00

3.7.3.6 Computation of the replacement and O&M costs

Table 3.16: Summary of replacement and O&M costs in HOMER Software

Component	Cost	Tax + Shipping	Capital = Cost + shipping+Tax	The percentage for O&M Per year including Installation cost (from Cost)	Replacement 50%(from Capital)
Solar PV array	$399,087.15	25% = $99,772	$498,860	2% = $7,982	50% = $249,430
3 Phase invertors	$367,200.00	25% = $91,800	$459,000	2% = $7,344	50% = $229,500
Battery Storage	$397,600.00	25% = $99,400	$497,000	2% = $7,952	50% = $248,500

The general assumptions made are as follows,

- For the calculation of capital cost, 25% was assumed as the relevant charge for the shipping and tax values, this is based upon actual shipping costs that are being provided by the suppliers and tax quotations that are received from the Sri Lankan customs.
- A new proposal has been made by the government that for the import of inverters and solar panels, no tax will be charged, but it's still under implementation, if this is brought forward, only the shipping cost will be charged which is 13.5% of the capital cost.
- For the calculation of the Operation and Maintenance (O&M) cost, 2% of the net cost was taken as an assumption
- Replacement cost is assumed as 50% of the capital cost.

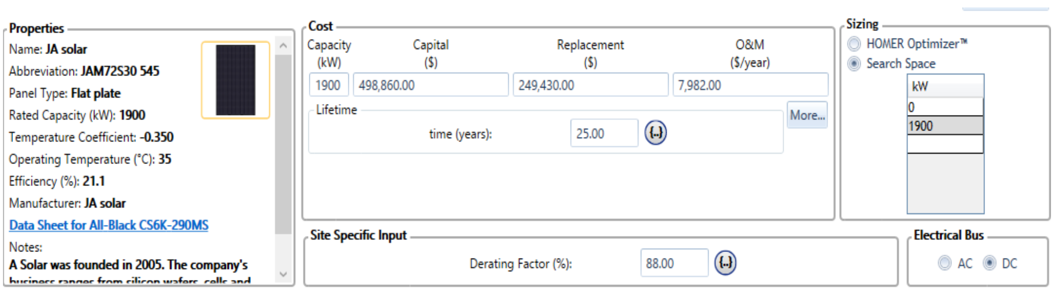


Figure 3.47: Interface to add component costs

Due to the limited area available for the solar panels the number of solar panels has to be limited, therefore from the capacity optimizer in the Homer Pro software, the values are added through the search space criteria. The Same procedure is followed with the other components to get the most feasible optimization.

With the limited area available for the solar panels the number of solar panels has to be limited, therefore from the capacity optimizer in the Homer Pro software, the values are added through the search space criteria. The Same procedure is followed with the other components to get the most feasible optimization. With the Homer Optimizer results for a specific budget plan Software will calculate the necessary number of components to get the best result.

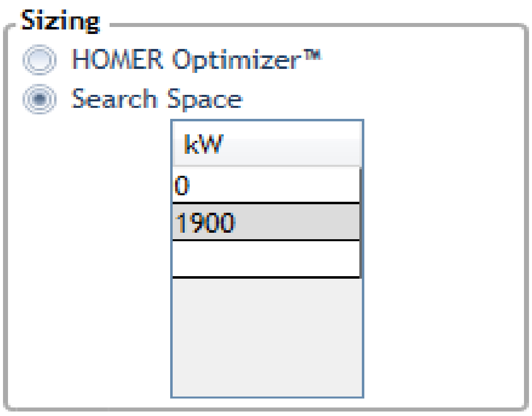


Figure 3.48: Homer search space

3.7.3.7 Control strategies

Based on HOMERs initiatives there are 3 main control strategies. The HOMER pro simulated under these 3 control strategies to get the best configuration. A custom-made control strategy can also be added by designing it through the MATLAB software.

<u>Cycle Charging</u>

Under the Cycle charging strategy, whenever a generator is required, it operates at full capacity, and surplus power charges the battery bank. Cycle. Cycle charging is abbreviated as "CC" in the tables on the Results page.

<u>Load Following</u>

Under the load-following strategy, when a generator is needed, it produces only enough power to meet the demand. Load following tends to be optimal in systems with a lot of renewable power that sometimes exceeds the load. The load following is abbreviated "LF" in the tables on the Results page.

Generator Order

Under the generator order configuration, HOMER itself follows a specific order of generator combinations. Here it priories on each generator such that it is powered up under certain conditions and is followed up with a certain combination such that it meets the operating capacity. The generator dispatch strategy/generator order strategy supports systems which compose of paves wind turbines, generators, converters, and battery storage systems. The generator order strategy does not compile with systems that incorporate Thermal or CHP components, Hydrogen components, the Grid, the Hydroelectric component, or the Hydrokinetic component.

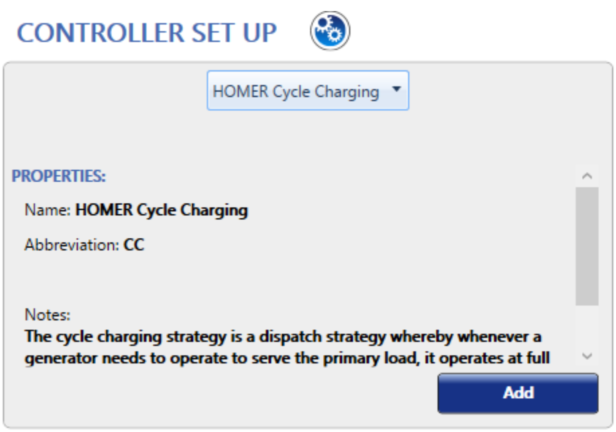


Figure 3.49: Controller Setup

4 RESULTS AND ANALYSIS

4.1 The hybrid solar PV power system for a given critical load

The continuous power outages which occurred due to the economic crisis on the island resulted in the constant usage of diesel generators as standby by power generators, especially in the health sector, which requires an uninterrupted power supply for the operation of critical machinery. Thereupon resulted in yearly higher expenses on fuel costs, especially during the economic instability of the country. Consequently, adverse impacts on the environment due emission of greenhouse gases to the environment rose, increasing the demand for renewable energy.

The University Hospital of KDU which is located at Werahara consists of suitable capacity for the installation of a solar plant that has the potential of converting the current stand-by power system into a green energy power system. The introduction of a hybrid Solar PV system with the capability of islanded operation to compensate for the demand of the hospital during a power outage will create initial steps of reducing unwanted expenses on fuel and adverse environmental effects due to the usage of diesel generators.

The preliminary site assessment of the hospital concluded the location of the hospital obtained required solar irradiance, temperature, and weather throughout the year to support this proposed design. The demand requirement of the hospital is comparatively large as this is a commercial-scale building. Yet the abundant area of rooftops in the hospital assured the installation of a solar plant to provide for this demand. As a result of a comprehensive analysis of the load requirement of the hospital, the demand could be summarized as depicted in Table 4.1. With the utilization of this data, the required component of the system was identified to achieve the main objectives of the proposal.

Table 4.1: Summary of Load requirement of UHKDU

Load		
Average Daily units consumed	33469	kWh
Day (05:30 – 18:30)	21543	kWh
Peak (18:30 – 22:30)	54775	kWh
Off Peak (22:30 - 05:30)	6449	kWh
Units consumed During sun peak (08:00 - 15:00)	12498	kWh
Units consumed during an outage (11:30 - 13:30)	3881	kWh

4.1.1 Components of the Hybrid Solar PV system

The proposed hybrid Solar PV system with the capability of islanded operation consists of the following components.

- Solar Plant
- Inverter
- Li-ion Battery storage
- Installed Diesel generator
- Grid

Figure 4.1 presents the schematic representation of HOMER simulation model of the hybrid system architecture considered in this paper.

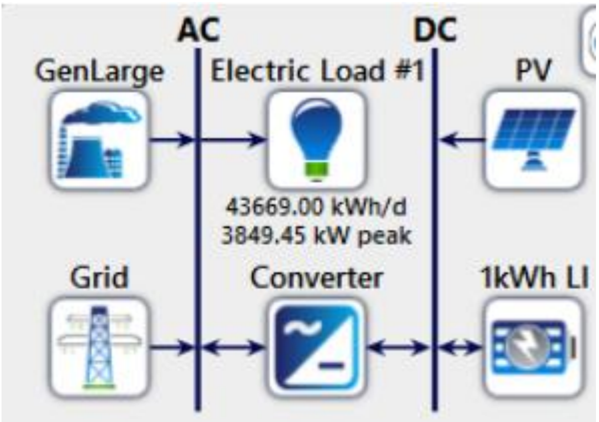


Figure 4.1:Schematic diagram of Hybrid Solar PV system using Homer Software

4.1.2 Capacities of the components of the proposed system

The computation of the capacities of each component of the proposed system plays a vital part in developing the most feasible power system for the selected site. be summarized as depicted below. Preceding a thorough site assessment to identify the potential capacity to install the solar plant, as shown in table 4.2, the capacity of the possible solar plant and the ratings of the selected Solar panel were established.

Table 4.2: Summary of Solar PV System Capacity

Solar PV Array		
Rating of Selected Solar Panel	545	Wp
The capacity of Solar Plant	1900	kW
No Solar Panels can be installed	3487	
The total utilizable rooftop area	9030	m2
The daily average sum of solar GHI at Werahara	4.8	kWh/m2
Total Solar generation for an average day	8269	kWh

The inverter sizing, as depicted in table 4.3, was conducted afterward by investigating the maximum demand of the hospital. An inverter design margin of 25% was considered in deciding the capacity of the hybrid inverter to ensure the high reliability of the performance of the system.

Table 4.3: Summary of Inverter capacity

3 Phase Inverter		
Peak Demand	2122	kW
Inverter Design Margin	25	%
Inverter Size required	2652	kW
The capacity of a hybrid inverter	150	kW
No. of Inverters required	18	

A battery storage system was introduced to the proposed system in order to achieve the following aspects

- The available rooftop area of the site is not required to install a Solar plant generating the total demand requirement of the site. Therefore, a battery storage system is required to inject the remaining requirement of power

- Aggressive cloud cover may result in sudden voltage dips of solar power generation and thereby instant injection of power is maintain constant output Solar power

- Perform peak shaving to obtain economic benefits of the proposed design & provide the excess energy required to meet the load compensating for average peak demand during an outage

- Reduce usage of diesel generators and thereby reduce their negative impacts. The battery storage system is environmentally friendly and does not incur additional costs other than maintenance cost

The computation of the capacity of battery storage was done by considering two case studies by assuming the worst possible events that could occur in the system. The proposed design should be able to withstand any occurrences and supply an uninterrupted power supply to be considered as an alternative to a standby diesel generator. The required battery capacities vary depending on the time of the day. During sun peak hours, if an outage occurs along with the battery storage the Power generated from the Solar plant can be utilized. Yet in the Off-sun peak hours, the battery will solely have to provide the demand. Additionally, instead of using the battery independently the power generation could be shared among the existing diesel generator and battery. Thus, such scenarios were also considered sub-cases under each main case study. Table 4.4- 4.7 summarized the battery capacity for each subcase of the proposed design.

Table 4.4:Summary of Battery Sizing-Case 1. A

CASE 1 – Sub Case A				
	Peak shave & Outage		*Only outage*	
Load to be met by a battery	451.60	kWh	451.60	kWh
Load to be met during Peak Shaving (18:30-19:00)	764.63	kWh	0.00	kWh
Total Load to be met during one discharging cycle	1216.23	kWh	451.60	kWh
Nominal Voltage of a battery	48	V	48	V
Rated capacity of a battery	400	Ah	400	Ah
The total energy required by ESS during a daytime outage	764.63	kWh	544.56	kWh
Battery Capacity required	1188.05	kWh	846.11	kWh
Battery Capacity in Ah	24751.05	Ah	17627.29	Ah
No. of batteries needed	62		45	

Table 4.5: Summary of Battery Sizing-Case 1. C

CASE 1 – Sub Case C		
	Only Outage	
Load to be met by a battery	225.80	kWh
Load to be met during Peak Shaving (18:30-19:00)	0.00	kWh
Total Load to be met during one discharging cycle	225.80	kWh
Nominal Voltage of a battery	48	V
Rated capacity of a battery	400	Ah
The total energy required during a daytime outage	318.76	kWh
Battery Capacity required	495.27	kWh
Battery Capacity in Ah	10318.22	Ah
No. of batteries needed	26	

Table 4.6: Summary of Battery Sizing-Case 2. A

CASE 2 – Sub Case A		
	Outage Only (Peak shave considered)	
Load to be met by battery (1hr)	1727.36	kWh
Load to be met during Peak Shaving (18:30-19:00)	764.63	kWh
Total Load to be met during one discharging cycle	2491.99	kWh
Nominal Voltage of a battery	48	V
Rated capacity of a battery	400	Ah
The total energy required during an outage	1753.10	kWh
Battery Capacity required	2723.87	kWh
Battery Capacity in Ah	56747.3805	Ah
No. of batteries needed	142	

Table 4.7:Summary of Battery Sizing-Case 2. C

CASE 2 – Sub Case C		
	Outage Only (Peak shave considered)	
Load to be met by battery (0.5hr)	886.37	kWh
Load to be met during Peak Shaving (18:30-19:00)	764.63	kWh
Total Load to be met during one discharging cycle	1651.01	kWh
Nominal Voltage of a battery	48	V
Rated capacity of a battery	400	Ah
The total energy required during an outage	894.16	kWh
Battery Capacity required	1389.30	kWh
Battery Capacity in Ah	28943.734	Ah
No. of batteries needed	73	

4.2 Model and simulation of the islanded operation of the system in case of a grid power outage

In this study, MATLAB Simulink software was utilized to model the scaled hybrid Solar PV system to analyze the seamless transfer between two modes of operation and constant output power. Components of the system architecture were modeled and then combined to obtain seamless transfer between the islanded mode and gird-tied mode Thus the modeled Simulink was taken under two conditions, Islanded mode and Grid-tied mode.

The islanded mode denotes a power outage of the system. Thus, it is important to supply constant power to load in this condition. As shown in figure 4.6 the output waveform of the system depicts a constant output power. During this mode, the grid connection is ceased, and therefore output waveform, figure 4.5, gives no power.

Figure 4.8 portrays the Voltage, current and power supplied to the load during the grid-connected mode.

Islanded Mode

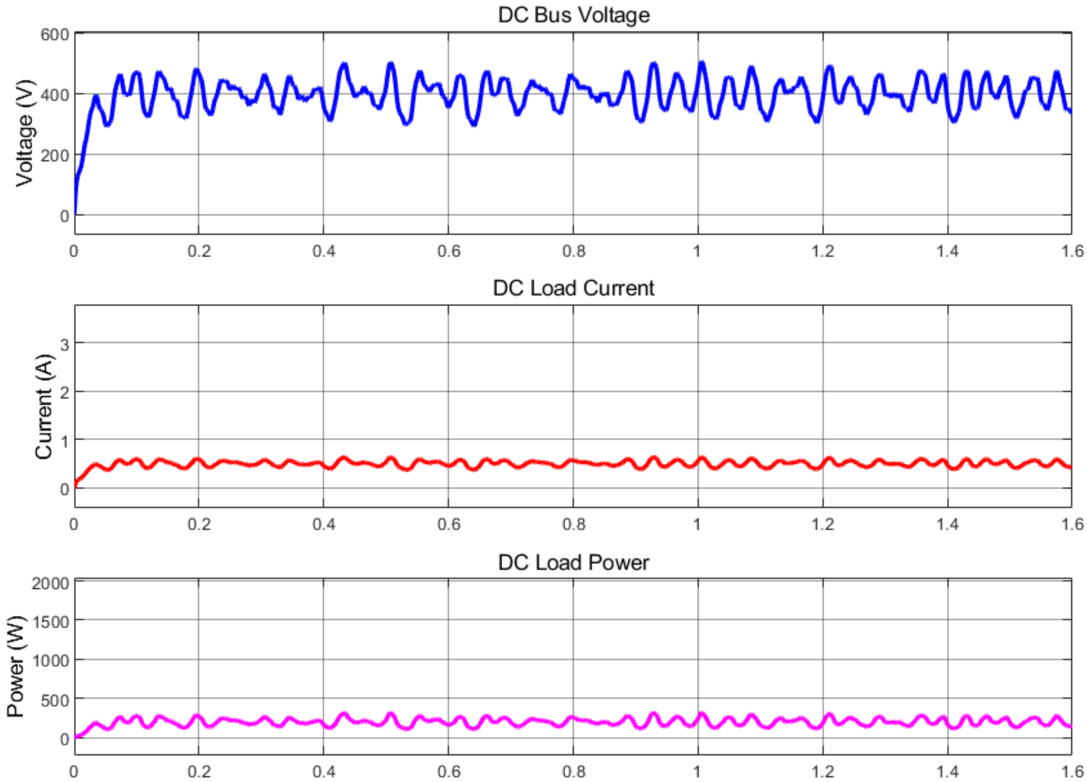


Figure 4.2:Islanded Mode: DC voltage, DC Load Current, DC Load Power

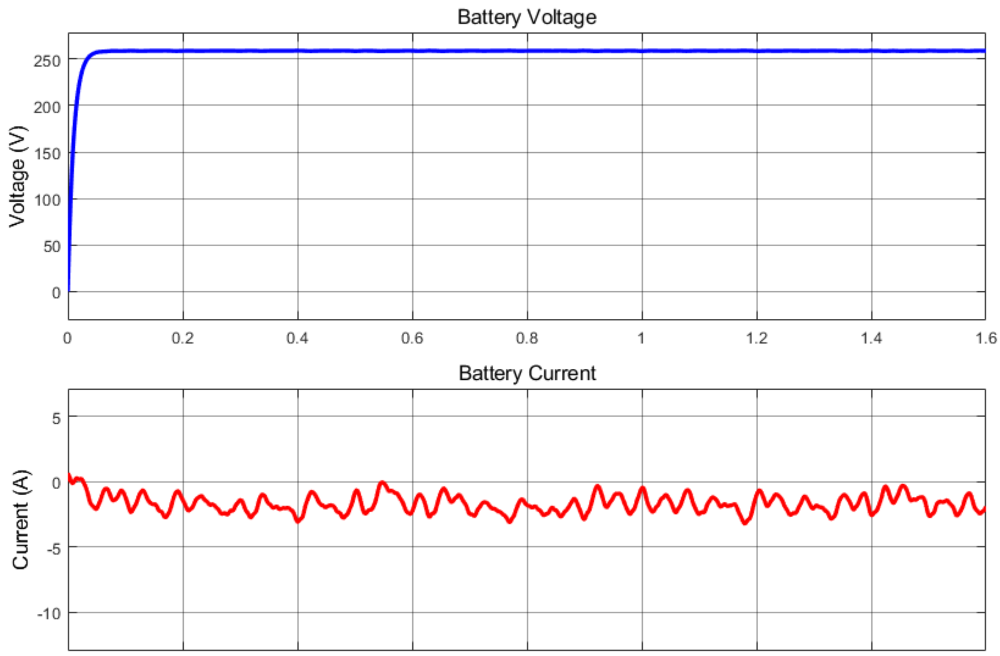


Figure 4.3:Islanded mode battery voltage and current

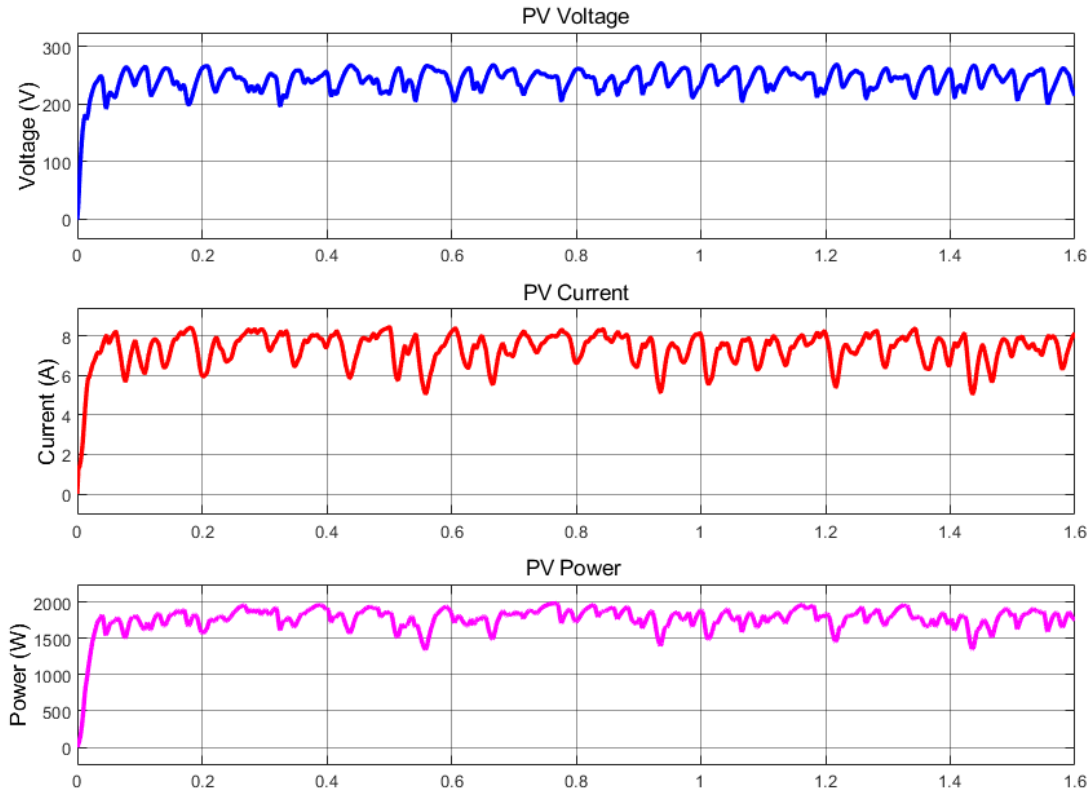


Figure 4.4:Islanded mode -PV voltage, PV current, and PV power

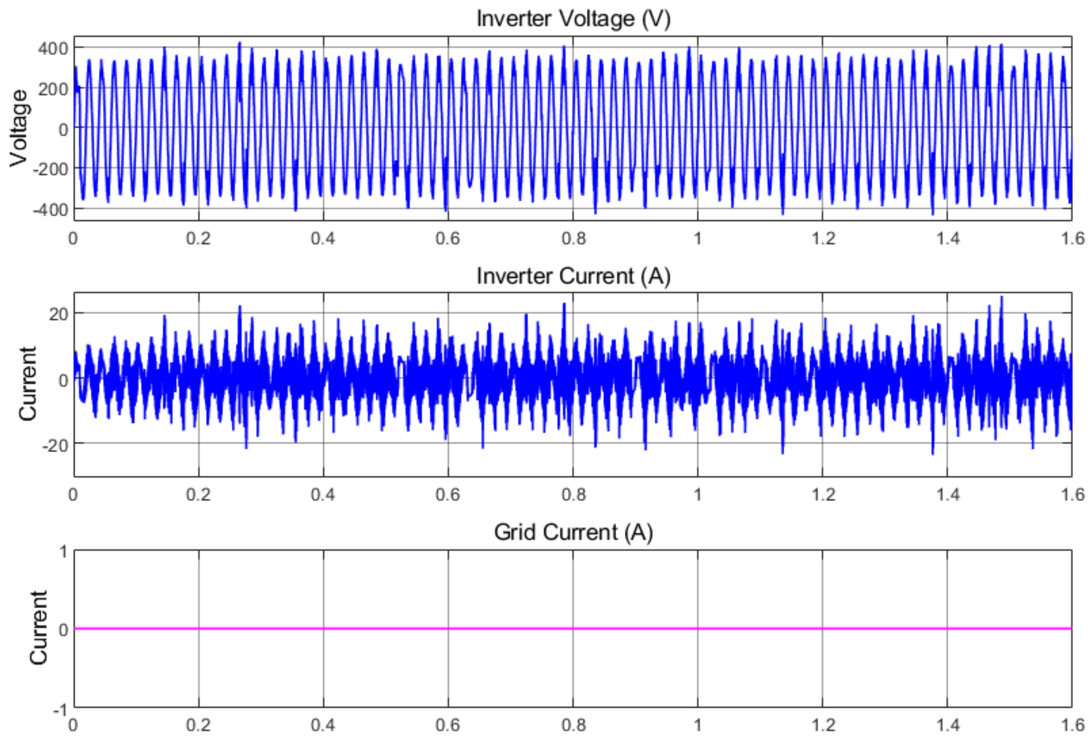


Figure 4.5:Islanded mode inverter output waveforms

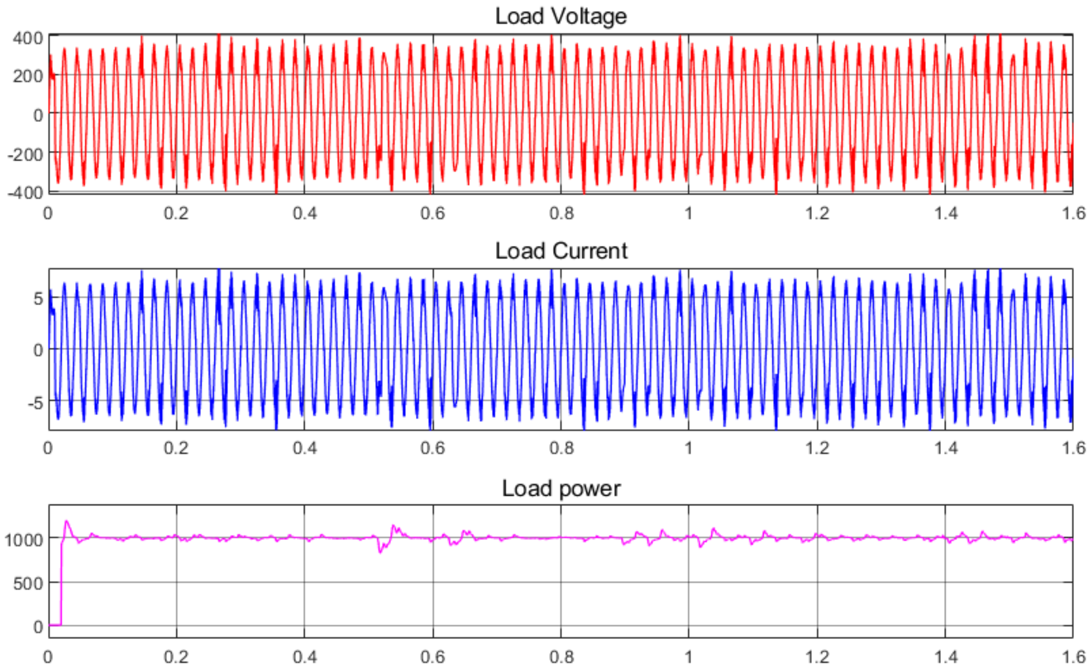


Figure 4.6:Islanded mode load output waveforms

Grid-connected mode

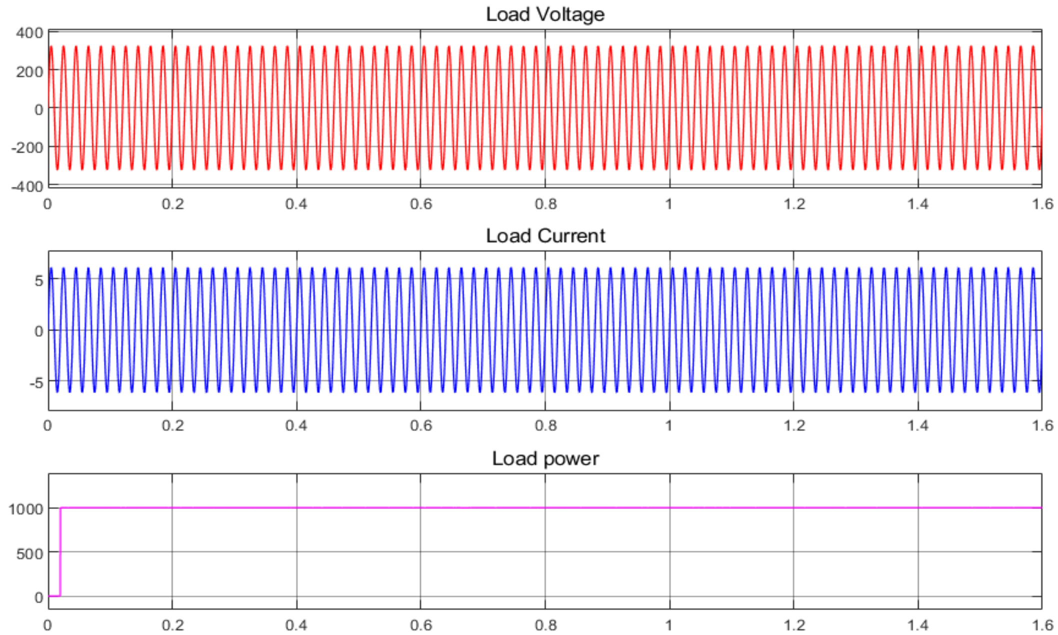


Figure 4.8:Grid-connected mode-Load Output waveforms

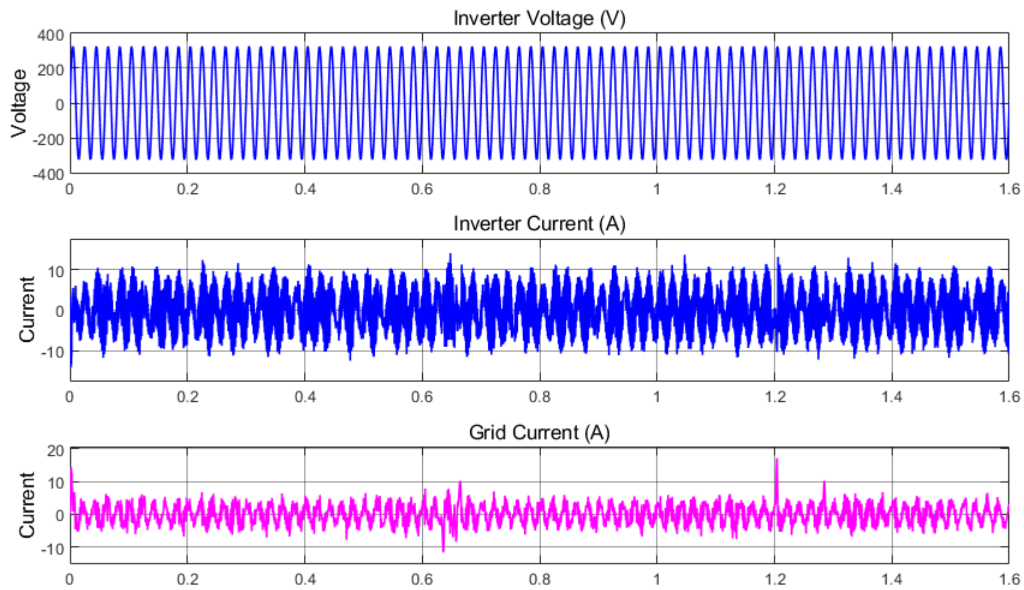


Figure 4.7:Grid connected mode: Inverter Output waveforms

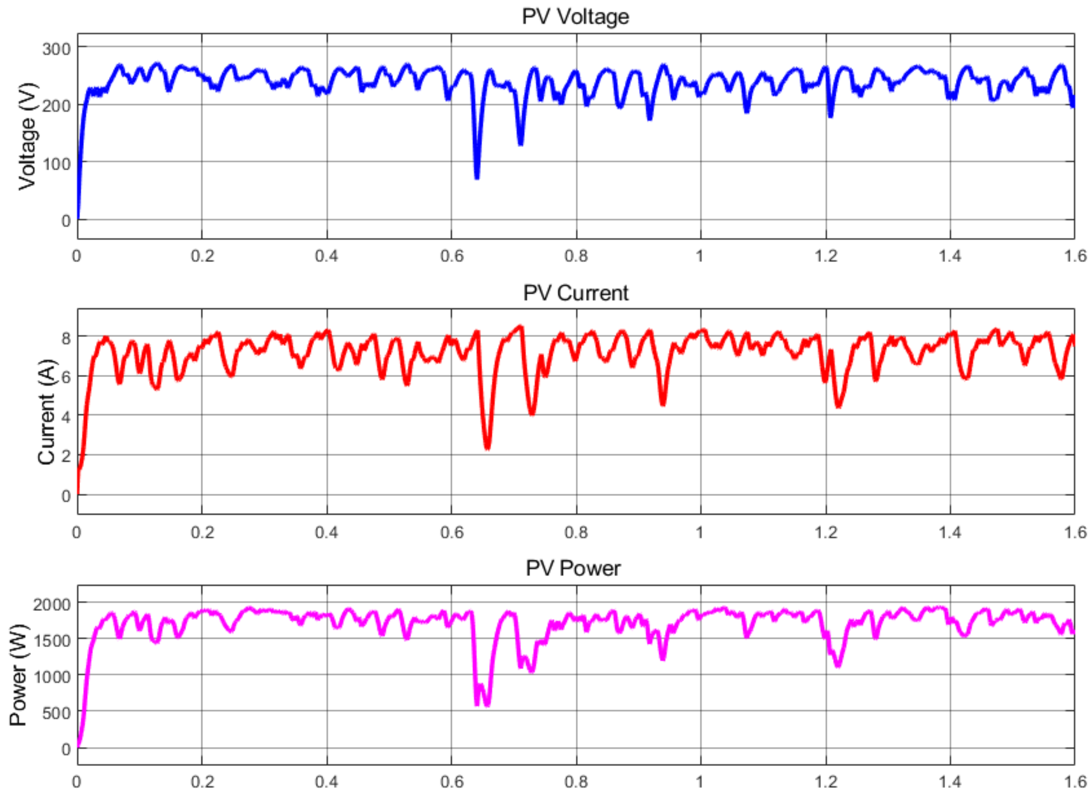


Figure 4.9:Grid connected mode-PV voltage, current, and power

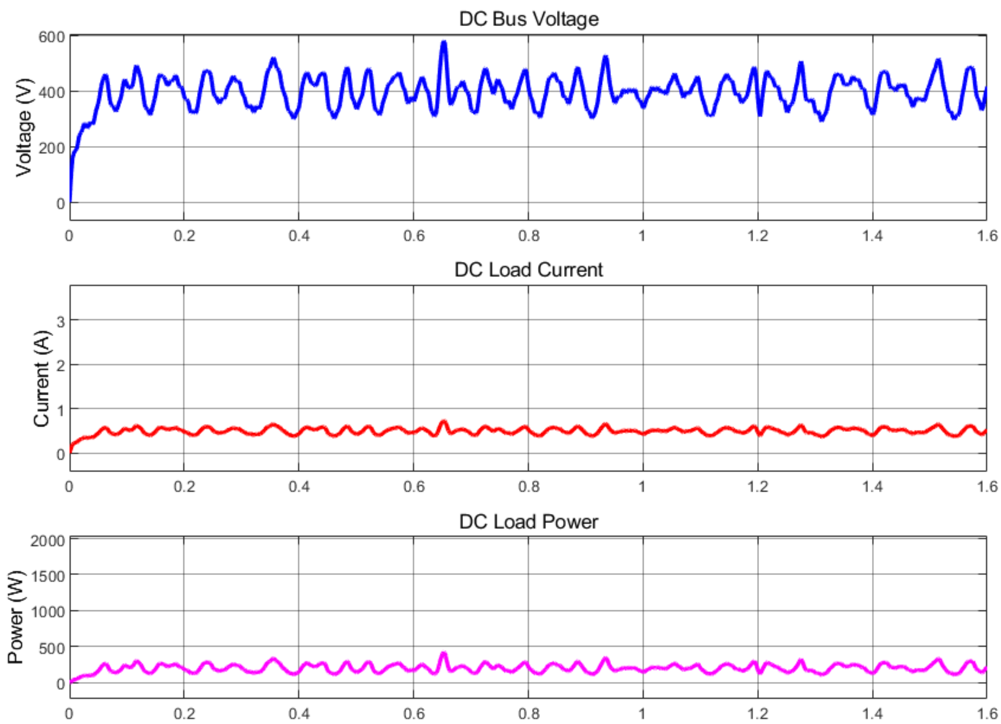


Figure 4.10:Grid connected mode DC load output waveform

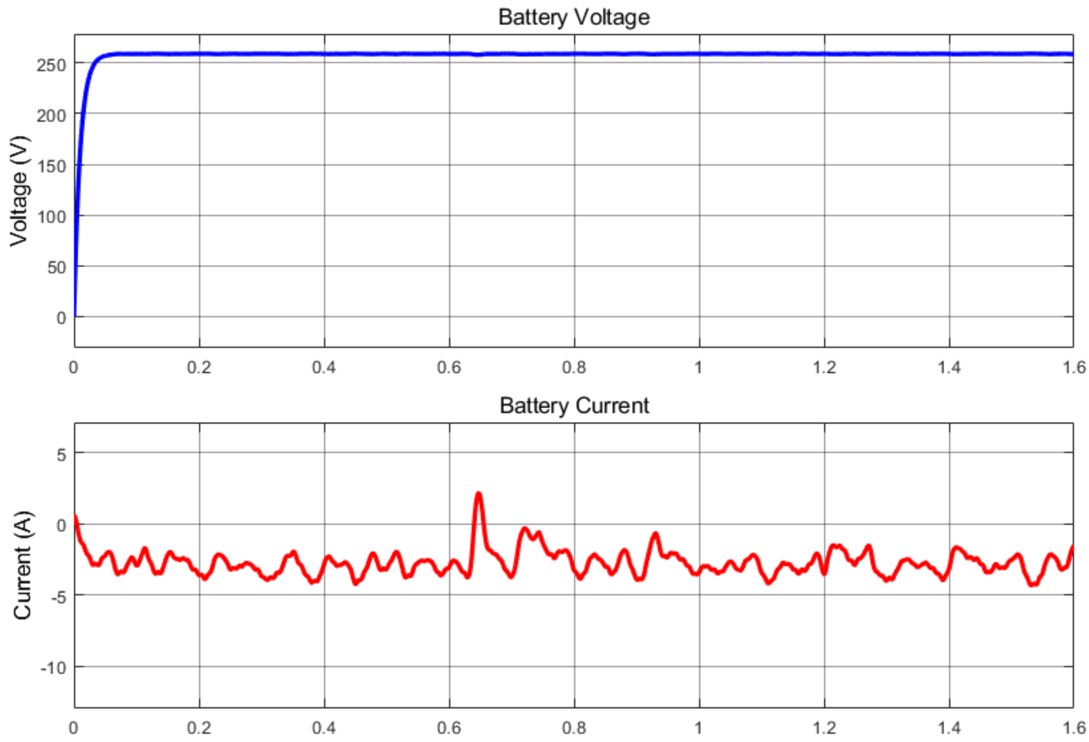


Figure 4.11:Grid connected mode -battery output waveform

4.3 Economic Analysis of the Hybrid Solar PV system

The feasibility and practicality of the proposed hybrid Solar PV system were investigated through economic analysis. Several parameters were analyzed before the comparison between the battery storage system and the diesel generator.

The capital post of all proposed components except for the already existing Diesel generator was computed concerning the investment, shipping & taxes, and maintenance cost. Computation of the capital cost was conducted for each subcase considering the performance of peak shaving and providing during an outage. Table 4.8 and Table 4.9 summarized the capital cost under each case. Subcase A during sun peak hours which could compensate during an outage and perform peak shaving has the highest investment cost. The difference in capital costs of each case depends on the capacity of the battery storage system as the rest of the components remain constant for each case. Thus, a cost of $1,418,511.00 is incurred due to the usage of 62 batteries.

An investment cost of $1,765,711 is incurred under case two where the demand during an outage is compensated using 142 batteries, making it the highest incurred cost out of all the cases. This storage capacity was computed to supply power for an outage of one hour for the maximum demand in off-sun peak hours and it could be used to shave the peak demand on normal days and obtain monetary benefits.

Table 4.8: Summary of Capital Cost of Case study 1

Capital Costs for Case 1	**Sub Cases A & B**		**Sub Case C**
	Outage + peak shaving	**Only outage**	**Only outage Case C**
Total Investment Cost	$1,418,511.00	$1,344,731	$1,258,631

Table 4.9: Summary of Capital Cost of Case study 2

Capital Costs for Case 2	**Sub Cases A & B**	**Sub Case C**
	Only Outage (peak shave included)	**Only outage Case C**
Total Investment Cost	$1,765,711	$1,456,031

The obtained Expenses should be investigated along with the benefits and profits gained from this project over the estimated lifetime of the project. Therefore, certain parameters such as Net present value and Levelized Cost of Energy were calculated. In order to perform precise calculations factors such as fuel consumption rates of diesel generators under each subcase, feed-in tariff, Inflation, and discount factors were analyzed. Table 4.10 and table 4.11 depicts the summarized LCOE values of each subcase which will be used to analyze the gains and costs of the proposed design.

Table 4.10:Case 1 LCOE Summary

CASE 1 LCOE Summary		
1. Sub Case A: LCOE for Battery (with peak shave)	0.058 $/kWh	21.02 Rs./kWh
2. Sub Case B: LCOE for DG (with peak shave)	0.680 $/kWh	244.75 Rs./kWh
3. Sub Case A: LCOE for Battery (only outage)	0.483 $/kWh	173.83 Rs./kWh
4. Sub Case B: LCOE for DG (only outage)	0.770 $/kWh	277.34 Rs./kWh
5. Sub Case C: LCOE for Battery + DG (only outage)	0.773 $/kWh	278.42 Rs./kWh

Table 4.11: Table 4.10: Case 2 LCOE Summary

CASE 2 LCOE Summary		
1. Sub Case A: LCOE for Battery	0.057 $/kWh	20.56 Rs./kWh
2. Sub Case B: LCOE for DG	0.363 $/kWh	130.71 Rs./kWh
3. Sub Case C: LCOE for Battery + DG	0.108 $/kWh	38.83 Rs./kWh

4.4 Comparison of battery storage and generator

The common notion of adopting Hybrid Solar PV systems is the inability to obtain monetary benefits due to high expenses on the installation of such systems. In special circumstances such as the UHKDU where a standby diesel generator is already established to compensate for the redundant power, installation of an alternative power system incorporating renewable energy such as this study may be profitless. Thus, this study investigates the veracity of such conceptions. Consequently, an in-depth study on the economic gains and losses of battery storage systems compared to Diesel generators is done. Thus, costs and savings analysis, as depicted in table 4.12, was conducted by obtaining the net costs per month, Net profits, and thus net savings obtained, and profits under each subcase over 25 years.

The subcases under Case 1 depict the Net savings and profits gained over a lifespan of 25 years that could be achieved from various capacities of battery storage systems during the sun's peak hours. The subcase A with the capability to peak shave and supply during power requires 62 batteries of rating 400Ah. It provides a net saving of $24259.29 leading to the highest saving compared to Subcase C and Subcase A which only provides for an outage. Thus, usage of 62 batteries is beneficial as not only could it compensate during an outage but also peak shave the evening which will support demand side management of the overall power system.

Case 2 discusses the scenarios where the load is taken care of solely by battery and generator due to the absence of solar power generation. Subcase A provides the highest saving compared to all the cases while utilizing 142 batteries. It was established that subcase A under case 1 which requires 62 batteries cannot compensate for the demand during off-sun peak hours as its capacity is not sufficient. The demand could not be held even for an hour using 62 batteries. Thus, compared to all the cases Subcase A under case 2 seems to be the most effective and economical option for the proposed system.

The current existing backup power system at UHKDU has an installed capacity of 7. 2MW.Subcase B under both scenarios used the diesel generator to compensate for the demand. In subcase b of case 1, the generator supplies the outage demand along with Solar power and thus the generator could be used to participate in peak shaving as it does not incur significant loss compared to solely using the generator to compensate for the demand during an outage. Even though the installation cost of the generator is not considered for the calculations in table 4.11, generators incur a daily running cost with the quantity of fuel used. With the worsened costs of fuel due to the economic crisis in Sri Lanka monthly net saving given to the system is comparatively less.

Thus, compared to the usage of 142 batteries to compensate for the demand during an outage and also peak shave on days where an outage didn’t occur, the savings obtained from the diesel generator is less. In fact, under each case,1 & 2 the incurred saving from using diesel generator is very low. Thus, it could be established that incorporating batteries provides a massive economic benefit and by implication, fewer adverse effects on the environment

As shown under subcase A of case study 2, usage of 142 batteries provides the highest savings compared to all the cases. Comparison between subcase A of both cases 1 & 2 also shows that even though 142 has a higher investment cost, it provides the capability to sustain an outage of more than 2 hours during the sun peak hours and also higher saving of the peak demand.

Thus, by considering the factors mentioned below battery capacity under subcase A of Case study 2 was selected. Table 4.12 depicts the technical parameters of the selected battery.

Table 4.12: Optimum Battery Capacity (4. Case 2: Sub Case A)

Optimum Battery Capacity (4. Case 2: Sub Case A)		
Nominal Voltage of a battery	48.00	V
Rated capacity of a battery	400	Ah
Total Battery Capacity	2723.87	kWh
No. of Batteries required	142	
Dimensions (W x L x H) mm	410 x 220 x 590	
Approx. Spatial Requirement	3.98	m2
Max. allowable DOD	75.00	%
Discharging C rate	1.29	C
Total dischargeable capacity	2042.90	kWh
Emergency capacity	544.77	kWh

Thus, the selection criteria of the most suitable battery capacity for the system can be considered as follows

- C rate of the battery for charging and discharging
- Payback Period of the battery
- Profits obtained after the breakeven margin is exceeded
- The number of autonomous hours that can be compensated by the battery.
- The spatial capacity of the facility

Table 4.13: Summary of Cost and Savings of each case study of the proposed system

	Case 1					Case 2		
	1. Sub Case A (peak shave + outage)	2. Sub Case B (peak shave + outage)	3. Sub Case A (Outage Only)	4. Sub Case B (outage only)	5. Sub Case C (outage only)	1. Sub Case A	2. Sub Case B	3. Sub Case C
Nett Cost incurred per month	$81,671.04	$96,638.17	$82,296.08	$82,702.25	$82,750.52	$81,753.08	$83,071.30	$82,774.95
Exported solar pv generation (kWh)	237788.12	237788.12	237788.12	237788.12	236971.28	248076.90	248076.90	248076.90
Feed-in-tariff ($/kWh)	0.096	0.096	0.096	0.096	0.096	0.096	0.096	0.096
Nett Income	$22,788.03	$22,788.03	$22,788.03	$22,788.03	$22,709.75	$23,774.04	$23,774.04	$23,774.04
Regular Electricity consumption charges per month	83142.31	83142.31	83142.31	83142.31	83142.31	83142.31	83142.31	83142.31
Nett Savings	$24,259.29	$9,292.16	$23,634.25	$23,228.09	$23,101.54	$25,163.27	$23,845.04	$24,141.39
Payback period for the Hybrid Solar PV system (years)	4.87	-	4.74	-	4.54	5.85	-	5.03
Profits gained over the project lifespan (25 years)	$5,859,276.04	-	$5,745,545.01	-	$5,671,830.39	$5,783,268.78	-	$5,786,385.53

4.5 Optimization of the Hybrid Solar PV system using HOMER Pro Software

4.5.1 Techno-economic analysis using HOMER Pro Software

The output results of the HOMER PRO software were obtained for the system optimization consisting of the Renewable source and the other components. Cost details such as Cost of Energy (COE), net present cost (NPC), operating cost, and capital costs, details of energy which could be generated by the renewable energy source given in above figure 4.12. The optimization results obtained for the Hybrid Energy renewable system consist of a large number of possible combinations, among these combinations 4 combinations are sorted as a categorized combination.

The optimization results show that the most feasible system configuration can be selected based on the minimum NPC value and Minimum LCOE value. According to the above categorization, the minimum NPC value consists of 1900kW Photovoltaics; 200Ah, 48V, 284 lithium-Ion batteries; 2676Kw, 18 150kW Hybrid Solar Inverters. The cost factors of the optimum configuration are $10.00M, $0.0634, $662,278, and $1.45M for COE, NPC, Operating costs, and Initial Capital cost respectively.

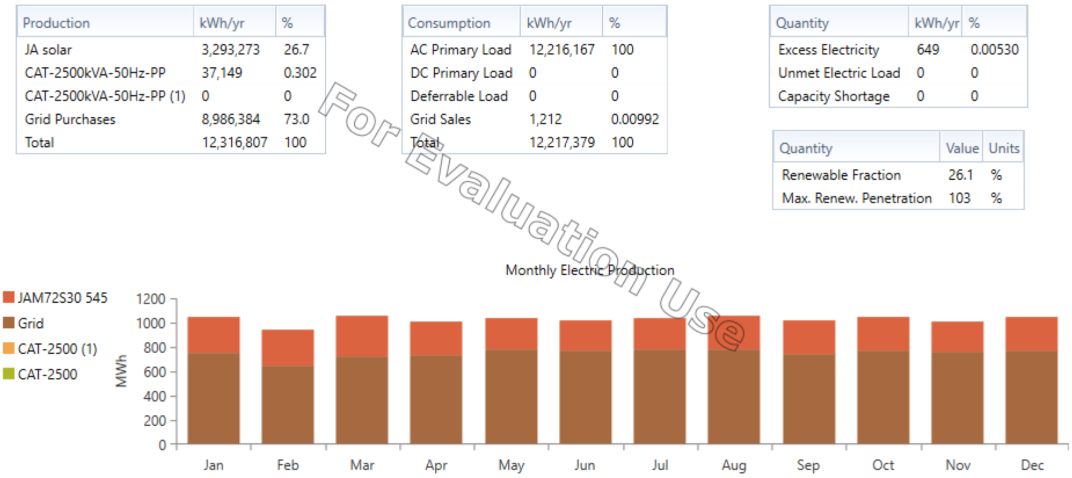
JAM72S30 545 (kW)	CAT-2500 (kW)	CAT-2500 (1) (kW)	GSO Battery	Atess Power 150 (kW)	Dispatch	NPC ($)	COE ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)	Total Fuel (L/yr)
1,900	2,000	2,000	284	2,676	LF	$10.0M	$0.0634	$662,278	$1.45M	26.1	10,494
1,900	2,000	2,000	284	2,676	CC	$10.0M	$0.0634	$662,278	$1.45M	26.1	10,494
1,900	2,000		284	2,676	LF	$10.0M	$0.0634	$662,278	$1.45M	26.1	10,494
1,900	2,000		284	2,676	CC	$10.0M	$0.0634	$662,278	$1.45M	26.1	10,494
	2,000	2,000	284	2,676	LF	$12.5M	$0.0794	$895,992	$951,920	0.000513	14,038
	2,000		284	2,676	LF	$12.5M	$0.0794	$895,992	$951,920	0.000513	14,038
	2,000	2,000	284	2,676	CC	$12.5M	$0.0794	$895,999	$951,920	0.000311	14,044
	2,000		284	2,676	CC	$12.5M	$0.0794	$895,999	$951,920	0.000311	14,044
1,900	2,000		284	2,676	GO	$41.9M	$0.265	$3.13M	$1.45M	25.0	2,582,015
	2,000		284	2,676	GO	$52.4M	$0.332	$3.98M	$951,920	0	3,298,247
1,900	2,000	2,000	284	2,676	GO	$52.7M	$0.334	$3.97M	$1.45M	15.9	3,281,432
	2,000	2,000	284	2,676	GO	$60.6M	$0.384	$4.61M	$951,920	0	3,826,172

Figure 4.12: Overall Optimization Results

JAM72S30 545 (kW)	CAT-2500 (kW)	CAT-2500 (1) (kW)	GSO Battery	Atess Power 150 (kW)	Dispatch	NPC ($)	COE ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)	Total Fuel (L/yr)
1,900	2,000	2,000	284	2,676	CC	$10.0M	$0.0634	$662,278	$1.45M	26.1	10,494
1,900	2,000		284	2,676	CC	$10.0M	$0.0634	$662,278	$1.45M	26.1	10,494
	2,000	2,000	284	2,676	LF	$12.5M	$0.0794	$895,992	$951,920	0.000513	14,038
	2,000		284	2,676	LF	$12.5M	$0.0794	$895,992	$951,920	0.000513	14,038

Figure 4.13: Categorized Optimization results\

Figure 4.14 shows how the production and consumption of electricity have taken place for the optimum configuration and thus based on the values a generation of 26.7% of what is consumed as an annual average. From the control strategies and due to the limitation of the solar panels due to the limited amount of area, the system is optimized to use its produced energy to meet the load, therefore only a little amount of energy is exported to the grid.



Production	kWh/yr	%
JA solar	3,293,273	26.7
CAT-2500kVA-50Hz-PP	37,149	0.302
CAT-2500kVA-50Hz-PP (1)	0	0
Grid Purchases	8,986,384	73.0
Total	12,316,807	100

Consumption	kWh/yr	%
AC Primary Load	12,216,167	100
DC Primary Load	0	0
Deferrable Load	0	0
Grid Sales	1,212	0.00992
Total	12,217,379	100

Quantity	kWh/yr	%
Excess Electricity	649	0.00530
Unmet Electric Load	0	0
Capacity Shortage	0	0

Quantity	Value	Units
Renewable Fraction	26.1	%
Max. Renew. Penetration	103	%

Figure 4.14: Production and consumption of electricity

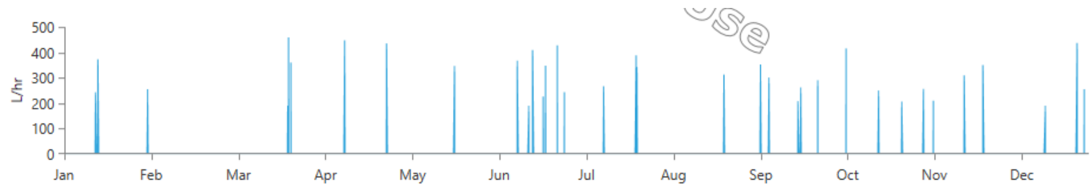


Figure 4.15: Fuel consumption over the year to supply during power outages

The amount of fuel consumed throughout the year is given in figure 4.15. According to the final report, the total fuel consumption for an average year is 10,494L which is 28.8L/day as a daily average.

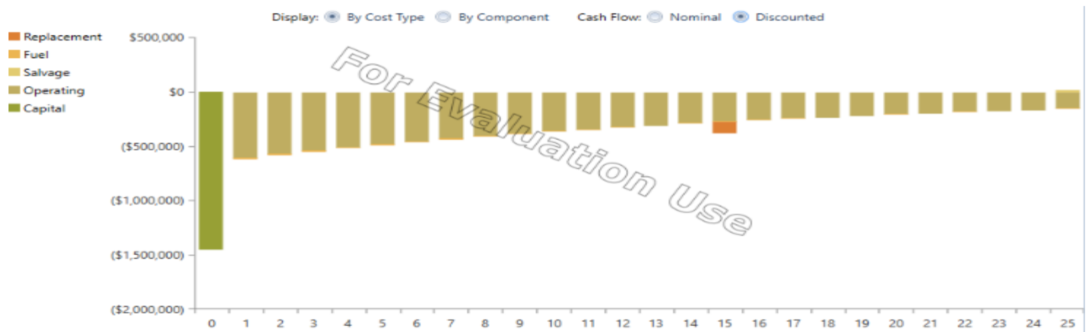


Figure 4.16: Cash flow analysis - Discounted

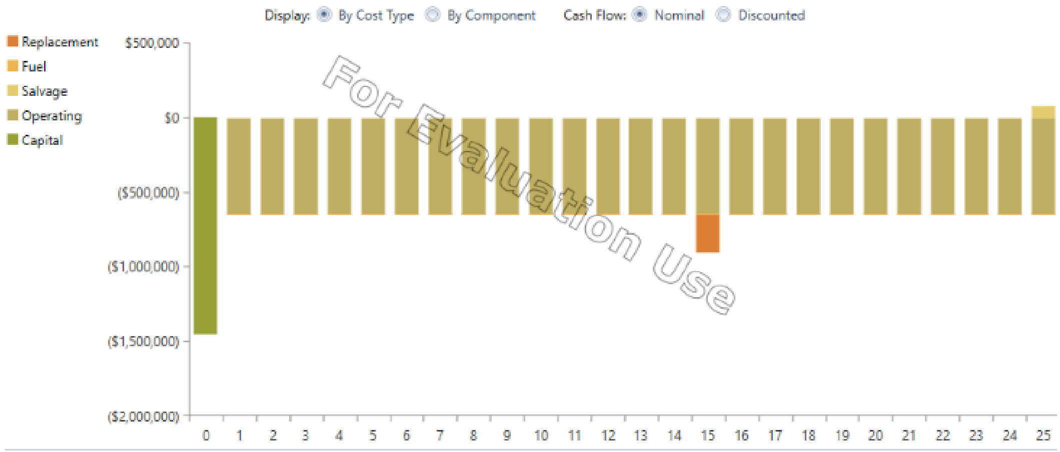


Figure 4.17: cash flow analysis by cost type

Figure 4.16 and Figure 4.17 depicts the cash flow analysis of total cost analysis for 25 years of project lifetime under a normal rate and a nominal discounted rate of 8.8% respectively.

When considering the Load Following control strategy (optimum 02) from the given optimizations as in figure 4.13. The initial capital cost for the Load following strategy is lesser than the Cycle charging strategy. The use of Photovoltaics is not initiated in this method, with the comparison of the economics with regard to these 2 cases both COE and NPC values are lesser in the first case and relevant to the 2nd case. Even though the initial capital is higher in the first scenario, when deliberating over the costs for a period of 25 years the optimum 1 configuration is more profitable than the optimum 2 configurations

4.5.1.1 Gas emissions

In the comparison of the gas emissions of the proposed HRES with the conventional coal-based power plants, the gas emission of the conventional power plant would be 0.814 kg/kWh for CO2, 4.631 g/kWh for CO, 5.823 g/kWh for SO2, and In 2.230 g/kWh In for In NO. The total energy consumed by the hospital load per year is 12216185kwH/year on average. This would emit 9,943,974.59kg of CO2, 46,050kg of CO, 268,152kg of SO2, and 597,979kg of NO. With the addition of Renewable energy the new emission output for the optimum 1 configuration is given in Fig 4.18.

Quantity	Value	Units
Carbon Dioxide	5,707,142	kg/yr
Carbon Monoxide	11.4	kg/yr
Unburned Hydrocarbons	0.630	kg/yr
Particulate Matter	0.630	kg/yr
Sulfur Dioxide	24,692	kg/yr
Nitrogen Oxides	12,199	kg/yr

Figure 4.18: Optimum 1 configuration -With renewable energy

Quantity	Value	Units
Carbon Dioxide	7,724,642	kg/yr
Carbon Monoxide	15.3	kg/yr
Unburned Hydrocarbons	0.842	kg/yr
Particulate Matter	0.842	kg/yr
Sulfur Dioxide	33,421	kg/yr
Nitrogen Oxides	16,510	kg/yr

Figure 4.19: Optimum 2 configuration - Without renewable energy

Hence it can be stated that for the same amount of electricity to be generated, gas emissions from the conventional coal-based power plants would be much higher than for the Hybrid Renewable Energy systems, also when considering the optimum 2 configurations which did not contain any Renewable energy source the output of gas emissions is comparatively higher than optimum 1, therefore, it is apparent that more priority should be given to Renewable energy generation than the Conventional coal power plants.

4.5.1.2 Net Present Cost Breakup Analysis

The net present Breakup analysis is given in table 4.14 & table 4.15 for the Optimum 1 and Optimum 2 configurations. It is noted that the final NPC value in table 02 is higher than the final NPC value in table 01, this is mainly due to new Renewable energy sources in the 2nd case. Even though the net capital cost is lower in the 1st scenario while considering it for a period of 25 years it is apparent that the Optimum 01 configuration can be selected based on the higher NPC values.

Table 4.14: Net Present Cost Breakup Analysis- Optimum 1 configurations.

Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Invertor	$454,920	$0	$94,095	$0.00	$0	$549,016
Generator	$0	$0	$0.00	$162,799	$0	$162,799
Battery	$497,000	$105,432	$102,799	$0	($19,843)	$685,388
Grid	$0	$0	$8,013,132	$0	$0	$8,013,132
PV arrays	$498,860	$0	$103,187	$0	$0	$602,047
System	$1,450,780	$105,432	$8,313,215	$162,799	($19,843)	$10,012,383

Table 4.15: Net Present Cost Breakup Analysis- Optimum 2 configurations.

Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Invertor	$454,920	$0	$94,095	$0	$0	$549,015
Generator	$0	$0	$0	$217,771	$0	$217,771
Battery	$497,000	$105,432	$102,799	$0	($19,843.38)	$685,388
Grid	$0	$0	$11,082,694	$0	$0	$11,082,694
System	$951,920	$105,432	$11,279,589	$217,771	($19,843.38)	$12,534,869

4.5.1.3 Salvage Analysis

Salvage value, which can be computed from equation 4.1, is the value that is reaming in a power system, at the end of the project's total lifetime. Homer has several assumptions with regard to the salvage value. They are

- The value of the components is directly proportional to their remaining life.
- The salvage value depends on the replacement cost rather than the initial capital cost and includes maintenance costs from the last event to the end of the total project.

$$s = C_{rep} \frac{R_{rem}}{R_{comp}} \tag{4.1}$$

$$R_{rem} = R_{comp} - (R_{proj} - R_{rep}) \tag{4.2}$$

$$R_{rem} = R_{rem} \, . INT \, \frac{R_{proj}}{R_{comp}} \tag{4.3}$$

Where,

Rrem	=	The remaining life of the component at the end of the project's lifetime
Rrep	=	The replacement cost duration is given by the below equation
Crep	=	Replacement cost ($)
R*comp*	=	Component lifetime (Yr)
Rproj	=	Project Lifetime (Yr)
INT()	=	approximation for a real number index {int (6.9897) = 6}

4.5.1.4 Sensitivity analysis

Sensitivity analysis enables the investors/designer to investigate into how the projected performance of a Hybrid renewable energy sources will vary along with changes in the cost of the components.

Discount rates

Homer pro software calculates the real discount rate by using the nominal discount rate and the expected inflation rate as shown in figure 4.20. Homer uses the real discount rates to calculate discount factors and annualized costs from net present costs. The Homer software uses the following equation to calculate the real discount rate factor.

$$i = \frac{i' - f}{1 + f} \tag{4.4}$$

i	=	Real discount rate
i'	=	Nominal discount rate (The rate at which money can be borrowed)
f	=	Expected inflation rate

Based on the inputs of the sensitivity analysis the nominal fixed discount rate for the system is taken as 8.00% annually, by this the O&M cost of the price of the components degrades by 8% per year. The expected inflation rate is taken as 2% and due to inflation the net cost of the components gets increased by 2% annually. Figure 4.17 shows the cost analysis for the system based on the Nominal discounted rate.

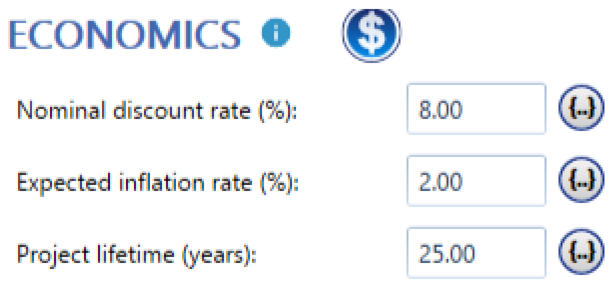


Figure 4.20: Sensitivity analysis inputs

Due to the nominal discount rate and inflation the net discounted value is 8% yearly, due to the discount factor investors can focus on improving the Renewable energy system by several upgrades and expanding the area of solar panels or focusing on increasing the battery capacity.

The drawback of this method is that the Nominal discount rate and inflation cannot be of a fixed value, according to the United States economic conferences the economic rates do change from time to time rapidly. For example, during Covid 19, economic inflation rates came to spike in which almost all the item costs increased drastically. Thus, the best scenario for a sensitivity analysis to conduct is to do the sensitivity analysis yearly and do conduct the project based on a yearly price-saving benefit.

5 FUTURE WORKS

1. **Comparison of Li-ion BESS & Hydrogen fuel cells for auxiliary power supply and storage**

The current study was done by comparing the economic viability of utilizing Li-ion batteries with a Diesel generator. This study can be further explored by identifying the prospects of feasibility and monetary benefit between the two types of battery storage. Even though Li-ion batteries are cheaper and more effective, the installation of Hydrogen fuel cells provides higher efficiency and energy storage density. Thus, the implementation of hydrogen fuel cells with Hybrid Solar PV to meet the required load can be explored to pursue in future installations.

2. **Implementation of Hybrid Solar PV systems for facilities already lacking secondary power sources**

The proposed Hybrid Solar PV system of the study was done at a site that has already installed standby diesel generators. Thus, the economic analysis of the proposed design and comparison between battery storage and the diesel generator was computed neglecting the capital cost of installation of the diesel generator. Thus, the study could be further pursued to investigate the nature of the energy economic performance of a site without any backup power systems.

3. **Modeling & simulating the power system can be further developed to analyze different scenarios under complex conditions.**

The intermittent nature of the Solar power generator depends on weather conditions and cloud coverage. The effect of cloud coverage on Solar PV generation is quite rapid compared to the change in weather conditions and it is impossible to predict the occurrences of cloud coverage. A sudden voltage drop which can be termed a voltage dip occurs as a result of the formation of clouds. The magnitude of the reduction of generated power depends on the area of the Solar plant that has been covered by the clouds and the period of coverage. This power deficit is compensated by a battery storage system providing a constant power output. This scenario could be modeled using MATLAB Simulink to observe its performance through simulation.

The proposed Hybrid Solar PV system has the capability of switching between the islanded mode and grid-tied mode, and this transfer should be conducted under any situation seamlessly. This occurrence can be Simulated using MATLAB Simulink and the Voltage transition could be observed.

6 CONCLUSION

The fundamental objective of the study was to design a Hybrid Solar PV system with the capability of islanded operation to compensate for the power deficit during a power outage and thereby use it as an alternative to diesel generators. The rapid spread of Covid -19 pandemic resulted in the rising demand for the health sector around the world. Concurrently, a sudden increment of power outages and fuel price hikes resulted in the island with the economic crisis and fossil fuel shortage. The health sector was compelled to rely on standby back power diesel generators to provide uninterrupted power supply to the vital machinery. With the inflation and sudden surge in the usage of DGs, the expense of fuel was increased resulting in an increase in the carbon footprint.

The proposed Hybrid Solar PV system consists of a 1.9MW rooftop solar plant along with a battery capacity of 2.7 MWh to cater to the demand during a power outage during sun peak hours or off-peak hours. Optimized design and control strategies were explored in this study to design this hybrid power system with the islanded capability to meet the electric loads of the hospital, UHKDU. The hybrid power system includes two main energy sources namely solar PV and Lithium-ion BESS, and a DC-AC Bi-directional converter.

A thorough economic analysis was conducted to identify the suitable capacities of the components. It was identified that the operation of the proposed system mainly depended on the capacity of the battery storage system, as the higher the capacity of the battery bank, the higher the availability of power to supply during a power outage, performing peak shaving and expenses incurred. It was identified that the usage of 142 units of 400Ah batteries provided the highest profit over the estimated lifetime of the system, resulting in a total payback period of 5.85 years with an investment cost of $1,765,711 for the system. Thus, the proposed design, the solar PV/DG/Li-ion/Inverter power system, could meet the daily electrical demand during a power outage and provide the capability of peak shaving during ordinary days. The project could generate profits of up to an estimation of $5.5 Mn based on the control strategies used in the system over the period of the project lifespan. Installation of such a system will increase renewable energy penetration and reduce fuel costs and the emission of greenhouse gases (GHG) to the environment.

The proposed design was modeled and simulated using MATLAB Simulink to observe its performance under grid-tied mode and islanded mode. HOMER Pro software was used to obtain a techno-economic analysis of the system and conclude the optimum configuration of the Hybrid Solar PV system and respective control strategies.

This research promotes the concept of microgrids integrated with renewable energy sources, which are directly assisting the efforts undertaken by the Sri Lankan government toward the development of the renewable energy sector. A similar approach to the proposed hybrid system design can be further developed to be implemented in factories, banks, military facilities, high-security areas, etc. The concept of microgrids using renewable energy sources can also be normalized in society through this study.

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8 APPENDIX I

8.1 Average hourly GHI for each month

Average hourly GHI for each month													
	January	February	March	April	May	June	July	August	September	October	November	December	**Average**
0:00	0	0	0	0	0	0	0	0	0	0	0	0	**0.00**
1:00	0	0	0	0	0	0	0	0	0	0	0	0	**0.00**
2:00	0	0	0	0	0	0	0	0	0	0	0	0	**0.00**
3:00	0	0	0	0	0	0	0	0	0	0	0	0	**0.00**
4:00	**0**	0	0	0	0	0	0	0	0	0	0	0	**0.00**
5:00	1.75	1.76	1.75	1.74	1.75	5.39	1.75	1.75	6.46	1.75	6.15	1.75	**2.81**
6:00	49.82	41.11	59.25	74.54	76.90	59.79	50.14	60.21	79.93	99.93	66.67	50.55	**64.07**
7:00	225.39	223.79	271.29	271.21	227.21	200.71	191.61	197.39	233.46	282.79	224.00	199.69	**229.04**
8:00	451.50	463.00	499.64	472.86	439.17	346.79	384.11	369.71	414.82	435.04	412.44	373.34	**421.87**
9:00	615.46	652.07	687.82	635.93	525.66	534.75	546.86	539.61	583.07	570.82	581.30	515.59	**582.41**
10:00	700.64	780.96	873.68	787.36	654.28	618.61	656.57	666.54	716.21	629.61	664.07	586.21	**694.56**
11:00	721.68	836.21	934.36	821.68	674.48	660.29	693.54	677.71	728.79	675.75	652.00	597.41	**722.82**
12:00	678.57	803.36	902.54	806.68	595.07	664.75	622.96	644.96	661.75	664.32	625.04	550.10	**685.01**
13:00	627.79	713.57	827.82	671.71	494.00	583.46	555.18	521.29	552.96	563.54	520.41	464.97	**591.39**
14:00	497.07	546.57	607.25	458.04	399.83	435.75	373.11	390.32	438.64	352.96	355.33	329.59	**432.04**
15:00	318.61	339.04	361.75	220.32	244.03	294.64	243.54	250.07	284.43	164.89	178.96	186.79	**257.26**
16:00	120.61	172.39	157.25	92.82	143.17	158.43	123.54	143.32	147.61	56.11	48.67	69.83	**119.48**
17:00	14.29	33.54	28.79	14.46	25.24	29.04	28.04	28.75	16.50	5.57	2.56	6.66	**19.45**
18:00	0	0	0	0	0	0	0	0	0	0	0	0	**0.06**
19:00	0	0	0	0	0	0	0	0	0	0	0	0	**0.00**
20:00	0	0	0	0	0	0	0	0	0	0	0	0	**0.00**
21:00	0	0	0	0	0	0	0	0	0	0	0	0	**0.00**
22:00	0	0	0	0	0	0	0	0	0	0	0	0	**0.00**
23:00	0	0	0	0	0	0	0	0	0	0	0	0	**0.00**
24:00:00	0	0	0	0	0	0	0	0	0	0	0	0	**0.00**

8.2 Monthly GHI data

January

DAY\T	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00:00
1st	0	0	0	0	0	2	65	267	533	705	772	671	607	546	337	146	85	12	0	0	0	0	0	0	0
2nd	0	0	0	0	0	2	59	270	541	723	844	880	805	691	459	280	116	14	0	0	0	0	0	0	0
3rd	0	0	0	0	0	1	50	270	539	688	736	834	789	772	604	350	140	13	0	0	0	0	0	0	0
4th	0	0	0	0	0	2	72	305	539	723	847	899	878	784	625	378	115	14	0	0	0	0	0	0	0
5th	0	0	0	0	0	2	64	269	519	724	836	758	819	782	617	382	139	14	0	0	0	0	0	0	0
6th	0	0	0	0	0	2	53	215	404	541	593	568	631	614	439	268	92	10	0	0	0	0	0	0	0
7th	0	0	0	0	0	2	42	203	521	712	793	892	878	778	487	265	104	11	0	0	0	0	0	0	0
8th	0	0	0	0	0	2	58	260	529	579	601	683	649	537	407	319	109	9	0	0	0	0	0	0	0
9th	0	0	0	0	0	1	43	174	290	392	414	487	466	438	344	194	77	10	0	0	0	0	0	0	0
10th	0	0	0	0	0	2	46	178	383	500	601	749	724	608	383	227	74	9	0	0	0	0	0	0	0
11th	0	0	0	0	0	2	57	221	492	647	671	630	719	685	557	395	153	16	0	0	0	0	0	0	0
12th	0	0	0	0	0	2	62	282	519	706	835	901	805	777	543	314	108	16	0	0	0	0	0	0	0
13th	0	0	0	0	0	2	60	277	514	701	813	698	527	541	482	394	131	12	0	0	0	0	0	0	0
14th	0	0	0	0	0	2	44	247	525	714	635	605	681	789	637	400	152	13	0	0	0	0	0	0	0
15th	0	0	0	0	0	2	62	296	541	732	863	918	901	810	652	421	167	18	0	0	0	0	0	0	0
16th	0	0	0	0	0	2	53	257	509	722	853	904	889	801	639	409	162	16	0	0	0	0	0	0	0
17th	0	0	0	0	0	2	61	291	532	723	855	917	902	812	643	357	108	13	0	0	0	0	0	0	0
18th	0	0	0	0	0	2	58	277	534	726	844	776	783	797	646	408	162	16	0	0	0	0	0	0	0
19th	0	0	0	0	0	2	60	286	529	720	852	859	818	810	652	416	146	13	0	0	0	0	0	0	0
20th	0	0	0	0	0	2	60	290	516	705	836	884	696	660	592	411	138	14	0	0	0	0	0	0	0
21st	0	0	0	0	0	2	61	297	526	707	730	763	705	575	477	345	158	19	0	0	0	0	0	0	0
22nd	0	0	0	0	0	2	53	198	296	450	678	683	586	482	403	290	133	17	0	0	0	0	0	0	0
23rd	0	0	0	0	0	1	46	194	454	707	669	412	372	488	388	264	128	21	0	0	0	0	0	0	0
24th	0	0	0	0	0	2	25	154	382	540	688	569	407	254	299	154	67	11	0	0	0	0	0	0	0
25th	0	0	0	0	0	2	26	95	350	408	349	386	280	192	160	160	70	8	0	0	0	0	0	0	0
26th	0	0	0	0	0	0	22	146	317	433	545	573	531	417	294	187	59	12	0	0	0	0	0	0	0
27th	0	0	0	0	0	1	20	92	220	229	271	403	440	470	376	212	30	7	0	0	0	0	0	0	0
28th	0	0	0	0	0	1	34	184	354	591	710	733	673	619	437	193	77	13	0	0	0	0	0	0	0
29th	0	0	0	0	0	1	45	158	296	520	781	848	751	735	675	446	144	10	0	0	0	0	0	0	0
30th	0	0	0	0	0	2	59	193	516	647	584	783	637	488	380	237	136	18	0	0	0	0	0	0	0
31st	0	0	0	0	0	2	49	272	535	734	871	926	852	835	684	475	238	40	0	0	0	0	0	0	0
avg.	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**1.75**	**49.82**	**####**	**####**	**#####**	**#####**	**#####**	**#####**	**#####**	**#####**	**#####**	**#####**	**14.29**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

February

DAY\	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00:00
1st	0	0	0	0	0	2	55	297	530	725	861	928	920	836	684	461	166	29	0	0	0	0	0	0	0
2nd	0	0	0	0	0	2	52	276	528	679	861	907	725	612	472	304	152	30	0	0	0	0	0	0	0
3rd	0	0	0	0	0	1	44	256	543	740	878	942	932	845	686	337	168	33	0	0	0	0	0	0	0
4th	0	0	0	0	0	2	48	260	530	737	876	906	819	547	387	273	159	32	0	0	0	0	0	0	0
5th	0	0	0	0	0	2	56	290	534	731	821	920	711	540	435	268	138	27	0	0	0	0	0	0	0
6th	0	0	0	0	0	2	50	272	527	725	865	934	927	841	678	304	131	25	0	0	0	0	0	0	0
7th	0	0	0	0	0	2	47	264	524	722	862	931	923	840	686	478	223	38	0	0	0	0	0	0	0
8th	0	0	0	0	0	2	30	146	362	630	838	929	922	837	680	462	199	29	0	0	0	0	0	0	0
9th	0	0	0	0	0	1	35	162	341	593	857	937	931	847	689	469	244	45	0	0	0	0	0	0	0
10th	0	0	0	0	0	2	45	254	486	655	863	934	927	844	687	441	228	44	0	0	0	0	0	0	0
11th	0	0	0	0	0	2	42	231	506	664	871	939	921	850	690	481	245	45	0	0	0	0	0	0	0
12th	0	0	0	0	0	2	42	245	532	722	803	884	872	790	489	422	249	46	0	0	0	0	0	0	0
13th	0	0	0	0	0	2	37	236	526	678	800	925	909	857	670	388	216	48	0	0	0	0	0	0	0
14th	0	0	0	0	0	2	46	258	534	730	843	651	781	832	661	211	116	22	0	0	0	0	0	0	0
15th	0	0	0	0	0	2	57	284	542	739	869	758	594	635	578	268	150	24	0	0	0	0	0	0	0
16th	0	0	0	0	0	2	53	250	467	646	793	788	841	803	550	216	167	44	0	0	0	0	0	0	0
17th	0	0	0	0	0	2	33	195	491	751	891	958	932	693	537	405	251	49	0	0	0	0	0	0	0
18th	0	0	0	0	0	2	27	218	533	742	880	834	710	571	363	354	144	31	0	0	0	0	0	0	0
19th	0	0	0	0	0	2	15	74	253	447	620	692	663	522	369	246	128	26	0	0	0	0	0	0	0
20th	0	0	0	0	0	2	36	178	359	466	573	661	698	603	505	350	173	40	0	0	0	0	0	0	0
21st	0	0	0	0	0	2	52	277	527	751	897	964	953	867	707	493	250	48	0	0	0	0	0	0	0
22nd	0	0	0	0	0	2	39	220	500	642	829	955	952	861	689	476	240	45	0	0	0	0	0	0	0
23rd	0	0	0	0	0	1	42	242	487	736	847	949	941	857	699	490	251	48	0	0	0	0	0	0	0
24th	0	0	0	0	0	2	31	210	453	486	716	940	896	863	700	461	251	42	0	0	0	0	0	0	0
25th	0	0	0	0	0	2	46	192	370	724	525	389	243	303	98	36	21	7	0	0	0	0	0	0	0
26th	0	0	0	0	0	0	17	157	300	393	385	535	526	460	255	109	26	8	0	0	0	0	0	0	0
27th	0	0	0	0	0	1	30	122	317	514	608	784	698	605	361	207	106	18	0	0	0	0	0	0	0
28th	0	0	0	0	0	1	44	200	362	490	535	540	627	419	299	83	35	16	0	0	0	0	0	0	0
avg.	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**1.76**	**41.11**	**223.79**	**463.00**	**#####**	**#####**	**#####**	**#####**	**#####**	**#####**	**#####**	**#####**	**33.54**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

March

DAY\	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00:00
1st	0	0	0	0	0	2	27	134	267	366	444	481	479	274	40	57	93	30	0	0	0	0	0	0	0
2nd	0	0	0	0	0	2	46	208	407	685	912	904	833	885	729	389	162	39	0	0	0	0	0	0	0
3rd	0	0	0	0	0	1	34	182	525	739	861	971	974	882	664	391	183	38	0	0	0	0	0	0	0
4th	0	0	0	0	0	2	50	209	438	443	740	969	958	793	558	304	176	40	0	0	0	0	0	0	0
5th	0	0	0	0	0	2	72	308	558	762	907	982	974	885	717	488	225	51	0	0	0	0	0	0	0
6th	0	0	0	0	0	2	48	308	493	766	921	979	967	879	723	498	257	45	0	0	0	0	0	0	0
7th	0	0	0	0	0	2	65	307	434	701	850	856	843	798	602	428	123	23	0	0	0	0	0	0	0
8th	0	0	0	0	0	2	33	271	481	727	908	976	929	794	538	243	111	21	0	0	0	0	0	0	0
9th	0	0	0	0	0	1	53	284	529	711	735	961	913	857	631	342	133	24	0	0	0	0	0	0	0
10th	0	0	0	0	0	2	56	241	442	652	875	876	848	775	333	125	13	9	0	0	0	0	0	0	0
11th	0	0	0	0	0	2	65	298	500	569	892	882	706	637	161	132	94	25	0	0	0	0	0	0	0
12th	0	0	0	0	0	2	82	328	581	780	916	975	902	782	477	129	77	15	0	0	0	0	0	0	0
13th	0	0	0	0	0	2	64	173	455	608	772	791	807	852	516	112	15	10	0	0	0	0	0	0	0
14th	0	0	0	0	0	2	75	330	495	648	736	802	756	696	612	379	117	15	0	0	0	0	0	0	0
15th	0	0	0	0	0	2	30	208	423	745	894	960	948	859	685	327	76	12	0	0	0	0	0	0	0
16th	0	0	0	0	0	2	50	203	357	659	927	967	960	886	714	394	112	18	0	0	0	0	0	0	0
17th	0	0	0	0	0	2	59	268	545	646	897	996	982	889	661	289	155	35	0	0	0	0	0	0	0
18th	0	0	0	0	0	2	75	266	479	651	813	870	899	843	602	467	252	47	0	0	0	0	0	0	0
19th	0	0	0	0	0	2	59	275	478	686	921	1000	986	888	712	490	227	35	0	0	0	0	0	0	0
20th	0	0	0	0	0	2	58	261	448	710	904	925	977	882	711	492	218	28	0	0	0	0	0	0	0
21st	0	0	0	0	0	2	54	245	536	801	935	986	967	873	704	484	239	43	0	0	0	0	0	0	0
22nd	0	0	0	0	0	2	51	270	516	659	896	986	970	876	712	492	229	44	0	0	0	0	0	0	0
23rd	0	0	0	0	0	1	66	302	592	707	932	993	974	878	711	492	245	44	0	0	0	0	0	0	0
24th	0	0	0	0	0	2	59	303	536	757	941	999	982	887	713	492	245	43	0	0	0	0	0	0	0
25th	0	0	0	0	0	2	53	249	501	689	957	1018	999	902	732	508	256	46	0	0	0	0	0	0	0
26th	0	0	0	0	0	0	77	318	600	761	932	1003	985	885	702	479	235	41	0	0	0	0	0	0	0
27th	0	0	0	0	0	1	56	277	424	557	676	568	474	552	524	306	154	20	0	0	0	0	0	0	0
28th	0	0	0	0	0	1	61	253	549	726	876	971	957	861	681	412	80	10	0	0	0	0	0	0	0
29th	0	0	0	0	0	1	52	241	503	657	902	932	867	811	525	201	93	13	0	0	0	0	0	0	0
30th	0	0	0	0	0	2	53	264	581	772	915	976	885	811	664	405	134	24	0	0	0	0	0	0	0
31st	0	0	0	0	0	2	83	336	516	709	893	963	856	848	382	219	112	25	0	0	0	0	0	0	0
avg.	0.00	0.00	0.00	0.00	0.00	1.75	59.25	####	####	####	####	####	####	####	####	####	####	28.79	0.00	0.00	0.00	0.00	0.00	0.00	0.00

April

DAY\T	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00:00
1st	0	0	0	0	0	2	74	304	586	685	859	920	829	846	674	318	88	12	0	0	0	0	0	0	0
2nd	0	0	0	0	0	2	48	205	462	723	760	828	673	710	529	372	209	23	0	0	0	0	0	0	0
3rd	0	0	0	0	0	1	48	262	456	454	786	903	954	860	689	437	221	26	0	0	0	0	0	0	0
4th	0	0	0	0	0	2	80	311	588	700	699	820	755	220	124	113	46	5	0	0	0	0	0	0	0
5th	0	0	0	0	0	2	30	150	374	509	819	742	957	678	259	52	11	5	0	0	0	0	0	0	0
6th	0	0	0	0	0	2	137	398	632	822	948	939	766	383	59	15	17	8	0	0	0	0	0	0	0
7th	0	0	0	0	0	2	109	305	488	542	613	599	738	759	518	156	10	4	0	0	0	0	0	0	0
8th	0	0	0	0	0	2	10	57	149	390	615	742	932	718	376	171	91	24	0	0	0	0	0	0	0
9th	0	0	0	0	0	1	80	358	573	700	931	990	966	868	517	233	119	24	0	0	0	0	0	0	0
10th	0	0	0	0	0	2	70	259	529	747	941	999	974	874	675	124	14	5	0	0	0	0	0	0	0
11th	0	0	0	0	0	2	85	300	539	624	502	408	420	523	450	334	153	19	0	0	0	0	0	0	0
12th	0	0	0	0	0	2	69	196	447	799	929	982	957	857	687	398	187	19	0	0	0	0	0	0	0
13th	0	0	0	0	0	2	73	271	444	624	919	817	637	688	682	397	214	18	0	0	0	0	0	0	0
14th	0	0	0	0	0	2	13	78	165	228	346	439	434	395	264	159	45	8	0	0	0	0	0	0	0
15th	0	0	0	0	0	2	112	391	625	774	931	988	961	860	692	476	204	37	0	0	0	0	0	0	0
16th	0	0	0	0	0	2	53	193	382	668	933	975	946	846	532	224	109	22	0	0	0	0	0	0	0
17th	0	0	0	0	0	2	52	236	561	803	925	980	955	854	499	220	107	15	0	0	0	0	0	0	0
18th	0	0	0	0	0	2	80	292	586	804	925	966	937	835	665	392	108	11	0	0	0	0	0	0	0
19th	0	0	0	0	0	2	66	273	556	760	922	974	947	845	674	458	221	31	0	0	0	0	0	0	0
20th	0	0	0	0	0	2	87	344	477	701	852	971	903	838	669	376	205	31	0	0	0	0	0	0	0
21st	0	0	0	0	0	2	34	140	330	475	722	757	765	624	325	105	38	9	0	0	0	0	0	0	0
22nd	0	0	0	0	0	2	52	185	308	414	662	760	787	454	350	233	107	17	0	0	0	0	0	0	0
23rd	0	0	0	0	0	1	47	187	512	696	736	829	844	597	321	100	15	5	0	0	0	0	0	0	0
24th	0	0	0	0	0	2	93	197	239	297	364	471	455	395	222	19	9	3	0	0	0	0	0	0	0
25th	0	0	0	0	0	2	111	374	627	792	924	972	944	843	587	395	212	32	0	0	0	0	0	0	0
26th	0	0	0	0	0	0	68	352	488	705	919	971	944	843	668	290	52	10	0	0	0	0	0	0	0
27th	0	0	0	0	0	1	112	340	474	640	899	782	804	537	356	125	51	8	0	0	0	0	0	0	0
28th	0	0	0	0	0	1	102	378	472	705	804	729	712	550	307	28	9	3	0	0	0	0	0	0	0
29th	0	0	0	0	0	1	125	405	580	618	550	537	532	490	292	53	12	2	0	0	0	0	0	0	0
30th	0	0	0	0	0	2	89	362	639	815	930	965	661	574	366	86	12	4	0	0	0	0	0	0	0
avg.	0.00	0.00	0.00	0.00	0.00	1.74	74.54	271.21	472.86	635.93	787.36	821.68	806.68	671.71	458.04	220.32	92.82	14.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00

May

DAY\Tim	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	#####
1st	0	0	0	0	0	2	73	204	315	504	884	900	539	704	635	306	167	23	0	0	0	0	0	0	0
2nd	0	0	0	0	0	2	78	212	425	596	857	662	748	695	522	323	107	28	0	0	0	0	0	0	0
3rd	0	0	0	0	0	1	72	142	460	516	870	920	827	783	515	243	185	30	0	0	0	0	0	0	0
4th	0	0	0	0	0	2	87	176	472	638	720	917	767	551	133	63	166	28	0	0	0	0	0	0	0
5th	0	0	0	0	0	2	85	217	364	509	686	869	686	642	609	249	166	27	0	0	0	0	0	0	0
6th	0	0	0	0	0	2	50	187	454	589	701	529	420	577	238	235	116	14	0	0	0	0	0	0	0
7th	0	0	0	0	0	2	123	274	373	633	429	45	28	60	106	99	104	29	0	0	0	0	0	0	0
8th	0	0	0	0	0	2	69	262	426	725	843	750	733	598	441	202	106	11	0	0	0	0	0	0	0
9th	0	0	0	0	0	1	22	30	117	39	26	27	26	23	20	38	33	6	0	0	0	0	0	0	0
10th	0	0	0	0	0	2	91	366	584	460	810	670	781	696	507	416	194	31	0	0	0	0	0	0	0
11th	0	0	0	0	0	2	78	228	359	343	656	904	796	538	350	283	193	31	0	0	0	0	0	0	0
12th	0	0	0	0	0	2	80	225	533	491	231	72	135	185	203	179	98	30	0	0	0	0	0	0	0
13th	0	0	0	0	0	2	126	228	453	330	833	783	894	589	599	317	211	35	0	0	0	0	0	0	0
14th	0	0	0	0	0	2	53	287	465	131	91	160	43	306	333	192	200	33	0	0	0	0	0	0	0
15th	0	0	0	0	0	2	113	393	543	366	639	919	597	517	639	432	206	33	0	0	0	0	0	0	0
16th	0	0	0	0	0	2	87	198	314	393	589	556	344	153	222	286	143	24	0	0	0	0	0	0	0
17th	0	0	0	0	0	2	87	287	584	751	712	759	861	586	613	417	196	32	0	0	0	0	0	0	0
18th	0	0	0	0	0	2	107	360	518	676	792	901	738	516	486	316	189	31	0	0	0	0	0	0	0
19th	0	0	0	0	0	2	103	326	431	753	863	852	889	792	566	417	172	36	0	0	0	0	0	0	0
20th	0	0	0	0	0	2	97	260	534	694	881	833	833	785	632	392	208	37	0	0	0	0	0	0	0
21st	0	0	0	0	0	2	146	345	588	608	887	866	903	812	652	449	224	41	0	0	0	0	0	0	0
22nd	0	0	0	0	0	2	66	192	407	704	869	911	880	760	455	301	102	20	0	0	0	0	0	0	0
23rd	0	0	0	0	0	1	44	285	561	713	880	808	525	528	267	212	181	30	0	0	0	0	0	0	0
24th	0	0	0	0	0	2	24	92	498	688	876	922	895	801	632	307	225	42	0	0	0	0	0	0	0
25th	0	0	0	0	0	2	134	340	581	782	891	934	906	810	551	158	100	10	0	0	0	0	0	0	0
26th	0	0	0	0	0	0	84	294	454	614	876	858	560	408	383	147	29	9	0	0	0	0	0	0	0
27th	0	0	0	0	0	1	40	150	603	783	832	927	542	99	23	34	38	7	0	0	0	0	0	0	0
28th	0	0	0	0	0	1	33	72	195	154	301	370	208	29	77	89	29	11	0	0	0	0	0	0	0
29th	0	0	0	0	0	1	7	13	22	71	80	28	107	299	342	233	140	28	0	0	0	0	0	0	0
30th	0	0	0	0	0	2	37	160	404	565	455	795	738	389	601	126	54	11	0	0	0	0	0	0	0
31st	0	0	0	0	0	2	85	200	439	525	655	675	595	494	400	245	144	25	0	0	0	0	0	0	0
avg.	0.00	0.00	0.00	0.00	0.00	1.75	76.90	227.21	439.17	525.66	654.28	674.48	595.07	494.00	399.83	244.03	143.17	25.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00

June

DAY\Tin	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	####
1st	0	0	0	0	0	5	33	88	129	173	132	121	61	25	31	19	14	6	0	0	0	0	0	0	0
2nd	0	0	0	0	0	2	5	11	17	22	26	63	152	134	106	63	45	14	0	0	0	0	0	0	0
3rd	0	0	0	0	0	1	4	10	16	21	24	25	29	58	82	105	64	12	0	0	0	0	0	0	0
4th	0	0	0	0	0	7	90	350	442	520	826	776	335	130	289	385	182	29	0	0	0	0	0	0	0
5th	0	0	0	0	0	5	65	169	364	578	542	414	758	759	607	314	169	23	0	0	0	0	0	0	0
6th	0	0	0	0	0	5	37	149	399	228	650	873	625	273	234	125	155	35	0	0	0	0	0	0	0
7th	0	0	0	0	0	4	66	271	465	671	780	882	854	762	625	399	219	27	0	0	0	0	0	0	0
8th	0	0	0	0	0	4	29	144	294	383	199	718	668	455	281	229	106	13	0	0	0	0	0	0	0
9th	0	0	0	0	0	4	29	96	116	379	610	605	389	321	482	283	125	30	0	0	0	0	0	0	0
10th	0	0	0	0	0	8	125	275	493	713	815	671	839	767	624	256	60	25	0	0	0	0	0	0	0
11th	0	0	0	0	0	8	127	246	499	562	171	28	54	302	447	432	217	28	0	0	0	0	0	0	0
12th	0	0	0	0	0	3	5	26	179	411	409	363	532	691	238	151	72	12	0	0	0	0	0	0	0
13th	0	0	0	0	0	5	77	127	274	562	748	851	829	741	488	281	193	32	0	0	0	0	0	0	0
14th	0	0	0	0	0	6	49	239	401	699	813	860	804	413	339	260	54	18	0	0	0	0	0	0	0
15th	0	0	0	0	0	4	41	148	362	524	389	291	540	515	287	191	86	16	0	0	0	0	0	0	0
16th	0	0	0	0	0	1	24	133	313	550	453	594	545	399	232	230	183	20	0	0	0	0	0	0	0
17th	0	0	0	0	0	12	96	342	545	705	758	629	739	652	454	303	178	30	0	0	0	0	0	0	0
18th	0	0	0	0	0	1	40	198	290	515	766	775	685	683	505	344	159	30	0	0	0	0	0	0	0
19th	0	0	0	0	0	10	58	241	315	619	798	841	823	737	582	384	130	25	0	0	0	0	0	0	0
20th	0	0	0	0	0	2	64	294	457	695	679	843	834	745	593	331	187	29	0	0	0	0	0	0	0
21st	0	0	0	0	0	9	47	297	194	543	808	857	837	750	605	416	207	43	1	0	0	0	0	0	0
22nd	0	0	0	0	0	5	52	215	489	671	717	819	836	753	625	367	216	47	1	0	0	0	0	0	0
23rd	0	0	0	0	0	10	67	257	486	697	807	860	842	758	616	373	210	46	1	0	0	0	0	0	0
24th	0	0	0	0	0	2	84	238	415	649	705	699	806	684	424	239	213	35	0	0	0	0	0	0	0
25th	0	0	0	0	0	3	39	98	273	478	569	424	539	666	343	271	136	19	0	0	0	0	0	0	0
26th	0	0	0	0	0	3	69	234	424	639	747	826	765	578	411	286	193	24	0	0	0	0	0	0	0
27th	0	0	0	0	0	4	80	214	355	700	822	883	866	777	494	333	210	45	1	0	0	0	0	0	0
28th	0	0	0	0	0	12	88	336	482	677	823	835	762	694	375	434	237	54	1	0	0	0	0	0	0
29th	0	0	0	0	0	9	108	91	88	335	126	629	851	767	613	321	233	55	1	0	0	0	0	0	0
30th	0	0	0	0	0	4	14	182	280	249	767	617	627	507	306	207	42	11	0	0	0	0	0	0	0
avg.	0.00	0.00	0.00	0.00	0.00	5.39	59.79	200.71	346.79	534.75	618.61	660.29	664.75	583.46	435.75	294.64	158.43	29.04	0.21	0.00	0.00	0.00	0.00	0.00	0.00

july

DAY	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	24:00:00
1st	0	0	0	0	0	2	21	205	326	649	767	814	796	718	481	265	207	50	1	0	0	0	0	0	0
2nd	0	0	0	0	0	2	68	151	246	656	774	813	664	617	339	266	196	56	1	0	0	0	0	0	0
3rd	0	0	0	0	0	1	89	266	504	637	721	820	807	680	500	326	214	51	1	0	0	0	0	0	0
4th	0	0	0	0	0	2	78	288	473	604	776	751	620	675	126	121	204	40	0	0	0	0	0	0	0
5th	0	0	0	0	0	2	66	256	459	656	748	736	721	705	403	254	207	47	1	0	0	0	0	0	0
6th	0	0	0	0	0	2	45	217	452	600	609	617	629	678	386	251	149	22	1	0	0	0	0	0	0
7th	0	0	0	0	0	2	60	218	531	696	769	809	820	712	266	271	101	18	1	0	0	0	0	0	0
8th	0	0	0	0	0	2	87	247	452	595	727	774	780	568	492	327	207	49	1	0	0	0	0	0	0
9th	0	0	0	0	0	1	85	246	477	674	749	730	598	568	415	324	218	53	1	0	0	0	0	0	0
10th	0	0	0	0	0	2	17	171	400	581	652	811	615	539	257	357	172	19	1	0	0	0	0	0	0
11th	0	0	0	0	0	2	7	56	186	245	328	575	564	296	93	30	17	10	0	0	0	0	0	0	0
12th	0	0	0	0	0	2	33	124	370	677	788	796	695	597	503	365	117	44	0	0	0	0	0	0	0
13th	0	0	0	0	0	2	31	168	254	368	438	417	508	540	324	179	78	38	1	0	0	0	0	0	0
14th	0	0	0	0	0	2	41	148	380	530	663	533	483	372	320	175	61	16	0	0	0	0	0	0	0
15th	0	0	0	0	0	2	29	97	230	311	557	686	566	703	525	300	169	29	0	0	0	0	0	0	0
16th	0	0	0	0	0	2	54	198	466	672	762	719	724	604	257	116	52	12	0	0	0	0	0	0	0
17th	0	0	0	0	0	2	13	69	114	240	453	356	280	249	185	60	63	21	0	0	0	0	0	0	0
18th	0	0	0	0	0	2	36	124	393	498	496	730	418	347	265	228	195	41	0	0	0	0	0	0	0
19th	0	0	0	0	0	2	25	97	331	616	771	825	782	341	338	99	25	28	0	0	0	0	0	0	0
20th	0	0	0	0	0	2	65	291	479	603	739	815	794	493	180	56	41	13	0	0	0	0	0	0	0
21st	0	0	0	0	0	2	27	165	398	468	723	805	725	563	567	255	60	16	0	0	0	0	0	0	0
22nd	0	0	0	0	0	2	61	197	302	356	365	351	272	508	381	285	104	25	0	0	0	0	0	0	0
23rd	0	0	0	0	0	1	28	105	267	580	714	482	214	319	363	298	45	11	0	0	0	0	0	0	0
24th	0	0	0	0	0	2	36	154	401	621	518	698	787	754	621	443	239	58	1	0	0	0	0	0	0
25th	0	0	0	0	0	2	47	150	188	392	567	675	648	490	366	297	148	46	0	0	0	0	0	0	0
26th	0	0	0	0	0	0	78	300	344	372	543	539	503	568	372	216	102	18	0	0	0	0	0	0	0
27th	0	0	0	0	0	1	62	178	380	682	796	827	683	594	371	397	225	27	0	0	0	0	0	0	0
28th	0	0	0	0	0	1	80	301	525	689	797	825	627	659	367	119	142	34	1	0	0	0	0	0	0
29th	0	0	0	0	0	1	46	218	487	672	762	847	723	602	515	401	133	21	1	0	0	0	0	0	0
30th	0	0	0	0	0	2	91	318	516	677	790	848	835	752	588	299	119	15	0	0	0	0	0	0	0
31st	0	0	0	0	0	2	76	264	500	637	784	842	829	749	601	296	66	14	0	0	0	0	0	0	0
avg.	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**1.75**	**50.14**	**191.61**	**384.11**	**546.86**	**656.57**	**693.54**	**622.96**	**555.18**	**373.11**	**243.54**	**123.54**	**28.04**	**0.36**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

August

DAY\T	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	####	####	####	####	####	####	####
1st	0	0	0	0	0	2	90	295	375	489	538	717	708	636	425	219	143	25	1	0	0	0	0	0	0
2nd	0	0	0	0	0	2	56	199	301	528	539	492	640	504	566	294	184	43	1	0	0	0	0	0	0
3rd	0	0	0	0	0	1	38	144	372	484	661	587	537	576	285	277	91	17	1	0	0	0	0	0	0
4th	0	0	0	0	0	2	38	117	255	484	655	519	532	419	378	235	85	24	0	0	0	0	0	0	0
5th	0	0	0	0	0	2	24	131	392	413	432	466	592	581	316	162	124	24	1	0	0	0	0	0	0
6th	0	0	0	0	0	2	41	265	525	604	496	698	660	620	346	243	187	44	0	0	0	0	0	0	0
7th	0	0	0	0	0	2	75	233	510	752	863	849	813	648	525	408	173	23	0	0	0	0	0	0	0
8th	0	0	0	0	0	2	68	220	530	576	664	558	516	421	325	154	141	35	1	0	0	0	0	0	0
9th	0	0	0	0	0	1	84	207	486	750	845	833	613	416	313	150	87	26	0	0	0	0	0	0	0
10th	0	0	0	0	0	2	18	42	151	346	638	467	481	518	543	362	140	25	0	0	0	0	0	0	0
11th	0	0	0	0	0	2	20	46	158	385	602	651	509	345	552	299	125	23	0	0	0	0	0	0	0
12th	0	0	0	0	0	2	48	156	197	394	679	904	804	487	422	345	219	46	1	0	0	0	0	0	0
13th	0	0	0	0	0	2	99	176	256	608	878	940	886	704	402	308	244	38	1	0	0	0	0	0	0
14th	0	0	0	0	0	2	100	288	581	765	886	940	922	744	403	183	142	27	0	0	0	0	0	0	0
15th	0	0	0	0	0	2	105	319	575	758	868	797	596	330	243	256	100	24	1	0	0	0	0	0	0
16th	0	0	0	0	0	2	45	174	345	499	587	489	667	519	417	217	128	19	0	0	0	0	0	0	0
17th	0	0	0	0	0	2	12	37	113	299	243	263	290	276	239	99	64	15	0	0	0	0	0	0	0
18th	0	0	0	0	0	2	34	204	363	599	867	845	665	476	390	277	133	21	0	0	0	0	0	0	0
19th	0	0	0	0	0	2	55	243	517	760	795	829	853	613	399	338	187	43	0	0	0	0	0	0	0
20th	0	0	0	0	0	2	99	304	544	699	886	887	912	814	548	376	209	32	0	0	0	0	0	0	0
21st	0	0	0	0	0	2	60	120	126	130	229	207	138	193	179	140	115	32	0	0	0	0	0	0	0
22nd	0	0	0	0	0	2	15	71	256	211	160	367	508	473	409	282	142	29	0	0	0	0	0	0	0
23rd	0	0	0	0	0	1	58	180	164	366	818	582	530	640	487	291	170	32	0	0	0	0	0	0	0
24th	0	0	0	0	0	2	28	97	236	411	498	503	528	516	335	248	108	23	0	0	0	0	0	0	0
25th	0	0	0	0	0	2	88	294	577	773	869	798	908	586	237	162	87	28	0	0	0	0	0	0	0
26th	0	0	0	0	0	0	110	318	437	765	824	904	843	656	545	286	193	41	0	0	0	0	0	0	0
27th	0	0	0	0	0	1	66	247	399	650	850	932	841	637	482	267	138	29	0	0	0	0	0	0	0
28th	0	0	0	0	0	1	88	316	444	576	732	775	554	499	310	240	127	22	0	0	0	0	0	0	0
29th	0	0	0	0	0	1	58	203	308	498	513	487	400	280	232	184	112	20	0	0	0	0	0	0	0
30th	0	0	0	0	0	2	89	263	434	427	456	528	575	414	389	199	113	21	0	0	0	0	0	0	0
31st	0	0	0	0	0	2	61	256	473	611	830	958	923	771	563	291	220	39	0	0	0	0	0	0	0
avg.	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**1.75**	**60.21**	**197.39**	**369.71**	**539.61**	**666.54**	**677.71**	**644.96**	**521.29**	**390.32**	**250.07**	**143.32**	**28.75**	**0.18**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

September

DAY\T	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	#####
1st	0	0	0	0	0	5	98	250	441	729	776	762	556	497	480	373	176	23	0	0	0	0	0	0	0
2nd	0	0	0	0	0	3	38	154	231	312	257	397	261	150	85	84	86	15	0	0	0	0	0	0	0
3rd	0	0	0	0	0	3	65	260	412	591	846	843	709	654	453	326	160	15	0	0	0	0	0	0	0
4th	0	0	0	0	0	2	50	159	321	506	546	627	630	512	408	435	190	26	0	0	0	0	0	0	0
5th	0	0	0	0	0	6	52	224	364	442	734	650	337	288	233	163	120	21	0	0	0	0	0	0	0
6th	0	0	0	0	0	6	48	159	250	306	524	610	590	490	369	251	115	13	0	0	0	0	0	0	0
7th	0	0	0	0	0	3	39	148	338	450	570	631	621	553	371	219	121	16	0	0	0	0	0	0	0
8th	0	0	0	0	0	6	92	305	547	680	809	790	636	412	528	358	203	22	0	0	0	0	0	0	0
9th	0	0	0	0	0	7	91	162	206	462	619	902	578	646	534	360	207	30	0	0	0	0	0	0	0
10th	0	0	0	0	0	7	80	283	590	723	719	614	599	428	352	176	140	12	0	0	0	0	0	0	0
11th	0	0	0	0	0	8	91	208	364	553	860	713	722	540	373	200	121	20	0	0	0	0	0	0	0
12th	0	0	0	0	0	3	42	184	381	642	466	391	475	413	309	156	115	11	0	0	0	0	0	0	0
13th	0	0	0	0	0	5	53	143	244	359	611	569	688	650	626	418	189	21	0	0	0	0	0	0	0
14th	0	0	0	0	0	3	77	241	399	446	513	641	592	486	374	276	170	19	0	0	0	0	0	0	0
15th	0	0	0	0	0	5	66	220	409	516	669	626	646	446	329	176	87	11	0	0	0	0	0	0	0
16th	0	0	0	0	0	7	63	182	451	675	887	918	648	423	478	272	186	21	0	0	0	0	0	0	0
17th	0	0	0	0	0	5	64	150	250	211	406	512	623	540	420	299	169	17	0	0	0	0	0	0	0
18th	0	0	0	0	0	5	76	147	172	431	430	365	286	238	91	47	34	7	0	0	0	0	0	0	0
19th	0	0	0	0	0	5	63	187	420	631	710	719	687	643	444	278	102	8	0	0	0	0	0	0	0
20th	0	0	0	0	0	5	97	294	542	764	892	933	901	722	611	335	86	16	0	0	0	0	0	0	0
21st	0	0	0	0	0	4	97	259	512	783	884	924	691	712	411	256	171	16	0	0	0	0	0	0	0
22nd	0	0	0	0	0	8	79	244	478	704	807	811	809	585	436	352	164	16	0	0	0	0	0	0	0
23rd	0	0	0	0	0	6	102	243	287	438	770	658	565	496	357	269	118	14	0	0	0	0	0	0	0
24th	0	0	0	0	0	12	100	376	516	793	845	947	869	793	574	332	183	16	0	0	0	0	0	0	0
25th	0	0	0	0	0	12	83	217	385	793	819	940	826	720	580	415	180	17	0	0	0	0	0	0	0
26th	0	0	0	0	0	10	100	253	570	798	801	927	746	640	550	367	182	20	0	0	0	0	0	0	0
27th	0	0	0	0	0	14	113	301	554	571	777	741	625	639	631	413	179	19	0	0	0	0	0	0	0
28th	0	0	0	0	0	6	139	295	488	597	885	811	809	553	364	297	168	14	0	0	0	0	0	0	0
29th	0	0	0	0	0	9	125	332	618	706	892	816	811	714	536	286	154	12	0	0	0	0	0	0	0
30th	0	0	0	0	0	9	91	361	547	755	763	777	810	547	540	232	119	12	0	0	0	0	0	0	0
avg.	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**6.46**	**79.93**	**233.46**	**414.82**	**583.07**	**716.21**	**728.79**	**661.75**	**552.96**	**438.64**	**284.43**	**147.61**	**16.50**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Octomber

DAY\T	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	#####
1st	0	0	0	0	0	2	92	341	425	610	706	657	850	723	472	312	165	17	0	0	0	0	0	0	0
2nd	0	0	0	0	0	2	131	295	607	726	882	886	795	666	427	243	134	17	0	0	0	0	0	0	0
3rd	0	0	0	0	0	1	155	401	596	775	898	822	770	774	592	286	92	13	0	0	0	0	0	0	0
4th	0	0	0	0	0	2	148	314	401	523	654	623	488	416	294	192	120	11	0	0	0	0	0	0	0
5th	0	0	0	0	0	2	19	59	214	312	342	385	446	553	290	176	92	9	0	0	0	0	0	0	0
6th	0	0	0	0	0	2	98	328	474	671	877	776	801	625	471	302	154	12	0	0	0	0	0	0	0
7th	0	0	0	0	0	2	93	360	470	723	808	880	889	712	461	221	89	12	0	0	0	0	0	0	0
8th	0	0	0	0	0	2	116	375	578	795	905	940	899	787	605	366	98	11	0	0	0	0	0	0	0
9th	0	0	0	0	0	1	72	182	326	488	738	823	636	315	319	247	104	9	0	0	0	0	0	0	0
10th	0	0	0	0	0	2	130	329	477	448	527	555	517	524	372	277	79	8	0	0	0	0	0	0	0
11th	0	0	0	0	0	2	117	331	443	741	763	737	684	689	231	178	45	7	0	0	0	0	0	0	0
12th	0	0	0	0	0	2	53	249	454	610	713	861	706	598	582	279	75	6	0	0	0	0	0	0	0
13th	0	0	0	0	0	2	76	303	543	639	434	541	670	703	570	280	63	6	0	0	0	0	0	0	0
14th	0	0	0	0	0	2	107	357	553	718	710	798	883	769	514	158	50	5	0	0	0	0	0	0	0
15th	0	0	0	0	0	2	112	277	451	628	743	758	629	628	372	187	46	6	0	0	0	0	0	0	0
16th	0	0	0	0	0	2	105	316	586	778	788	798	834	746	476	122	21	4	0	0	0	0	0	0	0
17th	0	0	0	0	0	2	94	296	428	640	594	571	612	235	43	18	16	4	0	0	0	0	0	0	0
18th	0	0	0	0	0	2	94	336	531	616	619	699	715	549	163	13	11	2	0	0	0	0	0	0	0
19th	0	0	0	0	0	2	94	224	307	446	433	532	539	532	100	35	21	3	0	0	0	0	0	0	0
20th	0	0	0	0	0	2	97	239	289	431	535	691	732	577	246	166	63	5	0	0	0	0	0	0	0
21st	0	0	0	0	0	2	155	406	609	644	668	630	365	196	256	148	49	5	0	0	0	0	0	0	0
22nd	0	0	0	0	0	2	106	325	485	553	436	500	677	739	553	168	33	5	0	0	0	0	0	0	0
23rd	0	0	0	0	0	1	78	169	320	522	769	739	761	737	551	246	74	5	0	0	0	0	0	0	0
24th	0	0	0	0	0	2	71	221	444	389	720	646	609	608	292	168	59	3	0	0	0	0	0	0	0
25th	0	0	0	0	0	2	81	195	215	366	424	427	414	354	268	79	28	3	0	0	0	0	0	0	0
26th	0	0	0	0	0	0	101	255	419	704	574	569	638	486	367	202	73	4	0	0	0	0	0	0	0
27th	0	0	0	0	0	1	71	218	532	716	683	594	503	306	203	40	21	2	0	0	0	0	0	0	0
28th	0	0	0	0	0	1	70	233	399	559	618	897	844	563	352	157	30	3	0	0	0	0	0	0	0
29th	0	0	0	0	0	1	118	286	427	579	745	725	698	474	221	23	9	2	0	0	0	0	0	0	0
30th	0	0	0	0	0	2	165	360	399	418	433	554	564	624	288	70	14	2	0	0	0	0	0	0	0
31st	0	0	0	0	0	2	157	375	407	326	376	672	848	734	423	99	34	2	0	0	0	0	0	0	0
avg.	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**1.75**	**99.93**	**282.79**	**435.04**	**570.82**	**629.61**	**675.75**	**664.32**	**563.54**	**352.96**	**164.89**	**56.11**	**5.57**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

November

DAY\T	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	####
1st	0	0	0	0	0	3	32	151	98	53	43	68	58	95	110	37	19	1	0	0	0	0	0	0	0
2nd	0	0	0	0	0	3	43	142	237	362	561	517	645	175	77	46	41	3	0	0	0	0	0	0	0
3rd	0	0	0	0	0	7	57	216	328	528	578	319	294	701	404	125	30	3	0	0	0	0	0	0	0
4th	0	0	0	0	0	8	121	332	555	649	786	868	792	558	249	52	31	3	0	0	0	0	0	0	0
5th	0	0	0	0	0	2	19	52	96	189	462	454	453	437	304	177	50	3	0	0	0	0	0	0	0
6th	0	0	0	0	0	5	51	198	290	289	507	278	149	81	89	46	29	2	0	0	0	0	0	0	0
7th	0	0	0	0	0	9	63	266	446	630	616	644	833	635	495	143	9	1	0	0	0	0	0	0	0
8th	0	0	0	0	0	7	79	237	369	664	718	796	730	641	327	101	22	2	0	0	0	0	0	0	0
9th	0	0	0	0	0	7	64	246	407	499	567	596	619	480	302	188	44	2	0	0	0	0	0	0	0
10th	0	0	0	0	0	10	95	363	595	756	752	651	705	644	510	185	62	2	0	0	0	0	0	0	0
11th	0	0	0	0	0	6	84	315	550	749	833	880	838	724	545	326	100	2	0	0	0	0	0	0	0
12th	0	0	0	0	0	9	92	313	534	743	844	808	806	705	486	244	86	3	0	0	0	0	0	0	0
13th	0	0	0	0	0	10	87	306	507	721	832	797	769	703	517	316	92	3	0	0	0	0	0	0	0
14th	0	0	0	0	0	8	77	269	448	636	771	779	786	632	458	263	53	3	0	0	0	0	0	0	0
15th	0	0	0	0	0	10	92	294	493	694	826	863	816	700	504	244	54	3	0	0	0	0	0	0	0
16th	0	0	0	0	0	6	53	173	362	498	741	699	762	695	521	305	87	3	0	0	0	0	0	0	0
17th	0	0	0	0	0	8	85	286	471	659	734	830	788	660	502	270	58	2	0	0	0	0	0	0	0
18th	0	0	0	0	0	7	96	299	564	724	675	651	640	699	532	236	29	2	0	0	0	0	0	0	0
19th	0	0	0	0	0	6	93	318	422	665	700	637	634	450	239	81	31	3	0	0	0	0	0	0	0
20th	0	0	0	0	0	7	26	73	174	298	266	327	480	330	203	169	45	2	0	0	0	0	0	0	0
21st	0	0	0	0	0	5	69	140	359	536	550	561	462	410	282	190	83	3	0	0	0	0	0	0	0
22nd	0	0	0	0	0	6	55	181	467	656	656	745	699	620	493	304	74	3	0	0	0	0	0	0	0
23rd	0	0	0	0	0	4	62	181	412	550	739	720	660	426	282	175	44	3	0	0	0	0	0	0	0
24th	0	0	0	0	0	2	67	203	393	559	711	658	499	374	282	110	21	3	0	0	0	0	0	0	0
25th	0	0	0	0	0	4	34	121	302	360	408	427	398	327	298	135	13	2	0	0	0	0	0	0	0
26th	0	0	0	0	0	4	49	158	411	591	572	723	758	613	419	218	75	3	0	0	0	0	0	0	0
27th	0	0	0	0	0	5	45	189	405	698	731	611	493	390	241	74	16	2	0	0	0	0	0	0	0
28th	0	0	0	0	0	2	17	44	108	302	422	319	221	146	82	48	26	3	0	0	0	0	0	0	0
29th	0	0	0	0	0	5	76	269	564	712	831	781	769	571	408	215	70	4	0	0	0	0	0	0	0
30th	0	0	0	0	0	4	49	222	432	668	680	501	317	400	24	17	10	2	0	0	0	0	0	0	0
avg.	0.00	0.00	0.00	0.00	0.00	6.15	66.67	224.00	412.44	581.30	664.07	652.00	625.04	520.41	355.33	178.96	48.67	2.56	0.00	0.00	0.00	0.00	0.00	0.00	0.00

December

DAY\T	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	####
1st	0	0	0	0	0	2	43	86	214	338	433	575	476	250	216	88	26	4	0	0	0	0	0	0	0
2nd	0	0	0	0	0	2	73	304	445	617	764	753	667	658	510	300	90	5	0	0	0	0	0	0	0
3rd	0	0	0	0	0	1	58	253	421	383	373	225	252	289	193	47	18	3	0	0	0	0	0	0	0
4th	0	0	0	0	0	2	44	164	258	347	442	531	551	454	407	187	57	3	0	0	0	0	0	0	0
5th	0	0	0	0	0	2	69	285	473	632	575	568	501	500	351	181	57	5	0	0	0	0	0	0	0
6th	0	0	0	0	0	2	47	162	416	522	698	789	623	452	255	135	40	5	0	0	0	0	0	0	0
7th	0	0	0	0	0	2	34	146	388	513	516	505	420	318	217	135	48	3	0	0	0	0	0	0	0
8th	0	0	0	0	0	2	66	268	480	653	735	612	728	477	491	194	77	5	0	0	0	0	0	0	0
9th	0	0	0	0	0	1	32	94	131	284	329	408	473	414	362	222	70	4	0	0	0	0	0	0	0
10th	0	0	0	0	0	2	12	32	69	182	510	559	680	623	462	226	72	7	0	0	0	0	0	0	0
11th	0	0	0	0	0	2	47	138	308	377	442	424	402	395	146	122	37	3	0	0	0	0	0	0	0
12th	0	0	0	0	0	2	44	178	360	391	596	729	483	509	467	99	10	4	0	0	0	0	0	0	0
13th	0	0	0	0	0	2	71	302	498	652	753	769	762	647	224	53	22	6	0	0	0	0	0	0	0
14th	0	0	0	0	0	2	70	305	509	664	754	594	679	595	337	169	68	4	0	0	0	0	0	0	0
15th	0	0	0	0	0	2	18	108	303	489	585	726	581	627	434	255	74	7	0	0	0	0	0	0	0
16th	0	0	0	0	0	2	51	254	509	656	627	576	492	461	280	163	65	6	0	0	0	0	0	0	0
17th	0	0	0	0	0	2	68	188	287	592	508	693	715	355	230	151	68	4	0	0	0	0	0	0	0
18th	0	0	0	0	0	2	59	205	329	356	433	573	513	301	143	86	61	7	0	0	0	0	0	0	0
19th	0	0	0	0	0	2	49	189	304	470	694	529	515	462	323	208	65	8	0	0	0	0	0	0	0
20th	0	0	0	0	0	2	42	182	366	513	610	583	278	116	109	235	63	8	0	0	0	0	0	0	0
21st	0	0	0	0	0	2	72	234	434	656	763	756	646	565	427	266	90	6	0	0	0	0	0	0	0
22nd	0	0	0	0	0	2	76	307	510	672	779	821	796	704	554	362	136	12	0	0	0	0	0	0	0
23rd	0	0	0	0	0	1	50	231	456	671	727	626	675	638	457	305	94	12	0	0	0	0	0	0	0
24th	0	0	0	0	0	2	59	259	495	658	698	789	755	698	546	351	117	10	0	0	0	0	0	0	0
25th	0	0	0	0	0	2	62	266	491	630	596	648	605	601	482	198	44	8	0	0	0	0	0	0	0
26th	0	0	0	0	0	0	46	130	308	425	424	498	270	191	138	64	50	7	0	0	0	0	0	0	0
27th	0	0	0	0	0	1	47	136	194	401	418	460	418	423	337	266	122	11	0	0	0	0	0	0	0
28th	0	0	0	0	0	1	29	194	442	648	750	683	501	344	308	177	121	10	0	0	0	0	0	0	0
29th	0	0	0	0	0	1	59	254	436	630	660	618	674	502	263	183	124	10	0	0	0	0	0	0	0
30th	0	0	0	0	0	2	34	127	278	369	419	435	415	358	285	191	87	8	0	0	0	0	0	0	0
31st	0	0	0	0	0	2	51	200	374	516	586	598	550	465	330	186	68	7	0	0	0	0	0	0	0
avg.	0.00	0.00	0.00	0.00	0.00	1.75	50.55	199.69	373.34	515.59	586.21	597.41	550.10	464.97	329.59	186.79	69.83	6.66	0.00	0.00	0.00	0.00	0.00	0.00	0.00

9 APPENDIX II

9.1 Load profiles

Time (hrs)	29 Aug - 2022 (Monday)		31 Aug - 2022 (Wednesday)		02 Sep - 2022 (Friday)		03 Sep - 2022 (Saturday)		04 Sep - 2022 (Sunday)	
	Max. Demand (W)	Max.Demand (kW)	Max. Demand (W)	Max.Demand (kW)	Max. Demand (W)	Max.Demand (kW)	Max. Demand (W)	Max.Demand (kW)	Max. Demand (W)	Max.Demand (kW)
0:00	983077.91	983.08	849465.14	849.47	1021954.64	1021.95464	813992.3	813.9923	975928.4	975.9284
0:15	951866.64	951.87	812196.55	812.20	979660.62	979.66062	806852.84	806.85284	923134.59	923.13459
0:30	894623.65	894.62	686128.62	686.13	967971.47	967.97147	783467.84	783.46784	711892.32	711.89232
0:45	882458.76	882.46	659664.71	659.66	982431.31	982.43131	681223.8	681.2238	631599.36	631.59936
1:00	722673.55	722.67	638112.32	638.11	914969.94	914.96994	666931.48	666.93148	615869.76	615.86976
1:15	708545.39	708.55	641130.92	641.13	922672.25	922.67225	640243.1	640.2431	602317.85	602.31785
1:30	722013.54	722.01	622717.75	622.72	918759.11	918.75911	576899.23	576.89923	589824.64	589.82464
1:45	736634.19	736.63	627830.29	627.83	904560.6	904.5606	595784.8	595.7848	602924.26	602.92426
2:00	731427.84	731.43	608006.64	608.01	891990.32	891.99032	582735.43	582.73543	637763.89	637.76389
2:15	748407.1	748.41	670318.62	670.32	861723.84	861.72384	644404.15	644.40415	641177.83	641.17783
2:30	758045.87	758.05	708414.73	708.41	848667.77	848.66777	652588.9	652.5889	655202.13	655.20213
2:45	734238.73	734.24	703975.6	703.98	846654.25	846.65425	644581.72	644.58172	650535.18	650.53518
3:00	759962.23	759.96	719855.96	719.86	874381.22	874.38122	652676.01	652.67601	651268.89	651.26889
3:15	762655.86	762.66	710361.24	710.36	882227.59	882.22759	656552.29	656.55229	835172.82	835.17282
3:30	767590.84	767.59	723182.79	723.18	887038.6	887.0386	693046.96	693.04696	920474.46	920.47446
3:45	744443.71	744.44	808859.67	808.86	889775.78	889.77578	716927.8	716.9278	931319.34	931.31934
4:00	738791.77	738.79	1150062.89	1150.06	891997.02	891.99702	736701.2	736.7012	728405.89	728.40589
4:15	901083	901.08	1175605.48	1175.61	928200.22	928.20022	925325.67	925.32567	755700.67	755.70067
4:30	1130671.43	1130.67	1186641.32	1186.64	945119.17	945.11917	1137355.26	1137.35526	998107.3	998.1073
4:45	1142729.12	1142.73	1185418.47	1185.42	947715.64	947.71564	1130647.98	1130.64798	1136092.2	1136.0922
5:00	1182543.92	1182.54	1120332.45	1120.33	957716.24	957.71624	1138296.69	1138.29669	1144983.86	1144.98386
5:15	1217376.85	1217.38	910919.44	910.92	1019626.19	1019.62619	1160395.18	1160.39518	922692.35	922.69235
5:30	1217088.72	1217.09	975549.82	975.55	1035372.53	1035.37253	1162381.9	1162.3819	837303.6	837.3036
5:45	1220402.16	1220.40	1013186.94	1013.19	1057460.97	1057.46097	1086397.4	1086.3974	840637.13	840.63713

6:00	1167065.6	1167.07	1275390.41	1275.39	1067069.6	1067.0696	1081747.2	1081.7472	927292.29	927.29229
6:15	1155711.48	1155.71	1405019.69	1405.02	1076909.39	1076.90939	1098244.01	1098.24401	1199623.68	1199.62368
6:30	1162854.29	1162.85	1402155.2	1402.16	1191053.65	1191.05365	1098337.82	1098.33782	1209982.77	1209.98277
6:45	1205932.27	1205.93	1377436.78	1377.44	1256963.83	1256.96383	1100803.63	1100.80363	1207342.74	1207.34274
7:00	1193797.53	1193.80	1463110.31	1463.11	1219665.09	1219.66509	1114667.12	1114.66712	1169005.41	1169.00541
7:15	1304638.41	1304.64	1534283.8	1534.28	1207382.94	1207.38294	1158274.44	1158.27444	1123129.94	1123.12994
7:30	1450422.78	1450.42	1528511.25	1528.51	1373962.54	1373.96254	1219681.85	1219.68185	1125498.59	1125.49859
7:45	1608790.82	1608.79	1549932.99	1549.93	1390868.08	1390.86808	1091754.51	1091.75451	1238962.74	1238.96274
8:00	1592605.58	1592.61	1409187.45	1409.19	1430096.59	1430.09659	1287649.11	1287.64911	1050683.34	1050.68334
8:15	1568510.32	1568.51	1654455.22	1654.46	1507856.74	1507.85674	1323353.11	1323.35311	1218586.3	1218.5863
8:30	1620526.87	1620.53	1643097.75	1643.10	1564587.14	1564.58714	1122985.88	1122.98588	1497088.92	1497.08892
8:45	1643020.7	1643.02	1668935.16	1668.94	1781906.82	1781.90682	1077706.75	1077.70675	1418745.82	1418.74582
9:00	1801331.78	1801.33	1808233.37	1808.23	1849150.42	1849.15042	1461525.63	1461.52563	1379296.19	1379.29619
9:15	1709443.47	1709.44	1766944.44	1766.94	1793190.59	1793.19059	1640250.01	1640.25001	1395277.06	1395.27706
9:30	1616975.57	1616.98	1769892.69	1769.89	1656110.26	1656.11026	1535533.45	1535.53345	1312930.37	1312.93037
9:45	1641057.43	1641.06	1748105.78	1748.11	1649376.19	1649.37619	1593804.99	1593.80499	1486063.12	1486.06312
10:00	1621083.02	1621.08	1799050.24	1799.05	1773008.46	1773.00846	1515250.82	1515.25082	1544284.4	1544.2844
10:15	1700880.14	1700.88	1820059.88	1820.06	1768867.51	1768.86751	1558496.32	1558.49632	1479687.53	1479.68753
10:30	1703925.55	1703.93	1842969.14	1842.97	1761419.82	1761.41982	1607822.59	1607.82259	1493510.81	1493.51081
10:45	1669075.87	1669.08	1755895.2	1755.90	1717273.09	1717.27309	1557729.1	1557.7291	1494445.54	1494.44554
11:00	1788496.83	1788.50	1781538.29	1781.54	1737773.5	1737.7735	1493708.48	1493.70848	1362457.65	1362.45765
11:15	1776087.37	1776.09	1791240.72	1791.24	1768971.37	1768.97137	1493527.56	1493.52756	1368913.66	1368.91366
11:30	1833913.32	1833.91	1795247.66	1795.25	1740895.96	1740.89596	1476173.08	1476.17308	1419174.65	1419.17465
11:45	1866665.72	1866.67	1804608.36	1804.61	1765470.32	1765.47032	1470477.59	1470.47759	1427047.83	1427.04783
12:00	1781082.65	1781.08	1853241.12	1853.24	1807238.34	1807.23834	1438803.98	1438.80398	1420628.68	1420.62868
12:15	1875577.48	1875.58	1775219.65	1775.22	1798514.19	1798.51419	1473737.42	1473.73742	1560938.68	1560.93868
12:30	2057997.23	2058.00	1768968.01	1768.97	1805174.56	1805.17456	1516209	1516.209	1270033.3	1270.0333
12:45	2121558.86	2121.56	1746363.63	1746.36	1771675.05	1771.67505	1493299.74	1493.29974	1075137.09	1075.13709
13:00	2055893.25	2055.89	1718438.99	1718.44	1787364.44	1787.36444	1465968.11	1465.96811	1097929.08	1097.92908

13:15	1923637.34	1923.64	1699483.07	1699.48	1750501.24	1750.50124	1489262.65	1489.26265	1122262.21	1122.26221
13:30	1850798.76	1850.80	1632500.8	1632.50	1408075.15	1408.07515	1485805.15	1485.80515	1117836.49	1117.83649
13:45	1818934.19	1818.93	1622597.35	1622.60	1388238.11	1388.23811	1448616.97	1448.61697	1067749.7	1067.7497
14:00	1822458.69	1822.46	1620168.39	1620.17	1679153.53	1679.15353	1478561.83	1478.56183	1034196.58	1034.19658
14:15	1840657.45	1840.66	1632899.48	1632.90	1805804.41	1805.80441	1454345.96	1454.34596	1117866.64	1117.86664
14:30	1849971.24	1849.97	1624446.71	1624.45	1725330.53	1725.33053	1428652.61	1428.65261	1372789.94	1372.78994
14:45	1768244.35	1768.24	1596327.75	1596.33	1694427.49	1694.42749	1465525.87	1465.52587	1362166.18	1362.16618
15:00	1736825.37	1736.83	1702943.92	1702.94	1664539.59	1664.53959	1476645.47	1476.64547	1368015.78	1368.01578
15:15	1761198.7	1761.20	1661665.04	1661.67	1666151.07	1666.15107	1194212.97	1194.21297	1380438.64	1380.43864
15:30	1807861.49	1807.86	1658308.05	1658.31	1656763.57	1656.76357	1078641.48	1078.64148	1391467.78	1391.46778
15:45	1768773.7	1768.77	1694410.74	1694.41	1671065.94	1671.06594	1200722.57	1200.72257	1400543.71	1400.54371
16:00	1745562.91	1745.56	1726452.88	1726.45	1729759.61	1729.75961	1418876.48	1418.87648	1416182.85	1416.18285
16:15	1690189.38	1690.19	1666857.98	1666.86	1682798.65	1682.79865	1428980.94	1428.98094	1397950.59	1397.95059
16:30	1601932.78	1601.93	1612181.31	1612.18	1647553.63	1647.55363	1409894.36	1409.89436	1377848.87	1377.84887
16:45	1621337.64	1621.34	1554609.99	1554.61	1644652.28	1644.65228	1399813.35	1399.81335	1381942.92	1381.94292
17:00	1624208.84	1624.21	1563324.08	1563.32	1603132.18	1603.13218	1391152.86	1391.15286	1161383.51	1161.38351
17:15	1595721.35	1595.72	1508620.6	1508.62	1631023.32	1631.02332	1384770.56	1384.77056	1219685.2	1219.6852
17:30	1635780.73	1635.78	1513763.29	1513.76	1522926.33	1522.92633	1227431.06	1227.43106	1360682	1360.682
17:45	1611638.56	1611.64	1513438.31	1513.44	1492428.67	1492.42867	1383618.06	1383.61806	1371439.77	1371.43977
18:00	1640092.54	1640.09	1480582.05	1480.58	1473640.26	1473.64026	1147107.94	1147.10794	1174942.12	1174.94212
18:15	1567739.76	1567.74	1526594.89	1526.59	1447035.64	1447.03564	1091751.16	1091.75116	992230.9	992.2309
18:30	1525181.07	1525.18	1495450.63	1495.45	1455743.03	1455.74303	1340034.19	1340.03419	977224.96	977.22496
18:45	1521807.33	1521.81	1420658.83	1420.66	1430893.96	1430.89396	1353257.77	1353.25777	958527.01	958.52701
19:00	1548277.94	1548.28	1245401.99	1245.40	1413593.08	1413.59308	1329983.33	1329.98333	955273.89	955.27389
19:15	1532977.19	1532.98	1054918.11	1054.92	1393508.11	1393.50811	1342563.65	1342.56365	957150.05	957.15005
19:30	1507726.08	1507.73	1364260.11	1364.26	1366069.26	1366.06926	1282580.12	1282.58012	949876.57	949.87657
19:45	1525841.08	1525.84	1379426.86	1379.43	1312980.62	1312.98062	1242463.79	1242.46379	951065.93	951.06593
20:00	1488053.19	1488.05	1327045.13	1327.05	1176583.76	1176.58376	1242617.91	1242.61791	1255395.9	1255.3959
20:15	1447591.78	1447.59	1304983.49	1304.98	1179290.79	1179.29079	1221032.01	1221.03201	1287297.33	1287.29733

20:30	1382425.36	1382.43	1313439.61	1313.44	1182443.41	1182.44341	1217319.89	1217.31989	1292044.68	1292.04468
20:45	1326066.84	1326.07	1152481.8	1152.48	1284255.27	1284.25527	1203231.94	1203.23194	1292567.33	1292.56733
21:00	1185512.27	1185.51	1170905.02	1170.91	1253476.19	1253.47619	1176027.61	1176.02761	1253771.01	1253.77101
21:15	1228875.03	1228.88	1075023.18	1075.02	1212029.79	1212.02979	1147895.26	1147.89526	1077338.22	1077.33822
21:30	1224536.41	1224.54	1151332.65	1151.33	1152582.31	1152.58231	1131773.68	1131.77368	871704.34	871.70434
21:45	1232469.89	1232.47	1171018.93	1171.02	1121005.86	1121.00586	1101255.92	1101.25592	873191.87	873.19187
22:00	1229478.08	1229.48	1129277.71	1129.28	1096475.06	1096.47506	1123870.35	1123.87035	967056.84	967.05684
22:15	1176553.61	1176.55	1098116.7	1098.12	1083000.21	1083.00021	1114650.36	1114.65036	1234413.05	1234.41305
22:30	1178181.85	1178.18	1095744.7	1095.74	1052579.61	1052.57961	1079609.72	1079.60972	1223678.74	1223.67874
22:45	1194588.2	1194.59	1089617.02	1089.62	1019103.54	1019.10354	1082537.87	1082.53787	1184758.46	1184.75846
23:00	1165611.57	1165.61	1051866	1051.87	993219.23	993.21923	1081572.99	1081.57299	951541.67	951.54167
23:15	1115072.5	1115.07	1008958.88	1008.96	962875.69	962.87569	1042210.47	1042.21047	1002499.52	1002.49952
23:30	1086273.44	1086.27	960781.76	960.78	838278.53	838.27853	1001135.96	1001.13596	1025335.08	1025.33508
23:45:00	1056228.07	1056.23	912815.71	912.82	813339	813.339	976621.91	976.62191	934763.43	934.76343
24:00:00	1100324.54	1100.32	869117.92	869.12	813992.3	813.9923	975928.4	975.9284	925221.82	925.22182

9.2 Energy consumption Hourly

Time(hrs)	29 Aug - 2022 (Monday)				
	Max. Demand (W)	Max.Demand (kW)	Time Intervals		Energy Consumed (kWh)
0:00	983077.91	983.08	0:00	1:00	852.88
1:00	722673.55	722.67	1:00	2:00	727.05
2:00	731427.84	731.43	2:00	3:00	745.70
3:00	759962.23	759.96	3:00	4:00	749.38
4:00	738791.77	738.79	4:00	5:00	960.67
5:00	1182543.92	1182.54	5:00	6:00	1174.80
6:00	1167065.6	1167.07	6:00	7:00	1180.43
7:00	1193797.53	1193.80	7:00	8:00	1393.20
8:00	1592605.58	1592.61	8:00	9:00	1696.97
9:00	1801331.78	1801.33	9:00	10:00	1711.21
10:00	1621083.02	1621.08	10:00	11:00	1704.79
11:00	1788496.83	1788.50	11:00	12:00	1784.79
12:00	1781082.65	1781.08	12:00	13:00	1918.49
13:00	2055893.25	2055.89	13:00	14:00	1939.18

14:00	1822458.69	1822.46	14:00	15:00	1779.64
15:00	1736825.37	1736.83	15:00	16:00	1741.19
16:00	1745562.91	1745.56	16:00	17:00	1684.89
17:00	1624208.84	1624.21	17:00	18:00	1632.15
18:00	1640092.54	1640.09	18:00	19:00	1594.19
19:00	1548277.94	1548.28	19:00	20:00	1518.17
20:00	1488053.19	1488.05	20:00	21:00	1336.78
21:00	1185512.27	1185.51	21:00	22:00	1207.50
22:00	1229478.08	1229.48	22:00	23:00	1197.54
23:00	1165611.57	1165.61	23:00	24:00:00	1132.97
24:00:00	1100324.54	1100.32	24:00:00	-	550.16

9.3 Energy Consumption -15 mins

Time(hrs)	**29 Aug - 2022 (Monday)**					
	Max. Demand (W)	**Max.Demand (kW)**	**Time Intervals**		**Energy Consumed (kW15min)**	**Energy Consumed (kWh)**
0:00	983077.91	983.08	0:00	0:15	967.47	241.87
0:15	951866.64	951.87	0:15	0:30	923.25	230.81
0:30	894623.65	894.62	0:30	0:45	888.54	222.14
0:45	882458.76	882.46	0:45	1:00	802.57	200.64
1:00	722673.55	722.67	1:00	1:15	715.61	178.90
1:15	708545.39	708.55	1:15	1:30	715.28	178.82
1:30	722013.54	722.01	1:30	1:45	729.32	182.33
1:45	736634.19	736.63	1:45	2:00	734.03	183.51
2:00	731427.84	731.43	2:00	2:15	739.92	184.98
2:15	748407.1	748.41	2:15	2:30	753.23	188.31
2:30	758045.87	758.05	2:30	2:45	746.14	186.54
2:45	734238.73	734.24	2:45	3:00	747.10	186.78
3:00	759962.23	759.96	3:00	3:15	761.31	190.33
3:15	762655.86	762.66	3:15	3:30	765.12	191.28
3:30	767590.84	767.59	3:30	3:45	756.02	189.00
3:45	744443.71	744.44	3:45	4:00	741.62	185.40
4:00	738791.77	738.79	4:00	4:15	819.94	204.98
4:15	901083	901.08	4:15	4:30	1015.88	253.97
4:30	1130671.43	1130.67	4:30	4:45	1136.70	284.18
4:45	1142729.12	1142.73	4:45	5:00	1162.64	290.66
5:00	1182543.92	1182.54	5:00	5:15	1199.96	299.99
5:15	1217376.85	1217.38	5:15	5:30	1217.23	304.31
5:30	1217088.72	1217.09	5:30	5:45	1218.75	304.69
5:45	1220402.16	1220.40	5:45	6:00	1193.73	298.43
6:00	1167065.6	1167.07	6:00	6:15	1161.39	290.35
6:15	1155711.48	1155.71	6:15	6:30	1159.28	289.82

6:30	1162854.29	1162.85	6:30	6:45	1184.39	296.10
6:45	1205932.27	1205.93	6:45	7:00	1199.86	299.97
7:00	1193797.53	1193.80	7:00	7:15	1249.22	312.30
7:15	1304638.41	1304.64	7:15	7:30	1377.53	344.38
7:30	1450422.78	1450.42	7:30	7:45	1529.61	382.40
7:45	1608790.82	1608.79	7:45	8:00	1600.70	400.17
8:00	1592605.58	1592.61	8:00	8:15	1580.56	395.14
8:15	1568510.32	1568.51	8:15	8:30	1594.52	398.63
8:30	1620526.87	1620.53	8:30	8:45	1631.77	407.94
8:45	1643020.7	1643.02	8:45	9:00	1722.18	430.54
9:00	1801331.78	1801.33	9:00	9:15	1755.39	438.85
9:15	1709443.47	1709.44	9:15	9:30	1663.21	415.80
9:30	1616975.57	1616.98	9:30	9:45	1629.02	407.25
9:45	1641057.43	1641.06	9:45	10:00	1631.07	407.77
10:00	1621083.02	1621.08	10:00	10:15	1660.98	415.25
10:15	1700880.14	1700.88	10:15	10:30	1702.40	425.60
10:30	1703925.55	1703.93	10:30	10:45	1686.50	421.63
10:45	1669075.87	1669.08	10:45	11:00	1728.79	432.20
11:00	1788496.83	1788.50	11:00	11:15	1782.29	445.57
11:15	1776087.37	1776.09	11:15	11:30	1805.00	451.25
11:30	1833913.32	1833.91	11:30	11:45	1850.29	462.57
11:45	1866665.72	1866.67	11:45	12:00	1823.87	455.97
12:00	1781082.65	1781.08	12:00	12:15	1828.33	457.08
12:15	1875577.48	1875.58	12:15	12:30	1966.79	491.70
12:30	2057997.23	2058.00	12:30	12:45	2089.78	522.44
12:45	2121558.86	2121.56	12:45	13:00	2088.73	522.18
13:00	2055893.25	2055.89	13:00	13:15	1989.77	497.44
13:15	1923637.34	1923.64	13:15	13:30	1887.22	471.80
13:30	1850798.76	1850.80	13:30	13:45	1834.87	458.72
13:45	1818934.19	1818.93	13:45	14:00	1820.70	455.17
14:00	1822458.69	1822.46	14:00	14:15	1831.56	457.89
14:15	1840657.45	1840.66	14:15	14:30	1845.31	461.33
14:30	1849971.24	1849.97	14:30	14:45	1809.11	452.28
14:45	1768244.35	1768.24	14:45	15:00	1752.53	438.13
15:00	1736825.37	1736.83	15:00	15:15	1749.01	437.25
15:15	1761198.7	1761.20	15:15	15:30	1784.53	446.13
15:30	1807861.49	1807.86	15:30	15:45	1788.32	447.08
15:45	1768773.7	1768.77	15:45	16:00	1757.17	439.29
16:00	1745562.91	1745.56	16:00	16:15	1717.88	429.47
16:15	1690189.38	1690.19	16:15	16:30	1646.06	411.52
16:30	1601932.78	1601.93	16:30	16:45	1611.64	402.91
16:45	1621337.64	1621.34	16:45	17:00	1622.77	405.69
17:00	1624208.84	1624.21	17:00	17:15	1609.97	402.49
17:15	1595721.35	1595.72	17:15	17:30	1615.75	403.94

17:30	1635780.73	1635.78	17:30	17:45	1623.71	405.93
17:45	1611638.56	1611.64	17:45	18:00	1625.87	406.47
18:00	1640092.54	1640.09	18:00	18:15	1603.92	400.98
18:15	1567739.76	1567.74	18:15	18:30	1546.46	386.62
18:30	1525181.07	1525.18	18:30	18:45	1523.49	380.87
18:45	1521807.33	1521.81	18:45	19:00	1535.04	383.76
19:00	1548277.94	1548.28	19:00	19:15	1540.63	385.16
19:15	1532977.19	1532.98	19:15	19:30	1520.35	380.09
19:30	1507726.08	1507.73	19:30	19:45	1516.78	379.20
19:45	1525841.08	1525.84	19:45	20:00	1506.95	376.74
20:00	1488053.19	1488.05	20:00	20:15	1467.82	366.96
20:15	1447591.78	1447.59	20:15	20:30	1415.01	353.75
20:30	1382425.36	1382.43	20:30	20:45	1354.25	338.56
20:45	1326066.84	1326.07	20:45	21:00	1255.79	313.95
21:00	1185512.27	1185.51	21:00	21:15	1207.19	301.80
21:15	1228875.03	1228.88	21:15	21:30	1226.71	306.68
21:30	1224536.41	1224.54	21:30	21:45	1228.50	307.13
21:45	1232469.89	1232.47	21:45	22:00	1230.97	307.74
22:00	1229478.08	1229.48	22:00	22:15	1203.02	300.75
22:15	1176553.61	1176.55	22:15	22:30	1177.37	294.34
22:30	1178181.85	1178.18	22:30	22:45	1186.39	296.60
22:45	1194588.2	1194.59	22:45	23:00	1180.10	295.02
23:00	1165611.57	1165.61	23:00	23:15	1140.34	285.09
23:15	1115072.5	1115.07	23:15	23:30	1100.67	275.17
23:30	1086273.44	1086.27	23:30	23:45:00	1071.25	267.81
23:45:00	1056228.07	1056.23	23:45:00	24:00:00	1078.28	269.57
24:00:00	1100324.54	1100.32	24:00:00	-	-	-

9.3.1 Maximum Demand

Time(hrs)	**Maximum demand (kVA)**				
	29 Aug (Monday)	31 Aug (Wednesday)	02 Sep (friday)	03 Sep (Saturday)	04 Sep (Sunday)
0:00	1019870.76	872685.97	1061250.15	850788.50	1008794.71
0:15	987228.92	831772.28	1016858.85	840496.42	955846.78
0:30	926933.81	703851.64	1001658.60	811261.82	735783.22
0:45	915382.02	680054.55	1017167.08	702642.18	654337.75
1:00	752477.69	658495.46	946492.78	690718.51	640906.45
1:15	740249.15	663561.09	953896.92	664033.48	626614.13
1:30	755124.42	642447.59	951528.27	598126.65	612861.21
1:45	775082.08	645479.60	938492.30	616831.30	628460.14
2:00	766150.21	626925.71	926159.90	600424.94	666284.87
2:15	786000.66	691066.94	895849.85	669243.18	669675.36
2:30	797602.70	734248.79	881718.35	678828.35	686165.47

2:45	768964.45	732697.60	878723.19	670060.65	679729.57
3:00	797307.88	747686.78	908795.36	680563.80	681478.42
3:15	799361.60	737408.11	915613.19	685237.44	872213.58
3:30	806387.15	751382.15	921131.12	719467.32	959870.48
3:45	780774.21	842111.26	922427.68	740651.18	973214.67
4:00	778395.51	1201948.78	927315.74	759643.96	764374.56
4:15	942063.71	1227022.32	965515.71	961833.75	792248.95
4:30	1180724.71	1239478.69	985647.58	1192088.89	1040086.39
4:45	1196008.72	1236604.14	987862.12	1181920.77	1185465.37
5:00	1232992.53	1160358.32	992696.59	1192892.95	1194393.88
5:15	1269410.15	953980.68	1060449.43	1213386.66	950399.22
5:30	1267108.50	1020339.80	1074346.42	1216720.19	858246.24
5:45	1271182.45	1058187.99	1093935.54	1127582.47	861107.38
6:00	1214398.44	1329869.42	1107561.16	1125907.33	957491.78
6:15	1199610.28	1460557.39	1116362.36	1144049.13	1254551.63
6:30	1207161.82	1459552.31	1234845.24	1141968.60	1266066.56
6:45	1255365.75	1439256.27	1302450.67	1145148.02	1260679.30
7:00	1239706.51	1522701.86	1266843.83	1159678.21	1217825.79
7:15	1357623.19	1596602.48	1256099.46	1212666.35	1171082.59
7:30	1509498.38	1591305.67	1424297.24	1278710.54	1172901.80
7:45	1677485.09	1612606.79	1442841.08	1132048.40	1282643.78
8:00	1665025.38	1467660.00	1488679.70	1337732.54	1099520.47
8:15	1643171.46	1729226.92	1578671.74	1389186.24	1275266.45
8:30	1696229.95	1729273.82	1645546.81	1179629.17	1566034.46
8:45	1728329.04	1759191.88	1864940.32	1139238.12	1486579.07
9:00	1894325.68	1899977.62	1935808.93	1527482.72	1444653.58
9:15	1801576.35	1856701.97	1884251.37	1712274.47	1462520.66
9:30	1701288.88	1859610.02	1740798.81	1613461.12	1377366.43
9:45	1726911.87	1833946.82	1730506.73	1668164.60	1563381.04
10:00	1705433.18	1891451.14	1864940.32	1589389.31	1621421.40
10:15	1792101.74	1914045.47	1864833.11	1636119.10	1556978.64
10:30	1798477.34	1937899.51	1856725.42	1684091.86	1570966.08
10:45	1760150.06	1854219.40	1810886.80	1634082.13	1572597.67
11:00	1884887.93	1877249.27	1835223.28	1570738.26	1429841.97
11:15	1877222.47	1892409.32	1859981.90	1570731.56	1439567.85
11:30	1933983.03	1895980.73	1833115.95	1554104.09	1494489.09
11:45	1963609.61	1898285.72	1857656.80	1552355.24	1504740.97
12:00	1875326.21	1942161.07	1899093.14	1512369.57	1494850.93
12:15	1978370.97	1866216.78	1900195.39	1548924.55	1630319.76
12:30	2173967.40	1861251.66	1906989.77	1592233.70	1317587.27
12:45	2237445.27	1837970.52	1870032.76	1564141.55	1110703.73
13:00	2166462.75	1812799.81	1884968.33	1538116.52	1133653.19
13:15	2035094.67	1791632.70	1849810.43	1559796.23	1170379.03
13:30	1953699.46	1714241.09	1488961.12	1553477.59	1174717.65

13:45	1925483.35	1703165.04	1464309.71	1517374.90	1125997.78
14:00	1926562.14	1701610.51	1775179.45	1551594.73	1091777.96
14:15	1941367.06	1710961.15	1899595.68	1527894.80	1178262.25
14:30	1951813.25	1702531.83	1818478.55	1505528.29	1445249.93
14:45	1861452.67	1671575.19	1780576.76	1547125.45	1431909.09
15:00	1824978.10	1783508.26	1747492.68	1558878.25	1439889.48
15:15	1846500.34	1742872.63	1752320.44	1262032.82	1452845.03
15:30	1894081.11	1741385.11	1745227.88	1141643.62	1464386.77
15:45	1857827.66	1777608.40	1755342.40	1267614.39	1475687.29
16:00	1836781.16	1811111.27	1813567.03	1495222.81	1488214.01
16:15	1782952.11	1751687.24	1767651.35	1503521.47	1469097.27
16:30	1687060.21	1693291.74	1731860.24	1482960.76	1445028.81
16:45	1701814.87	1635308.34	1725488.00	1472303.50	1449481.35
17:00	1706468.42	1640052.34	1683441.90	1461267.65	1216612.98
17:15	1678908.96	1580031.96	1711594.36	1456218.77	1269557.56
17:30	1718539.50	1580758.97	1597754.97	1283179.83	1423724.34
17:45	1689971.61	1579629.92	1564084.60	1452134.77	1435835.63
18:00	1714334.89	1542796.87	1539352.78	1189288.05	1230995.76
18:15	1639120.96	1589235.20	1510657.58	1123880.40	1038893.69
18:30	1595061.34	1556874.78	1518252.68	1397236.98	1022370.07
18:45	1594387.94	1483191.93	1494639.86	1414517.76	1002925.01
19:00	1621890.44	1297348.19	1476417.65	1389762.49	997088.81
19:15	1605979.93	1085057.28	1451441.26	1404704.77	1000171.07
19:30	1577130.61	1421513.15	1423312.26	1340798.05	991875.77
19:45	1593185.18	1438683.37	1368421.16	1297532.45	993205.83
20:00	1553407.23	1379658.02	1221996.89	1299539.27	1307801.08
20:15	1511779.92	1357844.31	1221005.21	1271360.01	1340442.92
20:30	1445380.59	1366568.46	1228529.95	1265637.72	1345766.53
20:45	1381738.55	1197516.35	1330167.59	1253141.16	1346054.65
21:00	1227457.86	1215711.76	1299147.29	1226643.74	1306380.56
21:15	1277960.08	1112951.77	1255409.30	1196507.91	1122892.07
21:30	1271805.60	1192045.33	1191760.56	1177538.59	909699.94
21:45	1282523.17	1216174.10	1160817.31	1146076.05	910661.47
22:00	1272934.65	1172757.73	1139563.09	1168345.41	1003712.33
22:15	1221484.30	1141583.32	1124205.38	1154776.75	1285099.54
22:30	1226677.24	1139700.46	1093546.91	1120138.13	1276522.81
22:45	1241763.58	1131857.44	1057082.39	1122409.63	1233364.42
23:00	1211775.17	1090983.94	1029429.13	1122975.83	978585.18
23:15	1162968.20	1047242.60	997651.66	1077937.92	1039905.47
23:30	1125900.63	993581.06	873185.17	1036504.93	1063749.46
23:45:00	1096347.75	946321.92	848205.43	1012205.30	968286.40

10 APPENDIX III

10.1 Cost and Savings Analysis

Costs & Savings								
	CASE 1					CASE 2		
	1. Sub Case A (peak shave + outage)	2. Sub Case B (peak shave + outage)	3. Sub Case A (Outage Only)	4. Sub Case B (outage only)	5. Sub Case C (outage only)	1. Sub Case A	2. Sub Case B	3. Sub Case C
LCOE for Battery ($/kWh)	0.058		0.483			0.057		
LCOE for DG ($/kWh)		0.680		0.770			0.363	
LCOE for Battery + DG					0.773			0.108
LCOE for Solar PV (+ inverter) ($/kWh)	0.01784	0.01784	0.01784	0.01784	0.01784	0.01784	0.01784	0.01784
Units consumed during Day time (normal day)	21542.51	21542.51	21542.51	21542.51	21542.51	21542.51	21542.51	21542.51
Units consumed during Peak time (normal day)	5477.47	5477.47	5477.47	5477.47	5477.47	5477.47	5477.47	5477.47
Units consumed during Off peak (normal day)	6448.97	6448.97	6448.97	6448.97	6448.97	6448.97	6448.97	6448.97
Per unit charge during Day (05:30 – 18:30)	$0.08	$0.08	$0.08	$0.08	$0.08	$0.08	$0.08	$0.08
Per unit charge during Peak (18:30 – 22:30)	$0.09	$0.09	$0.09	$0.09	$0.09	$0.09	$0.09	$0.09
Per unit charge during Off Peak (22:30 - 05:30)	$0.04	$0.04	$0.04	$0.04	$0.04	$0.04	$0.04	$0.04
Costs estimated during an outage day								
Total units consumed during outage by ESS	544.56	544.56	544.56	544.56	544.56	1753.10	1753.10	1753.10
Cost of units consumed during the Case per day ($)	$31.80	$370.22	$262.95	$419.52	$421.16	$100.14	$636.53	$189.09
Units consumed to charge the battery per day (kWh)	544.56	0.00	544.56	0.00	371.46	1753.10	0	1041.97
Units consumed during Day time	20997.95	20997.95	20997.95	20997.95	20997.95	19789.41	19789.41	19789.41
Units consumed during Peak time	5477.47	5477.47	5477.47	5477.47	5477.47	5477.47	5477.47	5477.47
Units consumed during Off peak (inc. batt.)	6993.53	6448.97	6993.53	6448.97	6820.43	8202.07	6448.97	7490.95
Units consumption charges per day	$2,422.46	$2,401.28	$2,422.46	$2,401.28	$2,415.73	$2,375.46	$2,307.29	$2,347.81
Total costs per day	$2,454.26	$2,771.50	$2,685.41	$2,820.80	$2,836.89	$2,475.60	$2,943.82	$2,536.89
Days of Operation per month	3	3	3	3	3	3	3	3
Costs estimated during a normal day								
Total units consumed during peak shaving (*allowing max capacity to peak shave*)	891.04	891.04	0	0	0	2042.91	0	1041.97
Cost of units consumed during the Case per day ($)	$52.04	$605.78	$0.00	$0.00	$0.00	$116.70	$0.00	$112.39
Units consumed to charge the battery per day (kWh)	891.04	0	0	0	0	2042.91	0	520.99
Units consumed during Day time	21542.51	21542.51	21542.51	21542.51	21542.51	21542.51	21542.51	21542.51
Units consumed during Peak time	4586.43	4586.43	5477.47	5477.47	5477.47	3434.56	5477.47	4435.49
Units consumed during Off peak	7340.01	6448.97	6448.97	6448.97	6448.97	8491.88	6448.97	6969.96
Units consumption charges per day	$2,394.14	$2,359.48	$2,443.64	$2,443.64	$2,443.64	$2,330.14	$2,443.64	$2,365.49
Total Costs per day	$2,446.17	$2,965.26	$2,443.64	$2,443.64	$2,443.64	$2,446.84	$2,443.64	$2,477.88
Days of Operation per month	27	27	27	27	27	27	27	27
Units generated by Solar PV (kWh)	8269.23	8269.23	8269.23	8269.23	8269.23	8269.23	8269.23	8269.23
Total cost of solar PV generation	$147.56	$147.56	$147.56	$147.56	$147.56	$147.56	$147.56	$147.56
Max. Demand Charges (Rs.1400/kVA)	$3.89	$3.89	$3.89	$3.89	$3.89	$3.89	$3.89	$3.89
Maximum Demand	2121.56	2121.56	2121.56	2121.56	2121.56	2121.56	2121.56	2121.56
Total Demand charges (per month)	$8,250.51	$8,250.51	$8,250.51	$8,250.51	$8,250.51	$8,250.51	$8,250.51	$8,250.51
Fixed Charges (Rs.4000)	$11.11	$11.11	$11.11	$11.11	$11.11	$11.11	$11.11	$11.11
Unit consumption charges	$71,909.06	$70,909.93	$73,245.61	$73,182.08	$73,225.42	$70,040.26	$72,900.09	$70,911.65
Total Electricity charges per month	$80,170.67	$79,171.55	$81,507.23	$81,443.70	$81,487.03	$78,301.88	$81,161.71	$79,173.27
Nett Cost incurred per month	$81,671.04	$96,638.17	$82,296.08	$82,702.25	$82,750.52	$81,753.08	$83,071.30	$82,774.95
Exported solar pv generation (kWh)	237788.12	237788.12	237788.12	237788.12	236971.28	248076.90	248076.90	248076.90
Feed-in-tariff ($/kWh)	0.096	0.096	0.096	0.096	0.096	0.096	0.096	0.096
Nett Income	$22,788.03	$22,788.03	$22,788.03	$22,788.03	$22,709.75	23774.04	23774.04	23774.04
Regular Electricity consumption charges per month	83142.31	83142.31	83142.31	83142.31	83142.31	83142.31	83142.31	83142.31
Nett Savings	**$24,259.29**	**$9,292.16**	**$23,634.25**	**$23,228.09**	**$23,101.54**	**$25,163.27**	**$23,845.04**	**$24,141.39**
Payback period for the Hybrid Solar PV system (years)	4.87	-	4.74	-	4.54	5.85	-	5.03
Profits gained over the project lifespan (25 years)	$5,859,276.04	-	$5,745,545.01	-	$5,671,830.39	$5,783,268.78	-	$5,786,385.53