STAND-ALONE HYBRID ENERGY SYSTEM FOR A REMOTE FISHING ISLAND

Battalangunduwa Island, Sri Lanka

By

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Declaration of the Candidate and the supervisor

I declare that this is my own work and this thesis does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any other university or institute of higher learning and to the best of my knowledge and belief this does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

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The above candidate carried out this research for his Master degree under my supervision.

Dr. A.G.T. Sugathapala Date:

This is dedicated to

my parents,

my lovely wife Arosha and

my little princess Rehansa

for their love, endless support and

encouragement.

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Thusitha Weerasooriya

Content

Notations

AC	Alternating Current
COE	Cost of Energy
DC	Direct Current
DG	Diesel generator
DHI	Diffuse Horizontal Irradiance
DNI	Direct Normal Irradiance
GHI	Global Horizontal Irradiance
kVA	kilovolt Ampere
kWh	kilowatt hour
LPG	Liquid Petroleum Gases
NASA	National Aeronautics and Space Administration
NCRF	Non-Conventional Renewable Energy
NPC	Net Present Cost
NREL	National Renewable Energy Laboratory
PV	Photo voltaic
R & D	Research and development
RES	Renewable Energy Sources
RO	Reverse Osmosis
SEA	Sustainable Energy Authority
TNPC	Total Net Present Cost
UN	United Nations
UNDP	United Nations Development Program
US	United States
USA	United States of America
USAID	United States Agency for International Development
WTG	Wind turbine generator

List of Figures

List of Tables

List of Annexes

ABSTRACT

A detailed study on present and future energy demand, resource availability and technology options were studied to propose an optimum system to cater for the basic energy requirements of a remote fishing island, ‘Battalangunduwa’ in the North-Western coast of Sri Lanka. The aim of this project is to supply basic energy requirements to the people living in the island. At first, energy related issues such as, limited electricity supply to the island for household use, low price for fish production due to non-availability of ice at a reasonable rate and drinking water issues as well as health issues were identified. Further, the electricity demand to provide basic energy requirements for the existing residents was calculated as 327 kWh/day. Then to supply the energy demand, utilizing renewable energy sources such as wind and solar along with diesel generators in a hybrid system was developed by a modelling using a computer software (HOMER).The optimum option indicates that the share of annual energy generation from wind, solar and diesel generators are 85 %, 6 % and 9 % respectively without ice plants and 83 %, 0 % and 17 % respectively with ice plants. Economic evaluation was also carried out to find the viability of the system proposed and it is concluded that the project is technically feasible, environmental friendly, economically viable and also contributes to the socio economic development of the island community.

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

Currently around 1.5 billion people worldwide live without access to electricity, and without a concerted effort, this number is not likely to drop. Grid extension is often costly and not feasible in isolated rural areas, and therefore is unlikely to be accomplished within the medium term in many areas. In such situations, electricity mini-grids can power household use and local businesses. They provide centralized electricity generation at the local level using a village distribution network and, when fed with renewable or hybrid systems, increase access to electricity without undermining the fight against climate change.

Sri Lanka is an island in the Indian Ocean with an area of 65,610 square kilometres and a population of approximately 20.2 million. The country has a human development index of 0.750 ranking 73 out of 187 countries according to the 2014 human development report of United Nations Development Program (UNDP) [1]. Biomass, petroleum and hydro are the major primary energy supply sources which cater the Sri Lanka energy demand. The average per capita annual electricity consumption in year 2015 was 408.25 kWh [2]. Electricity supply system mainly consists of major hydro power plants and fossil fuel based thermal power plants with a considerable amount of non-conventional renewable energy (NCRE) plants such as, mini hydro plants and wind power plants connected to the national grid. The national energy policy targets to achieve 10% energy share from NCRE by year 2015 had been accomplished in time and future target is set to generate 20% energy share by year 2020 [3].

Even though as a country the electrification level (access to grid electricity) is at about 98%, the Northern part of the country consists of a fleet of small islands with significant number of habitants who deprive access to reliable energy sources, especially access to the national grid when it comes to electricity. Sri Lanka has set an ambitious goal of 100% energy self-sufficiency by 2030, for which these remote islands cannot be forgotten [4]. Also according to the agreement among 193 countries of UN General Assembly (including Sri Lanka) adopting to the 2030 development agenda titled ‘Transforming our world’: the 2030 agenda for sustainable development describes 17 goals (Sustainable Development Goals) to be achieved by all its member countries. As per this agreement all countries are to aim ‘Affordable and Clean Energy’ ensuring access to affordable, reliable, sustainable and clean energy for all [5]. Hence future energy system designs to be more with renewable energy.

1.2 PROBLEM STATEMENT

Presently the habitants of Battalangunduwa island are living a hard life mainly due to non availability of electricity which creates many other societal issues as well. Electricity is provided only to 50-60 houses using a 132 kVA diesel generator and even that supply is limited for 2-3 hours a day from 6.00 pm to 10.00 pm. Further households have to pay about Rs. 1200.00 per month for this limited supply. Limited numbers of households use solar PV and small portable gasoline generators and most of the families use kerosene lamps for lighting which is unsafe as well. Due to lack of basic living conditions which is directly related to lack of facilities, teachers and other professionals (e.g. medical officers) are unwilling to provide their services to the island. Therefore the children of the island are forced to attend schools in the mainland far away from their parents which makes them vulnerable in the society.

The main livelihood of the people living in the island is fishing. However due to the shortage of ice making facilities the storage options are very limited and the villagers are forced to sell their fish yield at a lower price to the merchants (middle men) travelling from the main island. Sometimes lack of ice effects the freshness of fish and a considerable portion of the harvest is thrown away due to spoilage. The better scenario would be to take the fish yield to the mainland (Kalpitiya) where it could be sold at a higher price. Another issue is the access to water. The islanders dig small pits in the sand dunes which collect rainwater during the rainy season and use that for drinking and bathing. After few days sea water flows through sand from the bottom to these pits and the water is not potable due to salinity. Also since the quality of drinking water is below the satisfactory level a lot of sanitation issues prevail in the island. Thus a water purification system is a must for the island which again needs electricity. The nearest hospital is in the Kalpitiya town which is approximately 3 hours boat ride away. However since a medical centre also needs continuous and reliable electricity supply development of proper healthcare facilities to the habitants of the island has also become a main barrier due to non availability of electricity supply.

1.3 AIM AND OBJECTIVE

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The specific objective of this project is to propose an optimum system to cater for the basic energy requirements of ‘Battalangunduwa’ island with a detailed study on present and future energy demand, resources availability and technology options. It is expected to have continuous electricity supply for the permanent households together with street lighting facility as well as a solution for their drinking water issue with a ‘Reverse Osmosis’ plant for the habitants in the

‘Battalangunduwa’ island. In addition it is expected that the fishing industry which is their main livelihood would be developed by maintaining cold room facilities. Also the medical facilities of the island would improve with a permanent staff when electricity is provided. Further, tourism studies point out that there is a remarkable potential to promote eco-tourism in Kalpitiya peninsula including the ‘Battalangunduwa’ island. Availability of electricity will promote investments in the sector and employment opportunities will be created for the islanders which will elevate their living standards further.

1.4 METHODOLOGY

The modelling of the system was started with the estimation of the energy demand. As the selected location is supplied with limited electricity at present an anticipated demand load for the island was calculated taking sample houses (20 each from medium/small houses and temporary huts). Also the electricity/energy for other requirements such as street lighting, water purification (Reverse Osmosis) plant, ice plants as well as for naval detachment, police post, medical centre, primary school etc were considered while preparing the demand loads. Annexes A1 and A2 depict the demand loads prepared without and with considering ice plants respectively. Also the summery of hourly loads for ‘off’ and ‘on’ seasons are attached as Annexes A3 and A4 respectively. Then to supply the above ascertained energy demand, possible energy sources were studied in addition to operating diesel generators alone. Accordingly, taking renewable energies also in to consideration, solar and wind were selected to use in a hybrid energy system along with diesel generators due to their high potential at the island. Then the selected hybrid energy system was simulated in a computer software named ‘HOMER’ and the aspects of economic, socio-economic development of the island society, environmental issues etc were evaluated in order to ascertain the viability of the project.

1.5 RESULTS OF THE STUDY

The simulation was carried out in two steps to find the best suited configuration for the demand load without and with ice plants. The most economical system for the option one of supplying basic electricity needs (without ice plants) is 50 kW solar PV, 03 numbers of 100 kW wind turbines, 50 kW diesel generator with batteries and control equipment. The cost of energy (COE) for this hybrid power system is US$ 0.165 per kWh with the renewable energy fraction of 74 %. Also the optimum economic system for supplying electricity demand with ice plants is 08 numbers of 100 kW wind turbines, 02 numbers of 50 kW and 100 kW diesel generators with batteries and control equipment. The COE for the best hybrid power system with ice plants is only US$ 0.152 per kWh with the renewable energy fraction of 63 %.

In addition, simulations were also carried out for above two steps taking only RESs into consideration. With that the most economical system for the demand without ice plants is 200 kW solar PV, two numbers of 100 kW wind turbines and control equipment. The COE for this hybrid system is US$ 0.166 per kWh. Also the optimum system for the demand with ice plants is 750 kW solar PV, six numbers of 100 kW wind turbines and control equipment. The COE for this hybrid system is US$ 0.155 per kWh.

It is concluded that the optimum options identified have the potential to serve the wider objective of demonstrating the feasibility of solar-wind-genset-battery storage hybrid system to meet the electricity/energy needs of the people living in 'Battalangunduwa' island besides the provision of electricity. Also by considering all the aspects the project is environmental friendly, economically viable and contributes to the socio economic development of the island society. However further studies on social and environmental issues as well as construction feasibility/limitations of the site are to be carried out prior to the implementation. Further it is necessary to obtain approvals from the various authorities such as, Central Environmental Authority, Coastal Conservation Department, Public Utilities Commission of Sri Lanka, SEA and local government authorities of the area etc.

CHAPTER 2: LITERATURE SURVEY

2.1 HYBRID ENERGY SYSTEMS

A combination of different but complementary energy generation systems based on renewable energy sources (RESs) or mixed (RESs- with a backup of Liquefied Petroleum Gas (LPG)/diesel/gasoline generator set) is known as a hybrid energy system ("hybrid system") [6]. For hybrid mini-grid systems, the power system will typically combine a diesel generator with a solar, wind, or a mini-hydro generator. During periods of high loads or when there is little renewable power available, the diesel generator is generally used as a backup source of supply. A battery is included in most hybrid power systems as a buffer to smooth out the hour by-hour or even second-by-second variations in the difference between what the energy source is supplying and what mini-grid customers are demanding [7]. The battery also helps to optimize dispatch of the diesel generator so that it can operate at close to full capacity when turned on, usually during the night time peak as experiences in many rural villages. Excess generation above what is needed to serve the load can be stored in batteries to be used at other times, particularly during peak loads. In case of a hybrid system with solar photovoltaic (PV) panels a multifunction inverter is included. The inverter converts the direct-current (DC) power of the PV panels and batteries into alternating-current (AC) power. It also serves as a battery charger, storing excess generation in batteries for future use [7].

Properly designed hybrid systems capture the best features of each energy resources and can provide "grid-quality" electricity, with a power range of 1 kW to several hundred kilowatts. Hybrid systems also offer the possibility to be upgraded through grid connection in the future. Furthermore, due to their high levels of efficiency, reliability and long term performance, these systems can also be used as effective backup solutions to the public grid in case of blackouts or weak grids, and for professional energy solutions, such as telecommunication stations or emergency rooms at hospitals etc [6]. The installation of a hybrid power system can be justified by analyzing the scenarios such as, supply of electricity at lower cost than either a renewable-only or a diesel-only systems, provide electricity for more hours of the day than a renewable-only systems, improve the operational efficiency of diesel generators by allowing them to operate at higher capacities, which in turn causes them to use lesser diesel fuel per kilowatt-hours (kWh) generated and extend the lives of diesel generators by reducing the number of hours of operation [7] etc. Since diesel is an expensive fuel and often difficult to distribute in rural/isolated areas diesel-only mini-grids will be more expensive on a lifetime basis than hybrid systems together with RESs. Therefore hybrid mini-grids, in contrast, utilize local renewable sources, making it is less likely that power will not be available. However, within hybrid power systems, the main advantage of diesel genset is their dispatchability. Gensets improve the quality of service and the security of supply as they are able to balance the intermittent production of RESs. For example, gensets will be working when RESs are not generating, or when the battery reaches a low stage of charge. It is very important to bear in mind that in developing countries, and especially in rural areas, the provisioning of fuel is an arduous task. Isolated villages should carefully consider their fuel reserves and calculate the amount needed to travel to the nearest city and bring more fuel.

2.2 LOCAL ENERGY SCENARIO

Even though as a country, the electrification level is at about 98% (access to grid electricity), the Northern as well as North-Western part of this island nation consists of a fleet of small islands, as shown in Figure 2.1 with significant number of habitants who deprive access to reliable energy sources. In particular, limited access to the national grid when it comes to electricity as illustrated in Figure 2.2 [3].

Figure 2.1: Fleet of small islands in the northern part of Sri Lanka

In the local energy scenario, about 40 % of electric power generation is from hydro power and most of the rest is from coal and oil based thermal power plants. Also, over 50 % of total primary energy consumption is derived from renewable and indigenous resources [3]. However it could be seen that Sri Lanka is moving more towards renewable energies as can be seen from Figure 2.3 [3].

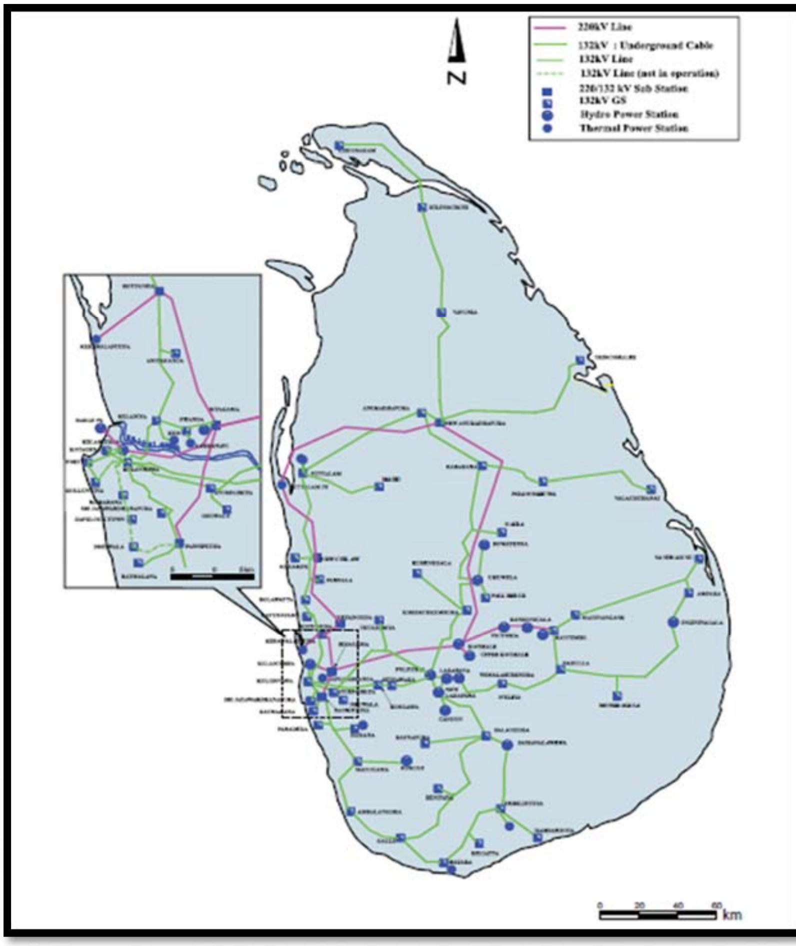

Figure 2.2: Transmission network of Sri Lanka

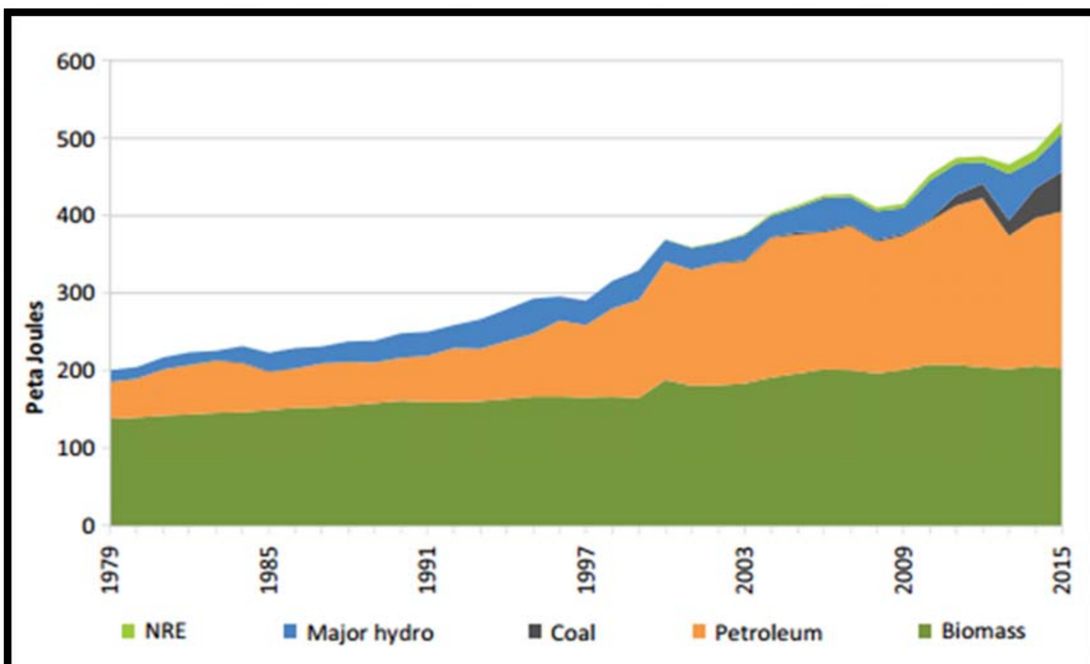

Figure 2.3: Energy share of Sri Lanka

2.3 RENEWABLE ENERGY SOURCES

2.3.1 Overview

In Sri Lanka, hydro, solar, wind and biomass resources have been harnessed in different levels. Though the tidal and wave energy are also prominent in the site, they were omitted due to their immaturity in technology as well as high cost involvement. Further biomass energy was ignored due to very poor potential in the island. Therefore, solar and wind resources are selected for the site and they are presented in the following two sections.

2.3.2 Wind Energy Resource

Wind is the air set in motion due to the pressure differentials, which are caused mainly by the uneven heating of the ground surface by the sun. In Sri Lanka, wind climate is mainly governed by the monsoon seasons. A comprehensive study of wind power potential in Sri Lanka has been done by the National Renewable Energy Laboratory (NREL) of the US department of energy in 2003 under contract to the United States Agency for International Development (USAID). One of the major outputs of the above study is the Sri Lanka wind resource map given in the Figure 2.4 [8]. Small wind power technology is very site specific since, wind conditions dramatically vary from place to place. Therefore, wind resources must be carefully studied before a system is installed. Topography and obstacles highly impact wind speeds, so turbines are normally located along ridges and hilltops at a height of at least 10 meters to minimize the influence that buildings and trees can have on the wind profile. This is an important consideration, given the fact that rural communities often are located on lower parts of slopes and in valleys. For this reason, gathering information on local wind resources throughout the year is necessary prior to the final decision on the installation.

Normally annual average wind speeds in the range of 5 to 6 m/s are the minimum to make a system operational and financially justifiable. Selection of turbines especially designed to work under low-speed winds can be a good idea, depending on the wind information collected. Wind power is also subjected to both seasonal variability and daily intermittency. This makes hour-by-hour and day-by-day evaluations of the expected production critical, and requires the combination of wind with other technologies. For example, batteries can provide stable supply of electricity to the grid for short periods when the wind is not blowing. For longer periods of low winds it may be necessary to use more genset power to match the users' demand. The volume of fuel required to run a genset for a whole village with a 100% direct genset operation is extremely large and normally special storage facilities need to be installed. For instance, to generate 1 kWh of electricity, a genset will consume at best 0.3 to 0.4 liters of diesel fuel. Diesel gensets in hybrid systems are smaller and therefore consume less fuel.

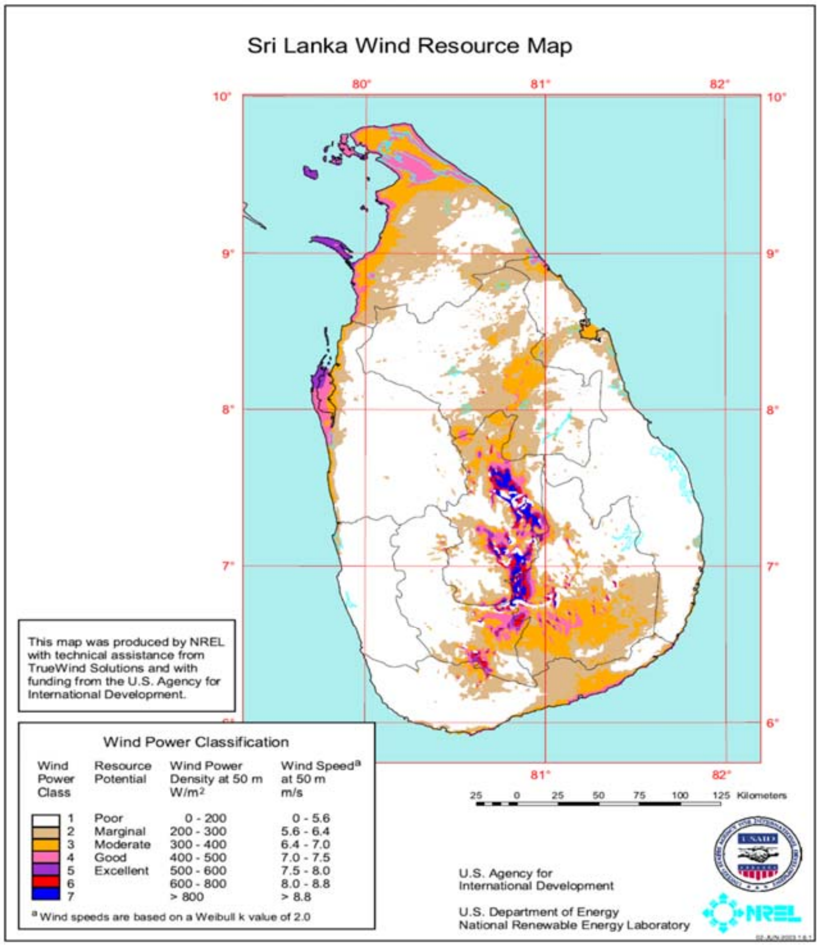

Figure 2.4: Wind resource map of Sri Lanka

2.3.3 Solar Energy Resource

Primary source of energy for solar power generation is the radiant energy emitted by the sun in the form of electro-magnetic waves (solar radiation). Three types of solar irradiance are measured namely, Global Horizontal Irradiance (GHI), Diffuse Horizontal Irradiance (DHI) and Direct Normal Irradiance (DNI). The solar energy falling on the surface during a day is expressed in kWh/m^2/day. Sri Lanka is located closer to the equator where considerably high solar energy resource remains throughout the year. According to the NREL, flat dry zone of the country which accounts for two-thirds of the land area, solar radiation varies from 4.0 – 4.5 kWh/m^2/day [8]. HOMER software imports hourly solar energy from the NASA's surface energy data according to the exact location of the island. Average daily solar radiant energy in Sri Lanka throughout the year is given in Figure 2.5 [8]. Solar PV is suitable for almost any location around the world and is also comparatively easy to install, maintain and scale up. However, initial investment costs are higher than those of other technologies. Solar PV generators are highly site specific and also seasons have an influence on electricity generation. During the warmer months, the insolation is higher than in cold months. Similarly, insolation is higher during dry season than during the rainy season. In addition the time of the day also influences the production profile, with peak production at around noon when the sun is perpendicular to the earth's surface, and no production during the nights. PV generators produce DC power and therefore extra components are necessary to adapt the voltage to the required applications (many loads and most of the grids). If the system includes batteries, normally the PV generator will be connected to the batteries through a charge controller. If instead the PV generator is connected to an AC bus bar feeder, it will need an inverter to adapt the voltage.

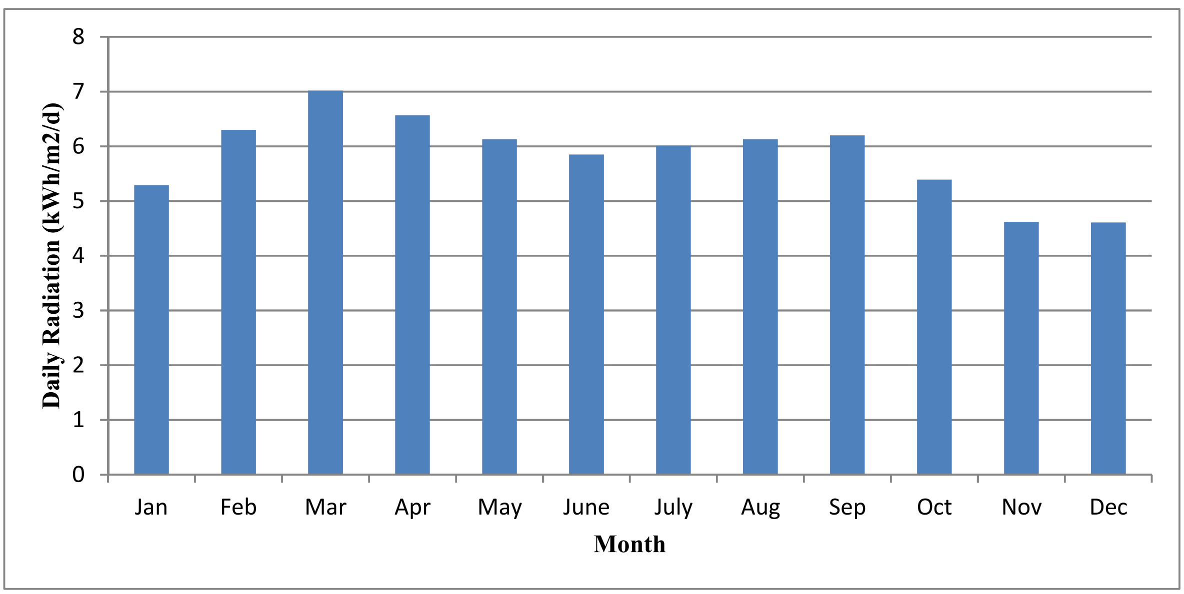

Figure 2.5: Average Monthly Solar Radiation

2.4 ENERGY SERVICES

2.4.1 Overview

The primary energy required for the selected location is to provide the basic energy needs such as lighting and other domestic needs of electricity, street lighting and other community facilities. In addition a water purification system as well as ice making machines are to be introduced. Though there are norms for general energy requirements such as lighting and other domestic needs, ice making machines and water purification systems are specific and hence need more analysis to identify the energy demand.

2.4.2 Ice Making Machines

The demand for ice in the island is basically based on the fish production. Fish production however varies from season to season. For ice demand calculation maximum fish production figures were selected as if ice is available fish production would be increased. Ice requirement for various activities is shown in Table 2.1 [9].

Table 2.1: Ice requirement for various fishing activities

Application	Fish	Prawn
On fishing vessel	1.0: 1	2.0: 1
Collection from artisanal fishermen	1.5: 1	1.5: 1
Re-icing at a collection centre	1.5: 1	1.5: 1
Re-icing for chill storage	1.0: 1	1.0: 1

However, for the selected project location a permanent ice storage facility is not required. Ice is required for island fishermen only for the use at fishing vessel and at the point of the collection centres as vendors from main land come directly to the island to buy fish. Therefore it is reasonable to assume that ice required per 1kg of fish production is 2.5 kg. In the island most of the fishing vessels are single day type. Fish harvest per single day vessel is around 100 kg per trip according to the details obtained from the fishermen in the island during visit, and the daily fish production in the island is approximately 24,000 – 26,000 kg. Normally fishermen go for fishing for 6 days a week. Then the effective daily fish production is around 22,300 kg. From this amount normally 30 % is used for dry fish production. Ice required for dry fish production is 1 kg per 1 kg of fish. Accordingly daily ice requirement can be estimated as 46 tonnes. As ice production varies with the time and due to turning off of industrial loads during peak hours it is prudent to use 6 nos. of 10 ton per day machines considering the redundancy and reliability. Typical power consumption of a 10 ton per day ice making machine is 42 kW [10]. Then for 6 Nos. of machines the power requirement is calculated as 252 kW.

2.4.3 Reverse Osmosis Technology

There are over 11,000 RO plants in operation throughout the world and the production is more than 20 million cubic meters of water per day. Most of them are located in West Asia and some of them are in North America as well. Design of plant sizes varies from 20 - 100 m^3/day to more than 500,000 m^3/day [11]. The main idea behind Reverse Osmosis (RO) systems is reversing the natural process driven by osmotic pressure of solvent transport across a semi-permeable membrane from a region of lower solute concentration into one of higher solute concentration to equalize the free energies. In RO, external pressure is applied to the high salt concentration water to cause it to migrate through the membrane pores leaving the salts and other non-permeates in a more concentrated brine. Illustration of simplified process flow of RO is shown in Figure 2.6 [12]. However the absence of beneficial ions can affect public health in the population over the long term. Therefore addition of these ions and minerals to desalinated water at the stage of post treatment can be proposed to avoid this issue [11].

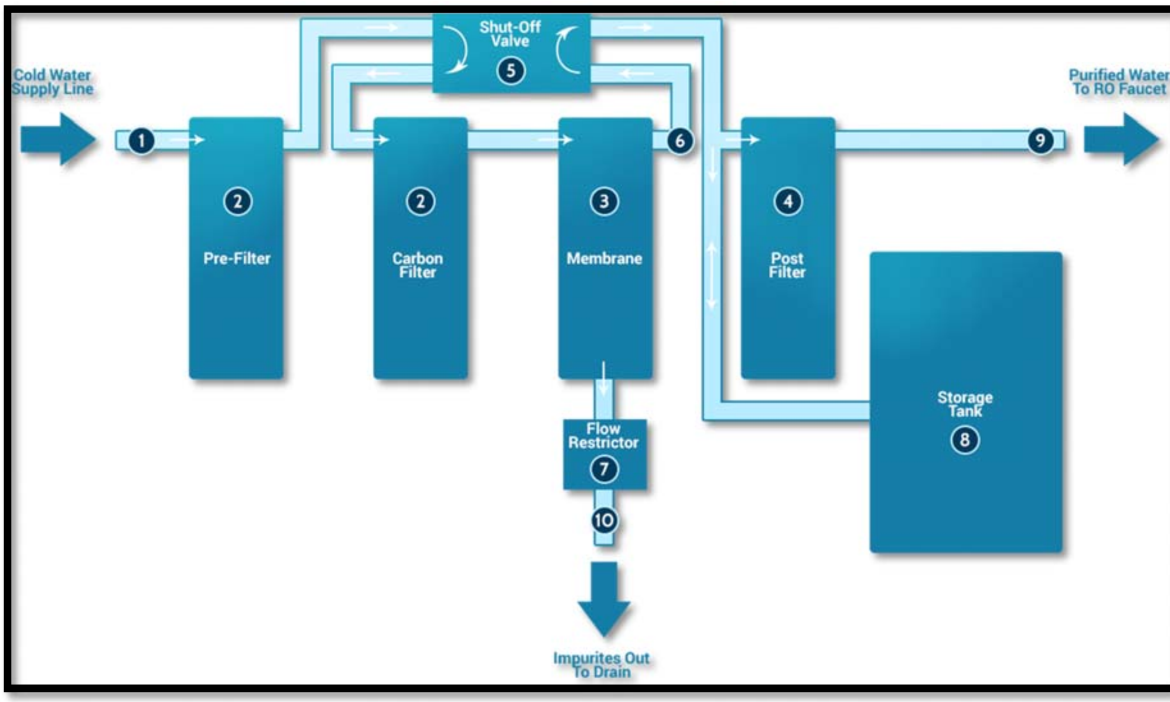

Figure 2.6: Simplified process flow of Reverse Osmosis system

A Reverse Osmosis system of Chinese make with a capacity closer to the requirement is around 35,000 US$ [12]. If the expected life time of the plant is 5 years and installation cost is 10,000 US$, capital cost component for 1 m^3 would be 1.03 US$. The daily operating and maintenance cost would be 1.5 US$/$m^3$ [13]. An energy cost of 4 kWh/m^3 at a unit price of 0.3 US$/kWh gives 1.3 US$/m^3. Then the total cost for 1000 litres become 3.83 US$. This is a bearable cost considering the cost of bottled drinking water. Further, according to theories the minimum absolute value of energy required to desalinate 1 m^3 of sea water is approximately 1 kWh by natural osmosis. Earlier in the 1970's the specific energy requirement for a sea water RO system was in the range of 7.0 kWh/m^3 to 9.0 kWh/m^3. However with the current technological advancements such as innovations in high efficiency pumps, energy recovery systems and overall higher efficiency improvements in the plants, the specific energy requirement has come down to around 2.5 kWh/m^3.

2.5 MODELLING OF HYBRID ENERGY SYSTEMS

The modelling tool used in the present study is the HOMER micropower optimization model which is a computer model developed by the U.S. National Renewable Energy Laboratory (NREL) to assist in the design of micro-power systems and to facilitate the comparison of power generation technologies across wide range of applications. HOMER models a power system's physical behaviour and its life-cycle cost, which is the total cost of installing and operating the system over its life span. HOMER allows the modeller to compare many different design options based on their technical and economic merits. It also assists in understanding and quantifying the effects of uncertainty or changes in the inputs. HOMER can model grid-connected and off-grid micro-power systems serving electric and thermal loads, and comprising any combination of photovoltaic (PV) modules, wind turbines, small hydro, biomass power, reciprocating engine generators, microturbines, fuel cells, batteries, and hydrogen storage etc. To limit input complexity, and to permit fast enough computation to make optimization and sensitivity analysis practical, HOMER's simulation logic is less detailed than that of several other time-series simulation models for micropower systems, such as Hybrid2, PV-DesignPro , and PV*SOL. On the other hand, HOMER is more detailed than statistical models such as RETScreen, which do not perform time-series simulations. Of all these models, HOMER is the most flexible in terms of the diversity of systems it can simulate.

HOMER's fundamental capability is simulating the long-term operation of a micropower system. Its higher-level capabilities, optimization and sensitivity analysis, rely on this simulation capability. The simulation process determines how a particular system configuration, a combination of system components of specific sizes, and an operating strategy that defines how those components work together, would behave in a given setting over a long period of time. HOMER can model two different dispatch strategies: load-following and cycle-charging. Load-following strategy is renewable power sources charge the battery but not the generators. Cycle-charging strategy is whenever the generators operate, they produce more power than required to serve the load and hence with surplus electricity the battery bank is charged. Also in HOMER, the best possible, or optimal, system configuration is the one that satisfies the user-specified constraints at the lowest total net present cost. Finding the optimal system configuration may involve deciding on the mix of components that the system should contain, the size or quantity of each component, and the dispatch strategy the system should use.

In HOMER, a micropower system must comprise at least one source of electrical or thermal energy (such as a wind turbine, a diesel generator, a boiler, or the grid), and at least one destination for that energy (an electrical or thermal load, or the ability to sell electricity to the grid). It may also comprise conversion devices such as an ac–dc converter or an electrolyser, and energy storage devices such as a battery bank or a hydrogen storage tank. In HOMER, the term load refers to a demand for electric or thermal energy. Serving loads is the reason for the existence of micropower systems, so the modelling of a micropower system begins with the modelling of the load or loads that the system must serve. HOMER models three types of loads.

Primary load is defined as electric demand that must be served according to a particular schedule, deferrable load that is electric demand that can be served at any time within a certain time span and the thermal load which is demand for heat. The HOMER user specifies an amount of primary load in kW for each hour of the year, either by importing a file containing hourly data or by allowing HOMER to synthesize hourly data from average daily load profiles. Economics play an integral role both in HOMER's simulation process, wherein it operates the system so as to minimize total net present cost, and in its optimization process, wherein it searches for the system configuration with the lowest total net present cost. HOMER uses the total net present cost as the economic figure of merit, and how HOMER calculates total net present cost.

CHAPTER 3: METHODOLOGY

3.1 OVERVIEW

The key elements of the methodology adopted to attain the objective of the study include following and more details of same are discussed in sections below:

- Literature survey on basic configurations and modelling tools of hybrid energy systems
- Ascertain the energy demand
- Study characteristics and potential of RESs in the proximity of the location
- Select the basic configurations and model and simulate the hybrid energy system
- Analyze the results and make recommendations

3.2 SELECTION OF THE SITE

As the Battalangunduwa island is located about 9.5 km away from the North-Western mainland, connecting it to the main grid is highly unlikely for many years ahead (as depicts in Figure 3.1 more clearly). Due to non availability of electricity to meet even the basic domestic needs, the people living in this island face the life full of hardships. Hence it was decided to explore feasibility to supply electricity for the Battalangunduwa island which will improve the living standard of the habitants living there in many ways.

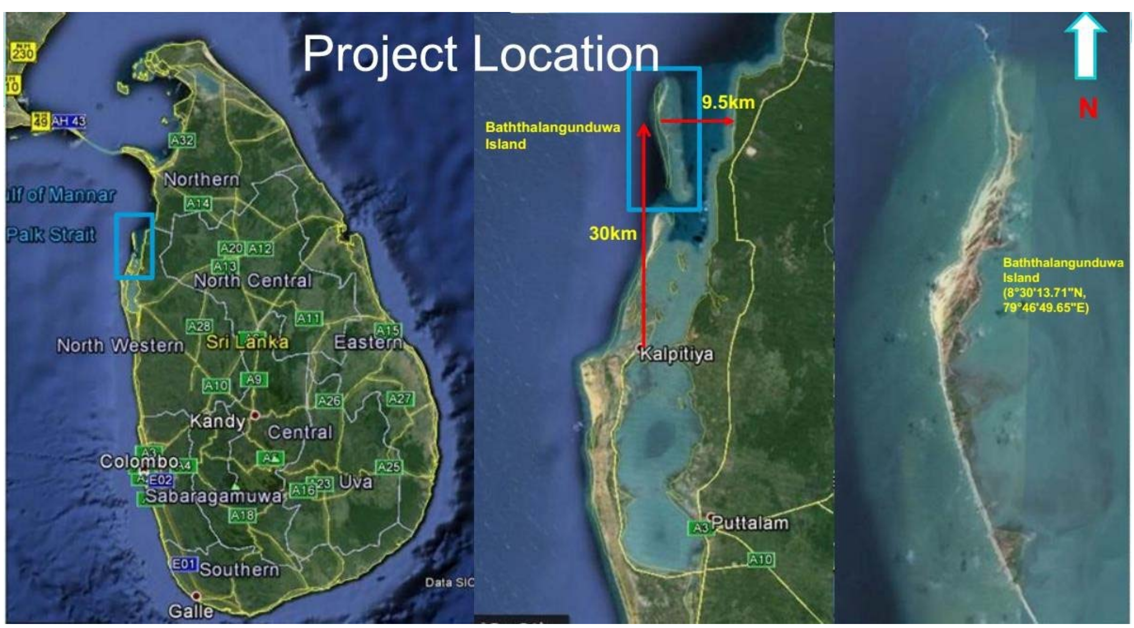

Figure 3.1: Location of Battalangunduwa island in the Indian ocean

3.3 COLLECTION OF DATA

During the visit to the island the total number of houses present there was obtained from the government official (Grama Niladhari) and same is indicated in Table 3.1. However as the Battalangunduwa island is not 100 % electrified, it was not possible to obtain the present electricity demand. Hence assuming each type of houses would be fitted with the appliances shown in Table 3.2, the total energy demand for the houses was calculated. In addition, the electricity requirements for street lighting, naval detachment, police post, medical center, pre-school etc as well as for the RO plant and ice making machines were considered while preparing the demand loads. The demand loads considering without and with ice plants are attached as annexes A1 and A2 respectively to this report. More details about the data and their collection are discussed in Chapter 4.

Table 3.1: House distribution at Battalangunduwa island

House Type	On season	Off Season
Medium House	100	100
Small Houses	200	200
Temporary huts	460	260

Table 3.2: Loads used in different types of houses at Battalangunduwa island

Appliance	Power Rating (W)	Medium size house s	Small size houses (Nos.)	Temporary huts (Nos.)
Fluorescent bulb	40	2	1	0
LED bulb	10	4	3	3
Fan	40	1	1	0
Table fan	25	2	1	1
TV	70	1	1	0
Radio	15	1	1	1
Water heater	1000	1	1	1
Iron	1000	1	1	0
Refrigerator	120	1	0	0
Washing machine	300	1	0	0
Communication	5	2	2	1

3.4 SELECTION OF ENERGY SOURCES

In order to supply the energy demand ascertained, possible energy sources were studied. Though the total load could be supplied by diesel generators alone considering their disadvantages/limitations such as, to supply electricity at a lower rates than either a diesel-alone or a renewable-alone system, improve the operational efficiency of the generators, use lesser diesel fuel for a healthy environment etc., use of RESs present in the island were considered.

Solar energy data for the island were obtained from the NREL report and it is observed that there is a very good potential with 4.0 – 4.5 kWh/m2/day (for a flat dry zone). Further the wind resource data for the island were obtained from the nearest wind mast at Mullipuram, Puttalam operated by the SEA. The annual average wind speed at 50 m height was calculated as 6.86 m/s and also could observe the wind potential in the island is very high almost throughout the year. However wave and tidal energy were not considered in the present study due to their immaturity in technology as well as high cost involvement even though the selected location is an island. Also the biomass energy source was ignored due to very poor potential in the island.

3.5 MODELLING AND SIMULATION

In order to supply the energy demand of the Battalangunduwa island, potential RESs selected were solar and wind. Then a hybrid system with two diesel generators and said RESs was designed for the location. Therefore, two generators, wind turbines, solar PV, a battery bank and an inverter with other necessary control equipment were selected and modeling and simulation were carried out using the software 'HOMER'. Detailed descriptions about the modeling and simulation as well as the results obtained with recommendations are depicted in Chapters 6 to 8.

CHAPTER 4: SITE DETAILS

4.1 OVERVIEW

Battalangunduwa is a remote fishing island in the Puttalam district (Kalpitiya AGA Division) spread in an area of 1.5 km^2(3.5km in length and 0.25 ~ 0.5 km in width), located in the Portugal bay about 30 km away from the Kalpitiya fishing harbour and 9.5 km away from the North-Western mainland (see Figure 3.1). Battalangunduwa has suffered from the conflict ended few years ago in the country and there is a naval detachment still operating to provide the security for fishermen. The island is the landmark which separates the Portugal bay and the Indian Ocean. Temperature in the island varies between 28 ºC to 34 ºC and the rainfall is very less which varies between 900 mm to 1,300 mm. Part of the island is covered by dense vegetation comprising coconut and palm trees. Island's Western side is covered with coral and limestone whereas the eastern side is sandy. Due to the sandy surface layer, retention of rainwater is very poor across the island. Although there are many numbers of hand-dug wells on the island they go dry within a short period after the rainy season causing water scarcity to the people for long periods. Part of the island is covered by dense vegetation comprising coconut and palm trees.

Permanent population in the island is about 1,700 belonging to 600 families staying in about 600 houses (including small huts) and about 400-500 fishermen migrate to the island for fishing during the season (short term migrants). The livelihood of the island population is based on fishing activities. The island has one primary school, three main churches, six small churches, one naval detachment, one police post and one communication tower. The habitants of the island have to either use the transport ferry which serves the main purpose of transporting dried fish to the mainland or a fishing boat which is on route to Kalpitiya fishing harbour to travel to the mainland. The fishermen and their families are leading a life full of hardships due to limited access to the mainland and other resources. The habitants of the island are based on two major locations in the island as indicated in Figure 4.1.

Figure 4.1: Major locations of Battalangunduwa island

4.2 EXISTING ENERGY DEMAND SCENARIO

Currently the Battalangunduwa island is supplied with limited power for a limited period of time. Only about 50-60 families get electricity supply for about 4 hours/day. Therefore, the islanders use electricity mostly for lighting. The price they pay for this limited supply is around Rs. 1,200.00, which is a very high value compared to the service they receive. However there is a high electricity requirement for other needs of the community such as entertainment, refrigeration, communication and house cooling etc. The main livelihoods in the island are fishing and making dry-fish. Due to lack of fresh fish preservation methods islanders tend to make dry fish. This is mainly due to lack of ice at reasonable price. Therefore it is very much essential to supply electricity for ice making plants as well. The other main difficulty faced by islanders is safe drinking water. Hence it is essential to supply electricity for RO plant in order to obtain safe drinking water.

Domestic load of the island was calculated using three categories of houses. Medium sized houses, small sized houses and temporary fishermen's huts which are erected during the 'on season' of the island. Table 3.1 in Section 3.3 depicts the approximate house distribution in 'on' and 'off' seasons. Also the pre-school, medical centre, churches, street lighting, police post & naval detachment as well as the RO plant were included in to the load. The electricity loads of the household energy services are as indicated in Table 3.2 of Section 3.3.

As indicated earlier the total population of the island during the season is around 1,700. Generally, the drinking water consumption per head is 10 litres per day. Then the water requirement for drinking purposes can be calculated as 17,000 litres per day. For ice making the water requirement is around 46 tonnes per day. Therefore total daily water requirement of the island is approximately 63 tonnes of water. Power consumption of a water desalination plant of similar capacity is around 4 kWh per ton [13]. Then the total energy requirement for water desalination per day is 250 kWh and due to the fact that the plant is not operating during peak hours, considering a 20 hour operating period the power requirement will be around 12.6 kW. The daily fish production in the island is approximately 24,000 – 26,000 kg. Normally fishermen go for fishing for 6 days a week. Then the effective daily fish production is around 22,300 kg. From this amount normally about 30% is used for dry fish production. Ice required for dry fish production is 1 kg per 1 kg of fish. With this daily ice requirement can be approximately estimated as 46 tonnes. As ice production varies with the time and due to turning off of industrial loads during peak hours it is prudent to use 6 nos. of 10 ton per day machines considering the redundancy and reliability. Typical power consumption of a 10 ton per day ice making machine is 42 kW [10]. Then for 6 Nos. of machines the power requirement is calculated as 252 kW. All these loads were weighted hourly to calculate total load profile and the Microsoft excel spreadsheets for 'on season' as well as 'off season' are attached in Annex A.1 and A.2 respectively.

4.3 RESOURCE AVAILABILITY

To supply the existing and estimated future electricity demand in the island it is important to identify and select most suitable resources. Also it is considered beneficial to harness the RESs that replenish continuously to the island rather than depending on imported fuel. Hence considering the location as well as resources available within the island, it is decided to use wind and solar energy resources in a hybrid system with small diesel generators to supply the basic electricity demand to the island. Figure 4.2 depicts the monthly average wind speeds at Battalangunduwa island for the year.

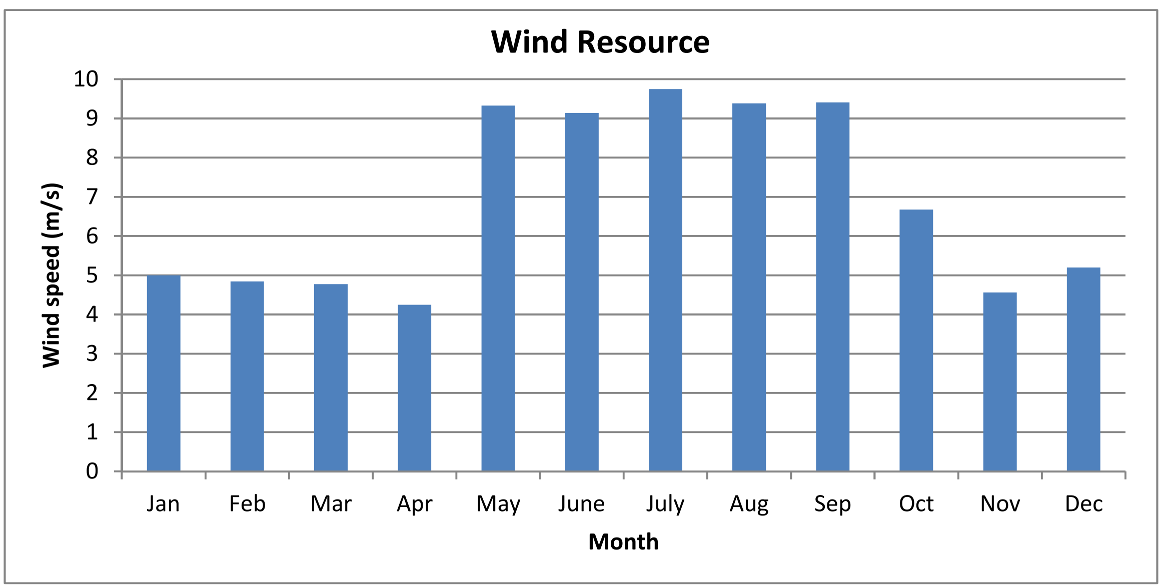

Figure 4.2: Monthly average wind speeds at Battalangunduwa island

Therefore it can be observed that the high wind season occurs between May to September months where maximum wind energy can be harnessed. The exact project location is about 40-50 km away from this wind mast but since no data available at the site these were assumed to be same at the site. Average monthly solar radiation in the site is shown in Figure 4.3.

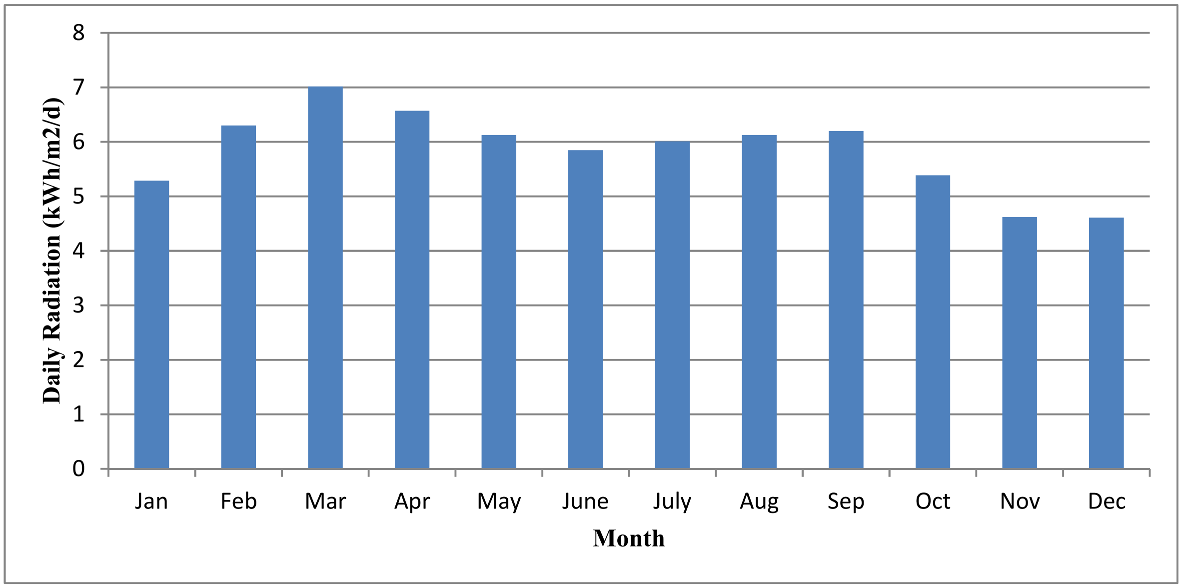

Figure 4.3: Average monthly solar radiation at Battalangunduwa island

CHAPTER 5: ENERGY CONVERSION TECHNOLOGIES

5.1 OVERVIEW

There are many technologies used to generate electricity. They are mainly categorized into two; conventional method and non-conventional method. Electricity generated from fossil fuel based resources such as diesel, coal, LPG and nuclear fuels are mainly falling under the conventional method. Also the electricity generated from solar PV, wind turbines, biomass, geo-thermal and tidal wave is categorized as non-conventional methods. Figure 5.1 provides a general overview of the types of energy available for use, how one form of energy could be converted to another form, and how energy is distributed as well as used to serve the consumer demand.

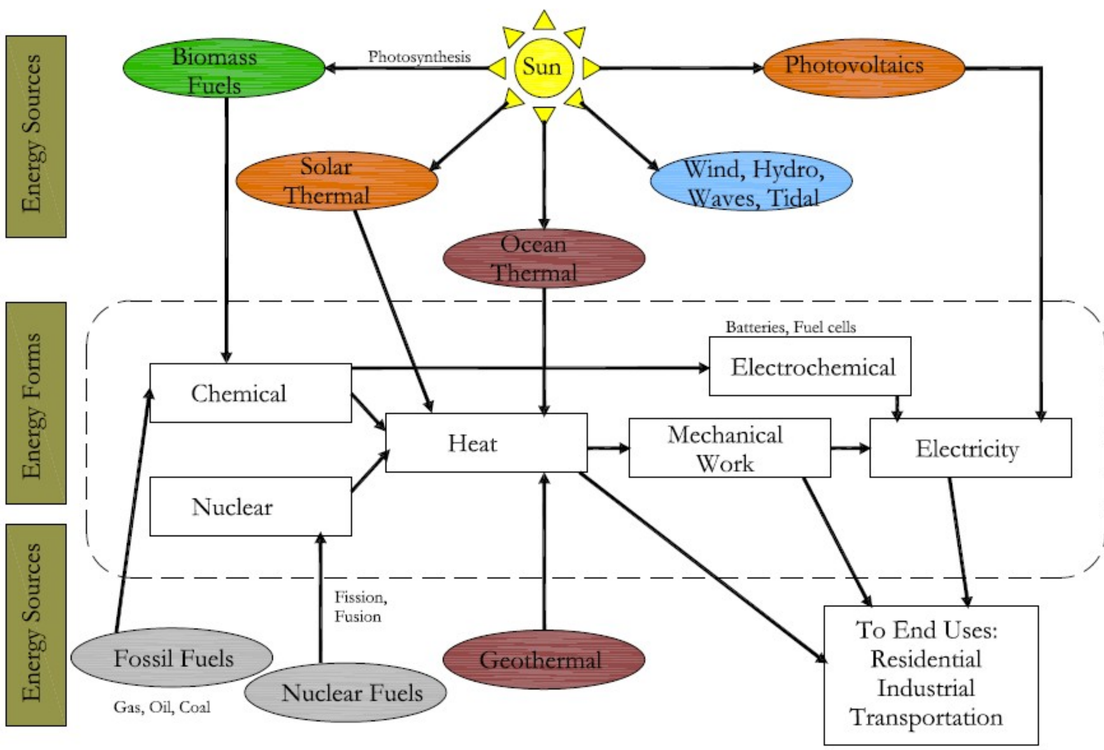

Figure 5.1: Energy sources and conversion processes for end users

5.2 ENERGY RESOURCES USED AND THEIR APPLICATIONS

As stated in previous chapters, wind and solar energy resources were selected in this project as RESs. Therefore in order to provide sustainable and reliable energy supply to the Battalangunduwa island, diesel generators were also combined along with storage facilities and their processes and applications are indicated below.

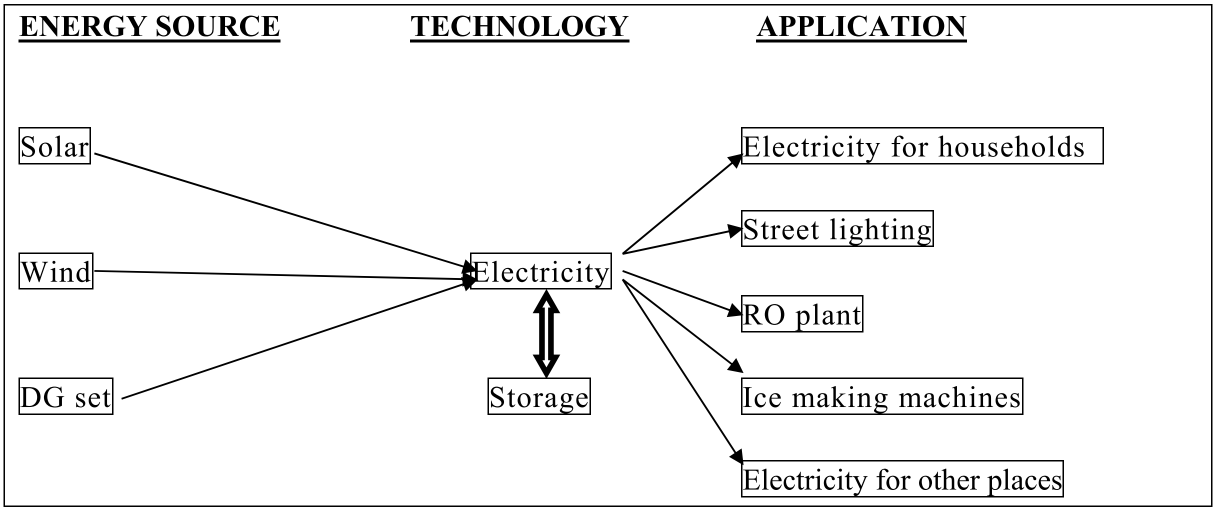

Figure 5.2: Processes and applications of energy supply to battalangunduwa island

The above resource/technology combinations could be used to cater for the electricity demand of the Battalangunduwa island, either individually (diesel only system) or by combining with other technologies (wind-solar-diesel hybrid system). However, to select the best combination out of many combinations; 'HOMER' hybrid power system optimization software was used in this project.

5.3 TECHNOLOGY STATUS AND TRENDS

5.3.1 Overview

Increased efforts in technology are essential for realizing the vision of improvements, with a main focus on reducing the investment costs and increasing performance and reliability to reach a lower COE. Good resource and performance assessments are also important to reduce financing costs. This identifies short, mid and long-term technology goals and milestones and related key research and development (R & D) issues.

5.3.2 Solar PV Technology Status and Trends

With the aim of achieving further significant cost reductions and efficiency improvements, R&D is predicted to continuously progress in improving existing technologies and developing new technologies. It is expected that a broad variety of technologies will continue to characterize the solar PV technology portfolio, depending on the specific requirements and economics of the various applications. Figure 5.3 gives an overview of the different solar PV technologies and concepts under development [14].

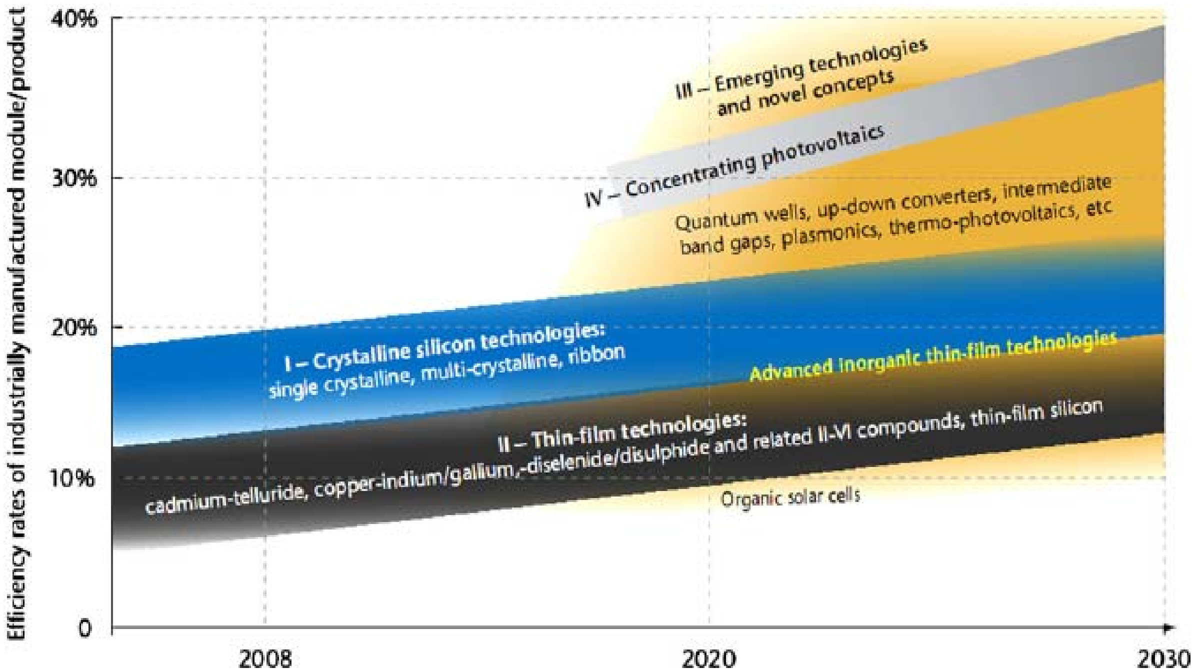

Figure 5.3: Solar PV technology status and trends

Table 5.1 summarizes a set of general technology targets for PV systems, expressed in terms of (maximum) conversion efficiency, energy-payback time, and operational lifetime. Typical commercial flat-plate module efficiencies are expected to increase from 16% in 2010 to 25% in 2030 with the potential of increasing up to 40% in 2050 [9].

Table 5.1: Solar PV general technology targets

Targets	2008	2020	2030	2050
Typical flat-plate module efficiencies (up to)	16%	23%	25%	40%
Typical maximum system payback time (in years) in 1500 kWh/kWp regime	2	1	0.75	0.5
Operational life time (in years)	25	30	35	40

Concurrently, the use of energy and materials in the manufacturing process will become significantly more efficient, leading to considerably shortened PV system energy pay-back times. The latter is expected to be reduced from maximum two years in 2010 to 0.75 year in 2030 and below 0.5 year in the long-term. Finally, the operational lifetime is expected to increase from 25 to 40 years [9].

5.3.3 Wind Energy Technology Status and Trends

Increased efforts in wind technology R & D are with a main focus on reducing the investment costs and increasing performance and reliability to reach a lower COE. Good resource and performance assessments are also important to reduce financing costs. Wind energy technology is already proven and making progress. No single element of onshore turbine design is likely to reduce dramatically the COE in the years ahead. Design and reliability can be improved in many areas, however; when taken together, these factors will reduce both COE and the uncertainties that stifle investment decisions. Greater potential for cost reductions, or even technology breakthrough, exists in the offshore sector. The growth in size of wind turbines and prospects are shown in the Figure 5.4 [15].

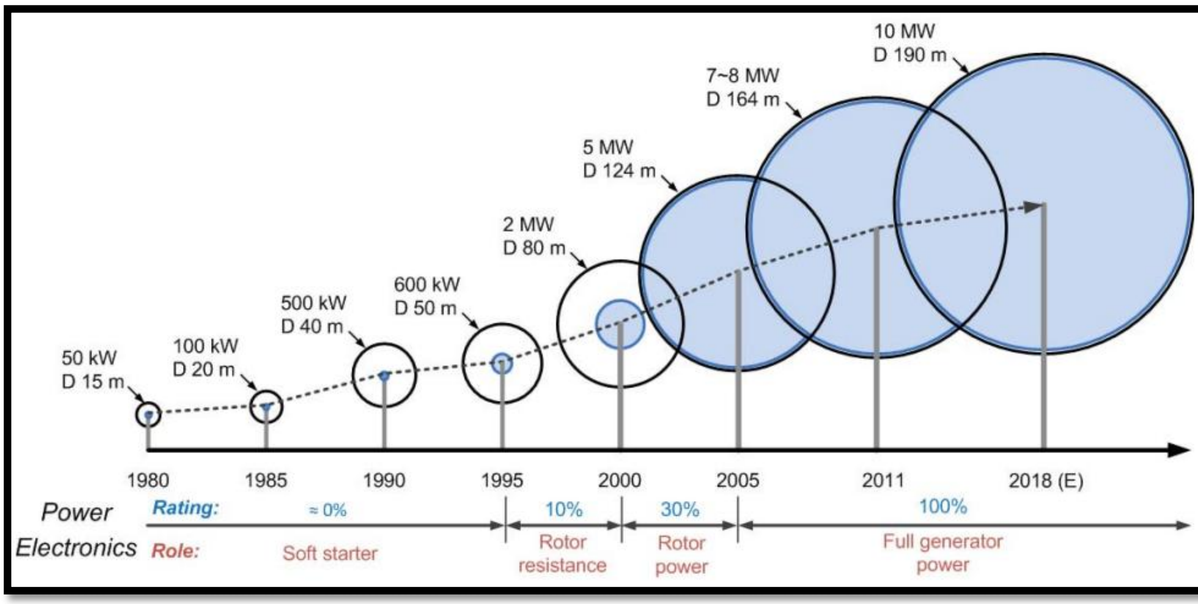

Figure 5.4: Growth in size of wind turbines and prospects

Cost reduction is the main driver for technology development but others include grid compatibility, acoustic emissions, visual appearance and suitability for site conditions. Reducing the cost of components, as well as achieving better performance and reliability (thereby optimizing operation and maintenance) all result in reducing the COE. R & D targets for up-scaling to 10 MW to 20 MW turbines will push the technology towards new solutions, which may help reduce costs for the 2 MW to 5 MW turbine size (seen as sufficient for most applications). Further enlargement of land-based turbines is limited by logistics constraints as well as sound and visibility regulations. Offshore up-scaling will bring more direct benefits. Advanced rotors, with larger swept area and higher reach, provide greater energy capture and have already reduced the cost of wind energy. As rotors become larger with longer, more flexible blades, a fuller understanding of their behaviour during operation is required to inform new designs. Noise reduction technologies are important to increase the amount of land available for wind projects. Other promising technologies can be developed to improve blade pitch control and advance blade bearing and pitch systems and hub design, materials and manufacture etc.

5.4 TECHNOLOGY OPTIONS ANALYSIS BY 'HOMER' SOFTWARE

HOMER can do extensive analysis considering all the electricity generating options and their operational characteristics, resource data, energy storage facility, load pattern and have overall control of the system. Initially load data, resource data, and equipment data along with the equipment capacities to be entered into the HOMER. After that it carries out several iterative calculations and gives the best combinations in merit order based on discounted lifecycle cost called "Net Present Cost" (NPC). The outputs in the HOMER software is directly influenced by the inputs provided to it and the assumptions made regarding the inputs. Therefore, all the technical as well as economic inputs given to HOMER software have to be verified from the relevant sources. Table 5.2 depicts the assumptions made/details given to the HOMER software during this study.

Table 5.2 – Details provided to HOMER' software

Sr. No.	Detail	Value/Description
1	Project life time	20 years
2	Wind resource data	Puttalam data, Sri Lanka
3	Solar resource data	NASA data for Sri Lanka
4	Daily noise to the load	5%
5	Hourly noise to the load	5%
6	Wind Turbine Generator life time	25 years
7	Solar PV life time	20 years
8	Battery Floating life time	5 years
9	Converter life time	5 years
10	Diesel Generator life time	15,000 running hours
11	Operator wages	US$9500 per annum
12	Diesel Price (at site)	0.9 $ per litre

Sr. No.	Detail	Value/Description
13	Commercial interest rate	8% per annum.
14	Carbon/GHG emission credits	0
15	Installation Rate	2%

CHAPTER 6: MODELLING AND SIMULATION

6.1 OVERVIEW

The hybrid energy system for the Battalangunduwa island consists with two diesel generators, wind turbines, solar PVs, a battery bank and an inverter/converter. Modelling and simulation were carried out using the software ‘HOMER’ in order to find the optimum option for the respective load profiles with/without considering ice plants. In addition to these two simulations, additional simulations were carried out taking only renewable energy resources into consideration which will enable to promote eco-tourism in the island. The details of inputs given for each machine with load profiles for above purpose are discussed below.

6.2 ELECTRICAL LOAD PROFILES

The loads considered for each family as well as other requirements in the island for ‘off’ and ‘on’ seasons are attached as annex A1 and A2 respectively for this report. However for the simulation purposes ‘off’ season loads were not considered and only with and without ice plants were considered.

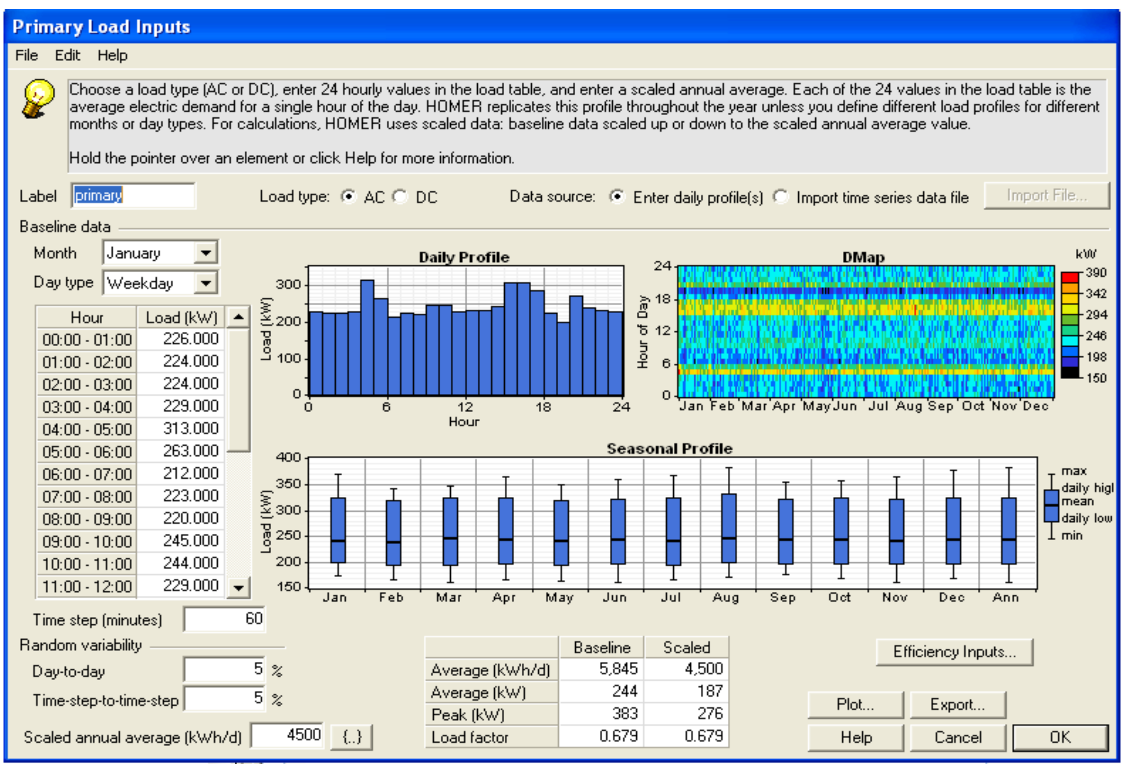

Figure 6.1: Electrical load profile with ice plants

The load characteristics show that, there is a base load throughout the day, and the peak loads are mainly at morning and in the evening. The scaled average loads with and without ice plants are 4500KWh/day and 1300 kWh/day respectively and Figures 6.1 and 6.2 shows the respective daily electrical loads used for simulation. The hourly load was calculated with the islanders' life style and adjusting ('on' and 'off') the fixed loads (ice making machines and RO plant) to avoid sharp peaks. Further the variations of the load ('day-to-day' as well as 'time-step-to-time-step') were set to 5% and 10% for the load with/without ice plants respectively considering their life style as well as to meet any eventuality.

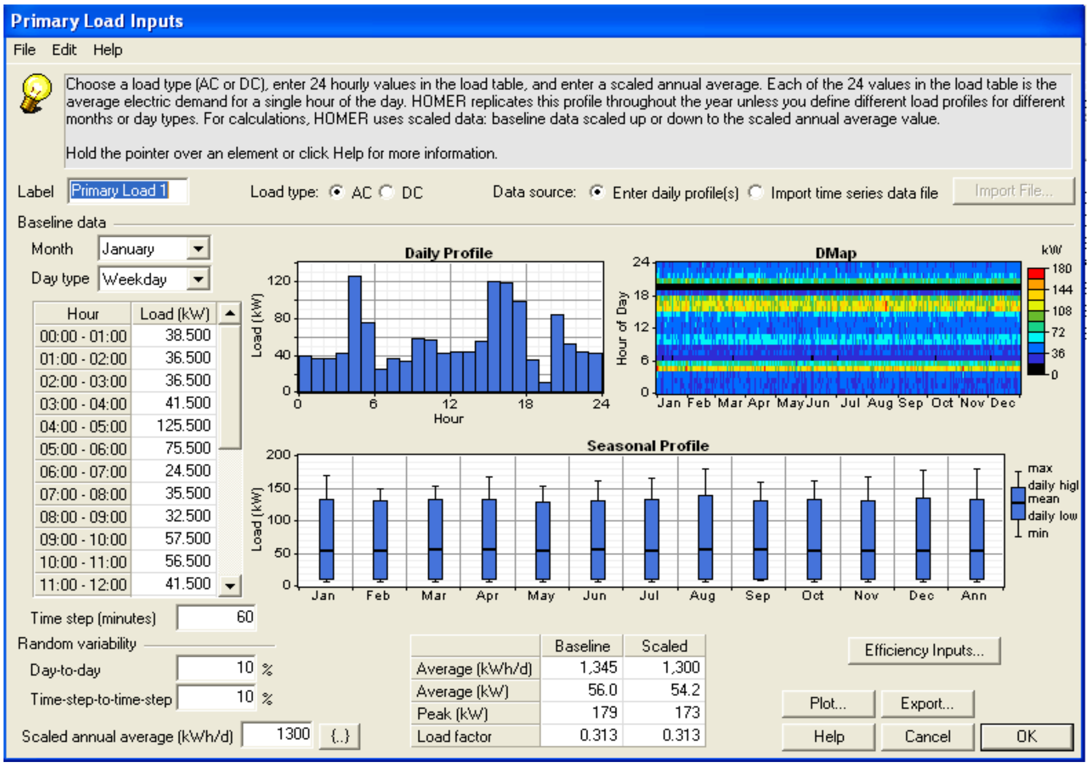

Figure 6.2: Electrical load profile without ice plants

6.3 SOLAR PV GENERATOR DATA

The Solar PV panels considered in this study are Astronergy 255 Silver Poly CHSM 6610P [30]**.** The cost parameters are shown in Table 6.1. The lifetime of the PV panels are defined as 20 years and the de-rating factor is 90% of the electricity produced from each panel. Ground reflectance is considered as 20 %, and the temperature effect is also considered, where, the nominal operating temperature is 35 °C and temperature coefficient is -0.5 %/°C. The sizes considered for the optimization is from 0 kW to 300 kW (Figure 6.3).

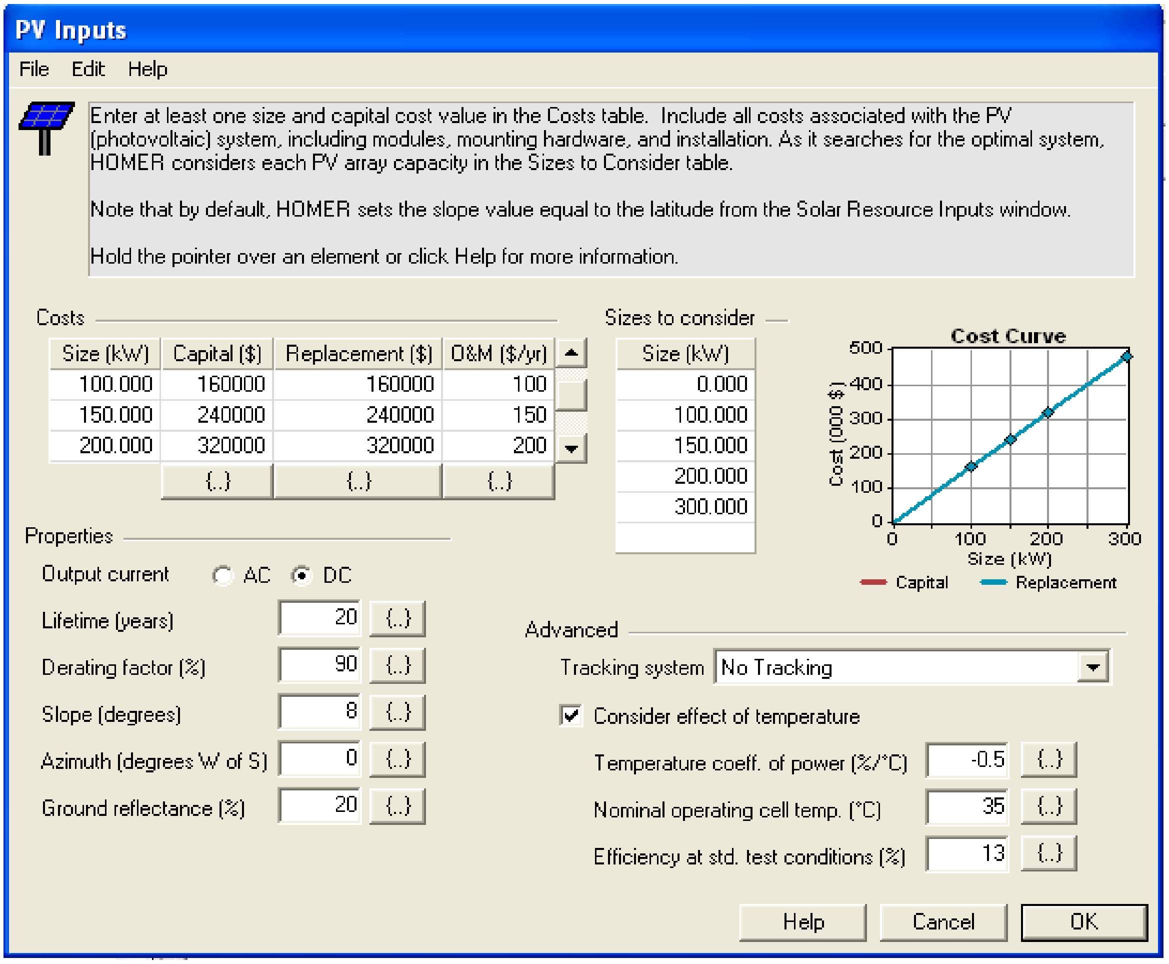

Figure 6.3: Solar PV input data

6.4 BATTERY

Hoppecke 10 OPzS 1000 batteries have been used for making the battery bank. The capacity of this battery is 2 V and 1000 Ah. 12 batteries per string have been considered to develop a 24V bus. The lifetime is considered as 5 years for each battery, but may vary based on the number of charging cycles. Initial cost and replacement cost are similar for a single battery, which is assumed as $ 500 and O & M cost of 10 $/year/pc is considered. The roundtrip efficiency is 80% and the state of charge (SOC) is defined as 40 % to 100 % in the simulation. The number of batteries is considered from 0 to 144 (see Figure 6.4). Minimum state of charge of 40 % is considered in order to avoid damaging the battery bank by excessive discharge.

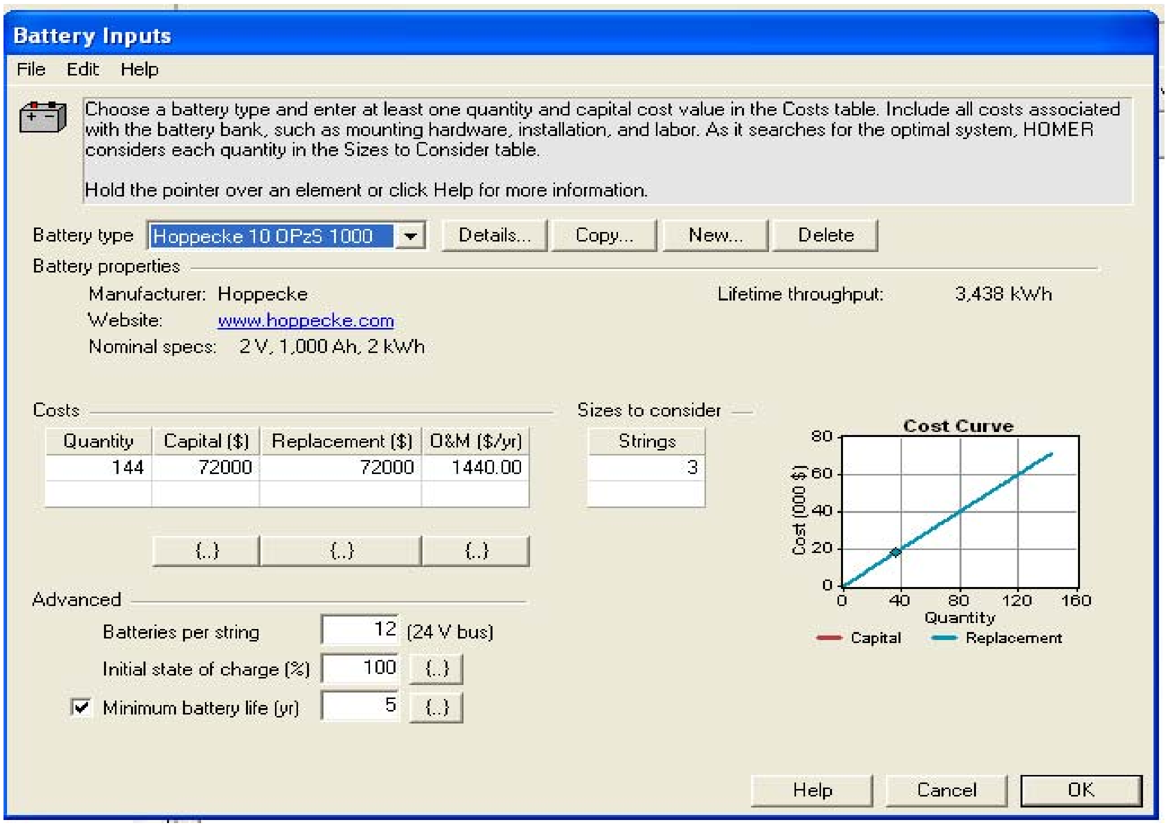

Figure 6.4: Battery input data

6.5 DIESEL GENERATOR DATA

Two diesel generators are used in the study as base load servers. The initial capital, replacement cost and O & M cost is given in the Table 4.2. The generator operating lifetime is defined around 15000 hours and the minimum load ratio is 30 %. To consider the fuel efficiency, HOMER fuel curve parameters are used. The data is extracted from the manufacturer datasheets. The diesel generator sizes are considered from 0 kW to 300 kW (see Figure 6.5).

6.6 WIND TURBINE DATA

The wind turbine used in this analysis is the VAVIN 100 kW DC wind turbine by Norvento nED factory. Table 4.2 shows the cost data and the wind speed versus power characteristics curve taken from the datasheet is incorporated in the HOMER simulator. The turbine hub height is considered as 25 m. For simulation, 8 wind turbines are considered for each of 100 kW maximum capacities. The lifetime of each turbine is considered 25 years (see Figure 6.6).

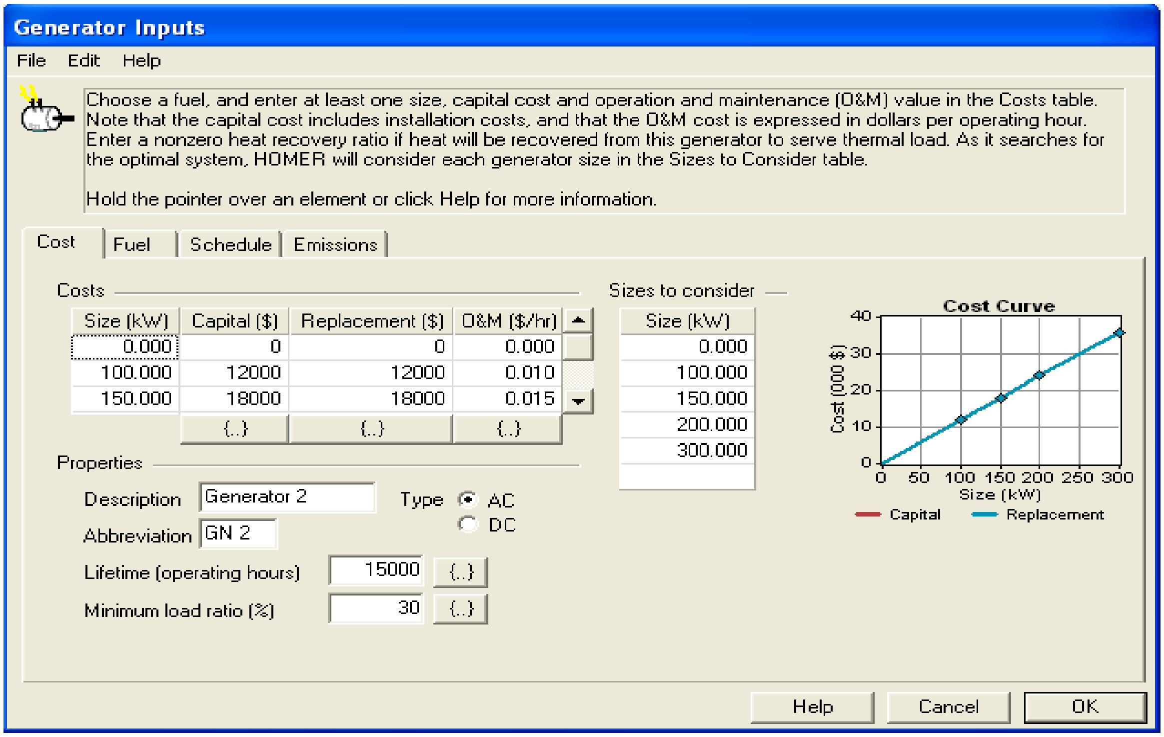

Figure 6.5: Diesel generator input data

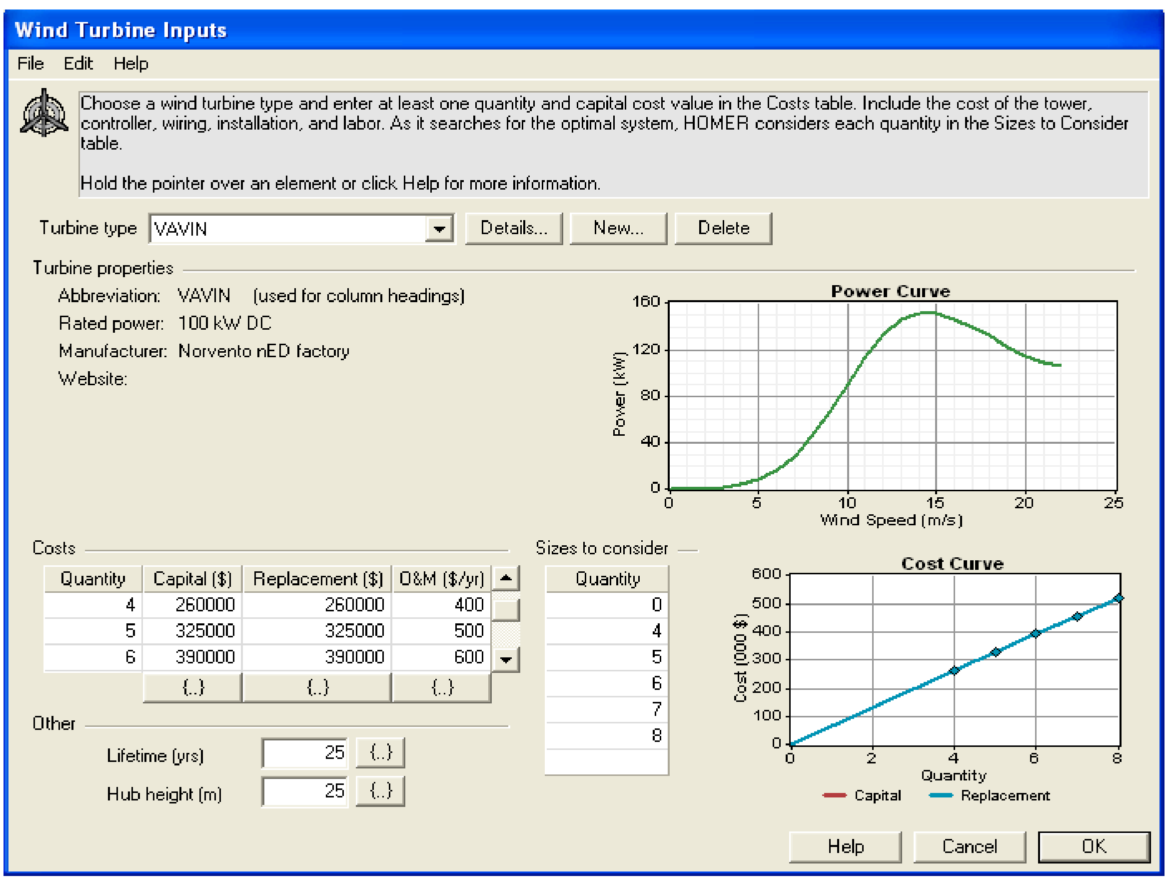

Figure 6.6: Wind turbine input data

6.7 CONVERTER

For generating sufficient power, conversion converters are necessary and LEONICS converters are used in the HOMER software. The conversion efficiency of both inverter and rectifier are considered as 90% and the lifetime of converter is 15 years. The sizing of converter is considered from 0 kW to 300 kW, while the relative conversion ratio of AC and DC is considered 100% (see Figure 6.7). The other relevant HOMER input data for the system component is given in Table 5.2 in Section 5.4.

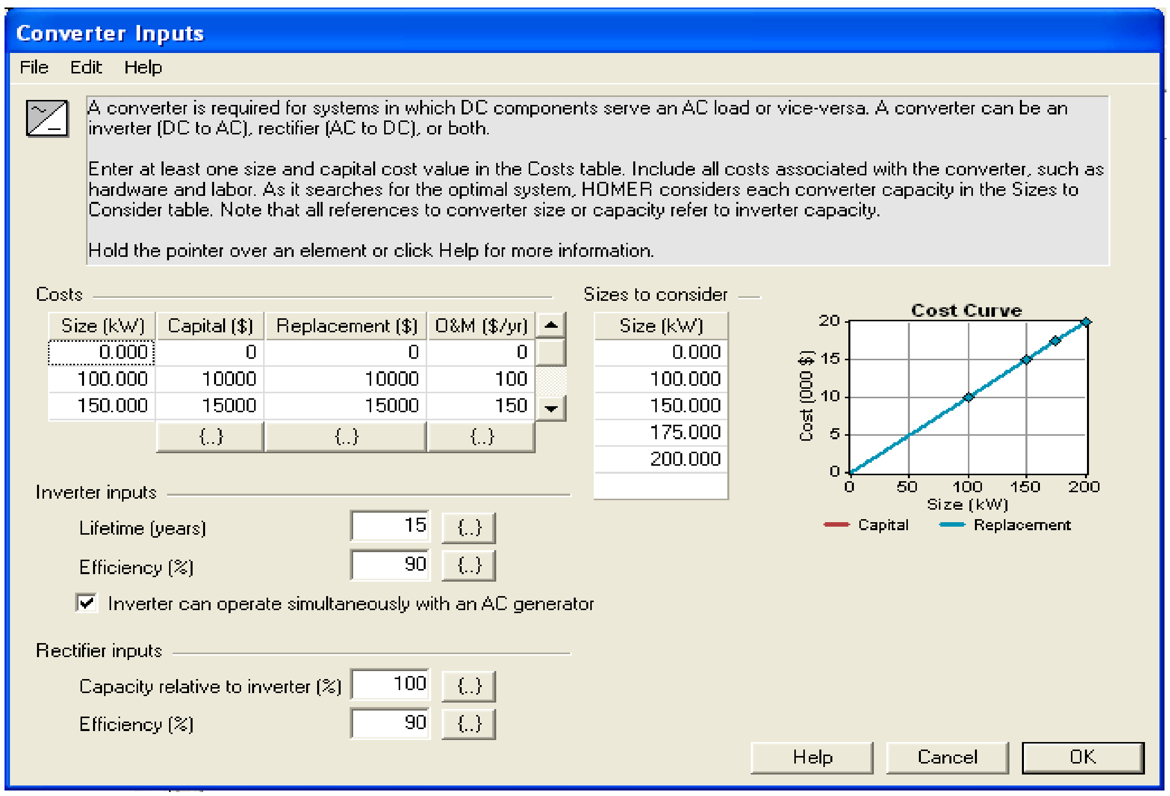

Figure 6.7: Converter input data

Table 6.1 – Input data on component cost

Component	Capital Cost ($)	Replacement Cost ($)	O & M cost ($)
PV	1600 $/KW	1600 $/KW	1 $/yr/KW
Battery	500 $/pc	500$/pc	10 $/PC/yr
Diesel Generators	120$/KW	120 $/KW	0.005 $/hr/50KW
Wind turbine	650 $/KW	650 $/KW	1 $/yr/KW
Converter	100 $/KW	100 $/KW	1 $/yr/KW

CHAPTER 7: RESULTS AND DISCUSSION

7.1 OVERVIEW

The input data of each component and variables defined for controlling and optimizing the system enable HOMER to come up with the most economical and efficient system. The optimization is performed considering flexibility in source selection. The optimal configurations are found after performing several simulations considering 5.04 kWh/m^2/day of solar radiation with 0.509 of clearness index, 6.88 m/s of annual scaled average wind speed and 0.9 $/L of diesel price. Also the simulation was carried out in two steps such as for the total load with and without ice plants taking in to consideration that introduction of ice plants to the island would be in the second stage of providing electricity. HOMER suggests many systems with different configurations, considering initial capital, operating cost, total net percent cost (TNPC) and COE etc.

7.2 RESULTS FOR LOAD PROFILE WITHOUT ICE PLANTS

Technology options ranked based on the NPC for the Category-1 (without introducing ice plants) is presented in Figure 7.1.

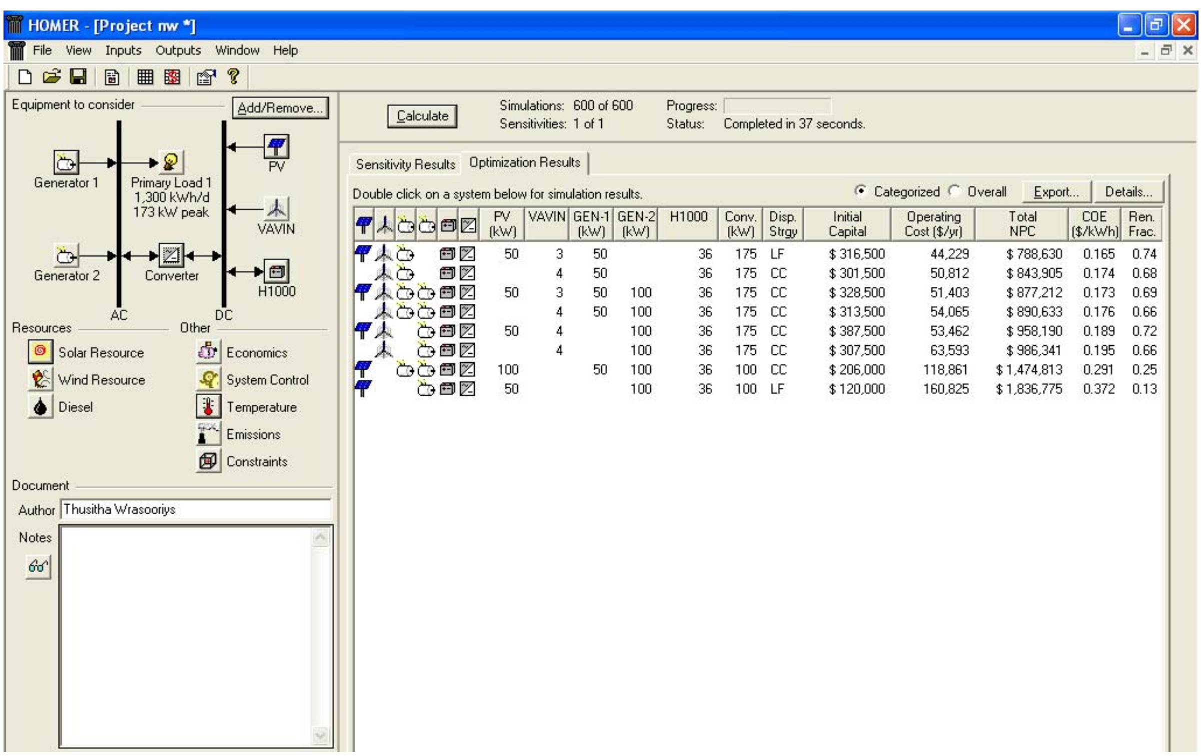

Figure 7.1: Simulation results for the load profile without considering ice plants

The Table 7.1 clearly depicts the details of the optimum configuration obtained and the energy production by component for the best option configuration is shown in Figure 7.2.

Table 7.1: Details of the optimum result for simulation without ice plants

Description	Value
Solar PV	50 kW
WTGs	300 kW
DG set	50 kW
Converter	175 kW
Battery (2 V/1000 Ah)	36 Nos.
Initial capital ($)	316,500.00
TNPC ($)	788,630.00
Operating cost ($/year)	44,229.00
COE ($/kWh)	0.165
Renewable fraction (%)	74
Excess electricity (%)	61.6
Unmet electric load (%)	5.8
Capacity shortage (%)	8.8

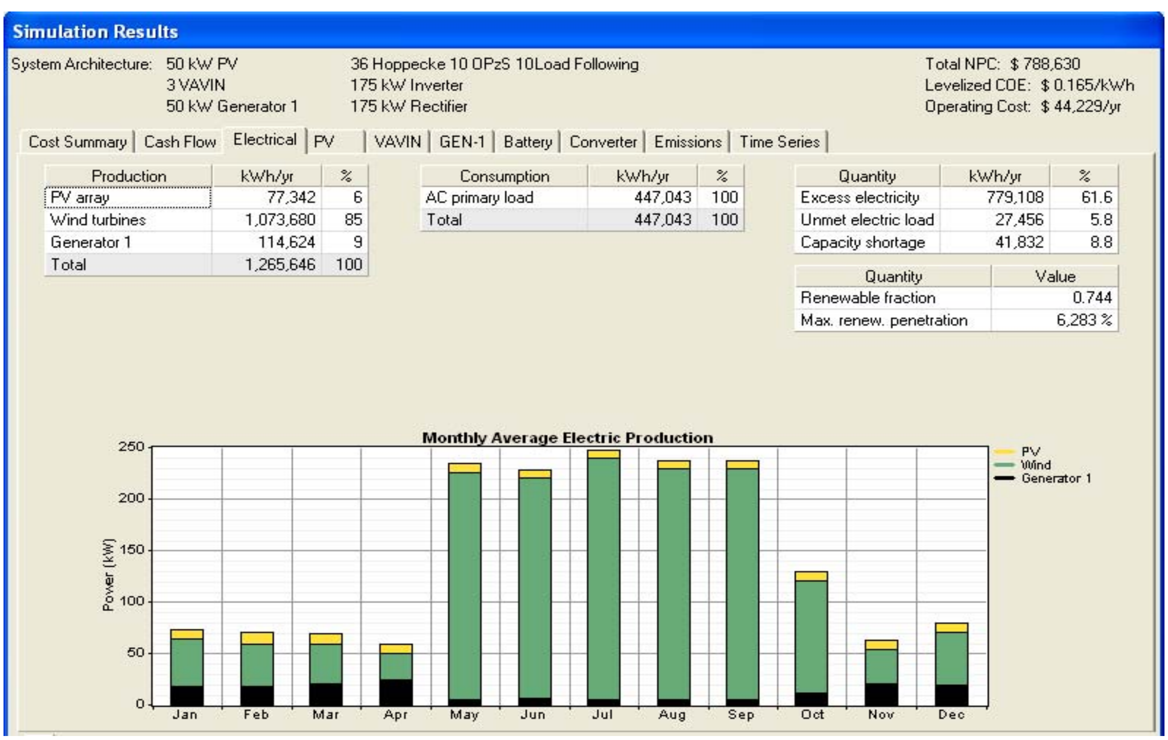

Figure 7.2: Energy production by component for the load profile without ice plants

Further, the NPC by cost type is indicated in Figure 7.3 and same depicts that the TNPC is $788,630.00 and the operating cost is $ 44,229.00/year. Here excess electricity has generated and that is when the system produces more energy than the system can use. It may be when the power generation exceeds the demand or when batteries cannot absorb surplus. Also it may be due to insufficient AC/DC conversion capability. However this could be further studied and take remedial actions. Further, it shows both ‘unmet electric load’ and ‘capacity shortage’ values as 5.8%. Both are almost same, meaning electrical demand that goes un-served because electrical production falls short of demand. The difference is that the capacity shortage comprises both unmet load and unmet operating reserve. Also the renewable fraction is lower than the energy generation from renewable sources because of the excess electricity generation.

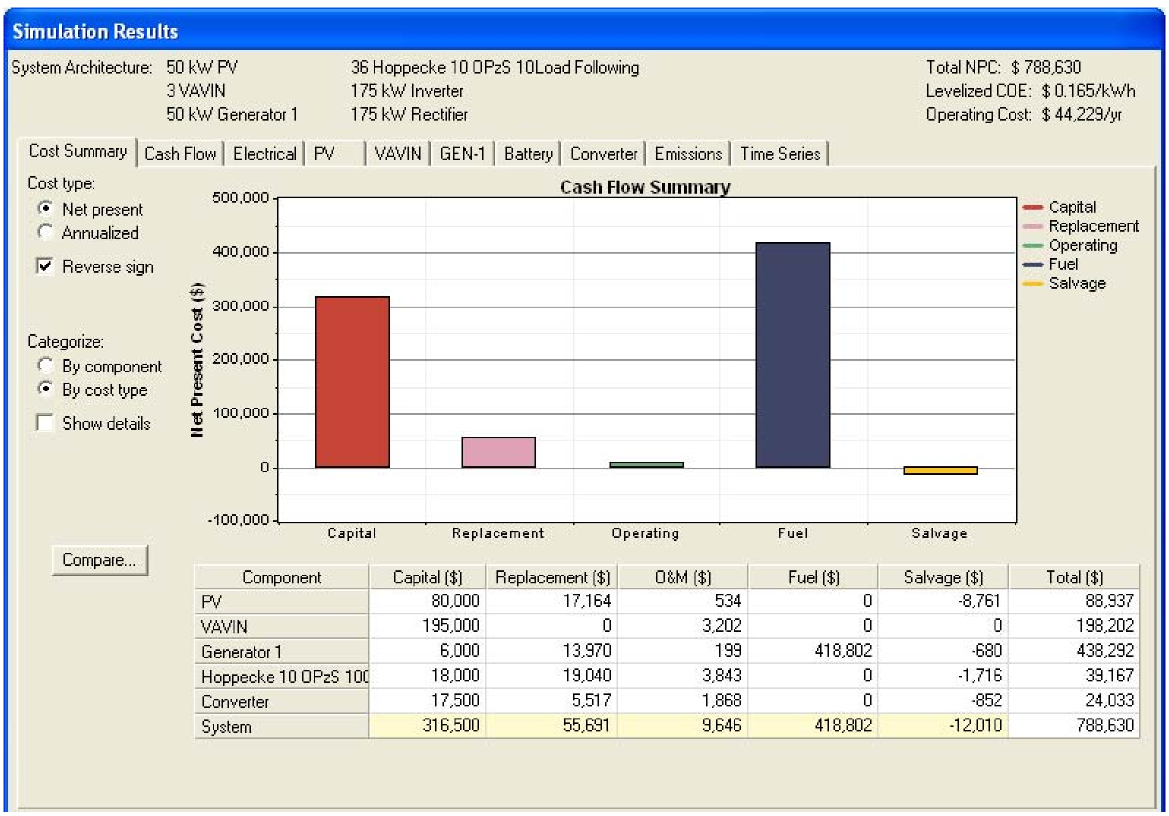

Figure 7.3: NPC by cost type for the load profile without ice plants

The Table 7.2 depicts the total cost involvement for the project of supplying electricity to Battalangunduwa island without considering ice plants.

Table 7.2: Cost involvement for the project without ice plants

Sr. No.	Description	Capacity	Cost (US$)
1	WTG	300 kW	195,000.00
2	Solar PV	50 kW	80,000.00
3	DG set (Large)	--	--
4	DG Set (Small)	50 kW	6,000.00
5	Hybrid Controller	175 kW	17,500.00
6	Battery	36 Nos	18,000.00
7	Fixed O & M cost (per year)	--	9,646.00
8	Fuel Cost	--	418,802.00
9	**Total cost ($)**	**744,948.00**	

7.3 RESULTS FOR LOAD PROFILE WITH ICE PLANTS

Technology options ranked based on the NPC for the Category-2 (with introducing ice plants) is presented in Figure 7.4 and the Table 7.3 depicts the details of the optimum configuration obtained by simulation.

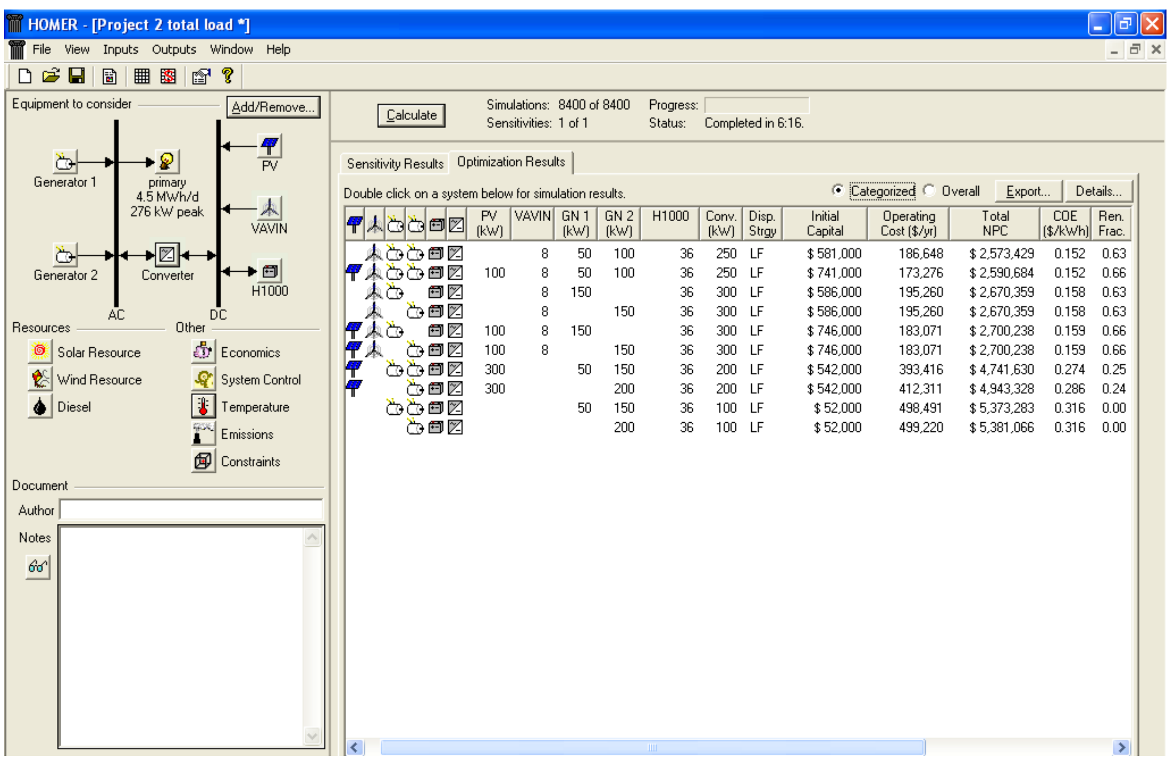

Figure 7.4: Simulation results for the load profile with considering ice plants

Table 7.3: Details of the optimum result for simulation with ice plants

Description	Value
Solar PV	--
WTGs	800 kW
DG set (small)	50 kW
DG set (large)	100 kW
Converter	250 Kw
Battery (2V/1000Ah)	36 Nos.
Initial capital ($)	581,000.00
TNPC ($)	2,573,429.00
Operating cost ($/year)	186,648.00
COE ($/kWh)	0.152
Renewable fraction (%)	63
Excess electricity (%)	50.7
Unmet electric load (%)	3.7
Capacity shortage (%)	3.7

The energy production by component for the best option configuration is shown in Figure 7.5.

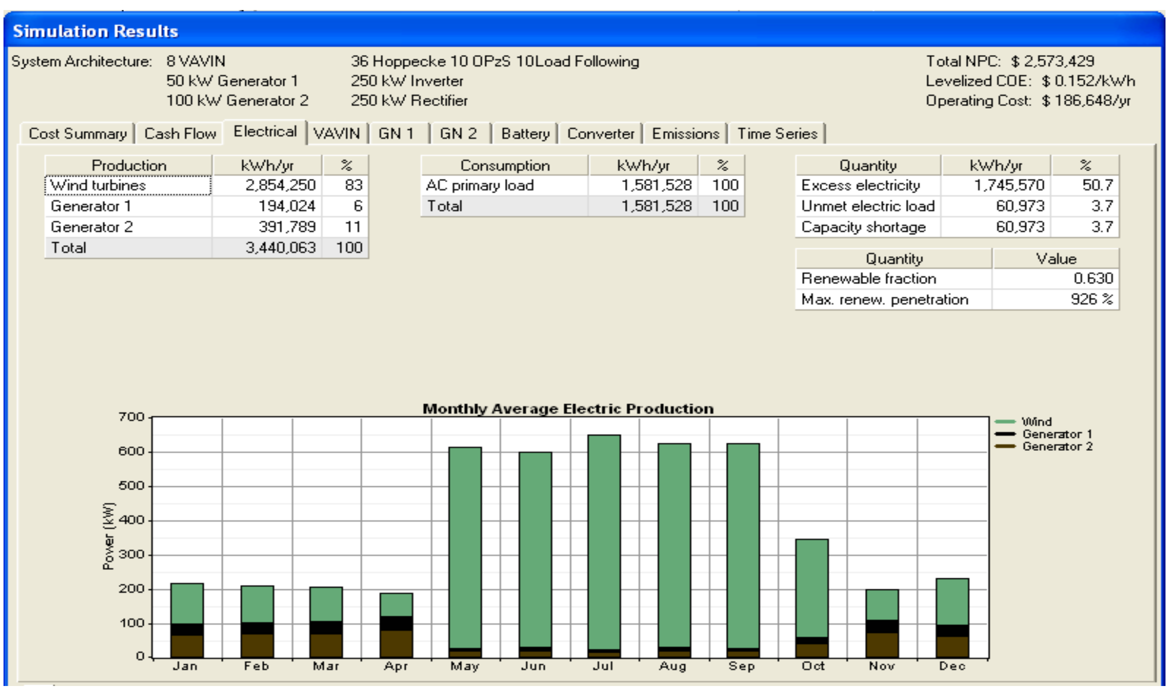

Figure 7.5: Energy production by component for the load profile with ice plants

Further, the NPC by cost type is indicated in Figure 7.6 and same depicts that the total NPC is $ 2,841,873 and the operating cost is $ 168,235/year. Also the Table 7.2 depicts the total cost involvement for the project of supplying electricity to Battalangunduwa island with considering ice plants.

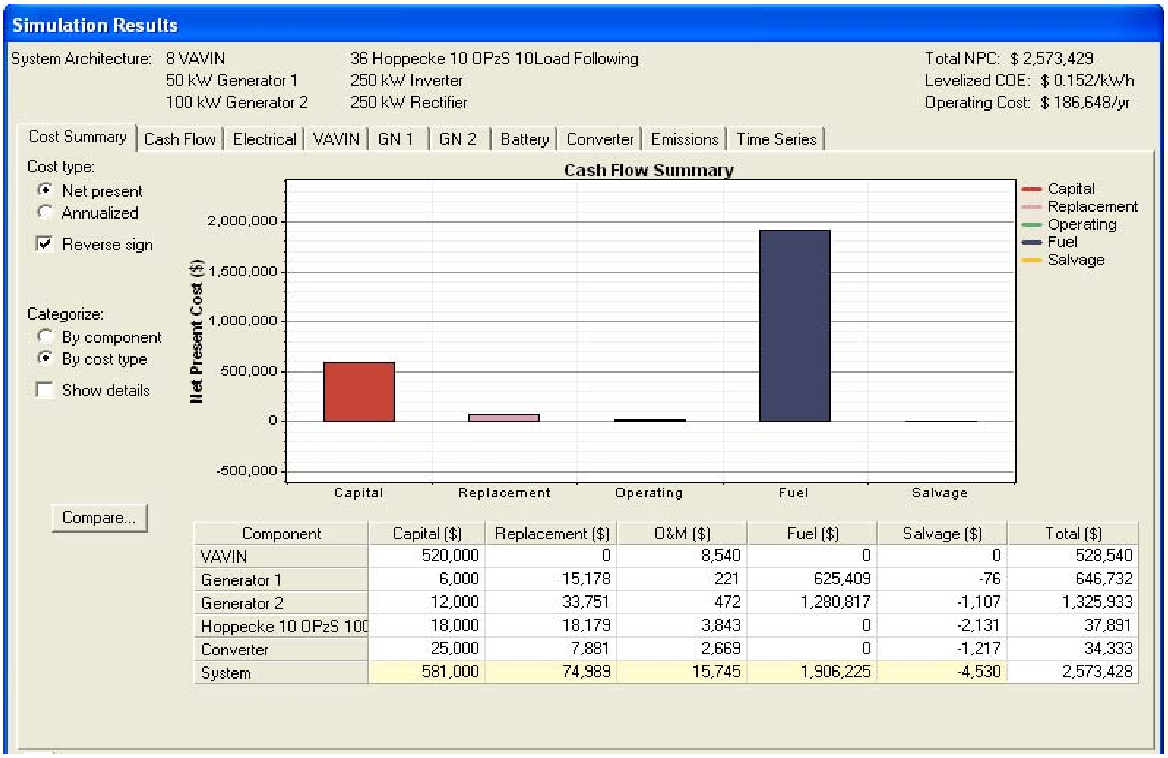

Figure 7.6: NPC by cost type for the load profile with ice plants

Table 7.4: Cost involvement for the project with ice plants

Sr. No.	Description	Capacity	Cost (US$)
1	WTG	800 kW	520,000.00
2	Solar PV	----	----
3	DG set (Large)	100 kW	12,000.00
4	DG Set (Small)	50 kW	6,000.00
5	Hybrid Controller	250 kW	25,000.00
6	Battery	36 Nos	18,000.00
7	Fixed O & M cost (per year)	--	15,645.00
8	Fuel Cost	--	1,906,225.00
Total cost ($)			**2,502,870.00**

There is a strong reason for categorizing the island demand profile in to two and thereby analyzing into two separate categories. The first priority is to implement the project of supplying the island's domestic demand (without ice plants) and same is in line with the government's 100%

electrification target. This will improve the socio economic development in the island society up to a certain extent. Further the next identified problem such as ice demand to be met by some means for the full scale development of the island society. This needs additional investment on these areas and same will emerge slowly depending on the availability of capital for the investment in these areas or depending on the government's support to provide above facilities. Hence it is strongly suggested to implement the system proposed for the category-1(without ice plants) as the stage-1 of the project and by monitoring the performance of the development in the island; the system proposed in category-2 (with ice plants) could be expanded as the stage-2 of the project. Hence power system infrastructure proposed for the stage-1 to be designed in such a way to accommodate the future expansions as well.

7.4 SPECIAL CONSIDERATION

As seen in Figure 7.4, the best option for the load profile with ice plants does not include solar PV. However, the best option for the load profile without ice plants includes 50 kW solar PV as seen in Figure 7.1. Hence it is essential to consider same if the stage II is going to be entertained and opt for the second best option of the Figure 7.4. A comparison between the best and the second best options are shown in Table 7.4 and same depicts COE for both options are equal.

Table 7.5: Comparison between the best and second best options for the stage II

Description	Best option	Second best option
Configuration	08 Nos Wind turbines, 50 kW and 100 kW diesel generators	100 kW solar PV, 08 Nos wind turbines, 50 kW and 100 kW diesel generators
Initial capital	$ 581,000.00	$ 741,000.00
Operating cost	$ 186,648.00	$ 173,276.00
Cost of Energy (COE)	$ 0.152	$ 0.152
Renewable fraction	63%	66%
Total NPC	$ 2,573,429.00	$ 2,590,684.00

7.5 RESULTS FOR SIMULATION ONLY WITH RENEWABLE ENERGY SOURCES

The previous results illustrate that the best options include major fractions of RESs, and therefore it is interesting to explore the option of 100 % RES scenario for the system. If feasible, such system would be an ideal case as a pilot project to demonstrate the concept of 100 % RESs. The optimum technology option derived through the simulation for the Category-1 (without introducing ice plants) is presented in Figure 7.7 and the details of the configuration are indicated in Table 7.5.

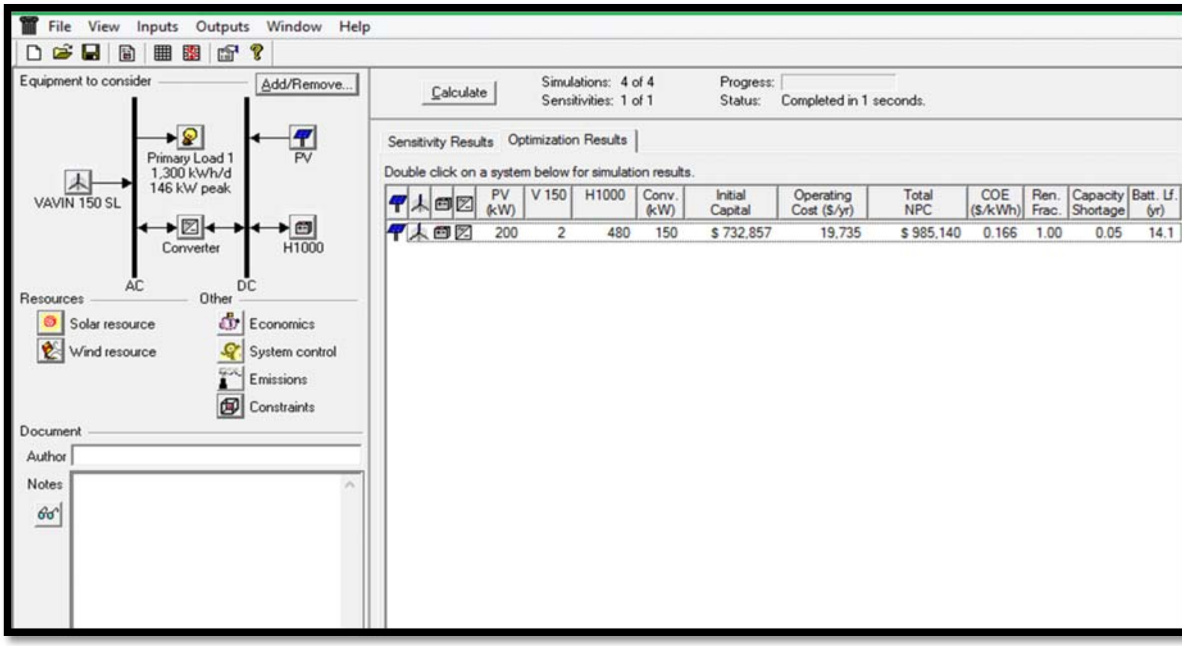

Figure 7.7: Simulation results for the load profile without ice plants (only with RES)

Further, the NPC by cost type is indicated in Figure 7.8 and same depicts that the TNPC is $ 985,140 and the operating cost is $ 19,735/year.

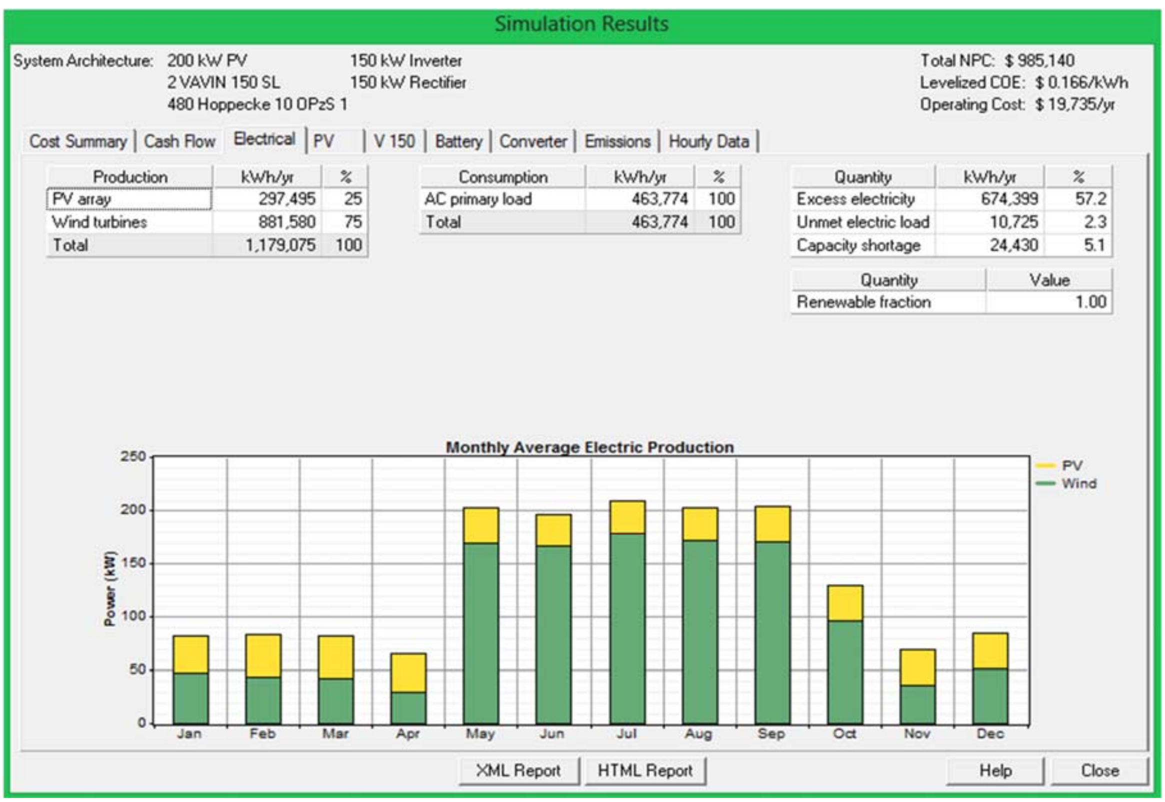

Figure 7.8:Monthly average electricity production for the load profile without ice plants (only with RESs)

Table 7.6: Details of the result for simulation without ice plants (RESs only)

Description	Value
Solar PV	200 kW
WTGs	200 kW
Converter	150 kW
Battery (2V/1000Ah)	480 Nos.
Initial capital ($)	732,857.00
TNPC ($)	985,140.00
Operating cost ($/year)	19,735.00
COE ($/kWh)	0.166
Renewable fraction (%)	100
Excess electricity (%)	57.2
Unmet electric load (%)	2.3
Capacity shortage (%)	5.1

Further, Technology option for the Category-2 (with introducing ice plants) is presented in Figure 7.9 and the details of the configuration is presented in Table 7.7.

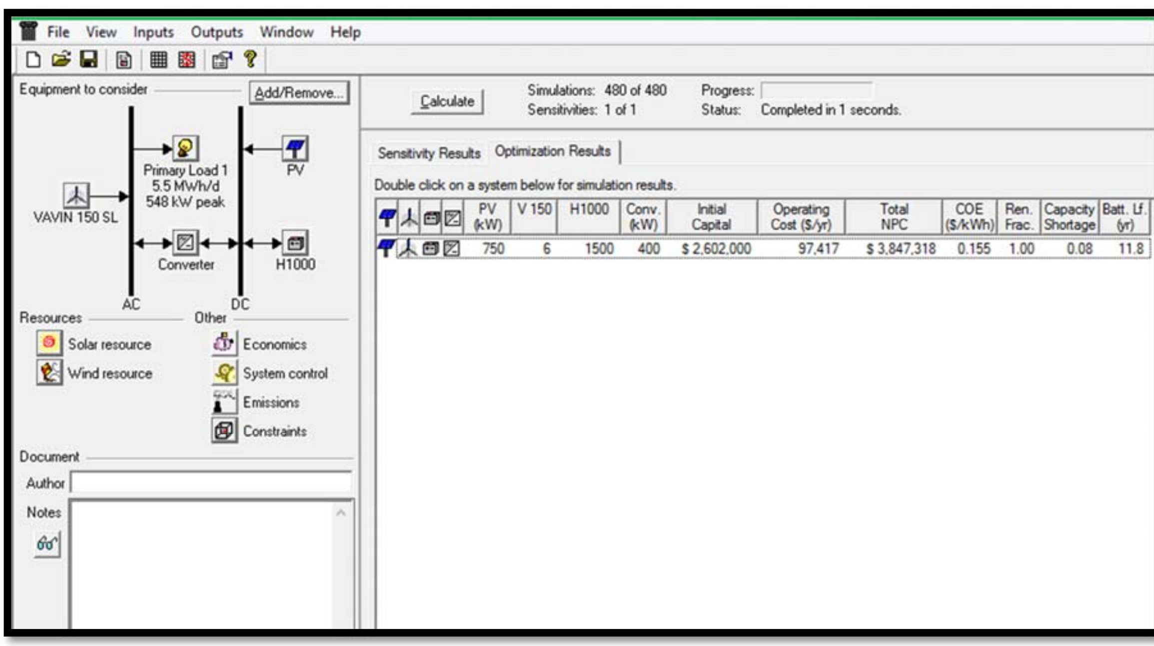

Figure 7.9: Simulation results for the load profile with ice plants (only with RESs)

Table 7.7: Details of the result for simulation with ice plants (RESs only)

Description	Value
Solar PV	750 kW
WTGs	600 kW
Converter	400 kW
Battery (2V/1000Ah)	1500 Nos.
Initial capital ($)	2,602,000.00
TNPC ($)	3,847,318.00
Operating cost ($/year)	97,417.00
COE ($/kWh)	0.155
Renewable fraction (%)	100
Excess electricity (%)	53.2
Unmet electric load (%)	3.5
Capacity shortage (%)	7.6

Further, the NPC by cost type is indicated in Figure 7.10 and same depicts that the TNPC is $ 3,847,318 and the operating cost is $ 97,417/year.

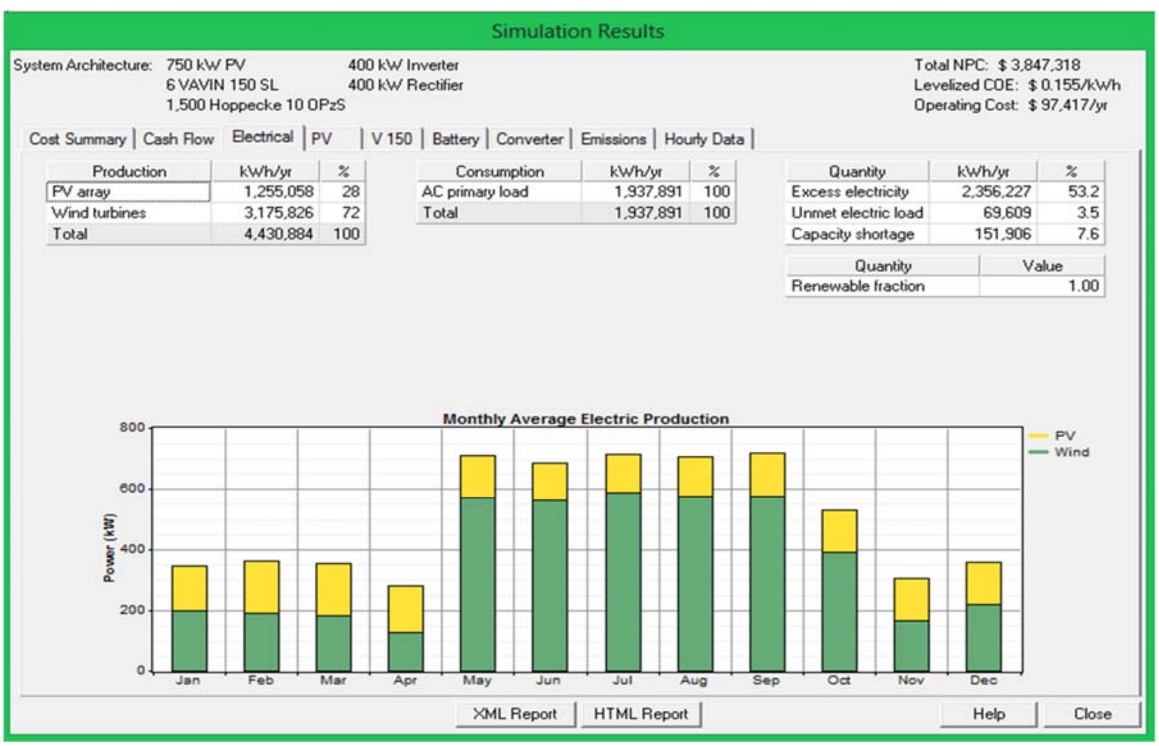

Figure 7.10: Monthly average electricity production for the load profile without ice plants (only with RES)

7.6 COMPARISON OF RESULTS FOR ALL TYPES OF SIMULATIONS

A cost comparison among all the simulations carried out (i.e. considering with and without ice plants for the configurations of RESs in combination with DG sets as well as only with RESs) is presented in Table 7.4 and comparison of installation capacity is shown in Table 7.5.

Table 7.8: Comparison of cost involvement among all the simulation results

Description	With Ice plants		Without Ice plants	
	RESs + DG	**Only RESs**	**RESs + DG**	**Only RESs**
Initial capital ($)	581,000.00	2,602,000.00	316,500.00	732,857.00
TNPC ($)	2,573,429.00	3,847,318.00	788,630.00	985,140.00
COE ($/kWh)	0.152	0.155	0.165	0.166
Renewable Fraction (%)	63	100	74	100
O & M cost ($/Yr)	186,648.00	97,417.00	44,229.00	19,735.00
Unmet electricity load (%)	3.7	3.5	5.8	2.3
Capacity shortage (%)	3.7	7.6	8.8	5.1
Excess electricity (%)	50.7	53.2	61.6	57.2

Table 7.9: Comparison of installation capacity among all simulation results

Description	With ice plants		Without ice plants	
	RESs+DG	**Only RESs**	**RESs+DG**	**Only RESs**
Wind (kW)	800	600	300	200
Solar (kW)	--	750	50	200
DG (kW)	150	--	50	--
Total capacity (kW)	**950**	**1350**	**400**	**400**
Converter (kW)	250	400	175	150
Battery (2V/1000Ah) (Nos.)	36	1500	36	480

7.7 PROJECT IMPLEMENTATION

The result from the HOMER software analysis reveals that the details of required equipment, their sizes and their operating characteristics. Technical design of the power plant should be carried out in order to identify exact issues relating to actual implementation of the power project. The schematic diagram shown in Figure 7.11 illustrates the configurations and the power flows between the components of the power plant.

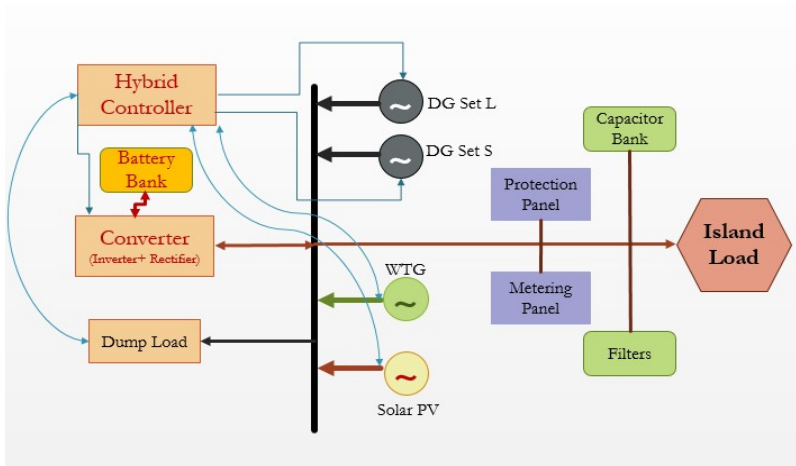

Figure 7.11: Power plant configuration

As indicated in the Figure 7.11, two DG sets, solar PV and a WTG will be connected to the AC bus bar and will be directly pumping power to the consumers. Batteries are connected to the DC bus which coupled to the AC bus through a converter. Dump load is connected to AC bus to dissipate the excess energy (if necessary, after fully charged the batteries) to maintain the system stability. Hybrid controller performs the controlling task of the whole system and keeps the whole power system stable under varying generating and load conditions.

The main function of the hybrid controller is to manage and control the power system in an optimal manner. It will control of DG sets, solar PV, wind turbine, converter, charge controller and the dump load. During the windy season or sunny season the hybrid controller makes maximum use of wind to supply the village load and to charge the batteries. Further when wind turbine /solar PV output higher than the actual demand, it will switch on the dump load to dissipate the excess energy. Therefore, the hybrid controller effectively maintains the demand - supply balance of the power system in the most economic manner. Proposed two DG sets could operate either individually or in synchronism (depending on the necessity) to meet the island load. They also charge the batteries during low wind / low sun shine periods to maintain the batteries charged at the desired level. DG sets also perform the critical task of maintaining the frequency and the voltage of the power system. DG sets' efficiencies are higher when they are operating more than 70% of the prime rating. Therefore, instead of having a single DG set, two DG sets of different capacities are more economical. During low load periods, the smaller DG set is operated and during high load periods, either the larger DG set or both together are used. WTGs are used to harness the abundant wind resource available in the island. The operational cost of WTGs is negligible but the capital cost is quite substantial making it uneconomical to use lot of WTGs. The cost of large WTG (per kW cost) is lower than small WTG. However the wind potential at the present site is very high. Taking into the consideration of all factors, it is proposed to use 3 nos. of WTGs of 100 kW capacity at the stage-1 of the project. Also it is proposed to install locally assembled VAVIN WTGs considering cost effectiveness as well as giving priority to local suppliers. Solar PV is used to harness the abundant solar resource available in the island. The operational cost of solar PV is negligible but the capital cost is quite substantial. The price of the solar PV is getting down in the international market. Taking into the consideration of all factors, it is proposed to use 50 kW Solar PV at the stage-1 of the project. Battery bank is used to store the excess energy generated by the WTGs, solar PV and the DG sets. Excess energy will be stored in the batteries and is available when required. The efficient use of batteries is facilitated by providing the hybrid controller along with the control of battery charger. The converter includes a rectifier and an inverter which enable energy to flow from AC bus to DC bus and vice versa. It is recommended to use static converter where semiconductor diodes and thyristors perform the relevant conversions with minimum amount of energy losses. In addition to the above components, a capacitor bank and harmonic filters are also included in the design to mitigate the impact of harmonics that might be created by the large number of intended to be used in the system (as an efficiency measure for island lighting). A capacitor bank is incorporated to the system to maintain the system power factor at a satisfactory level.

7.8 POWER PLANT LOCATION

There are many factors to be considered to find the best location to construct the power plant such as, availability of land to locate the power plant (including solar PV) and the WTGs, predominant wind direction, shading effects of the solar PV, transportation and logistics issues for the equipment specially WTGs and DG sets, distance to main land, operational logistics, transporting diesel to the power plant etc. By considering all these factors, it is recommended to select a location close to the northern part of the island to install the power plant in the case of the best option having WTGs and DG sets. The recommended location and the arrangements are shown in the Figure 7.12. WTGs are sited in such a way so that they would face the predominant wind directions of both South-West as well as North-East winds during the monsoons without any obstructions. The selected land location is in close proximity to the highly populated island houses such that the distribution line losses could be reduced to a reasonable extent.

Figure 7.12: Power plant location

CHAPTER 8: CONCLUSIONS AND RECOMMENDATIONS

8.1 CONCLUSIONS

The study of power generation by a hybrid energy system for the isolated island, Battalangunduwa in the North-Western area of Sri Lanka performed in two different options; namely (i) at its first phase supplying power without considering the ice plants and (ii) the second stage is to supply the total load including the demand for ice plants to cater their demand for main livelihood of fishing clearly indicates the viability of the concept. The results from the software 'HOMER' illustrate the most economic configuration to supply the energy demand and demonstrate the capability of the tool for the modelling, simulation and optimization of hybrid energy systems.

The most economic/optimum system for the option one of supplying basic electricity needs (without ice plants) is 50 kW solar PV, 03 numbers of 100 kW WTGs, 50 kW diesel generator with batteries and other control equipment. The COE for this optimum hybrid power system is US$ 0.165/kWh with the renewable energy fraction of 74%. The most economic configuration for supplying electricity demand with ice plants is 08 numbers of 100 kW WTGs, 02 numbers of 50 kW and 100 kW diesel generators with batteries and other control equipment. The COE for the optimum hybrid power system is US$ 0.152/kWh with the renewable energy fraction of 63%.

Further when consider the simulation results for supplying energy needs only with RES; the cost of energy is only marginally higher than the same with the inclusion of DG sets. The only difference in this simulation is the exorbitant capital cost as well as NPC. Also the simulations considering only-RESs for both with and without ice plants provide better scenario for the study as same could demonstrate the concept of 100 % RESs for a hybrid mini-grid system especially because the same could be used to promote eco-tourism in the island as it is a 100 % green energy consuming island.

Besides the provision of electricity supply to the island population, the above project has the potential to serve the wider objective of demonstrating the feasibility of solar-wind-battery-storage systems to meet the electricity needs of people in remote regions in Sri Lanka and elsewhere in the developing world. Hence the project could, thus, be a lesson learning experience as well. In order to meet this objective, significant volume of additional activities concerning monitoring & evaluation, documentation and dissemination of project experience will have to be incorporated in the project design. As these activities will have to be undertaken in the post-electrification phase, the project life will have to be extended by about 2-3 years after commissioning the power plant. These downstream activities would entail additional costs on necessary equipment, staff, logistics, reporting, publications, seminars, etc. The key outputs of the project, if it is re-oriented to meet the wider objective, are; analysis of technical performance of the wind battery- storage hybrid system, assessment of post-electrification socio-economic changes in the community, validation of performance indicators of the plant as foreseen in the design and optimization stage, documentation on lessons learnt and wider dissemination of project experience through media, education institutions, workshops, seminars, etc. Also this hybrid energy system for Battalangunduwa island helps to realize the government's vision of 100 % energy self sufficiency by the year 2030.

8.2 RECOMMENDATIONS

Implementation of hybrid energy system to cater for the energy requirement in the Battalangunduwa island in two stages as Stage 1: 50 kW of solar PV, 300 kW of WTGs and 50 kW of Diesel Gen together with 72 kWh of battery storage for the load without ice plants and Stage 2: 800 kW of WTGs and 50 kW & 100 kW of Diesel Gen-sets together with 72 kWh of battery storage for the load with ice plants is recommended. Also if the financial constraints are minimal, it is recommended to proceed with the RESs-only results which in turn will provide many other advantages as well. Further, the sensitivity analysis has proved that the system can also handle the increase in load in the near future and also the effect of change in interest rate on the system, which is; in most cases the optimum system is sustainable.

However, further studies on social and environmental issues as well as construction feasibility/limitations of the site are to be carried out whilst seeking approvals from relevant authorities prior implementation of the project.

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ANNEX - 1

Hourly load calculation for off- season

Hourly Load Calculations for off season

			Hour of the Day																								
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Hours/day	Wh/day
Pre School																												
Number of Schools		**1**																										
User Controlled Loads	**Rated Power(W)**	**Number of Units**																										
LED bulb	15	5						0.50	1.00	0.50																	2	150.0
Fan	40	3							1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00											8	960.0
Computer	120	1							0.50	0.50	0.50	0.50	5.00	0.50	0.50	0.50											8.5	1020.0
Table fan	25	2							1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00											8	400.0
Communications	5	1							1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00				1.00	1.00	1.00	1.00	1.00	1.00	1.00	15	75.0
Medical centre																											**Daily Load (Wh/day)**	**2605.0**
Number of MOH/Medical centre building		**1**																										
User Controlled Loads	**Rated Power(W)**	**Number of Units**																										
Fluorescent bulb	40	2	0.25	0.25	0.25	0.50	0.50	1.00	1.00	0.25										0.50	0.50	0.50	0.50	0.50	0.50	0.50	7.5	600.0
LED bulb	15	4	0.25	0.25	0.25	0.25	0.50	0.50	0.25		0.25	0.25								0.25	0.50	0.50	0.50	0.25	0.25	0.25	5.25	315.0
Fan	40	2								0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50				7	560.0
Radio	15	1						0.50	0.50	0.50										0.50	0.50	0.50	0.50				3.5	52.5
Table fn	25	2							0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50								5.5	275.0
TV	100	1						1.00	1.00	0.50	0.50	0.50	0.50	0.50	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00				13.5	1350.0
Communications	5	1						1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00								12	60.0
Air conditioning	1500	1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	24	36000.0
Refrigerator	120	1	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	12	1440.0
																											Daily Load (Wh/day)	**40652.5**
Churches																												
Number of Churches		**3**																										
User Controlled Loads	**Rated Power(W)**	**Number of Units**																										
Fluorescent bulb	40	2	0.25	0.25	0.25	0.25	0.25	0.50	0.25									0.50	1.00	0.50	0.25	0.25	0.25	0.25	0.25	0.25	5.5	1320.0
LED bulb	20	5					0.25	0.50	0.25										1.00	1.00	0.50	0.25	0.25				4	1200.0
Fan	100	1						1.00	1.00	1.00			1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00					13	3900.0
Communications	5	1						1.00	1.00	1.00									1.00	1.00	1.00						6	90.0
																											Daily Load (Wh/day)	**6510.0**
Street lighting & Deferrable loads																												
User Controlled Loads	**Rated Power(W)**	**Number of Units**																										
Street lights (CFL bulb)	15	50	1.00	1.00	1.00	1.00	1.00	0.50												0.50	1.00	1.00	1.00	1.00	1.00	1.00	12	9000.0
Ice plants	187500	1	1.00	1.00	1.00	1.00	1.00	0.50	0.50	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.50	0.50	0.50	1.00	1.00	1.00	1.00	21.5	4031250.0
Water desalination plant	6000	1	1.00	1.00	1.00	1.00	1.00	0.50	0.50	0.50	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	**0.50**	0.50	**0.50**	1.00	1.00	1.00	1.00	21	126000.0
																											Daily Load (Wh/day)	**4166250.0**
House Type 1 (Medium)																												
Number of houses in the community		**100**																										
User Controlled Loads	**Rated Power**	**Number of Units**																										
Fluorescent bulb	**40**	**2**						0.5	0.25											0.5	1	1	0.5	0.1	0.1		3.95	31600.0
LED bulb	**10**	**4**				0.2	0.25	0.5	0.2											0.5	1	1	0.75	0.25	0.1	0.1	4.85	19400.0
Fan	**40**	**1**	0.5	0.5	0.5	0.5	0.5					0.5	0.5	0.5	0.5	0.5	0.5	0.5			1	1	1	0.5	0.5	0.5	10.5	42000.0
Table fan	**25**	**2**	0.5	0.5	0.5	0.5	0.5					0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	10	50000.0
TV	**70**	**1**						0.5	0.5												1	1	0.5				3.5	24500.0
Radio	**15**	**1**					0.25	0.75	0.75	0.75	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.5	0.75	0.75	0.75	0.5	0.25	0.1	8.35	12525.0
Water heater	**1000**	**1**					0.1	0.1	0.05									0.1	0.1								0.45	45000.0
Iron	**1000**	**1**						0.1	0.1											0.1	0.1						0.4	40000.0
Refrigerator	**120**	**1**	0.2	0.2	0.2	0.2	0.2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.2	0.2	0.2	9.6	115200.0
Communication	**5**	**2**						0.5	0.5													0.5	0.5				2	2000.0
Washing machine	**300**	**1**										0.50	0.50														1	30000.0
																											Daily Load (Wh/day	**412225.0**

House Type 2 (Small)																										
Number of homes in the community		**200**																								
User Controlled Loads	**Rated Power**	**Number of Units**																								
Fluorescent bulb	**40**	**1**						0.5	0.25											0.5	0.8	0.8	0.2	0.1			3.15	25200.0
LED bulb	**10**	**3**				0.5	0.5	0.5												0.5	0.8	0.8	0.75	0.2	0.1	0.1	4.75	28500.0
Fan	**40**	**1**	0.5	0.5	0.5	0.5	0.5					0.2	0.2	0.2	0.25	0.25	0.25	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.35	66800.0
Table fan	**25**	**1**										0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	3	15000.0
TV	**70**	**1**						0.2	0.25	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.25	0.5	0.75	0.5	0.25	0.1	0.1	3.9	54600.0
Radio	**15**	**1**					0.25	0.75	0.75	0.75	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.5	0.2						5.45	16350.0
Water heater	**1000**	**1**					0.1	0.1	0.05									0.1	0.1								0.45	90000.0
Iron	**1000**	**1**							0.1	0.1										0.1	0.1						0.4	80000.0
Communication	**5**	**2**						0.5	0.5													0.5	0.5				2	4000.0
Refrigerator	**120**	**1**	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	12	288000.0
																									Daily Load (Wh/day)	**668450.0**
House Type 3 (Temporary huts)																										
Number of homes in the community		**260**																								
User Controlled Loads	**Rated Power**	**Number of Units**																								
LED bulb	**10**	**3**	0.2	0.2	0.2	0.2	0.5	0.5	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.75	1	1	0.5	0.25	0.2	0.2	6.8	53040.0
Table fan	**25**	**1**	0.2	0.2	0.2	0.2	0.2					0.2	0.2	0.2	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.3	0.4	0.3	0.2	0.2	4.7	30550.0
TV	**70**	**0**						0.2	0.25	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.25	0.5	0.75	0.5	0.25	0.1	0.1	3.9	0.0
Radio	**15**	**1**					0.25	0.75	0.75	0.75	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.5	0.75	0.75	0.75	0.5	0.25	0.1	8.35	32565.0
Communication	**5**	**1**						0.5	0.5													0.5	0.5				2	2600.0
Water heater	**1000**	**1**					0.1	0.1	0.05									0.1	0.1								0.45	117000.0
																									Daily Load (Wh/day)	**235755.0**
Police post																										
Number of police posts		**1**																								
User Controlled Loads	**Rated Power**	**Number of Units**																								
Fluorescent bulb	**40**	**4**	0.25	0.25	0.25	0.5	1	0.25												1	1	0.5	0.5	0.5	0.5	0.5	7	1120.0
LED bulb	**15**	**8**	0.25	0.25	0.25	0.25	0.75	0.75												0.5	0.75	0.75	0.5	0.25	**0.2**	0.2	5.65	678.0
Fan	**40**	**4**	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	12	1920.0
Table fan	**25**	**4**	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	12	1200.0
TV	**70**	**2**					0.5	1	1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.25	0.75	1	1	1	0.5			7.9	1106.0
Radio	**15**	**2**					0.5	0.75	1	0.25	0.25	0.25	0.25	0.25	0.1	0.1	0.1	0.25	0.25	0.25	0.1	0.1	0.1	0.1			4.95	148.5
Water heater	**1000**	**1**				0.25	0.25	0.25				0.25					0.25							0.25			1.5	1500.0
Iron	**1000**	**2**					0.25	0.25	0.25											0.25	0.25						1.25	2500.0
Communication	**5**	**4**	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	**0.5**	0.5	12	240.0
Refrigerator	**120**	**1**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	**1**	1	24	2880.0
																									Daily Load (Wh/day)	**13292.0**
Naval Detachment																										
Number of police posts		**1**																								
User Controlled Loads	**Rated Power**	**Number of Units**																								
Fluorescent bulb	**40**	**4**	0.1	0.1	0.1	0.2	0.25	0.5												0.25	0.75	0.75	0.25	0.1	0.1	0.1	3.55	568.0
LED bulb	**10**	**8**	0.25	0.25	0.25	0.25	0.75	0.25												0.5	0.5	0.5	0.25	0.1	**0.1**	0.1	4.05	324.0
Fan	**40**	**4**	0.25	0.25	0.25	0.25	0.25	0.25	0.5	0.5	0.5	0.5	0.5	0.5	1	1	1	1	1	1	1	1	0.5	0.25	0.25	0.25	13.75	2200.0
Table fan	**25**	**4**	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	12	1200.0
TV	**70**	**2**					0.5	1	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	1	1	1	0.5			12	1680.0
Radio	**15**	**2**	0.5	0.5	0.5	0.5	0.5	1	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	1	1	1	0.5	**0.5**	0.5	15	450.0
Water heater	**1000**	**1**				0.25	0.25	0.25				0.25					0.25							0.25			1.5	1500.0
Iron	**1000**	**2**					0.25	0.25	0.25											0.25	0.25						1.25	2500.0
Communication	**5**	**4**	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	**0.5**	0.5	12	240.0
Refrigerator	**120**	**1**	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	**0**	0	16	1920.0
Daily Load (Wh/day)																										**12582.0**
																									Total Daily Village Load (kWh/day)	**5558.3**
																									Total Monthly Village Load (kWh)	166750

ANNEX - 3

Summary of hourly load for off-season

SUMMERY OF HOURLY LOAD - OFF SEASON

Time	Total Load (kWh)
0001-0100	224
0100-0200	222
0200-0300	222
0300-0400	227
0400-0500	289
0500-0600	237
0600-0700	198
0700-0800	219
0800-0900	218
0900-1000	242
1000-1100	242
1100-1200	227
1200-1300	228
1300-1400	228
1400-1500	239
1500-1600	285
1600-1700	284
1700-1800	185
1800-1900	212
1900-2000	187
2000-2100	263
2100-2200	235
2200-2300	228
2300-2359	226

ANNEX - 2

Hourly load calculation for on22- season

HOURLY LOAD CALCULATIONS - ON SEASON

			Hour of the Day																									
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Hours/day	Wh/day
Pre School																												
Number of Schools		1																										
User Controlled Loads	**Rated Power(W)**	**Number of Units**																										
LED bulb	15	5						0.50	1.00	0.50																	2	150.0
Fan	40	3							1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00											8	960.0
Computer	120	1							0.50	0.50	0.50	0.50	5.00	0.50	0.50	0.50											8.5	1020.0
Table fan	25	2							1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00											8	400.0
Communications	5	1							1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00				1.00	1.00	1.00	1.00	1.00	1.00	1.00	15	75.0
																											Daily Load (Wh/day)	**2605.0**
Medical centre																												
Number of Medical centre buildings		1																										
User Controlled Loads	**Rated Power(W)**	**Number of Units**																										
Fluorescent bulb	40	2	0.25	0.25	0.25	0.50	0.50	1.00	1.00	0.25										0.50	0.50	0.50	0.50	0.50	0.50	0.50	7.5	600.0
LED bulb	15	4	0.25	0.25	0.25	0.25	0.50	0.50	0.25		0.25	0.25								0.25	0.50	0.50	0.50	0.25	0.25	0.25	5.25	315.0
Fan	40	2								0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50				7	560.0
Radio	15	1						0.50	0.50	0.50										0.50	0.50	0.50	0.50				3.5	52.5
Table fn	25	2							0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50								5.5	275.0
TV	100	1						1.00	1.00	0.50	0.50	0.50	0.50	0.50	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00				13.5	1350.0
Communications	5	1						1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00								12	60.0
Air conditioning	1500	1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	24	36000.0
Refrigerator	120	1	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	12	1440.0
																											Daily Load (Wh/day)	**40652.5**
Churches																												
Number of Churches		3																										
User Controlled Loads	**Rated Power(W)**	**Number of Units**																										
Fluorescent bulb	40	2	0.25	0.25	0.25	0.25	0.25	0.50	0.25									0.50	1.00	0.50	0.25	0.25	0.25	0.25	0.25	0.25	5.5	1320.0
LED bulb	20	5					0.25	0.50	0.25										1.00	1.00	0.50	0.25	0.25				4	1200.0
Fan	100	1						1.00	1.00	1.00			1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00					13	3900.0
Communications	5	1						1.00	1.00	1.00									1.00	1.00	1.00						6	90.0
																											Daily Load (Wh/day)	**6510.0**
Street lighting & Deferrable loads																												
User Controlled Loads	**Rated Power(W)**	**Number of Units**																										
Street lights (CFL bulb)	15	50	1.00	1.00	1.00	1.00	1.00	0.50												0.50	1.00	1.00	1.00	1.00	1.00	1.00	12	9000.0
Ice plants	187500	1	1.00	1.00	1.00	1.00	1.00	0.50	0.50	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.50	0.50	1.00	1.00	1.00	1.00	22	4125000.0
Water desalination plant	6000	1	1.00	1.00	1.00	1.00	1.00	0.50	0.50	0.50	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	**0.50**	0.50	**0.50**	1.00	1.00	1.00	1.00	21	126000.0
																											Daily Load (Wh/day)	**4260000.0**
House Type 1 (Medium)																												
Number of houses in the community		**100**																										
User Controlled Loads	**Rated Power**	**Number of Units**																										
Fluorescent bulb	**40**	**2**						0.5	0.25											0.5	1	1	0.5	0.1	0.1		3.95	31600.0
LED bulb	**10**	**4**				0.2	0.25	0.5	0.2											0.5	1	1	0.75	0.25	0.1	0.1	4.85	19400.0
Fan	**40**	**1**	0.5	0.5	0.5	0.5	0.5					0.5	0.5	0.5	0.5	0.5	0.5	0.5			1	1	1	0.5	0.5	0.5	10.5	42000.0
Table fan	**25**	**2**	0.5	0.5	0.5	0.5	0.5					0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	10	50000.0
TV	**70**	**1**						0.5	0.5												1	1	0.5				3.5	24500.0
Radio	**15**	**1**					0.25	0.75	0.75	0.75	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.5	0.75	0.75	0.75	0.5	0.25	0.1	8.35	12525.0
Water heater	**1000**	**1**					0.1	0.1	0.05									0.1	0.1								0.45	45000.0
Iron	**1000**	**1**						0.1	0.1											0.1	0.1						0.4	40000.0
Refrigerator	**120**	**1**	0.2	0.2	0.2	0.2	0.2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.2	0.2	0.2	9.6	115200.0
Communication	**5**	**2**						0.5	0.5													0.5	0.5				2	2000.0
Washing machine	**300**	**1**										0.50	0.50														1	30000.0
																											Daily Load (Wh/day)	**412225.0**

House Type 2 (Small)																												
Number of houses in the community		**200**																										
User Controlled Loads	**Rated Power**	**Number of Units**																										
Fluorescent bulb	**40**	**1**						0.5	0.25											0.5	0.8	0.8	0.2	0.1			3.15	25200.0
LED bulb	**10**	**3**				0.5	0.5	0.5												0.5	0.8	0.8	0.75	0.2	0.1	0.1	4.75	28500.0
Fan	**40**	**1**	0.5	0.5	0.5	0.5	0.5					0.2	0.2	0.2	0.25	0.25	0.25	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.35	66800.0
Table fan	**25**	**1**										0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	3	15000.0
TV	**70**	**1**						0.2	0.25	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.25	0.5	0.75	0.5	0.25	0.1	0.1	3.9	54600.0
Radio	**15**	**1**					0.25	0.75	0.75	0.75	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.5	0.2						5.45	16350.0
Water heater	**1000**	**1**					0.1	0.1	0.05									0.1	0.1								0.45	90000.0
Iron	**1000**	**1**						0.1	0.1											0.1	0.1						0.4	80000.0
Communication	**5**	**2**						0.5	0.5													0.5	0.5				2	4000.0
Refrigerator	**120**	**1**	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	12	288000.0
																											Daily Load (Wh/day)	**668450.0**
House Type 3 (Temporary huts)																												
Number of houses in the community		**460**																										
User Controlled Loads	**Rated Power**	**Number of Units**																										
LED bulb	**10**	**3**	0.2	0.2	0.2	0.2	0.5	0.5	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.75	1	1	0.5	0.25	0.2	0.2	6.8	93840.0
Table fan	**25**	**1**	0.2	0.2	0.2	0.2	0.2					0.2	0.2	0.2	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.3	0.4	0.3	0.2	0.2	4.7	54050.0
TV	**70**	**0**						0.2	0.25	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.25	0.5	0.75	0.5	0.25	0.1	0.1	3.9	0.0
Radio	**15**	**1**					0.25	0.75	0.75	0.75	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.5	0.75	0.75	0.75	0.5	0.25	0.1	8.35	57615.0
Communication	**5**	**1**						0.5	0.5													0.5	0.5				2	4600.0
Water heater	**1000**	**1**					0.1	0.1	0.05									0.1	0.1								0.45	207000.0
																											Daily Load (Wh/day)	**417105.0**
Police post																												
Number of police posts		**1**																										
User Controlled Loads	**Rated Power**	**Number of Units**																										
Fluorescent bulb	**40**	**4**	0.25	0.25	0.25	0.5	1	0.25												1	1	0.5	0.5	0.5	0.5	0.5	7	1120.0
LED bulb	**10**	**8**	0.25	0.25	0.25	0.25	0.75	0.75												0.5	0.75	0.75	0.5	0.25	**0.2**	0.2	5.65	452.0
Fan	**40**	**4**	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	12	1920.0
Table fan	**25**	**4**	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	12	1200.0
TV	**70**	**2**					0.5	1	1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.25	0.75	1	1	1	0.5			7.9	1106.0
Radio	**15**	**2**					0.5	0.75	1	0.25	0.25	0.25	0.25	0.25	0.1	0.1	0.1	0.25	0.25	0.25	0.1	0.1	0.1	0.1			4.95	148.5
Water heater	**1000**	**1**				0.25	0.25	0.25				0.25					0.25							0.25			1.5	1500.0
Iron	**1000**	**2**					0.25	0.25	0.25											0.25	0.25						1.25	2500.0
Communication	**5**	**4**	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	12	240.0
Refrigerator	**120**	**1**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	**1**	1	24	2880.0
																											Daily Load (Wh/day)	**13292.5**
Naval Detachment																												
Number of police posts		**1**																										
User Controlled Loads	**Rated Power**	**Number of Units**																										
Fluorescent bulb	**40**	**4**	0.1	0.1	0.1	0.2	0.25	0.5												0.25	0.75	0.75	0.25	0.1	0.1	0.1	3.55	568.0
LED bulb	**10**	**8**	0.25	0.25	0.25	0.25	0.75	0.25												0.5	0.5	0.5	0.25	0.1	**0.1**	0.1	4.05	324.0
Fan	**40**	**4**	0.25	0.25	0.25	0.25	0.25	0.25	0.5	0.5	0.5	0.5	0.5	0.5	1	1	1	1	1	1	1	1	0.5	0.25	0.25	0.25	13.75	2200.0
Table fan	**25**	**4**	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	12	1200.0
TV	**70**	**2**					0.5	1	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	1	1	1	0.5			12	1680.0
Radio	**15**	**2**	0.5	0.5	0.5	0.5	0.5	1	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	1	1	1	0.5	**0.5**	0.5	15	450.0
Water heater	**1000**	**1**				0.25	0.25	0.25				0.25					0.25							0.25			1.5	1500.0
Iron	**1000**	**2**					0.25	0.25	0.25											0.25	0.25						1.25	2500.0
Communication	**5**	**4**	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	**0.5**	0.5	12	240.0
Refrigerator	**120**	**1**	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	**0**	0	16	1920.0
																											Daily Load (Wh/day)	**12582.0**
																											Total Daily Village Load (kWh/day)	**5832.5**
																											Total Monthly Village Load (kWh)	**174975.6**

ANNEX – 4

Summary of hourly load for on-season

SUMMERY OF HOURLY LOAD - ON SEASON

Time	Total Load (kWh)
0001-0100	226
0100-0200	224
0200-0300	224
0300-0400	229
0400-0500	313
0500-0600	263
0600-0700	211
0700-0800	223
0800-0900	220
0900-1000	244
1000-1100	244
1100-1200	229
1200-1300	231
1300-1400	231
1400-1500	242
1500-1600	308
1600-1700	306
1700-1800	286
1800-1900	222
1900-2000	197
2000-2100	271
2100-2200	239
2200-2300	231
2300-2359	229