UNIVERSITY OF NAIROBI

FINAL YEAR PROJECT

DEPARTMENT OF ELECTRICAL AND INFORMATION ENGINEERING

DESIGN OF AN ENERGY CENTER FOR ENERGY EFFICIENT AND SUSTAINABLE NEIGHBOURHOOD DEVELOPMENT

PROJECT NO: 114

By

NGURE KELVIN MARUGA

REG. NO: F17/23619/2008

SUPERVISOR: DR. CYRUS WEKESA

EXAMINER: PROF. M. K. MANG'OLI

A PROJECT REPORT SUBMITTED TO THE DEPARTMENT OF ELECTRICAL AND INFORMATION ENGINEERING IN PARTIAL FULFILLMENT OF THE REQUIREMENTS OF BSc. ELECTRICAL AND ELECTRONIC ENG. OF THE UNIVERSITY OF NAIROBI

April, 2014

DECLARATION

This is to certify that this project report is my original work and has not been presented for a degree award in any other university or institution of higher learning. Information from other sources has been duly acknowledged.

Ngure Kelvin Maruga

Sign..............................

Date..............................

This project report has been submitted for examination with my approval as the university supervisor.

Dr. Cyrus Wekesa

Sign...............................

Date...............................

DEDICATION

This project is dedicated to my family for the moral and financial support and also to those who have shown great faith in me throughout my pursuit for higher learning.

ACKNOWLEDGEMENT

I acknowledge the massive input by my supervisor, Dr. Wekesa, for the useful comments and suggestions which have led to the improvement of this project and for the guidance and moral support that he granted unto me during the development of this project.

Contents

ABSTRACT

As the world population increases, there is consequent increase in energy use. The rapid depletion of fossil fuel resources on a worldwide basis has necessitated an urgent search for alternative energy sources to cater to the present day demands. Alternative energy resources such as solar and wind have attracted energy sectors to generate power on a large scale. Plus, there is increasing cost of energy due to the exhaustible nature of fossils. Therefore, there is need to conceptualize an energy center for energy efficient and sustainable neighborhood development by applying a hybrid power system (wind-solar-diesel generator). This kind of hybrid system can attenuate individual fluctuations, increase overall energy output and reduce energy storage requirements significantly. This system can be adopted for new establishments in order to minimize carbon emissions and also reduce the cost of energy.

CHAPTER 1: INTRODUCTION

1.1 Background

Energy efficiency can be defined as a goal to reduce the amount of energy and cost required to provide products and services. Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. In this case, the goal is to power a neighborhood with relatively cheap and sustainable energy. For energy to be sustainable, it must be renewable, for example, solar, wind, biomass et cetra. There arises the need to combine different types of renewable energy in order to decrease the cost of energy production. We know that solar energy or wind energy cannot be relied on, alone for the whole year, without increased cost due to storage of energy. When one is at its prime, the other may be low and vice versa. Also, a backup system is required because weather is really unpredictable and can cause disruption of power in case of insufficient energy stored, preferably a diesel generator.

A hybrid power system is now needed to cater for the above constraints. A hybrid power system is just a power system that combines various energy sources into one reliable source. In this case, it combines power generated due to wind energy, solar energy and diesel, in such a way that there occurs no disruption of power to the consumers. Power generated by wind and solar supplies the neighborhood as it charges storage batteries. When there is no charge stored in the batteries and there is no power being generated, the diesel generator provides the power needed.

This type of system can be very useful, especially now that the cost of fossil fuels is sky-high and also because it is very friendly to the environment due to low carbon emissions.

1.2 Problem Statement

To conceptualize and design an energy center that will contribute towards an energy efficient and sustainable neighborhood.

1.3 Main Objectives

This project is composed of two primary objectives. First and foremost is the design of a stand-alone hybrid solar- wind- diesel power system. Then there is the optimization process.

1.4 Project Scope

This project entails the following:

i. Investigating the solar energy and wind energy capacities of the projected neighborhood.

ii. Designing a hybrid power system that incorporates solar energy, wind energy and diesel generators, which acts as backup for the two renewable sources of energy.

iii. Determining the optimal combination, of solar, wind and diesel for cost efficiency, to be incorporated in the energy center.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter will seek to describe and discuss the researches from various sources such as textbooks, articles and the internet. It consists of information which is vital in the development of this project. The research will focus mainly on the history of solar and wind energy and ways of converting solar radiation and wind into energy.

2.2 Solar

Solar energy has been around for many years. Its history spans from the 7^{th} Century B.C. to today. We started out concentrating the sun's heat with glass and mirrors to light fires. Today, we have everything from solar-powered buildings to solar-powered vehicles. In the 7^{th} Century B.C. a magnifying glass used to concentrate sun's rays to make fire and to burn ants. Greeks and Romans also used burning mirrors to light torches for their religious purposes at around 3^{rd} Century B.C. As early as 212 BC, the Greek scientist, Archimedes, used the reflective properties of bronze shields to focus sunlight and to set fire to wooden ships from the Roman Empire which were besieging Syracuse.

In 1767 the Swiss scientist Horace de Saussure was credited with building the world's first solar collector, later used by Sir John Herschel to cook food during his South Africa expedition in the 1830s. On September 27, 1816, Robert Stirling applied for a patent for his economizer at the Chancery in Edinburgh, Scotland. Robert Stirling was actually a minister in the Church of Scotland. But, in his spare time, he built heat engines in his home workshop. Lord Kelvin used one of the working models during some of his university classes. This engine was later used in the dish/Stirling system, a solar thermal electric technology that concentrates the sun's thermal energy in order to produce power. In 1839, the photovoltaic effect was discovered by the French scientist, Edmond Becquerel, while experimenting with an electrolytic cell made up of two metal electrodes placed in an electricity conducting solution. He found out that he could increase electricity generation when he exposed it to light. In the 1860s a French mathematician, August Mouchet proposed an idea for solar-powered steam engines. In the following two decades, he and his assistant, Abel Pifre, constructed the first solar powered engines and used them for a variety of applications. These engines became the predecessors of modern parabolic dish collectors. In the early 1900s, Wilhelm Hallwachs discovered that a combination of copper and cuprous oxide is photosensitive. Albert Einstein published his paper on the photoelectric effect. William J. Bailley of the Carnegie Steel Company invents a solar collector with copper coils and an insulated box. The existence of a barrier layer in photovoltaic devices was noted. Robert Millikan provided experimental proof of the photoelectric effect. Polish scientist Jan Czochralski developed a way to grow single-crystal silicon. Audobert and Stora discover the photovoltaic effect in cadmium sulfide (CdS).

In the mid 1950s Dr. Dan Trivich, Wayne State University, makes the first theoretical calculations of the efficiencies of various materials of different band gap widths based on the spectrum of the sun. Photovoltaic technology is born in the United States when Daryl Chapin, Calvin Fuller, and Gerald Pearson develop the silicon photovoltaic (PV) cell at Bell Labs—the first solar cell capable of converting enough of the sun's energy into power to run everyday electrical equipment. Bell Telephone Laboratories produced a silicon solar cell with 4% efficiency and later achieved 11% efficiency. Architect Frank Bridgers designed the world's first commercial office building using solar water heating and passive design. This solar system has been continuously operating since that time and the Bridgers-Paxton Building, is now in the National Historic Register as the world's first solar heated office building. Hoffman Electronics achieved 8% efficient photovoltaic cells. The Vanguard I space satellite used a small (less than one watt) array to power its radios. Later that year, Explorer III, Vanguard II, and Sputnik-3 were launched with PV-powered systems on board. Despite faltering attempts to commercialize the silicon solar cell in the 1950s and 60s, it was used successfully in powering satellites. It became the accepted energy source for space applications and remains so today.

In the 1960s, Hoffman Electronics achieves 14% efficient photovoltaic cells. Silicon Sensors, Inc., of Dodgeville, Wisconsin, is founded. It starts producing selenium and silicon photovoltaic cells. Bell Telephone Laboratories launches the first telecommunications satellite, the Telstar, which had initial power of 14 watts. NASA launches the first Nimbus spacecraft—a satellite powered by a 470-watt photovoltaic array.

In the 1970s, Dr. Elliot Berman, with help from Exxon Corporation, designs a significantly less costly solar cell, bringing price down from $100 a watt to $20 a watt. Solar cells begin to power navigation warning lights and horns on many offshore gas and oil rigs, lighthouses, railroad crossings and domestic solar applications began to be viewed as sensible applications in remote locations where grid connected utilities could not exist affordably. The Institute of Energy Conversion is established at the University of Delaware to perform research and development on thin-film photovoltaic (PV) and solar thermal systems, becoming the world's first laboratory dedicated to PV research and development. The University of Delaware builds "Solar One," one of the world's first photovoltaic (PV) powered residences. The system is a PV/thermal hybrid. The roof-integrated arrays fed surplus power through a special meter to the utility during the day and purchased power from the utility at night. In addition to electricity, the arrays acted as flat-plate thermal collectors, with fans blowing the warm air from over the array to phase-change heat-storage bins. The NASA Lewis Research Center starts installing 83 photovoltaic power systems on every continent except Australia. These systems provide such diverse applications as vaccine refrigeration, room lighting, medical clinic lighting, telecommunications, water pumping, grain milling, and classroom television. The Center completed the project in 1995, working on it from 1976-1985 and then again from 1992-1995. David Carlson and Christopher Wronski, RCA Laboratories, fabricate first amorphous silicon photovoltaic cells. Total photovoltaic manufacturing production exceeds 500 kilowatts.

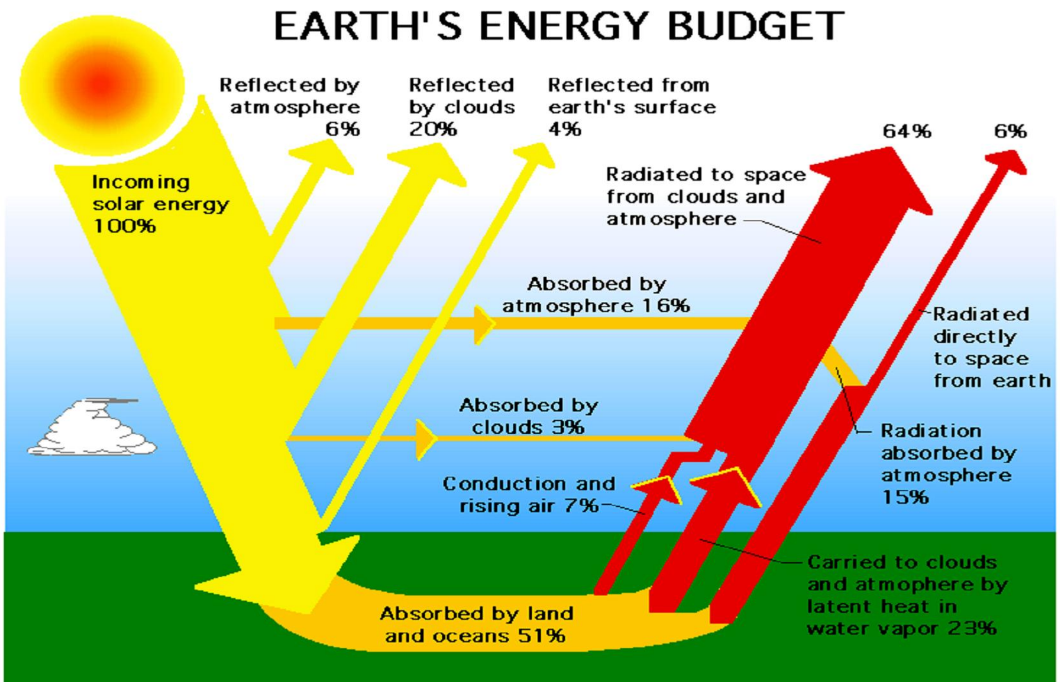
In the 1980s, ARCO Solar becomes the first company to produce more than 1 megawatt of photovoltaic modules in one year. At the University of Delaware, the first thin-film solar cell exceeds 10% efficiency using copper sulfide/cadmium sulfide. Paul MacCready builds the first solar-powered aircraft, the Solar Challenger, and flies it from France to England across the English Channel. The aircraft had over 16,000 solar cells mounted on its wings, which produced 3,000 watts of power. The first, photovoltaic megawatt-scale power station goes on-line in Hisperia, California. It has a 1-megawatt capacity system, developed by ARCO Solar, with modules on 108 dual-axis trackers. Australian Hans Tholstrup drives the first solar-powered car, the Quiet Achiever, almost 2,800 miles between Sydney and Perth in 20 days, which was 10 days faster

than the first gasoline-powered car to do so. Volkswagen of Germany begins testing photovoltaic arrays mounted on the roofs of Dasher station wagons, generating 160 watts for the ignition system. ARCO Solar dedicates a 6-megawatt photovoltaic substation in central California. The 120-acre, unmanned facility supplies the Pacific Gas & Electric Company's utility grid with enough power for 2,000-2,500 homes. Solar Design Associates completes a stand alone, 4-kilowatt powered home in the Hudson River Valley. Worldwide photovoltaic production exceeds 21.3 megawatts, with sales of more than $250 million. The Sacramento Municipal Utility District commissions its first 1-megawatt photovoltaic electricity generating facility. The University of South Wales breaks the 20% efficiency barrier for silicon solar cells under 1-sun conditions. 1986 The world's largest solar thermal facility, located in Kramer Junction, California, was commissioned. The solar field contained rows of mirrors that concentrated the sun's energy onto a system of pipes circulating a heat transfer fluid. The heat transfer fluid was used to produce steam, which powered a conventional turbine to generate electricity. Dr. Alvin Marks receives patents for two solar power technologies he developed: Lepcon and Lumeloid. Lepcon consists of glass panels covered with a vast array of millions of aluminum or copper strips, each less than a micron or thousandth of a millimeter wide. As sunlight hits the metal strips, the energy in the light is transferred to electrons in the metal, which escape at one end in the form of electricity. Lumeloid uses a similar approach but substitutes cheaper, film-like sheets of plastic for the glass panels and covers the plastic with conductive polymers, long chains of molecular plastic units.
In the 1990s, University of South Florida develops a 15.9% efficient thin-film photovoltaic cell made of cadmium telluride, breaking the 15% barrier for the first time for this technology. First solar dish generator using a free-piston Stirling engine is tied to a utility grid. The National Renewable Energy Laboratory develops a solar cell, made from gallium indium phosphide and gallium arsenide, which becomes the first one to exceed 30% conversion efficiency. The world's most advanced solar-powered airplane, the Icare, flew over Germany. The wings and tail surfaces of the Icare are covered by 3,000 super-efficient solar cells, with a total area of 21 m^2. The U.S. Department of Energy, along with an industry consortium, begins operating Solar Two, an upgrade of its Solar One concentrating solar power tower project. Operated until 1999, Solar Two demonstrated how solar energy can be stored efficiently and economically so that power can be produced even when the sun isn't shining. It also fostered commercial interest in power towers. The remote-controlled, solar-powered aircraft, "Pathfinder" sets an altitude record, 80,000 feet, on its 39th consecutive flight on August 6, in Monrovia, California. This altitude is higher than any prop-driven aircraft thus far. Subhendu Guha, a noted scientist for his pioneering work in amorphous silicon, led the invention of flexible solar shingles, a roofing material and state-of-the-art technology for converting sunlight to electricity. 1999 Construction was completed on 4 Times Square, the tallest skyscraper built in the 1990s in New York City. It incorporates more energy-efficient building techniques than any other commercial skyscraper and also includes building-integrated photovoltaic (BIPV) panels on the 37th through 43rd floors on the south and west-facing facades that produce a portion of the buildings power. Spectrolab, Inc. and the National Renewable Energy Laboratory develop a photovoltaic solar cell that converts 32.3 percent of the sunlight that hits it into electricity. The high conversion efficiency was achieved by combining three layers of photovoltaic materials into a single solar cell. The cell performed most efficiently when it received sunlight concentrated to 50 times normal. To use such cells in practical applications, the cell is mounted in a device that uses lenses or mirrors to concentrate sunlight

onto the cell. Such systems are mounted on tracking systems that keep them pointed toward the sun. Cumulative worldwide installed photovoltaic capacity reaches 1000 megawatts.
In the 2000s, at the International Space Station, astronauts begin installing solar panels on what will be the largest solar power array deployed in space. Each wing of the array consists of 32,800 solar cells. Sandia National Laboratories develops a new inverter for solar electric systems that will increase the safety of the systems during a power outage. Inverters convert the direct current (DC) electrical output from solar systems into alternating current (AC), which is the standard current for household wiring and for the power lines that supply electricity to homes. NASA's solar-powered aircraft, Helios, sets a new world record for non-rocket-powered aircraft: 96,863 feet, more than 18 miles high. The National Space Development Agency of Japan, or NASDA, announces plans to develop a satellite-based solar power system that would beam energy back to Earth. A satellite carrying large solar panels would use a laser to transmit the power to an airship at an altitude of about 12 miles, which would then transmit the power to Earth. NASA successfully conducts two tests of a solar-powered, remote-controlled aircraft called Pathfinder Plus. In the first test in July, researchers demonstrated the aircraft's use as a high-altitude platform for telecommunications technologies. Then, in September, a test demonstrated its use as an aerial imaging system for coffee growers. ATS Automation Tooling Systems Inc. in Canada starts to commercialize an innovative method of producing solar cells, called Spheral Solar technology. The technology, based on tiny silicon beads bonded between two sheets of aluminum foil, promises lower costs due to its greatly reduced use of silicon relative to conventional multicrystalline silicon solar cells. The technology is not new. It was championed by Texas Instruments (TI) in the early 1990s. But despite U.S. Department of Energy (DOE) funding, TI dropped the initiative. Powerlight Corporation installs the largest rooftop solar power system in the United States, a 1.18 megawatt system, at the Santa Rita Jail in Dublin, California.
This shows that solar energy has been around for ages, and it can only grow bigger and create more interest, from the research being carried out. In the future we can expect to see energy-efficient buildings being built. In effect, the buildings will conserve enough and produce their own energy supply to create a new generation of cost-effective buildings that have zero net annual need for non-renewable energy. The future can only promise great things in the field of solar energy, if the past is to go by.
The solar energy flux reaching the Earth's surface represents a few thousand times the current use of primary energy by humans. The potential of this resource is enormous and makes solar energy a crucial component of a renewable energy portfolio aimed at reducing the global emissions of greenhouse gasses into the atmosphere. Nevertheless, the current use of this energy resource represents less than 1% of the total electricity production from renewable sources. Even though the deployment of photovoltaic systems has been increasing steadily for the last 20 years, solar technologies still suffer from some drawbacks that make them poorly competitive on an energy market dominated by fossil fuels: high capital cost, modest conversion efficiency, and intermittency. From a scientific and technical viewpoint, the development of new technologies with higher conversion efficiencies and low production costs is a key requirement for enabling the deployment of solar energy at a large scale.

2.2.1 Solar radiation

About 51% of the total solar energy reaches the ground. 6% is reflected by the atmosphere, 20% is reflected by the clouds, 4% is reflected from the earth's surface, 16% is absorbed by the atmosphere and the other 3% is absorbed by the clouds as shown in the figure below.



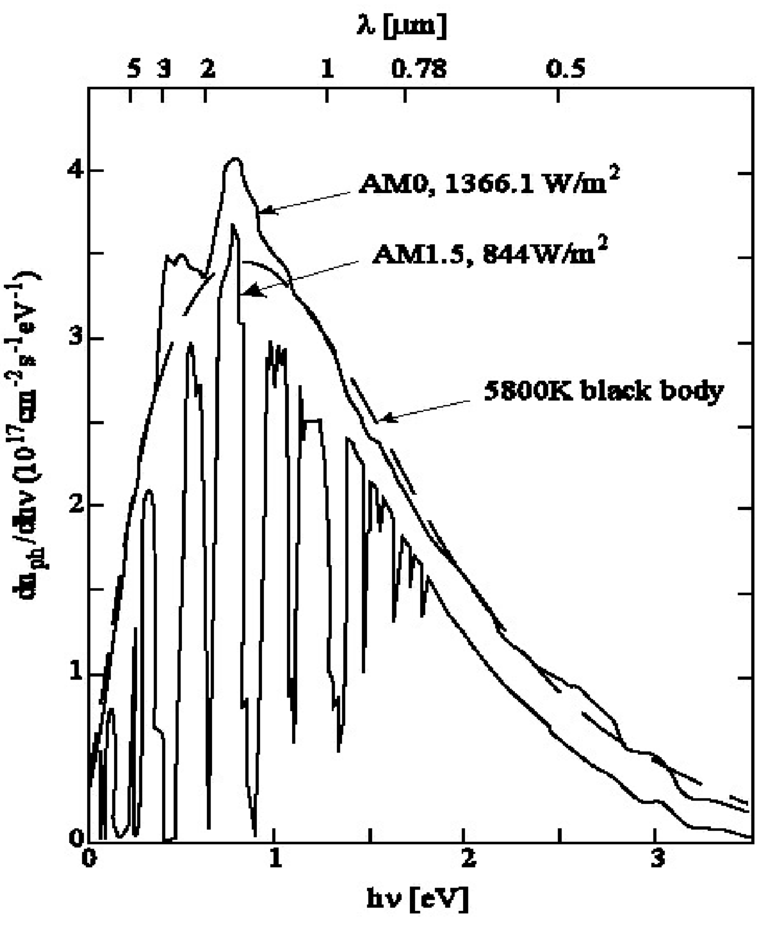
Since the impact of the atmosphere on the terrestrial solar radiation is substantially determined by the path length of the light through the atmosphere, the terrestrial solar radiation is characterized by the Air Mass.

Solar radiation represents the largest energy flow entering the terrestrial ecosystem. After reflection and absorption in the atmosphere, some 100,000TW hit the surface of the earth and undergo conversion to all forms of energy used by humans, with the exception of nuclear, geothermal, and tidal energy.

Solar radiation is an electromagnetic wave emitted by the Sun's surface that originates in the bulk of the Sun where fusion reactions convert hydrogen atoms into helium. Every second 3.89×10^{26}J of nuclear energy is released by the Sun's core. This nuclear energy flux is rapidly converted into thermal energy and transported toward the surface of the star where it is released in the form of electromagnetic radiation. The power density emitted by the Sun is of the order of $64 MW/m^2$ of which approximately $1370 W/m^2$ reach the top of the Earth's atmosphere with no significant absorption in the space. The latter quantity is called the solar constant.

The spectral range of the solar radiation is very large and encompasses nanometric wavelengths of gamma- and x-rays through metric wavelengths of radio waves. The energy flux is divided unevenly among the three large spectral categories. Ultraviolet (UV) radiation ($\lambda<400$nm) accounts for less than 9% of the total; visible light (VIS) (400nm<λ<700nm) for 39%; and infrared (IR) for about 52%.

The figure below shows that the pattern of the solar spectrum resembles closely the radiation of a perfect black body at 5800K. In the figure, AM0 indicates the *Air Mass Zero* reference spectrum measured – and partially modeled – outside the terrestrial atmosphere. Radiation reaching the Earth's surface is altered by a number of factors, namely the inclination of the Earth's axis and the atmosphere that causes both absorption and reflection of part of the incoming radiation. The influence of all these elements on solar radiation is visible in the ground-level spectrum, labeled AM1.5 in the figure, where the light absorption by the molecular elements of the atmosphere is particularly evident. Accounting for absorption by the atmosphere, reflection from cloud tops, oceans, and terrestrial surfaces, and rotation of the Earth (day/night cycles), the annual mean of the solar radiation reaching the surface is 170W/m^2 for the oceans and 180W/m^2 for the continents. Of this, about 75% is direct light, the balance of which is scattered by air molecules, water vapor, aerosols, and clouds.



2.2.3 Photovoltaic arrays

A photovoltaic system is an arrangement of components designed to supply usable electric power for a variety of purposes, using the sun as the power source. A photovoltaic array consists of multiple photovoltaic modules, casually referred to as solar panels, to convert solar radiation into usable direct current electricity. A photovoltaic system for residential, commercial, or industrial energy supply normally contains an array of photovoltaic (PV) modules, one or more DC to alternating current power converters (also known as inverters), a tracking system that supports the solar modules, electrical wiring and interconnections, and mounting for other components. A photovoltaic system may include any or all of the following: renewable energy credit revenue-grade meter, maximum power point tracker (MPPT), battery system and charger, GPS solar tracker, energy management software, solar concentrators, solar irradiance sensors, anemometer, or task-specific accessories designed to meet specialized requirements for a system owner. The number of modules in the system determines the total DC watts capable of being generated by the solar array; however, the inverter is what governs the amount of AC watts that can be distributed for consumption. This means that the rating of the inverter determines the available AC watts available for use by the consumer.

The physics of a PV cell is very similar to that of a PN junction diode formed by semiconductor material. When the junction absorbs light, the energy of the absorbed photon is transferred to the electron-proton system of the material, creating charge carriers that are separated at the junction. The charge carriers in the junction region create a potential gradient, get accelerated under the electric field, and circulate as current through an external circuit. The solar cell is the basic building of the PV power system and it produces about 1 W of power. To obtain high power, a great number of such cells are connected in series and parallel circuits on a panel, also known as a module. The solar array is a group of a several modules electrically connected in series parallel combination to generate the required current and voltage.

Below is an example of a photovoltaic array

2.2.2 PV array modeling

The output power from a PV panel can be calculated by an analytical model which defines the current-voltage relationships based on the electrical characteristics of the PV panel. This model includes the effects of radiation level and panel temperature on the output power. With a maximum power point tracker (MPPT), the output power from a PV panel is given as

$P_{pv} = V_{mpp}.I_{mpp}$ (1) P is power, the subscript 'pv' is

$V_{mpp} = V_{mpp,ref} + \mu_{v,oc} (T_c - T_{c,ref})$ (2) photovoltaic, 'mpp' is maximum

$I_{mpp} = I_{mpp,ref} + I_{sc,ref} (G_T / G_{ref}) + \mu_{I,sc} (T_c - T_{c,ref})$ (3) power point, V is voltage, I is current,

'sc' is short circuit, 'oc' is open circuit, 'ref' is reference value, G_T is the daily irradiance on a tilted surface, $\mu_{v,oc}$ and $\mu_{I,sc}$ are the temperature coefficients for open circuit voltage and short circuit current respectively, T_c is the panel operating temperature.

The typical value for G_{ref} is 1000 W/m^2 at reference operating conditions.
T_{Cref} is the PV panel temperature of 25°C at reference operating conditions and T_C corresponds to the PV panel operating temperature in °C at day t and can be expressed as

$$T_C (t) = T_a (t) + [(NOCT - 20)/ 800]* G_T$$

Where T_a (t) is the ambient temperature (°C) of the site under consideration at hour t and NOCT (Normal Operating Cell Temperature) is defined as the cell temperature when the PV panel operates under 800W/m² of solar irradiation and 20°C of ambient temperature, NOCT is usually between 42°C and 46°C.

2.3 Wind

Approximately 3200 B.C. the ancient Egyptians invented the sail. The way a boat moves is through the wind pushing the sail. Excluding modern times, a wind powered boat has been the primary form of water transportation in all of human history.
Romans used passive wind power in their extensive fleets. Some ships were large enough to carry almost a thousand tons of cargo, or a great number of passengers depending on the length of the trip and the accommodations of the passengers.
The Chinese reportedly invented the windmill. West of China in Persia windmills were used around 200 BC.
By 1000 A.D. the Vikings had explored and conquered the North Atlantic because of the power of the wind.
Around the 14th century, the Dutch used passive wind power to pump water from flooded fields with a device called a windmill. Much of Holland is below sea-level and is often flooded.

The windmill was the transition invention that led to modern wind power turbines and other devices.
French farmers used wind power to move water into pools where it was used for irrigation.
In 1854 a wind powered water pump was introduced in the United States. This type is very familiar because its blades rested on a wheel and it had a tail to keep the fan pointed into the wind.
In Denmark wind power was pioneered in 1890 starting (120) 5 - 25 kW wind powered systems.
In the 1930s a Frenchman named G. J. M. Darrieus invented a wind power design in the shape of an eggbeater.
By 1940 there were around 6 million windmills of the type introduced in the United States almost a century earlier in 1854.
In 1941 near Rutland, Vermont a giant 1.5 MW machine powered the Central Vermont Public Service electric grid.
Just as solar power technology accelerated during the oil embargo of 1973 - 1974, wind power made large strides. Westinghouse Electric Company received Department of Energy (DOE) / NASA contracts for building large scale wind turbines. The greatest capacity wind turbine was built in Oahu, Hawaii, with a 3.2 MW power rating.
A 25% tax credit for investors of wind turbines was made through the Public Utilities Regulatory Policies Act (PURPA) of 1978. Between 1981 and 1984 6,870 turbines were installed in California.
At the end of 1983, there were around 4600 wind turbines operating out of California. These turbines together produced 300000 KW of electricity.
The change in prices of wind power electricity dropped from 14 cents per kWh in 1985 to 5 cents per kWh in 1994 making wind power a much greater competitor in the electricity market.

The first known windmill was built by Heron of Alexandria in the 2nd century AD. By the 8th century large horizontal axis windmills with four blades were in use in Eastern Europe. During the 12th and 13th centuries the use of windmills became widespread for pumping water and grinding grain. The oldest were found in Turkey, Iran and Afghanistan, and they spread to Europe, beginning with Belgium and the Netherlands. In 1700 wind may have provided 2 per cent of Great Britain's power requirements – a relatively small amount compared to the 64% from animals, and even the 12% from watermills, but quite significant for driving water-wells, irrigation, and grain-grinding. The Industrial Revolution was the death knell for wind energy. By 1850 steam power provided 30 per cent of Britain's power, and wind was insignificant. Wind energy lingered longer in countries which were slower to industrialize. An estimated 20,000 windmills were still in action in France by the end of the nineteenth century, primarily used for water pumping and cereal grinding, but soon they too were swept away. In 1887 the first windmill for electricity production was built by Professor James Blyth in Andersonǿs College, Glasgow. He built three different types of turbine, one of which powered his home for twenty-five years. There was also experimentation using the multi-blade windmill design to generate electricity. The first use of a large windmill to generate electricity was a system built in Cleveland, Ohio, by Charles F. Brush. Inventors in northern Europe took the lead in trying to develop wind-electric generating systems. In Britain, wind energy remained largely the preserve of the inventor. In Britain, R. A. Fessenden constructed an experimental wind machine in

London in 1894. He launched a start-up venture, the Rollason Wind Motor Company, to build machines for the countryside. Fessenden was a visionary, who proposed to build large windmills on coastal cliffs, which would lift seawater for storage, which would turn turbines and dynamos. Considerable numbers of machines were built, but the wider vision was not achieved. British engineers continued to experiment with the cost and effectiveness of wind-energy systems. In the mid-1920s Oxford University engineers operated a windmill experimental station outside London. It was in Denmark that wind energy secured a broader basis. Denmark had a long tradition of using windmills to mill grain for flour. In 1891 Poul la Cour, a teacher at the Folk High School in Askov in the south of the country, began experimenting with how wind turbines could generate electricity. He became the first person in the world to carry out systematic experiments with artificial air currents in a wind tunnel. Like many subsequent ñgreenò inventors and entrepreneurs, he was motivated by a societal vision. He disliked the poor social conditions in towns as they industrialized, and wanted to improve rural life so people who not leave for the towns. He figured electricity was the key, but as power plants were only built to serve the cities, he needed to find a way to generate electricity locally. The wind powered a dynamo to generate electricity. This electricity was to be led into a tank of water, which it would then separate into hydrogen and oxygen. This power was used to provide the lighting for the High School and the houses of the nearby village.

In France, George Darrieus, was also an important innovator. During the 1920s he worked for the Compagnie-Electromécanique, an electrical machinery manufacturer, and he designed several wind turbines at Le Bouget near Paris. By 1930 he was planning to build a large turbine capable of producing 50kw of electricity, but his company decided this would be uneconomical. He also designed the first vertical axis wind turbine and patented the invention in the United States in 1931. The vertical axis of rotation enables the turbine to accept wind from any direction rather than being reoriented as the wind changes direction, but the invention was largely ignored until the late 1960s, when it began to be used in California and later elsewhere.

Wind turbines, like windmills, are mounted on a tower to capture the most energy. At 30 meters or more above ground, they can take advantage of the faster and less turbulent wind. Turbines catch the wind's energy with their propeller-like blades. Usually, two or three blades are mounted on a shaft to form a rotor. A blade acts much like an airplane wing. When the wind blows, a pocket of low-pressure air forms on the downwind side of the blade. The low pressure air pocket then pulls the blade toward it, causing the rotor to turn. This is called lift. The force of the lift is actually much stronger than the wind's force against the front side of the blade, which is called drag. The combination of lift and drag causes the rotor to spin like a propeller, and the turning shaft spins a generator to make electricity. Wind turbines can be used as stand-alone applications, or they can be connected to a utility power grid or even combined with a photovoltaic (solar cell) system. For utility-scale sources of wind energy, a large number of wind turbines are usually built close together to form a wind plant. Several electricity providers today use wind plants to supply power to their customers. Stand-alone wind turbines are typically used for water pumping or communications. However, homeowners, farmers, and ranchers in windy areas can also use wind turbines as a way to cut their electric bills. Small wind systems also have potential as distributed energy resources. Distributed energy resources refer to a variety of small, modular power-generating technologies that can be combined to improve the operation of the electricity delivery system also known as hybrid power systems.

One of the most important milestones of the wind energy history coincides with the USA government involvement in the wind energy research and development (R&D) after the oil crisis of 1973. Following, in the years between 1973 and 1986, the commercial wind turbine market evolved from domestic and agricultural to utility interconnected wind farm applications. In this context, the first large-scale wind energy penetration outbreak was encountered in California, where over 16,000 machines, ranging from 20 to 350 kW (a total of 1.7 GW), were installed between 1981 and 1990, as a result of the incentives (such as the federal investment and energy credits) given by the USA government. In northern
Europe on the other hand, wind farm installations increased steadily through the 80s and the 90s, with the higher cost of electricity and the excellent wind resources leading to the creation of a small but stable market. After 1990 most market activity shifted to Europe, with the last twenty years bringing wind energy at the front line of the global scene with major players from all world regions.

According to the data available, the global wind power capacity was increased during 2009 by 37.4 GW, thus reaching a total of almost 158 GW on the basis of remarkable development rates exhibited for the past twenty years. Europe is at the moment approaching, if not yet exceeded, 80 GW and is now heading to offshore applications. In fact, it is since the mid-90s that the EU market corresponds to over 50% of the global installed capacity, which is nowadays said to yield an overall of 260TWh/year. Although the EU held only 20% of the world wind energy generation in the early 90s, production of European wind parks managed to reach about 70% in the years after 2000, with a production of 100TWh/year already achieved by the end of 2007.

Concerning the present status of wind power capacity, the USA managed during 2009 to add a new 40% over its cumulative capacity. At the same time the Chinese achieved to install almost 14 GW, i.e. 20% and 40% of the EU and the USA cumulative capacity respectively, which leads to an aggregate (USA and China) of 62% of the 2009 capacity. As a result, China has reached the second place of the world ranking table together with the long-term leader of the EU, i.e. Germany. Besides, at the regional level, Asia has managed to marginally exceed the North Americans in terms of cumulative capacity, while the EU is still the world leader with almost 50%. At the same time, at the European level Germany (25.8 GW) and Spain (19.1 GW) are now followed by Italy (4850MW), France (4492MW), UK(4051MW), Portugal (3535MW) and Denmark (3465), with the latter presenting a long-term stagnation that calls for the improvement of the local legislation although considerable exploitation of the local wind potential has already been achieved. On the other hand, France and Portugal present remarkable developing rates since 2000, while for Italy and Netherlands the local wind energy market encountered an earlier start (i.e. since 1990) with analogous results only for the case of Italy.

European wind farms exceed oil-based generation by 20 GW and are down by 50 GW when compared to nuclear power. In fact, the developing rate of wind energy capacity is only comparable to the respective of natural gas installations, with the remarkable growth of

photovoltaic plants also designating the shift attempted in the EU to clean power generation technologies.
EU still remains the world leader, although the USA made a considerable come-back with over 10 GW installed in 2009. Meanwhile, China persists on its outstanding growth rates, each year doubling its cumulative capacity, and seems ready to overtake the first place in the world ranking table. On top of these, India following a steady growth rate, is the China's most important ally, adding more than 10 GW by some of the manufacturers (even at the levels of 7 MW) , while designs of machines that will exceed the nominal power of 10 MW are already underway.
The geographical distribution of wind power capacity has attracted particular attention. The global generating capacity of wind power grew from 13 megawatts in 1980 to 17,400 megawatts in 2000, and reached nearly 200,000 megawatts in 2010. However wind capacity has been highly skewed geographically. In 2010 the United States and China alone accounted for 42% of installed world power capacity**.** The relative importance of wind energy in electricity generation shows striking geographical variation. In 2008, wind supplied one-fifth of Denmark's electricity, and 13% of Portugal's, and 11% of Spain's. But in neighboring European countries, including Britain, France and Italy, as well as the United States, wind supplied less than 2% of electricity. In Japan the percentage was a tiny 0.3%. Overall, wind power provides a meager 1% of global electricity.
Wind speeds vary in intensity and seasonality. Both northern Europe and California, two centers of wind power, have strong and steadily westerly winds. The East Asian region, in contrast, has a monsoonal seasonal wind. This is one of the reasons behind the differences in the use of wind as a source of electrical energy. Another factor is public policy. Policy decisions, especially concerning access to electricity grids at favorable prices, alongside tax and other financial incentives, are widely perceived as key drivers behind the spread of wind energy. There are several reasons why public policy is so important. First, alternative energy, including wind and solar, is not able to compete with conventional form of power generation from fossil fuels. Public policy is also important because wind is variable according to the weather. While solar energy supplies are totally weather –dependent, that is, no sunlight, no energy – wind turbines keep turning even with very light winds, yet the amount of power generated varies greatly with wind speeds. This causes serious issues when wind supplies are connected to electricity power grids, as utilities require a base load level of power. The solution lies primarily in geographical aggregation, which in turn requires the extension of transmission and distribution grids, and sometimes electricity exchanges between different utilities and sometimes countries. Much of the wind energy generated in Denmark, for example, has to be exported to Germany and to Norway and Sweden, where hydroelectric power systems enable electricity to be stored. Public policy is typically crucial to finding solutions to the issue of wind variability. Public policy is also important because the construction of wind farms has a visual and sound effect which often provokes a reaction from local inhabitants, and can also have a significant effect on birds. The willingness of governments to explain the benefits of wind energy to their citizens, or else pay them off, is crucial.
Wind energy offers significant potential for near-term (2020) and long-term (2050) greenhouse gas (GHG) emissions reductions. A number of different wind energy technologies are available across a range of applications, but the primary use of wind energy of relevance to climate change mitigation is to generate electricity from larger, grid-connected wind turbines, deployed either on- or offshore. Focusing on these technologies, the wind power capacity installed by the end of

2009 was capable of meeting roughly 1.8% of worldwide electricity demand, and that contribution could grow to in excess of 20% by 2050 if ambitious efforts are made to reduce GHG emissions and to address the other impediments to increased wind energy deployment. Onshore wind energy is already being deployed at a rapid pace in many countries, and no insurmountable technical barriers exist that preclude increased levels of wind energy penetration into electricity supply systems. Moreover, though average wind speeds vary considerably by location, ample technical potential exists in most regions of the world to enable significant wind energy deployment. In some areas with good wind resources, the cost of wind energy is already competitive with current energy market prices, even without considering relative environmental impacts. Nonetheless, in most regions of the world, policy measures are still required to ensure rapid deployment. Continued advances in on-shore and offshore wind energy technology are expected, however, further reducing the cost of wind energy and improving wind energy's GHG emissions reduction potential.

Modern wind turbines have evolved from small, simple machines to large, highly sophisticated devices, driven in part by more than three decades of basic and applied research and development (R&D). Typical wind turbine nameplate capacity ratings have increased dramatically since the 1980s, from roughly 75 kW to 1.5 MW and larger; wind turbine rotors now often exceed 80 m in diameter and are positioned on towers exceeding 80 m in height. The resulting cost reductions, along with government policies to expand renewable energy (RE) supply, have led to rapid market development. From a cumulative capacity of 14 GW by the end of 1999, global installed wind power capacity increased 12-fold in 10 years to reach almost 160 GW by the end of 2009. Most additions have been onshore, but 2.1 GW of offshore capacity was installed by the end of 2009, with European countries embarking on ambitious programmes of offshore wind energy deployment. From 2000 through 2009, roughly 11% of all global newly installed net electric capacity additions (in GW) came from new wind power plants; in 2009 alone, that figure was likely more than 20%.

Wind energy has characteristics that pose new challenges to electric system planners and operators, such as variable electrical output, limited (but improving) output predictability, and location dependence. Acceptable wind electricity penetration limits and the operational costs of integration are system-specific, but wind energy has been successfully integrated into existing electric systems; in four countries (Denmark, Portugal, Spain, Ireland), wind energy in 2010 was already able to supply from 10 to roughly 20% of annual electricity demand. Detailed analyses and operating experience primarily from certain Organization for Economic Co-operation and Development (OECD) countries suggest that, at low to medium levels of wind electricity penetration (up to 20% of total electricity demand), the integration of wind energy generally poses no insurmountable technical barriers and is economically manageable.

The energy used and GHG emissions produced in the direct manufacture, transport, installation, operation and decommissioning of wind turbines are small compared to the energy generated and emissions avoided over the lifetime of wind power plants: the GHG emissions intensity of wind energy is estimated to range from 8 to 20 g CO_2 /kWh in most instances, whereas energy payback times are between 3.4 to 8.5 months. In addition, managing the variability of wind power output has not been found to significantly degrade the GHG emissions benefits of wind energy. Alongside these benefits, however, wind energy also has the potential to produce some detrimental impacts on the environment and on human activities and well-being. The construction and operation of wind power plants impacts wildlife through bird and bat collisions and through habitat and ecosystem modifications, with the nature and magnitude of those impacts being site and species-specific. For offshore wind energy, implications for benthic resources, fisheries and marine life must also be considered. Research is also underway on the potential impact of wind power plants on the local climate. As wind energy deployment increases and as larger wind power plants are considered, these existing concerns may become more acute and new concerns may arise. Though attempts to measure the relative impacts of various electricity supply technologies suggest that wind energy generally has a comparatively small environmental footprint, impacts do exist.

Given the commercial maturity and cost of onshore wind energy technology, wind energy offers the potential for significant near-term GHG emissions reductions: this potential is not conditioned on technology breakthroughs, and no insurmountable technical barriers exist that preclude increased levels of wind electricity penetration. As technology advances continue, greater contributions to GHG emissions reductions are possible in the longer term. Based on a review of the literature on the possible future contribution of RE supplies to meeting global energy needs under a range of GHG concentration stabilization scenarios, wind energy's contribution to global electricity supply could rise from 1.8% by the end of 2009 to 13 to 14% by 2050 in the median scenario for GHG concentration stabilization ranges of 440 to 600 and <440 ppm CO_2. At the 75th percentile of reviewed scenarios, and under similarly ambitious efforts to reduce GHG emissions, wind energy's contribution is shown to grow to 21 to 25% by 2050. Achieving the higher end of this range would be likely to require not only economic support policies of adequate size and predictability, but also an expansion of wind energy utilization regionally, increased reliance on offshore wind energy, technical and institutional solutions to transmission constraints and operational integration concerns, and proactive efforts to mitigate and manage social and environmental concerns.

2.3.1 Operation of a wind turbine

When wind blows past a wind turbine, the blades of the turbine capture the kinetic energy and rotate. The rotation triggers an internal shaft to spin. The shaft is connected to a gearbox thus increasing the speed of rotation, which is then connected to a generator producing electrical energy. Wind turbines usually consist of a steel tubular tower of up to 250 feet, which supports both a hub (secures the blades) and a nacelle (houses the shaft, gearbox, generator, and controls). It is also equipped with wind assessment equipment which configures the blades according to the direction of the wind, that is, it rotates automatically into the face of the wind and angles the blades to optimize energy capture.

Wind turbines often stand together in a windy area that has been through a robust development process in an interconnected group called a wind project or a wind farm which functions like a wind power plant. These turbines are connected so that electricity can travel from the farm to the power grid.

If the rotor of the wind turbine spins too slowly, most of the wind will pass straight through the gap between the blades, therefore giving it no power. But if the rotor spins too fast, the blades

will blur and act like a solid wall to the wind. Also, rotor blades create turbulence as they spin through the air. If the next blade arrives too quickly, it will hit that turbulent air. So, sometimes it is actually better to slow down the blades.
Wind power depends on:

- The amount of air (volume)
- The speed of air (velocity)
- The mass of air (density)

flowing through the area of interest.

The energy available for conversion mainly depends on the wind speed and the swept area of the turbine. The kinetic energy of a mass in motions is given by the equation:

$KE = ½ * m * v^2$; where m is mass and v is velocity.

The power in the wind is given by the rate of change of energy, that is, kinetic energy per unit time:

$P = dE/dt = ½ v^2 * dm/dt$; where dm/dt is the mass flow rate which is given by:

$dm/dt = \rho*A*dx/dt$; where dx/dt is the rate of change of distance (velocity, v) and A is the area swept by the turbine, which is given by:

$A = \pi r^2$; where r is the radius of the turbine (length of the blade).

So now we have:

$dm/dt = \rho*A*v$

giving us the power equation as:

$P = ½ \rho*A*v^3$

2.3.2 Betz law

A German physicist Albert Betz concluded in 1919 that no wind turbine can convert more than 16/27 (59.3%) of the kinetic energy of the wind into mechanical energy turning a rotor. To this day, this is known as the Betz Limit or Betz' Law. The theoretical maximum power efficiency of any design of wind turbine is 0.59, that is, no more than 59% of the energy carried by the wind can be extracted by a wind turbine. This is called the power coefficient and is defined as:

$C_{pmax} =0.59$

Also, wind turbines cannot operate at this maximum limit. The C_p value is unique to each turbine type and is a function of wind speed that the turbine is operating in. Once we incorporate various engineering requirements of a wind turbine - strength and durability in particular – the real world limit is well below the Betz Limit with values of 0.35-0.45 common even in the best designed wind turbines. By the time we take into account the other factors in a complete wind turbine

system - e.g. the gearbox, bearings, generator and so on - only 10-30% of the power of the wind is ever actually converted into usable electricity.
So we now have to take into account the effect of this limit into our power equation. This will give us the power available as:

$$P_{avail} = ½ ρ*A*v^3*C_p$$

2.4 Batteries

Batteries have benefited greatly from the technological advancement, enabling sufficient power density for use in electric power systems such as solar energy power systems and hybrid power systems. When compared to other battery technologies, lithium-ion (Li-Ion) batteries have several advantages in various aspects, such as higher energy densities and longer lifetimes. One of the key parameter that represents the available capacity in a battery is the battery State-of-Charge (SoC). There are basically two main methods used in SoC determination, i.e. measuring the battery open circuit voltage (OCV) and integrating the current flow into and out of the battery pack.
State of charge can be applied in various fields characterized as an important parameter for estimating residual capacity state of battery. It is obtained from current or collected data, such as voltage, current and temperature as well. The accuracy of estimation of SOC of power battery can be essential and premise in designing the battery management system.

2.5 Converter

A converter is a combination of an inverter and a rectifier.

- Inverter- Converts DC to AC power by switching the DC input voltage (or current) in a pre-determined sequence so as to generate AC voltage (or current) output.
- Rectifier – Converts AC to DC power by using power diodes or by controlling the firing angles of thyristors/controllable switches.

2.6 Hybrid power system

The rapid depletion of fossil fuel resources on a worldwide basis has necessitated an urgent search for alternative energy sources to cater to the present day demands. Alternative energy resources such as solar and wind have attracted energy sectors to generate power on a large scale.
A drawback, common to solar and wind options is their unpredictable nature and dependence on weather and climatic changes. Both of these would have to be oversized to make them completely reliable, resulting in an even higher total cost. Therefore, depending on the requirement and the availability of energy sources, more than two sources maybe combined, such as solar-wind-diesel system, which employs primary energy sources (solar and wind) coupled with secondary energy source (diesel generator) for power generation. This kind of

hybrid system can attenuate individual fluctuations, increase overall energy output and reduce energy storage requirements significantly. However, with the increased complexity in comparison with single energy systems, the optimum design of hybrid system becomes complicated through uncertain renewable energy supplies and load demand, non-linear characteristics of the components, and the fact that optimum configuration and optimum control strategy of the system are interdependent. This complexity makes the hybrid systems more difficult to design and analyze.

In order to efficiently and economically utilize the renewable energy resources, one optimum design method is necessary. It can help to guarantee the lowest investment but with full use of the energy sources and battery banks. Various optimization techniques, such as probabilistic approach, graphical construction method and iterative technique, have been recommended by researchers for renewable energy system designs.

One probabilistic approach has been presented by Tina based on the convolution technique to incorporate the fluctuating nature of the resources and the load, thus eliminating the need for time-series data. One graphical construction technique for figuring the optimum combination of battery and PV array in a hybrid solar-wind system has been presented by Borowy and Salameh. For the desired Loss of Power Supply Probability (LPSP), the PV array versus battery size is plotted and the optimal solution, which minimises the total system cost, can be chosen. However, in these kinds of graphical methods, only two parameters (either solar and wind turbine, solar and battery, or wind turbine and battery) were included in the optimization process.

Yang has proposed an iterative optimization technique following the loss of power supply probability (LPSP) method for a hybrid solar-wind system. The number selection of the PV module, wind turbine and battery ensures the load demand according to the reliability requirement, and the system cost is minimized. Besides these optimization techniques for designing solar and/or wind systems, also some diesel generator control strategies were found for the designing of power generation systems including diesel generators.

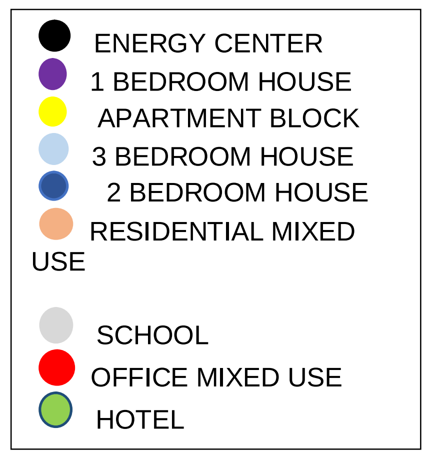
NREL (National renewable energy limited) developed the programme HOMER (Hybrid Optimization Model for Electric Renewables), which optimizes the hybrid systems. The user must enter the component parameters, and then the optimization can be carried out by choosing different combination of system configurations. This paper employs this programme to find the optimum design necessary to minimize the cost of energy.

CHAPTER 3: DESIGN

3.1 Introduction

The proposed neighborhood was to be located in Thika town in Kenya (1.0500° S, 37.0833° E). The hybrid power system was to provide electricity for the neighborhood with no connection to the Kenyan grid (the system was to be a stand – alone system).

Pictorial View of the Proposed Energy Efficient and Sustainable Neighbourhood Development.



The layout of the low zero carbon neighborhood has been inspired from the following book: Coyle, S. J. (2011). Sustainable and Resilient Communities: A Comprehensive Action Plan for Towns, Cities, and Regions. John Wiley & Sons.

Assumptions

In the proposed neighborhood design, the following assumptions were made:

- Location and weather data: Thika, Kenya
- Type of building in the proposed neighborhood:
    - 1-bedroom house:
        - The total number of 1-bedroom houses is 95

        - Assumed occupancy: two people per house
    - 2-bedroom house
        - Total number of 2-bedroom houses is 155
        - Assumed occupancy: three people per house
    - 3-bedrooom house
        - Total number of three bedroom houses is 120
        - Assumed occupancy: four people per house
    - Apartment block:
        - There are 40 apartment blocks in total
        - The apartment block is made up of 4 floors
        - In each floor of the apartment block there is a:
            - 1-bedroom unit (occupancy two people)
            - 2-bedroom unit (occupancy three people)
            - 3-bedroom unit (occupancy four people)
            - Therefore, there are nine people in total per floor
    - Residential mixed-use
        - There are 35 residential mixed-use blocks in total
        - Each residential mixed-use block is made up of 6 floors segregated as follows:
            - Ground floor retail (occupancy 50 people)
            - First floor offices (occupancy 30 people)
            - Second to fifth floor residential, each residential floor is made up of a:
              1-bedroom flat (Occupancy two people)
              3-bedroom unit (occupancy four people)
              Therefore, 6 people per residential floor
    - Office mixed-use:
        - There are 32 office mixed use blocks in total
        - Each office mixed-use block is made up of six floors segregated as follows:
            - Ground floor retail (occupancy fifty people)
            - First to third floor offices (Occupancy thirty people per floor)
            - Fourth to fifth floor residential, each residential floor is made up of a:
              1-bedroom unit (Occupancy two people)
              2-bedroom unit (Occupancy three people)
              Therefore, 5 people per residential floor
    - School:
        - Primary and secondary school. The assumed occupancy is 900 which include teachers, students and support staff. The total occupancy is for all the school blocks shown on the drawing
    - Hotel:

- A 95 bed roomed hotel is assume with an average of two people per room and 50 people as staff
- Energy Centers:
  - The buildings colored in black on the drawing are designated as potential sites for energy centers
- Agriculture:
  - It is assumed that there is a 10 km^2 of agricultural land north of the proposed neighborhood development.
- Industrial Area:
  - It is assumed that there is an industrial area 15 km to the south of the proposed development

The following table provides an energy breakdown per type of building and summarizes the total energy consumption of the neighborhood for a period of one year, which the study should be based upon.

	Number of buildings	Lighting (MWh)	Small Power	Cooling (MWh)	Domestic Hot Water	Occupancy (people)
1-bedroom house	1 97	0.84 MWh 81.91 MWh	0.57 MWh 55.03 MWh	0.77 MWh 74.59 MWh	0.66 MWh 63.65 MWh	2 194
2-bedroom house	1 154	1.10 MWh 169.32 MWh	0.78 MWh 120.17 MWh	0.87 MWh 133.24 MWh	0.87 MWh 134.46 MWh	3 462
3-bedroom house	1 119	1.67 MWh 198.37 MWh	1.37 MWh 163.48 MWh	1.55 MWh 184.61 MWh	1.47 MWh 174.72 MWh	4 476
Apartment	1 40	18.05 MWh 722.18 MWh	13.61 MWh 544.28 MWh	15.93 MWh 637.10 MWh	14.99 MWh 599.50 MWh	45 1800
Residential mixed-use	1 37	62.96 MWh 2329.37 MWh	35.64 MWh 1318.59 MWh	50.02 MWh 1850.60 MWh	9.64 MWh 356.73 MWh	104 3848
Office mixed-use	1 32	77.68 MWh 2485.77 MWh	50.10 MWh 1603.22 MWh	60.87 MWh 1947.89 MWh	5.33 MWh 170.48 MWh	150 4800
Hotel	1	13.83 MWh	14.90 MWh	43.71 MWh	34.80 MWh	240
School	6	411.80 MWh	272.58 MWh	303.83 MWh	280.93 MWh	900
Neighbourhood	**486**	**6,412.57 MWh 36.65%**	**4,092.25 MWh 23.39%**	**5,175.56 MWh 36.65%**	**1,815.26 MWh 10.38%**	

The hybrid system design was to provide for the load and have a reserve capacity to cater for increase in load or future expansion.

3.2 Data

The design involved collecting data on wind speed and solar radiation from the Kenya Meteorological Department. The data is given in the tables below

Solar radiation

Table 3.2.1

Month	Radiation (W/m^2)

January	25.5
February	25.6
March	26.4
April	16.5
May	17.9
June	14.7
July	12.5
August	17.7
September	20.6
October	22.2
November	19.3
December	17.2

Wind speed

Table 3.2.2

Month	Speed (m/s)
January	5.7
February	6.7
March	5.0
April	4.4
May	4.1
June	3.9
July	3.3
August	3.9
September	4.9
October	4.4
November	5.4
December	5.2

3.3 Design

The maximum demand was determined using the formula

Maximum demand = Total energy units / (load factor)*(8760)

8760 being the number of hours in a year. A composite load factor was considered by taking the average of typical residential load factor (0.3) and commercial load factor (0.25), giving a value of 0.275.

Maximum demand = 17495.64 MWh / (0.275)*(8760) = 7.2626MW

In order to cater for reserve capacity, maximum demand was incremented by 20% in order to determine the load that the power system had to meet (1.2*maximum demand). The load to be met was now

1.2*7.2626 = 8.71512MW

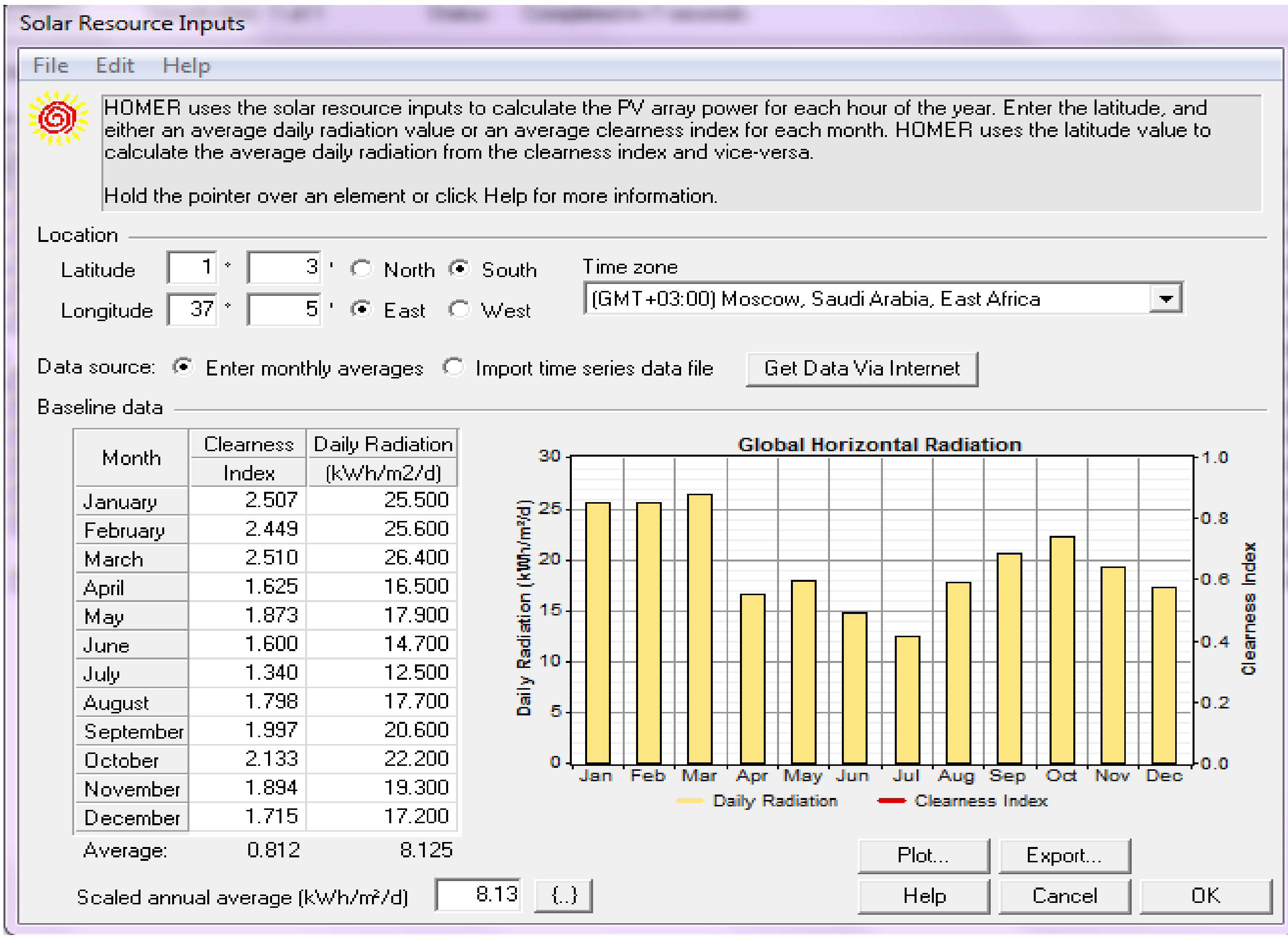
The capacity of the system was given by the equation

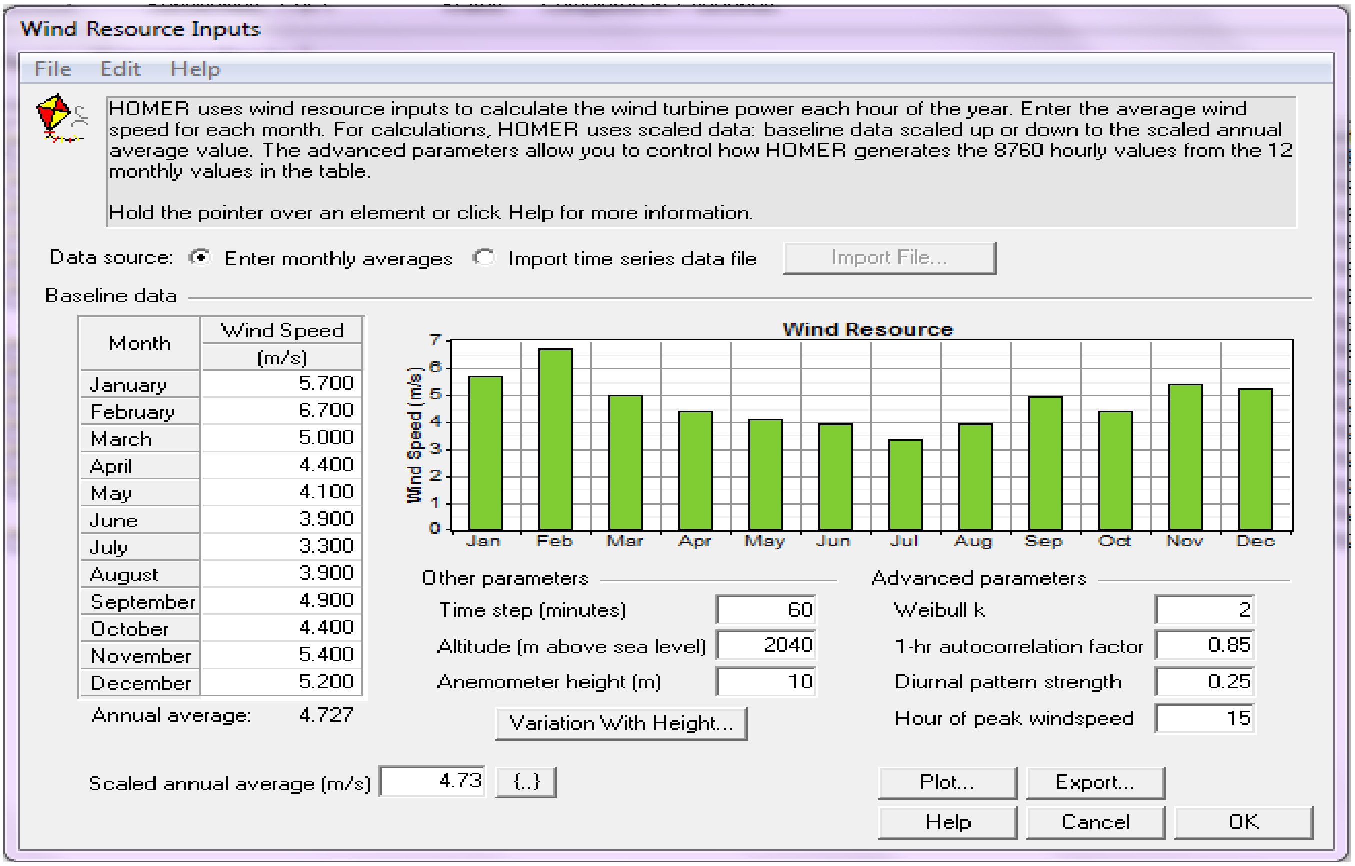
$$\text{Capacity (MVA)} = \text{load (MW)} / \text{power factor}$$

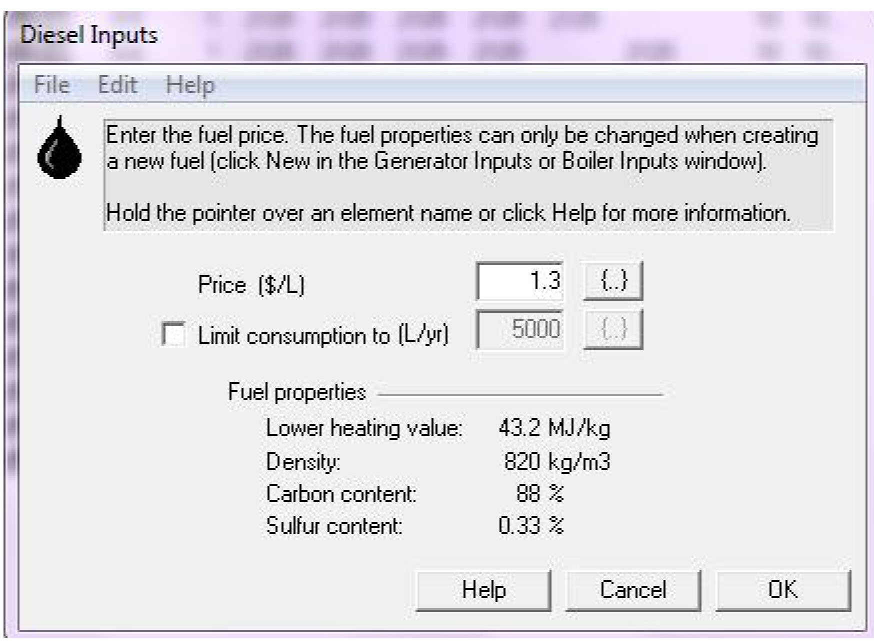
A power factor of 0.85 was chosen giving a capacity of

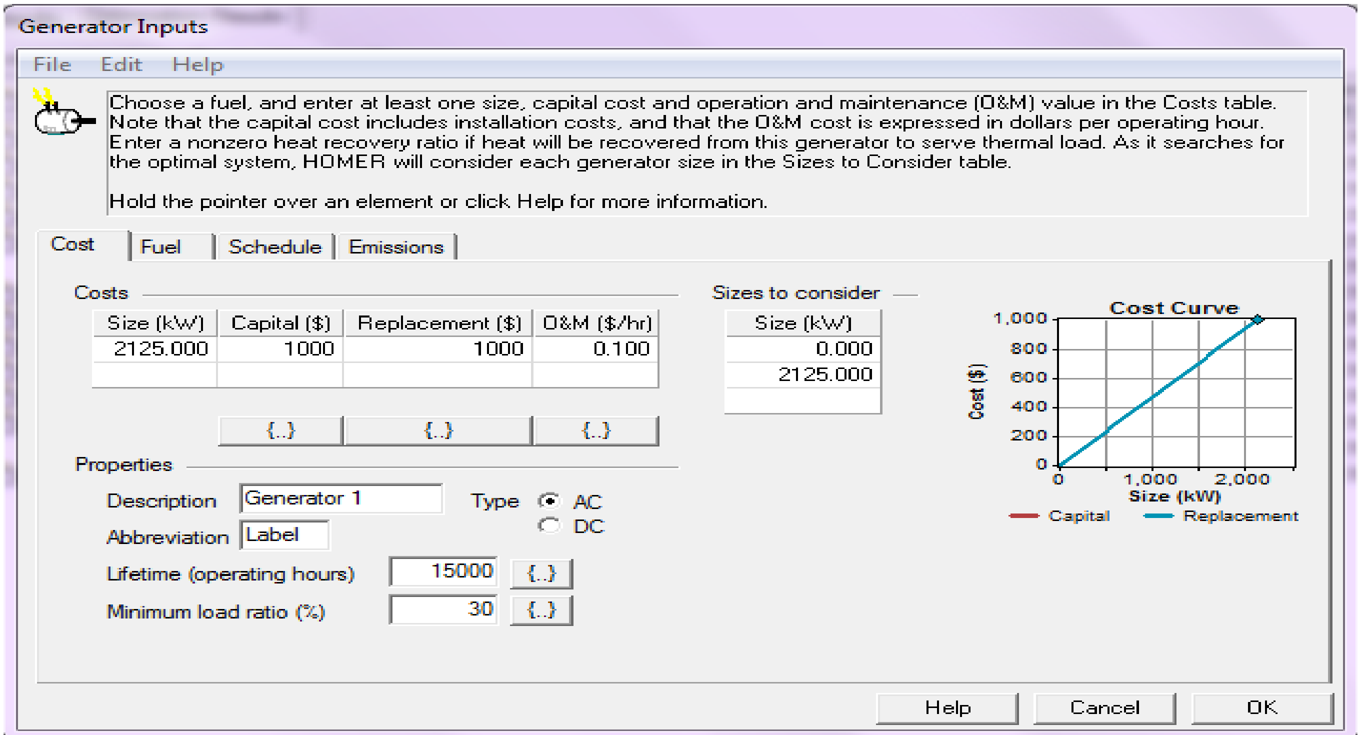
$$8.71512/0.85 = 10.253 \text{ MVA}$$

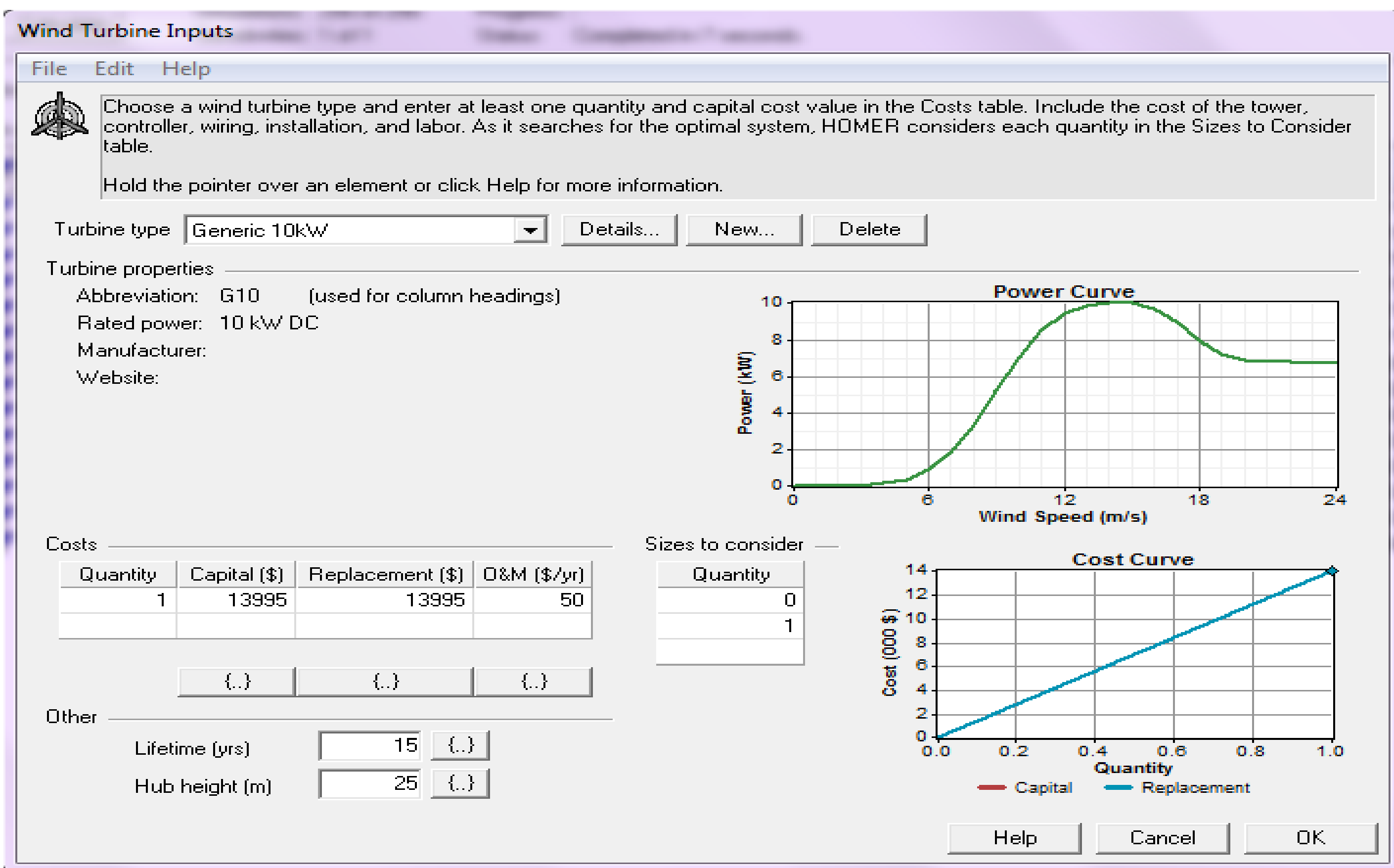
The system was designed using HOMER software which optimizes hybrid power systems to give the optimal topology of the system elements that satisfies the load. Different component parameters had to be entered as follows;

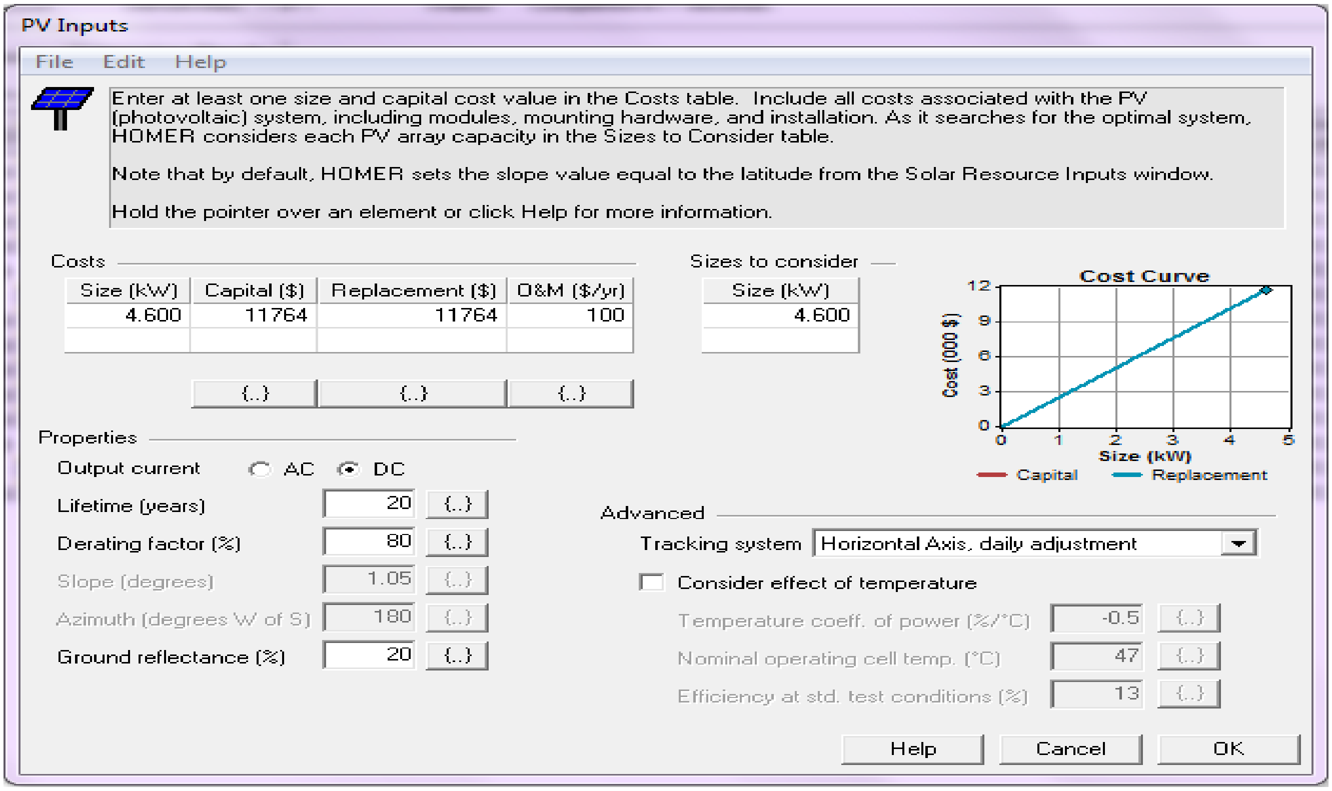


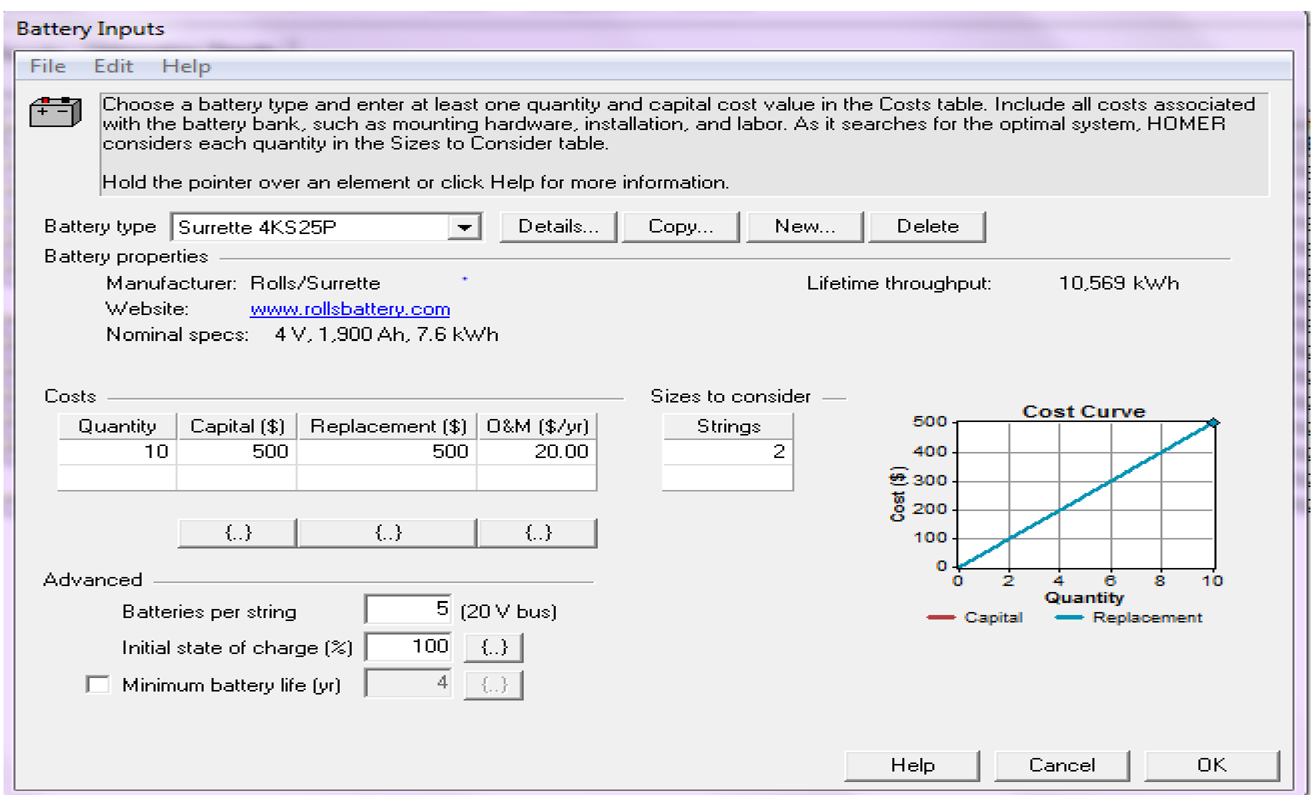

Wind Resource Inputs
File Edit Help
HOMER uses wind resource inputs to calculate the wind turbine power each hour of the year. Enter the average wind speed for each month. For calculations, HOMER uses scaled data: baseline data scaled up or down to the scaled annual average value. The advanced parameters allow you to control how HOMER generates the 8760 hourly values from the 12 monthly values in the table.
Hold the pointer over an element or click Help for more information.
Data source: Enter monthly averages Import time series data file Import File...
Baseline data
Month Wind Speed (m/s)
January 5.700
February 6.700
March 5.000
April 4.400
May 4.100
June 3.900
July 3.300
August 3.900
September 4.900
October 4.400
November 5.400
December 5.200
Annual average: 4.727
Wind Resource
Wind Speed (m/s)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Other parameters
Time step (minutes) 60
Altitude (m above sea level) 2040
Anemometer height (m) 10
Variation With Height...
Advanced parameters
Weibull k 2
1-hr autocorrelation factor 0.85
Diurnal pattern strength 0.25
Hour of peak windspeed 15
Scaled annual average (m/s) 4.73 {..}
Plot... Export...
Help Cancel OK

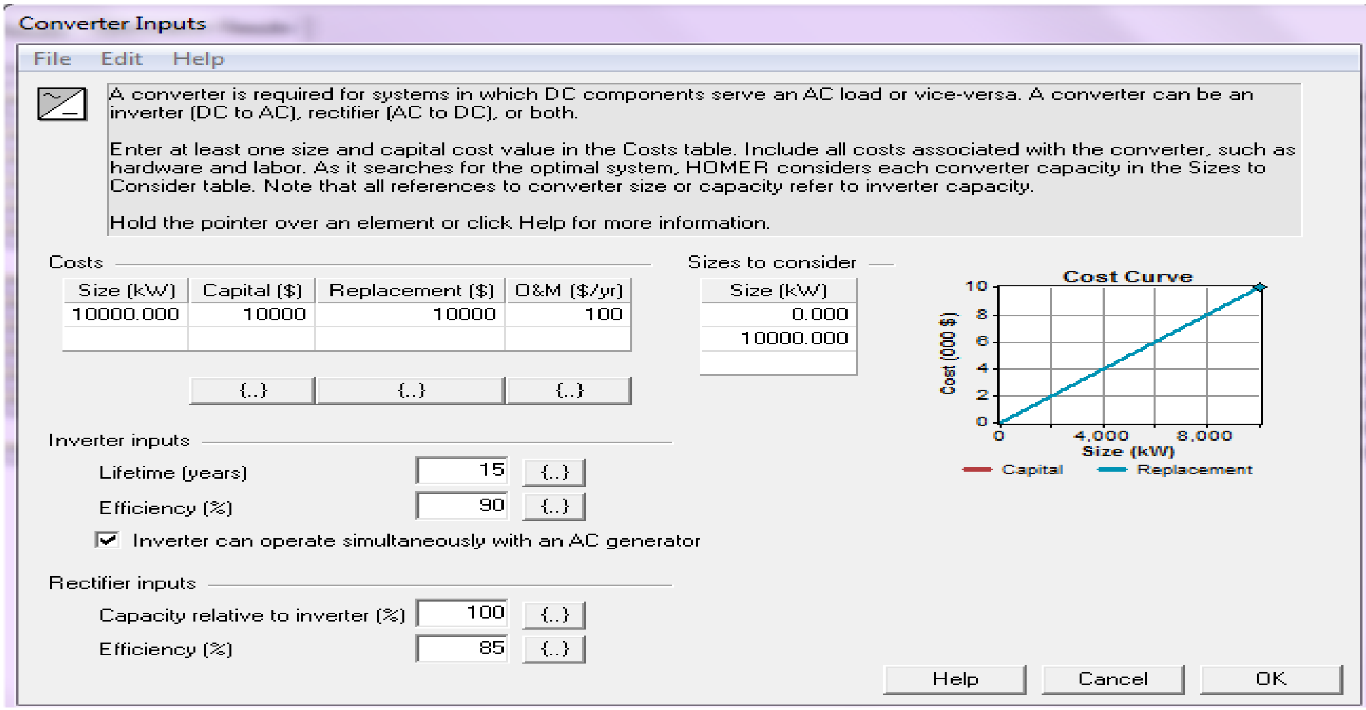

Diesel Inputs
File Edit Help
Enter the fuel price. The fuel properties can only be changed when creating a new fuel (click New in the Generator Inputs or Boiler Inputs window).
Hold the pointer over an element name or click Help for more information.
Price ($/L) 1.3 {..}
Limit consumption to (L/yr) 5000 {..}
Fuel properties
Lower heating value: 43.2 MJ/kg
Density: 820 kg/m3
Carbon content: 88 %
Sulfur content: 0.33 %
Help Cancel OK


Generator Inputs
File Edit Help
Choose a fuel, and enter at least one size, capital cost and operation and maintenance (O&M) value in the Costs table. Note that the capital cost includes installation costs, and that the O&M cost is expressed in dollars per operating hour. Enter a nonzero heat recovery ratio if heat will be recovered from this generator to serve thermal load. As it searches for the optimal system, HOMER will consider each generator size in the Sizes to Consider table.
Hold the pointer over an element or click Help for more information.
Cost
Fuel
Schedule
Emissions
Costs
Size (kW)
Capital ($)
Replacement ($)
O&M ($/hr)
2125.000
1000
1000
0.100
Sizes to consider
Size (kW)
0.000
2125.000
Cost Curve
Cost ($)
Size (kW)
Capital
Replacement
Properties
Description
Generator 1
Abbreviation
Label
Type
AC
DC
Lifetime (operating hours)
15000
Minimum load ratio (%)
30
Help
Cancel
OK

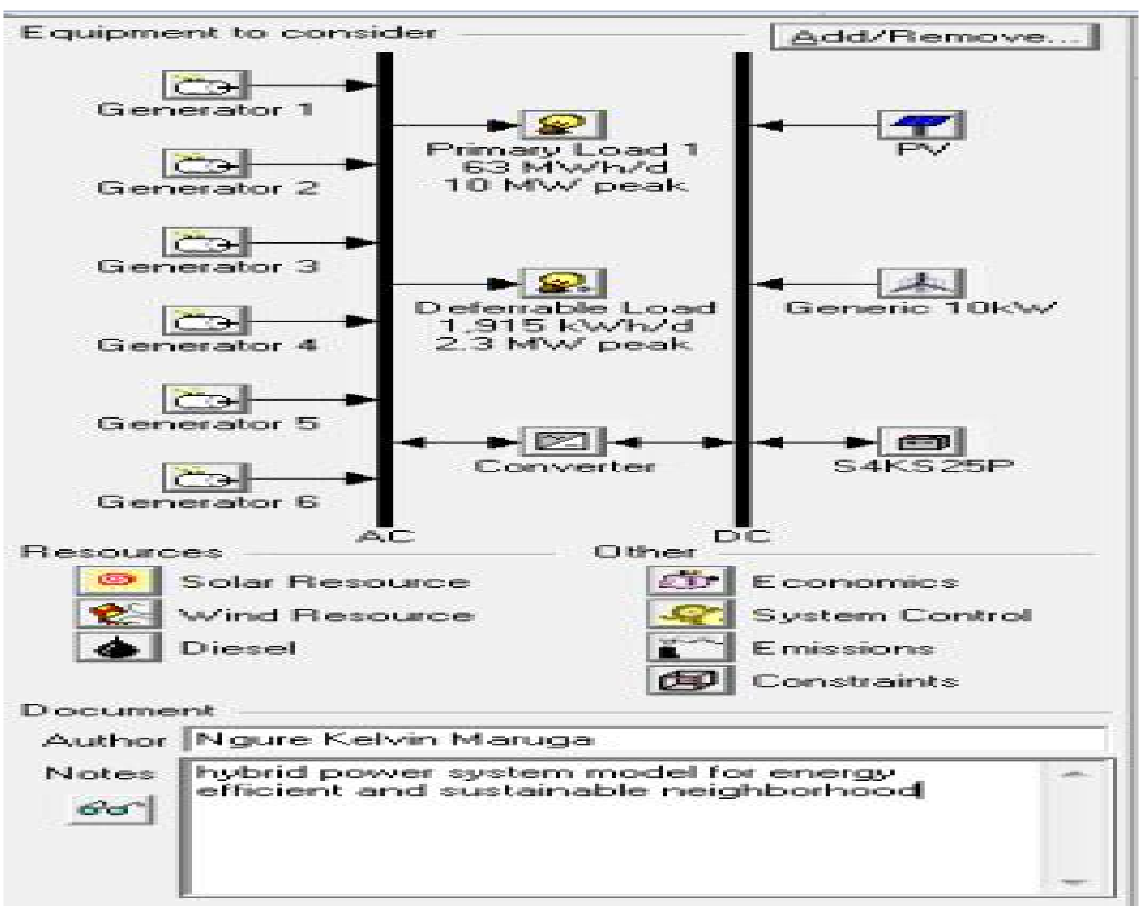

Wind Turbine Inputs
File Edit Help
Choose a wind turbine type and enter at least one quantity and capital cost value in the Costs table. Include the cost of the tower, controller, wiring, installation, and labor. As it searches for the optimal system, HOMER considers each quantity in the Sizes to Consider table.
Hold the pointer over an element or click Help for more information.
Turbine type
Generic 10kW
Details...
New...
Delete
Turbine properties
Abbreviation: G10 (used for column headings)
Rated power: 10 kW DC
Manufacturer:
Website:
Power Curve
Power (kW)
Wind Speed (m/s)
Costs
Quantity
Capital ($)
Replacement ($)
O&M ($/yr)
1
13995
13995
50
Sizes to consider
Quantity
0
1
Cost Curve
Cost (000 $)
Quantity
Capital
Replacement
Other
Lifetime (yrs)
15
Hub height (m)
25
Help
Cancel
OK


PV Inputs
File Edit Help
Enter at least one size and capital cost value in the Costs table. Include all costs associated with the PV (photovoltaic) system, including modules, mounting hardware, and installation. As it searches for the optimal system, HOMER considers each PV array capacity in the Sizes to Consider table.
Note that by default, HOMER sets the slope value equal to the latitude from the Solar Resource Inputs window.
Hold the pointer over an element or click Help for more information.
Costs
Size (kW) Capital ($) Replacement ($) O&M ($/yr)
4.600 11764 11764 100
Sizes to consider
Size (kW)
4.600
Cost Curve
Cost (000 $)
Size (kW)
Capital
Replacement
Properties
Output current AC DC
Lifetime (years) 20
Derating factor (%) 80
Slope (degrees) 1.05
Azimuth (degrees W of S) 180
Ground reflectance (%) 20
Advanced
Tracking system Horizontal Axis, daily adjustment
Consider effect of temperature
Temperature coeff. of power (%/°C) -0.5
Nominal operating cell temp. (°C) 47
Efficiency at std. test conditions (%) 13
Help Cancel OK


Battery Inputs
File Edit Help
Choose a battery type and enter at least one quantity and capital cost value in the Costs table. Include all costs associated with the battery bank, such as mounting hardware, installation, and labor. As it searches for the optimal system, HOMER considers each quantity in the Sizes to Consider table.
Hold the pointer over an element or click Help for more information.
Battery type Surrette 4KS25P Details... Copy... New... Delete
Battery properties
Manufacturer: Rolls/Surrette
Website: www.rollsbattery.com
Nominal specs: 4 V, 1,900 Ah, 7.6 kWh
Lifetime throughput: 10,569 kWh
Costs
Quantity Capital ($) Replacement ($) O&M ($/yr)
10 500 500 20.00
Sizes to consider
Strings
2
Cost Curve
Cost ($)
Quantity
Capital
Replacement
Advanced
Batteries per string 5 (20 V bus)
Initial state of charge (%) 100
Minimum battery life (yr) 4
Help Cancel OK



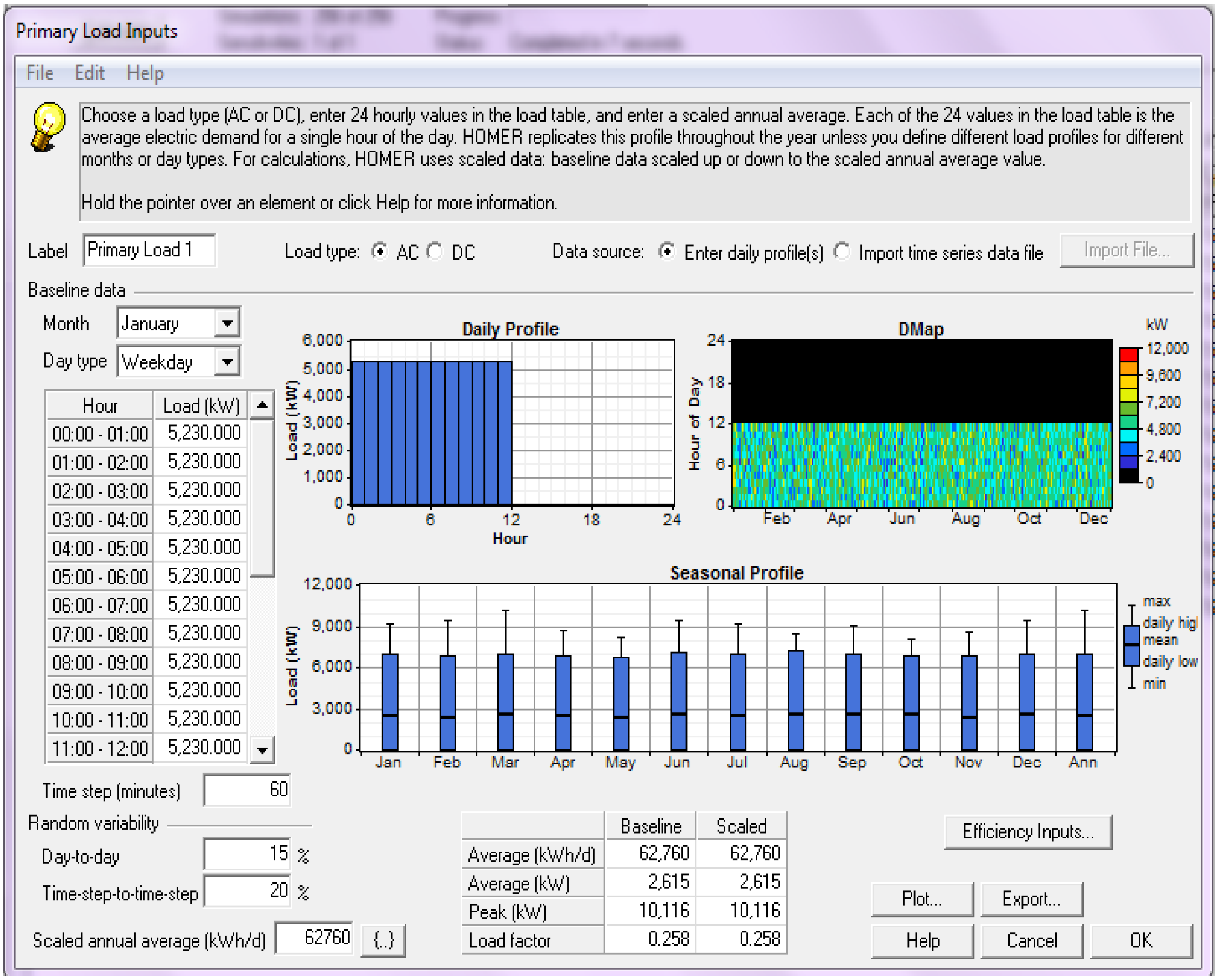
The design was as shown below



The primary load was calculated by using the same formula used to calculate the maximum demand. This primary load is load that has to be satisfied throughout the day and in this case it was the sum of lighting load and small power load.
Assuming that this primary load was operational throughout the day, and that it could maybe increase by about 20%, then we have

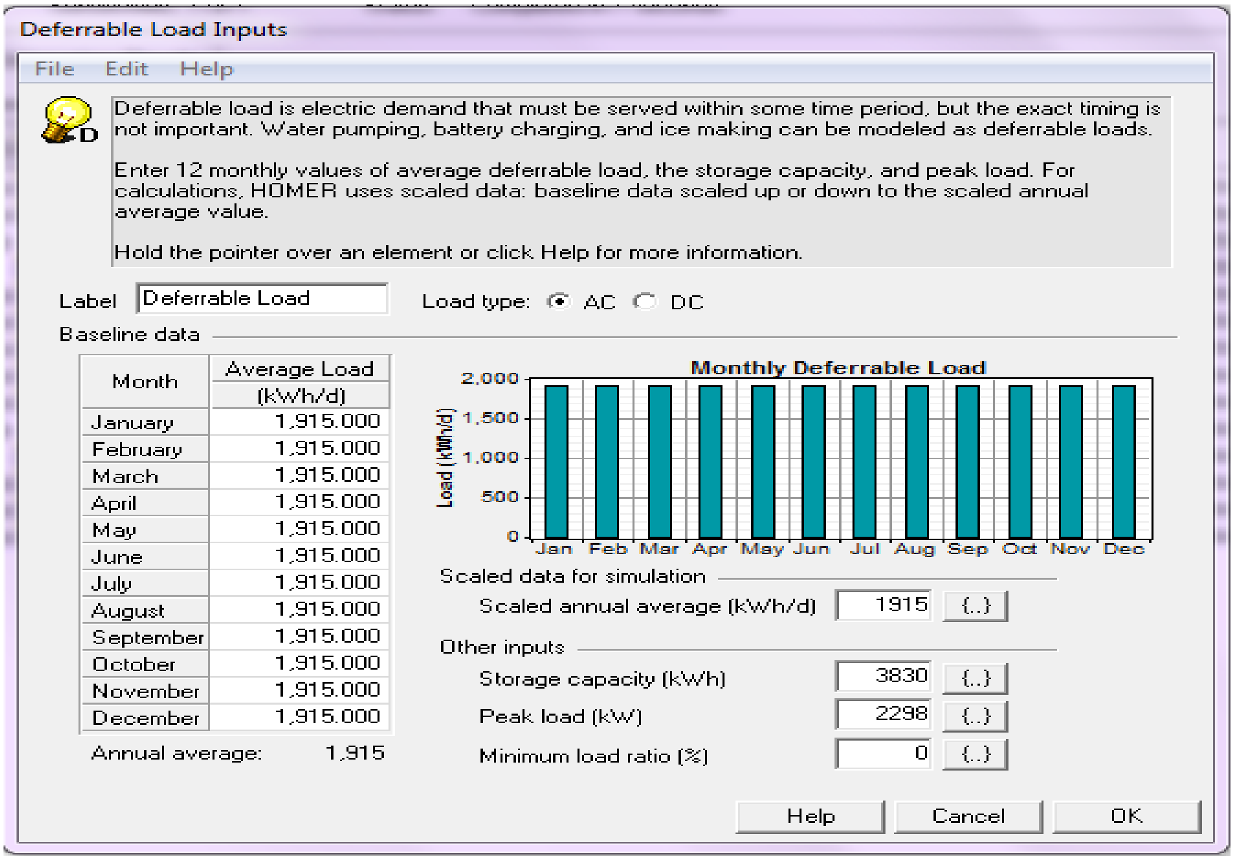
$$\text{Primary load} = 1.2*\{10504.82/ (8760*0.275)\} = 5.233\text{MW}$$

This value was input as shown below



The software then calculated the peak primary load and found it to be 10MW.

Deferrable load was also calculated using the same formula and was found to be a peak value of 2.3MW.



CHAPTER 4: RESULTS AND ANALYSIS

The software finished the simulation and gave different topologies for a hybrid power system as shown below.

PV (kW)	G10	Label (kW)	Label (kW)	Label (kW)	Label (kW)	Label (kW)	Label (kW)	S4KS25P	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Label (hrs)	Labe (hrs)
4.6	1	2125	2125	2125	2125	2125		10	10...	$ 41,259	10,759,777	$ 137,587,3...	0.456	0.00	8,274,286	4,379	4,35
4.6	1	2125	2125	2125	2125		2125	10	10...	$ 41,259	10,759,777	$ 137,587,3...	0.456	0.00	8,274,286	4,379	4,35
4.6	1	2125	2125	2125		2125	2125	10	10...	$ 41,259	10,759,777	$ 137,587,3...	0.456	0.00	8,274,286	4,379	4,35
4.6	1	2125	2125		2125	2125	2125	10	10...	$ 41,259	10,759,777	$ 137,587,3...	0.456	0.00	8,274,286	4,379	4,35
4.6	1	2125		2125	2125	2125	2125	10	10...	$ 41,259	10,759,777	$ 137,587,3...	0.456	0.00	8,274,286	4,379	
4.6	1		2125	2125	2125	2125	2125	10	10...	$ 41,259	10,759,777	$ 137,587,3...	0.456	0.00	8,274,286		4,37
4.6	1	2125	2125	2125	2125	2125	2125	10	10...	$ 42,259	10,759,980	$ 137,590,9...	0.456	0.00	8,274,456	4,379	4,35
4.6		2125	2125	2125	2125	2125		10	10...	$ 27,264	10,762,663	$ 137,610,2...	0.456	0.00	8,276,831	4,379	4,35
4.6		2125	2125	2125	2125		2125	10	10...	$ 27,264	10,762,663	$ 137,610,2...	0.456	0.00	8,276,831	4,379	4,35
4.6		2125	2125	2125		2125	2125	10	10...	$ 27,264	10,762,663	$ 137,610,2...	0.456	0.00	8,276,831	4,379	4,35
4.6		2125	2125		2125	2125	2125	10	10...	$ 27,264	10,762,663	$ 137,610,2...	0.456	0.00	8,276,831	4,379	4,35
4.6		2125		2125	2125	2125	2125	10	10...	$ 27,264	10,762,663	$ 137,610,2...	0.456	0.00	8,276,831	4,379	
4.6			2125	2125	2125	2125	2125	10	10...	$ 27,264	10,762,663	$ 137,610,2...	0.456	0.00	8,276,831		4,37
4.6		2125	2125	2125	2125	2125	2125	10	10...	$ 28,264	10,762,866	$ 137,613,8...	0.456	0.00	8,277,001	4,379	4,35

Label (hrs)	Label (hrs)	Label (hrs)	Label (hrs)
3,724	1,421	107	
3,724	1,421		107
3,724		1,421	107
	3,724	1,421	107
4,358	3,724	1,421	107
4,358	3,724	1,421	107
3,724	1,421	107	1
3,724	1,421	107	
3,724	1,421		107
3,724		1,421	107
	3,724	1,421	107
4,358	3,724	1,421	107
4,358	3,724	1,421	107
3,724	1,421	107	1

The results show that the different combinations have different costs, with the optimal model being the top most combination, since it has the least operating cost.

Detailed Optimization Results

#	PV (kW)	G10	Label (kW)	Label (kW)	Label (kW)	Label (kW)	Label (kW)	Label (kW)	Battery 1	Converter (kW)
1	4.6	1	2,125	2,125	2,125	2,125	2,125	0	10	10,000
2	4.6	1	2,125	2,125	2,125	2,125	0	2,125	10	10,000
3	4.6	1	2,125	2,125	2,125	0	2,125	2,125	10	10,000
4	4.6	1	2,125	2,125	0	2,125	2,125	2,125	10	10,000
5	4.6	1	2,125	0	2,125	2,125	2,125	2,125	10	10,000
6	4.6	1	0	2,125	2,125	2,125	2,125	2,125	10	10,000
7	4.6	1	2,125	2,125	2,125	2,125	2,125	2,125	10	10,000
8	4.6	0	2,125	2,125	2,125	2,125	2,125	0	10	10,000
9	4.6	0	2,125	2,125	2,125	2,125	0	2,125	10	10,000
10	4.6	0	2,125	2,125	2,125	0	2,125	2,125	10	10,000
11	4.6	0	2,125	2,125	0	2,125	2,125	2,125	10	10,000
12	4.6	0	2,125	0	2,125	2,125	2,125	2,125	10	10,000
13	4.6	0	0	2,125	2,125	2,125	2,125	2,125	10	10,000
14	4.6	0	2,125	2,125	2,125	2,125	2,125	2,125	10	10,000

Detailed Optimization Results

#	Total Capital Cost ($)	Total NPC ($)	Tot. Ann. Cap. Cost ($/yr)	Tot. Ann. Repl. Cost ($/yr)	Total O&M Cost ($/yr)	Total Fuel Cost ($/yr)	Total Ann. Cost ($/yr)	Operating Cost ($/yr)	COE ($/kWh)	PV Production (kWh/yr)
1	41,259	137,587,328	3,228	1,538	1,669	10,756,571	10,763,005	10,759,777	0.456	11,791
2	41,259	137,587,328	3,228	1,538	1,669	10,756,571	10,763,005	10,759,777	0.456	11,791
3	41,259	137,587,328	3,228	1,538	1,669	10,756,571	10,763,005	10,759,777	0.456	11,791
4	41,259	137,587,328	3,228	1,538	1,669	10,756,571	10,763,005	10,759,777	0.456	11,791
5	41,259	137,587,328	3,228	1,538	1,669	10,756,571	10,763,005	10,759,777	0.456	11,791
6	41,259	137,587,328	3,228	1,538	1,669	10,756,571	10,763,005	10,759,777	0.456	11,791
7	42,259	137,590,928	3,306	1,520	1,669	10,756,792	10,763,286	10,759,980	0.456	11,791
8	27,264	137,610,224	2,133	1,166	1,619	10,759,880	10,764,796	10,762,663	0.456	11,791
9	27,264	137,610,224	2,133	1,166	1,619	10,759,880	10,764,796	10,762,663	0.456	11,791
10	27,264	137,610,224	2,133	1,166	1,619	10,759,880	10,764,796	10,762,663	0.456	11,791
11	27,264	137,610,224	2,133	1,166	1,619	10,759,880	10,764,796	10,762,663	0.456	11,791
12	27,264	137,610,224	2,133	1,166	1,619	10,759,880	10,764,796	10,762,663	0.456	11,791
13	27,264	137,610,224	2,133	1,166	1,619	10,759,880	10,764,796	10,762,663	0.456	11,791
14	28,264	137,613,824	2,211	1,148	1,619	10,760,100	10,765,077	10,762,866	0.456	11,791

Detailed Optimization Results

#	Wind Production kWh/yr	Label Production kWh/yr	Label Production kWh/yr	Label Production kWh/yr	Label Production kWh/yr	Label Production kWh/yr	Label Production kWh/yr	Tot. Electrical Production kWh/yr	AC Primary Load Served kWh/yr	Deferable Load Served kWh/yr
1	11,347	9,272,902	8,381,812	4,716,617	1,141,857	71,433	0	23,607,758	22,907,400	698,062
2	11,347	9,272,902	8,381,812	4,716,617	1,141,857	0	71,433	23,607,758	22,907,400	698,062
3	11,347	9,272,902	8,381,812	4,716,617	0	1,141,857	71,433	23,607,758	22,907,400	698,062
4	11,347	9,272,902	8,381,812	0	4,716,617	1,141,857	71,433	23,607,758	22,907,400	698,062
5	11,347	9,272,902	0	8,381,812	4,716,617	1,141,857	71,433	23,607,758	22,907,400	698,062
6	11,347	0	9,272,902	8,381,812	4,716,617	1,141,857	71,433	23,607,758	22,907,400	698,062
7	11,347	9,272,902	8,381,812	4,716,617	1,141,857	70,796	638	23,607,758	22,907,400	698,062
8	0	9,273,152	8,384,032	4,722,194	1,143,949	71,503	0	23,606,622	22,907,400	698,044
9	0	9,273,152	8,384,032	4,722,194	1,143,949	0	71,503	23,606,622	22,907,400	698,044
10	0	9,273,152	8,384,032	4,722,194	0	1,143,949	71,503	23,606,622	22,907,400	698,044
11	0	9,273,152	8,384,032	0	4,722,194	1,143,949	71,503	23,606,622	22,907,400	698,044
12	0	9,273,152	0	8,384,032	4,722,194	1,143,949	71,503	23,606,622	22,907,400	698,044
13	0	0	9,273,152	8,384,032	4,722,194	1,143,949	71,503	23,606,622	22,907,400	698,044
14	0	9,273,152	8,384,032	4,722,194	1,143,949	70,866	638	23,606,622	22,907,400	698,044

Detailed Optimization Results

#	Ren. Fraction	Cap. Shortage kWh/yr	Cap. Shortage Frac.	Unmet Load kWh/yr	Unmet Load Frac.	Excess Electricity kWh/yr	Diesel L/yr	CO2 Emissions kg/yr	CO Emissions kg/yr	UHC Emissions kg/yr
1	0.00	484	0	0	0.00	0	8,274,286	21,788,918	53,783	5,957
2	0.00	484	0	0	0.00	0	8,274,286	21,788,918	53,783	5,957
3	0.00	484	0	0	0.00	0	8,274,286	21,788,918	53,783	5,957
4	0.00	484	0	0	0.00	0	8,274,286	21,788,918	53,783	5,957
5	0.00	484	0	0	0.00	0	8,274,286	21,788,918	53,783	5,957
6	0.00	484	0	0	0.00	0	8,274,286	21,788,918	53,783	5,957
7	0.00	0	0	0	0.00	0	8,274,456	21,789,366	53,784	5,958
8	0.00	484	0	0	0.00	0	8,276,831	21,795,620	53,799	5,959
9	0.00	484	0	0	0.00	0	8,276,831	21,795,620	53,799	5,959
10	0.00	484	0	0	0.00	0	8,276,831	21,795,620	53,799	5,959
11	0.00	484	0	0	0.00	0	8,276,831	21,795,620	53,799	5,959
12	0.00	484	0	0	0.00	0	8,276,831	21,795,620	53,799	5,959
13	0.00	484	0	0	0.00	0	8,276,831	21,795,620	53,799	5,959
14	0.00	0	0	0	0.00	0	8,277,001	21,796,068	53,801	5,959

Detailed Optimization Results

#	PM Emissions	SO2 Emissions	NOx Emissions	Label Fuel	Label Hours	Label Starts	Label Life	Label Fuel	Label Hours	Label Starts
	kg/yr	kg/yr	kg/yr	L/yr	hr/yr	starts/yr	yr	L/yr	hr/yr	starts/yr
1	4,054	43,756	479,909	3,062,656	4,379	366	3.43	2,836,313	4,358	385
2	4,054	43,756	479,909	3,062,656	4,379	366	3.43	2,836,313	4,358	385
3	4,054	43,756	479,909	3,062,656	4,379	366	3.43	2,836,313	4,358	385
4	4,054	43,756	479,909	3,062,656	4,379	366	3.43	2,836,313	4,358	385
5	4,054	43,756	479,909	3,062,656	4,379	366	3.43	0	0	0
6	4,054	43,756	479,909	0	0	0	1,000.00	3,062,656	4,379	366
7	4,054	43,757	479,918	3,062,656	4,379	366	3.43	2,836,313	4,358	385
8	4,056	43,769	480,056	3,062,718	4,379	366	3.43	2,836,862	4,358	385
9	4,056	43,769	480,056	3,062,718	4,379	366	3.43	2,836,862	4,358	385
10	4,056	43,769	480,056	3,062,718	4,379	366	3.43	2,836,862	4,358	385
11	4,056	43,769	480,056	3,062,718	4,379	366	3.43	2,836,862	4,358	385
12	4,056	43,769	480,056	3,062,718	4,379	366	3.43	0	0	0
13	4,056	43,769	480,056	0	0	0	1,000.00	3,062,718	4,379	366
14	4,056	43,770	480,066	3,062,718	4,379	366	3.43	2,836,862	4,358	385

Detailed Optimization Results

#	Label Life	Label Fuel	Label Hours	Label Starts	Label Life	Label Fuel	Label Hours	Label Starts	Label Life	Label Fuel
	yr	L/yr	hr/yr	starts/yr	yr	L/yr	hr/yr	starts/yr	yr	L/yr
1	3.44	1,812,234	3,724	703	4.03	527,034	1,421	831	10.56	36,048
2	3.44	1,812,234	3,724	703	4.03	527,034	1,421	831	10.56	0
3	3.44	1,812,234	3,724	703	4.03	0	0	0	1,000.00	527,034
4	3.44	0	0	0	1,000.00	1,812,234	3,724	703	4.03	527,034
5	1,000.00	2,836,313	4,358	385	3.44	1,812,234	3,724	703	4.03	527,034
6	3.43	2,836,313	4,358	385	3.44	1,812,234	3,724	703	4.03	527,034
7	3.44	1,812,234	3,724	703	4.03	527,034	1,421	831	10.56	35,889
8	3.44	1,813,628	3,724	703	4.03	527,557	1,421	831	10.56	36,066
9	3.44	1,813,628	3,724	703	4.03	527,557	1,421	831	10.56	0
10	3.44	1,813,628	3,724	703	4.03	0	0	0	1,000.00	527,557
11	3.44	0	0	0	1,000.00	1,813,628	3,724	703	4.03	527,557
12	1,000.00	2,836,862	4,358	385	3.44	1,813,628	3,724	703	4.03	527,557
13	3.43	2,836,862	4,358	385	3.44	1,813,628	3,724	703	4.03	527,557
14	3.44	1,813,628	3,724	703	4.03	527,557	1,421	831	10.56	35,906

Detailed Optimization Results

#	Label Hours	Label Starts	Label Life	Label Fuel	Label Hours	Label Starts	Label Life	Battery Autonomy	Battery Throughput	Battery Life
	hr/yr	starts/yr	yr	L/yr	hr/yr	starts/yr	yr	hr	kWh/yr	yr
1	107	91	140.19	0	0	0	1,000.00	0.02	23	12.0
2	0	0	1,000.00	36,048	107	91	140.19	0.02	23	12.0
3	1,421	831	10.56	36,048	107	91	140.19	0.02	23	12.0
4	1,421	831	10.56	36,048	107	91	140.19	0.02	23	12.0
5	1,421	831	10.56	36,048	107	91	140.19	0.02	23	12.0
6	1,421	831	10.56	36,048	107	91	140.19	0.02	23	12.0
7	107	91	140.19	329	1	1	15,000.00	0.02	23	12.0
8	107	91	140.19	0	0	0	1,000.00	0.02	23	12.0
9	0	0	1,000.00	36,066	107	91	140.19	0.02	23	12.0
10	1,421	831	10.56	36,066	107	91	140.19	0.02	23	12.0
11	1,421	831	10.56	36,066	107	91	140.19	0.02	23	12.0
12	1,421	831	10.56	36,066	107	91	140.19	0.02	23	12.0
13	1,421	831	10.56	36,066	107	91	140.19	0.02	23	12.0
14	107	91	140.19	329	1	1	15,000.00	0.02	23	12.0

A hybrid power system consisting of a 4.6kW photovoltaic array, a 10kW generic wind turbine and five 2.125MW diesel generators can supply power to a neighborhood with minimal green house gases emission.
Though it has a better initial capital cost, a system with more diesel generators and less renewable energy elements has a higher operating cost due to the increased fuel prices and also has more GHG emissions.
The capital cost for the solar panels and the wind turbines are very high as compared to the capital cost of a diesel generator, but for the lifetime of the project, they are relatively cheap since they don't require fuel to operate.
The battery state of charge set point for the diesel generator control is a user entered value and the HOMER software tool does not optimize this value.
Another concern for diesel generator design and control strategy selection is that the diesel generator shall not be lightly loaded. Running the diesel generator with a low capacity factor will increase fuel consumption and wear. The fuel consumption is higher than normal during a cold start of the diesel generator, especially under low capacity factors. Many of such starting periods in a short time also contribute to increased diesel generator wear.
The renewable energy fraction is the portion of the system's total energy production originating from renewable power sources.
The battery manufactures usually recommend that the battery state-of-charge should not fall under a certain level so as to increase the lifetime of the battery, hence minimizing the replacement cost of the batteries.

CHAPTER 5: CONCLUSION

The design of an energy center for energy efficient and sustainable neighborhood development is done in this paper by applying a hybrid power system model to supply power to a neighborhood in Thika town. The model is the optimal combination of solar wind and diesel energy systems. The system offers energy with reduced emission of green house gases (CO_2, CO, NOx, SO_2, UHC, and PM).

This model can serve as a reference to upcoming neighborhood development projects so that the depletion of the ozone layer can be minimized.

REFERENCES

Ahmad Agus Setiawan and Chem. V. Nayar, ñDesign of a hybrid power system for a remote island in Maldives,ò Proc. Curtin University of Technology, Australia.

Karim Mousa, Hamzah AlZu'bi and Ali Diabat, ñDesign of a hybrid solar-wind power plant using optimization,ò Proc. Masdar Institute of Science and Technology, Abu Dhabi, UAE.

ñHybrid power systems July 2, 2012ò Proc. Energy.gov

Saeid Lotfi Trazouei, Farid Lotfi Tarazouei and Mohammad Giammy, ñOptimal design of a hybrid solar-wind diesel power system for rural electrification using imperialist competitive algorithm,ò Proc. Islamic Azad University, Ardabil branch.

US Department of Energy, Energy Efficiency and Renewable Energy, The History of Solar.

Basic research needs for solar utilization, report of the basic energy science workshop on solar energy utilization April 18-21, 2005.

RWE npower renewables, ñwind turbine power calculations,ò The Royal Academy of Engineering.

Coyle, S. J. (2011). Sustainable and Resilient Communities: A Comprehensive Action Plan for Towns, Cities, and Regions. John Wiley & Sons.

www.wikipedia.com