DESIGN OF RENEWABLE ENERGY SYSTEM FOR A MOBILE OFFICE/HOSPITAL IN AN ISOLATED RURAL AREA

By

© Emadeddin A A Hussein

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Dedicated to my

Mother and father who have always been there for me when I needed them, even when I couldn’t admit that I needed them

ABSTRACT

This thesis proposes a standalone hybrid generation system by combining solar and wind energy with provision of a battery storage bank and diesel generator for back up usage. This thesis has discussed the optimization, sizing, and operational strategy of hybrid renewable energy system, which results in a minimum cost. Detailed AutoCAD drawings used in Energy3D and BEopt modeling which has been done for every component of the hybrid power system. The system dynamic model and simulations presented here was done in Matlab/Simulink, which is fast accurate software that includes dynamic and supervisory controllers. The proposed controller algorithm observes the available surplus/missing power in the system and regulates PV/Wind-Turbine and charging/discharging of the battery bank to maintain a stable system frequency. The simulation results obtained from Matlab/Simulink show that the overall hybrid framework is capable of working under the variable weather and load conditions.

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LIST OF ABBREVIATION

List of abbreviations	Description
A	Ampere
AC	Alternating Current
Ah	Ampere-hour
BB	Battery Bank
BC	Battery Capacity
CC	Capital Cost
DC	Direct Current
DCC	Daily Charging Capacity
DFC	Daily Fuel Consumption
DG	Diesel Generator
DOD	Depth of Discharge
NASA	National Aeronautics and Space Administration
DRT	Daily Running Time of the PV-system
DSH	Daily Sun Hour
ECS	Energy Conversion System
EPP	Electrical Power Processing
FC	Fuel Cost
HPSs	Hybrid Power systems
hr	Hour
Km	Kilo meters
KW	Kilo Watt
KWh	Kilo Watt hour
KWP	Kilo Watt peak
LCC	Life-cycle Cost
PMSs	Power Management Strategies
Pu	per unit
PV	Photovoltaic
RC	Replacement Cost
RESs	Renewable Energy Sources
SOC	State Of Charge
V	Voltage
VC	Variable Cost
WG	Wind Generator
PFC	Power Factor Correction
PV	Photovoltaic Cell
SA	Standalone
STC	Standard Test Condition

TSP	Tip Speed Ratio
UPS	Uninterrupted Power Supply
VAWT	Vertical Axis Wind Turbine
VSD	Variable Speed Drive
WECS	Wind Energy Conversion System

Introduction and Literature Review

1.1 Overview

As concerns about global warming and climate change have increased rapidly it is a fact that scientists and environmental proponents have giving frequent warnings on their potential impacts. These global issues are becoming a serious matter for the agendas of politicians, especially in developed countries, where the consequences of global warming are becoming more widespread. No one can deny that the demands for fossil fuels are rising with the rapid economic growth of developing countries. A sharp increase in fossil fuel prices will have destructive short and long-term impacts on the national and international economy, and security and the existence of mankind could be in jeopardy since plant resources are at risk. The rising consumption of energy and decreasing accessibility of natural resources are increasing the cost of electricity. In addition, greenhouse gases (GHGS) are becoming a threat to the natural ecosystem. One of the best opportunities to reduce energy consumption and limit Greenhouse Gases, is the use of Renewable. Energy Systems (RES), which are becoming a common choice for small communities around the world. Such hybrid power systems are designed for the generation of electrical power from a number of devices such as wind turbines, photovoltaic panels, geothermal, micro combined heat and power, micro-hydro and/or fossil fuel generators. Generally, hybrid power systems are independent of a large centralized electricity distribution system and are used in remote areas. Often they are known as stand-alone power systems (SAPS or SPS) or a remote area power supply (RAPS). Storage can be used in RAPS (e.g. battery bank, hydrogen storage, compressed air, pumped hydro storage etc.). Hybrid power systems range from small systems designed for one or several homes to very large ones for remote island grids or large communities. RAPS are considered as a solution to provide electricity to many isolated communities where the large scale electrical grid expansion is prohibitive and the transportation of diesel is also costly. RAPS system diminishes fuel cost, permits green energy generation and improves the standard of living for people in remote areas [1]. Abundant power of the Sun is the ultimate source of all renewable energy. From a very ancient time when our ancestors made fire, they used the power of photosynthesis, an indirect from of solar energy. Solar energy can be harnessed directly as thermal energy or electric energy caused by solar radiation or indirectly as biofuel, water or wind energy. Solar and wind are also considered as one of the most preferred renewable energy sources for their availability and inexhaustibility [2]. However, due to the intermittent characteristics of natural resources, it has been a challenge to continuously generate a highly reliable power with photovoltaic PV modules and wind turbines [3]. Studies were conduced using a fuel cell as another energy source to overcome this problem; simulated results showed that a PV/Wind hybrid power system may be a feasible solution for stand alone applications [4,5,6]. Since a multi source hybrid system increases energy availability significantly, it becomes an advantage for practical applications that need highly reliable power regardless of time and location [7,8]. In this project, the use of a *PV/*Wind-Turbine/fuel cell hybrid power system considered independent from the grid, produces clean and sustainable energy and gas to supply electricity to equipment in a mobile office. *PV*/Wind energy are used as the primary energy sources for the system and the fuel cell performs as a backup power for the continuous generation of high quality power. An optimal configuration has been determined by taking the total cost as the objective. A hybrid system is a cost effective solution to power a mobile office. Furthermore, it is expected that the proposed system will help communities to provide uninterrupted power for their sites.

1.2 Background

The international Energy Agency (IEA) estimates that in 2013, the total world energy consumption was 3.89×10^{20} joules [9]. From 2000–2012, coal was the source of energy with the largest growth, oil and natural gas had a considerable growth, followed by hydro power and renewable energy. The demand for renewable energy grew at a rate faster than any other time in history during this period, which could be explained by an increase in international investment in research on renewable energy. A huge drop in global demand for nuclear energy, is possibly due to the accidents that happened at multiple locations such as Three Mile Island and Chernobyl. Figure 1.1 shows the growth of energy demand from 1990 till 2035. The energy demand rose to almost 800 quadrillion British thermal units (Btu) in 2035, and it shows that the future energy consumption will be driven by the demand from countries outside of the Organization for Economic Cooperation and Development (OECD). The OECD is an international economic organization that stimulate economic progress and world trade. Much of the energy that is acquired by humans is lost as other forms of energy during the refinement process into usable energy.

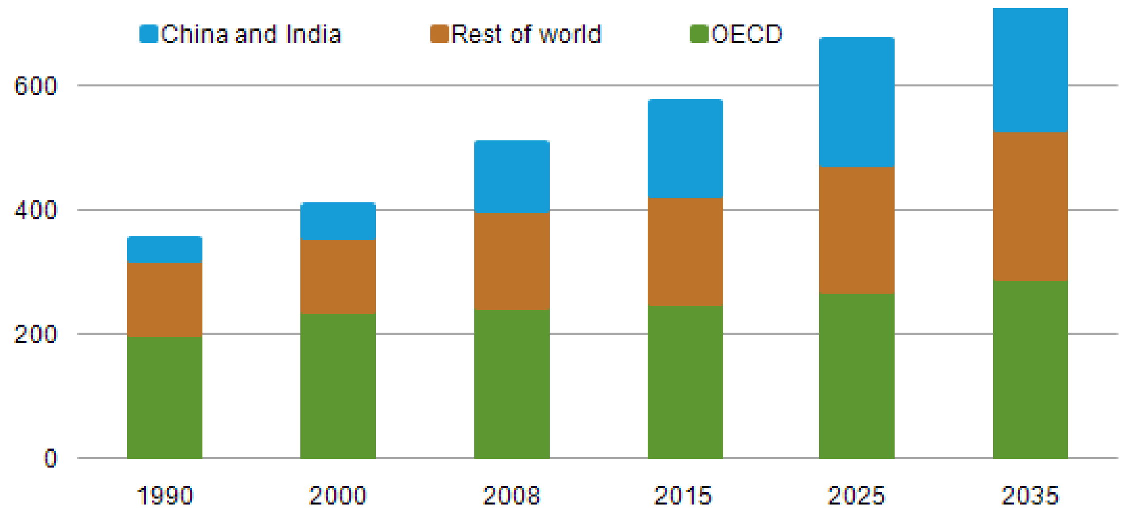


Fig 1.1 World Energy Consumption (quadrillion Btu) [10]

For instance, oil is extracted from the ground and it must be refined into gasoline, so it can be used in vehicles. For that reason, it has to be transported to gas stations over a long distance where it can be used by consumers. In 2012, the world's primary energy supply amounted at 155 terawatts per hour, which is about 32% less than the world total supply. While the worlds electricity consumption was roughly 19 TWh, an estimated of 18% loss in electricity resulted from grid and storages losses as well as self-consumption from power generation plants [10]. Moreover, connecting rural areas to the electric grid is a costly task that all major companies currently aim to fulfil. A hybrid energy system contains two or more renewable/non-renewable energy resources, Wind and Solar energy are the most rapidly developed renewable resources, offering the promise of clean and abundant energy without the negative impacts on the environment.

1.3 Renewable Energy

In recent years, 2007 to be specific, the United Nations' International Panel of Climate Change (IPCC), emphasize the many indicators on climate change and recommends that the world society respond to these serious problems. In the US, the European Union and China, policies have been formulated with the objective of decreasing CO_2 emissions. In many nations around the world, policies have also been drafted to raise the share of renewable energy as part of the global response to climate change [10]. In March 2007, the European Union defined a target of 20% of renewable energy for year 2020. In Denmark, there was a target of 30% renewable energy for the year 2025 which was proposed by the Danish Government [10]. According to [19], in 2009, with 16% of the global energy consumption was supplied by renewable energy, 2.8% supplied by nuclear power, and the rest supplied by fossil fuel. Figure 1.2 below shows the global generation of electricity by source and the growing role of wind and solar.

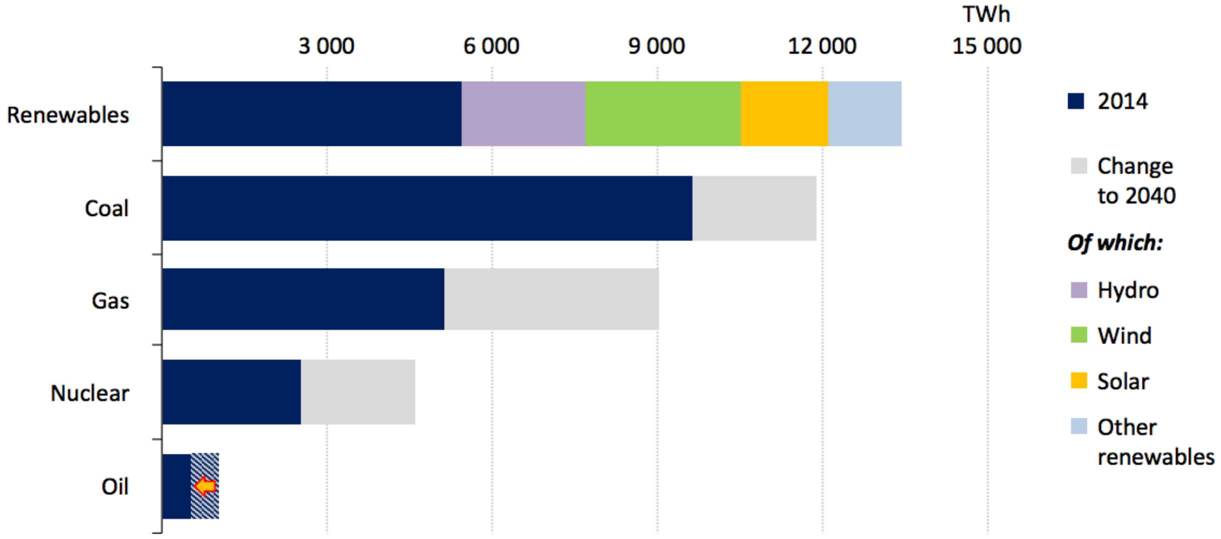


Fig 1.2 Global electrical generation by source in 2014 [10]

Beneath this positive look for renewables, however, there are conservative assumptions, and there is a major fallout in the costs of renewable energy. 40% of solar costs will drop by 2040, and 15% of wind costs will also drop as well between 2012-2030 [11]. In comparison, the world's electricity consumption was 18,608 TWh in 2012. Wind power could reach 2,000 GW by 2030, and supply up to 19% of global electricity, creating over 2 million new jobs and reducing CO_2 emissions by more than 3 billion tonnes per year [12]. By 2050, wind power could provide 30% of the global electricity supply [13]. On the other hand, solar has grown over 55% since 2000 and the rapid fall in the per kilowatt price of solar panels also supports future growth [14].

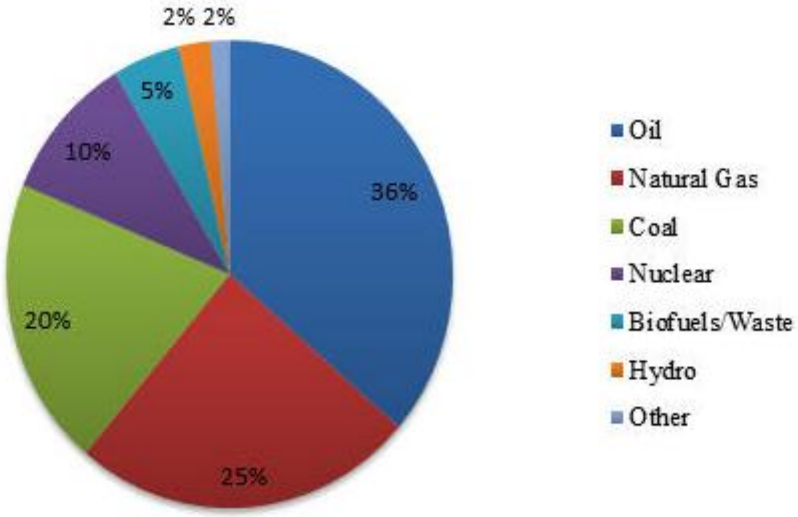


Fig 1.3 Global Energy Production in 2014 [14]

Figure 1.3 shows the world energy production in 2014. In which, oil production dropped to 36% from 81% in 2009, reflecting the remarkable change in the renewable energy industry as a result of global investment. China lead the world in the installation of wind turbines with 29GW capacity, while Germany lead in the installation of solar panels. Based on the International Energy Outlook (IEO), hydroelectric and other renewable energy capacity will rise to 2.7% per year by

2035 [20]. After further study, long-term annual growth for global installed generators are 2.0% for nuclear, 1.6% for natural gas, and 1.3% for coal, according to the International Energy Outlook [15]. Figure 1.4 estimates installed capacity of power plants running on petroleum products will fall by 1.0% a year, as higher oil costs and climate change concerns encourage a switch to cheaper and cleaner generating fuels. Many research projects in renewable energy have been conducted and carried out in the last decades, including mine which aims to provide new ways of renewable energy to be used in the field and be deployed to the benefit of our community, society and environment. These radical visions of the future which hold positive signs for successful action on climate change, even if they might be overly conservative. Yet like all other research initiatives they should be interpreted with due caution. The future may yet turn out to be more, or indeed less positive than the expected.

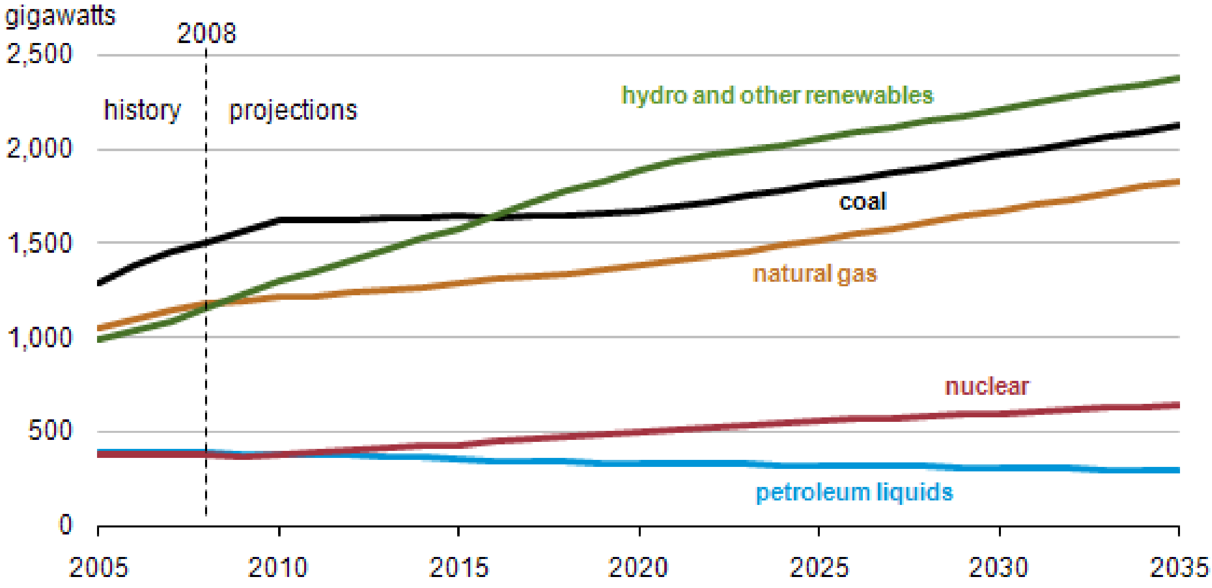


Fig 1.4 Global installed power generation capacity by energy source

1.4 Motivation

Coal, petroleum, natural gas, and other fossil fuels have traditionally been the leading sources of electric power generation. For decades, researchers from around the globe have been interested in expanding the development of hybrid renewable resources. Most people understand the impact of our reliance on fossil fuels for energy, for several important reasons: combustion of fossil fuels regularly accounts for the majority of the world anthropogenic greenhouse gas emissions, costs of fossil fuel could increase in the upcoming years, and the world's limited fossil fuel reserves, which are becoming harder and harder to find. The carbon dioxide released from burning fossil fuels is having an effect on the climate and is leading to global warming. These problems exist now and will have consequences for future generations. The emissions of carbon dioxide are a major environmental issue, as well as the waste of power generation from such sources as traditional coal-fired power plants. Homeowners and businesses can generate a great deal of their energy on their own. Sun, wind and water are free, so the cost of energy is much lower for those technologies, which has a positive impact on the community and would allow people to have a higher disposable income. There is currently a similar movement in support of renewable energy to advocate the electric utility companies to develop renewable forms of electricity generation, and maybe even maintain a specific percentage of renewable energy in their power generation portfolio. Many renewable resources depend on the geographical location, and the availability of these natural resources which influences site selection. Nevertheless, the impact of burning less fossil fuel reduces emissions and waste while society enjoys cleaner and fresher air and water. Oil spills and environmental accidents accrue less frequently, which leads to an earth that is less contaminated. Renewable energy projects tend to be situated away from urban areas, which can lead to the regeneration of areas that suffered as traditional industries have closed down. As a result, local services may prosper, which in turn may bring more jobs, with even more significant financial benefits because the disparity in price between oil and renewable energy is even greater. Renewable energy technologies such PV and Wind Turbines are now quite commonly seen on homes, offices, hospital, etc. With offshore production getting to nearly 30% of global crude oil output in 2015, there are now over two hundred thousand wind turbines operating worldwide, with a total capacity of 432,000 MW as of 2015, and total power output of the world's PV capacity is beyond 200 TWh of electricity [16-18]. The main of goal of this research is to design a standalone hybrid system that uses a combination of solar photovoltaics panels and wind turbines, battery banks with a diesel generator for back up for a remote area mobile office that is not connected to the grid. Such an office could be utilized for different jobs, office work, field deployments, first aid units, a response clinic for natural disasters or for residential reasons.

1.5 Thesis Objectives

The main objectives of this research are:

- Structural design and thermal analysis using energy 3D and BEOpt of two sites in Newfoundland, Canada, and Libya.
- Sizing of hybrid power system for a mobile office.
- Design of hybrid power system for a mobile clinic.
- Dynamic modelling and control of designed hybrid system in Simulink.

1.6 Literature Review

The following literature survey, consists of various papers published by the author at different domestic and international conferences and journals and various other important publications.

1.6.1 Renewable Energy in Power Generation

Power generation is a fast growing technology with new methods, devices, and new equipment coming out every year. Renewable energy is derived from resources which are continuously replenished such as wind, rain, sunlight, tides, waves and geothermal heat. There is a world-wide growing concern about the negative effects that conventional energy sources such as water, coal, oil, gas, uranium, have on the environment and the health of the general populace. Renewable energy sources use natural resources and do not cause any pollution, hence they are termed green energy sources [22]. Construction companies aim to have an uninterrupted power supply when working remotely or offshore, and are thus disconnected from the grid where fuel transportation cost is prohibitive. These companies are challenged to have such resources available on site. Therefore, renewable energy systems are becoming increasingly popular in the industry to provide uninterrupted power supply to remote areas. Currently, in most cases they use diesel generators to provide a power supply that is connected with backup batteries. Most of the world contractors and construction companies aim to get the job done efficiently, but not costly. How can such a job be done? Renewable energy is the answer. One example of major change in technology can be seen in telecommunication companies which have powered most of their mobile telecommunication stations with renewable resources. In most emerging markets the telecoms network runs on diesel fuel, although many efforts to power cell stations have focused on solar power. As a result, having a wind and solar combined pairing was more reliable and suitable, while strengthening the network connectivity. Additionally, installing wind turbine over cell towers can supply half of the power required by the cell network companies [23]. Figure 1.5 demonstrate a similar set up by Alcatel Lucent at Villarceaux using a conventional turbine towers. It shows the way Alcatel Lucent provides technology to manage the use of both renewable sources, and provides the necessary wireless coverage [24].

Fig. 1.5 solar- and wind-powered base station at Villarceaux [24]

Since the 1970's, companies have been researching the potential of renewable energy for powering its remote sites around Benin, and Niger [25]. The author gives a brief history of units that generate power and recent research developments, beginning with the first PV system of microwave stations to developments over the current decade in which describing when, hybrid wind/PV was applied to multiple communication stations. Moreover, companies have developed the DIMOSL software to size a site's equipment [26]. In other studies, automatic and manual controllable hydraulic systems are designed and installed to increase the efficiency by using vertical/horizontal axis control, to lift the wind turbine up and down and to prevent vibrations of the vehicle or container where the wind turbine is being installed. As a result of the lack of solar radiation in multiple site locations, the combination of wind turbine and photovoltaics resources will compensate for the lack of power supply. The system has been demonstrated in various exhibitions, conferences, energy forums, universities, governmental and nongovernmental organizations in Canada. In order to increase public awareness of renewable energy sources and its applications, part of the process involves public demonstration of several features of the application such as control, data acquisition, monitoring, and telemetry hardware and software. Also studies have shown how a small solar electric or photovoltaic (PV) systems can be a reliable and pollution-free producer of electricity for homes and offices [26]. PV technology is effective in that it uses both direct and scattered sunlight to generate electricity [27]. Additionally, there is an ample of solar resources across the world to power various solar electric systems including homes [28]. PV power systems can be designed to meet any electrical requirement, no matter how large or small and because of their modularity can connect them to an electric distribution (grid-connected), or standalone (off-grid) system. Many developing communities are forced to use these systems, as they are too far from electrical distribution. As a result, numerous software models been developed to simulate hybrid renewable energy systems. Several authors who have conducted multiple studies in this field, all have pointed to a potential solution to the logistical challenge of transporting fuel to mobile hospitals and offices in remote areas. The objective of this thesis is to determine the best configuration of a hybrid renewable system for a mobile office to help in solving a major crisis. Currently, some remote areas are in great need of small units, and containers that can be equipped with a solar panel system wired with wind turbines. The design of this unique system is what this thesis aims to elucidate. In terms of referring to the optimal sizing and operational strategy of the diesel generator and solar energy, with constant price of fuel so it could offer the lowest amount of total net present cost (TNPC). Through the use of the hybrid optimization model for electric renewable software (HOMER), after considering a variety of sensitivity variables such as wind speed, solar irradiation, load, and diesel price to perform a selection strategy of the power generation operational in order to obtain the finest system solution to a hybrid renewable energy system with the lowest TNPC [29].

1.7 Thesis Layout

Six chapters are written in this thesis. Chapter 1 includes the introduction, discussion of the literature review, an explanation of the thesis motivation, goals and purposes. In Chapter 2, the author lays out the structural design of the office and the thermal analysis of the Mobile Office discussed in this thesis, through the use of the various software," Energy3D, BEopt, and AutoCAD", for sizing and pre-feasibility of the proposed system. In Chapter 3, the author gives an overview of wind turbines, Photovoltaic systems, diesel generators, and batteries. Then, after connecting all the components together the Mobile Office is modelled in Newfoundland using the tools provided by HOMERPRO, which consists of a wind turbine, solar panels, batteries, diesel generator, and a convertor. Chapter 4, details the dynamic modeling of a Mobile Hospital for a remote area in the sub-Saharan region of Africa, to simulate the different uses of this kind of program. HOMER software tools were used in connecting the system with photovoltaics power given the abundance of these kind of resources in such an area. In Chapter 5, the simulation, modeling, and control of the designed hybrid power system is done in Simulink, which is developed by MathWorks as a graphical programming model for simulation and analysis of dynamic systems. Its primary interface is a graphical block diagramming tool and a customizable set of block libraries to present far more accurate reading of the situation in which this study is being conducted. Chapter 6 concludes the thesis and discussion of the products and gives a brief vision of future work.

Chapter 2 Structural Design and Thermal Analysis

2.1 Introduction

When designing a mobile office, there are many criteria that need to be taken under consideration: structural design must meet the proposed budget, exact type of offices, and accurate size measurements that are suitable for different locations. It is necessary to consider and evaluate different office designs and configure the power system accordingly to get the lowest total net present cost of that system, which means the lowest utility cost in comparison to the production cost. This kind of portable office/facility is designed to work in remote areas where there is no modern utility connection or grid connectivity. In such places, there is also no power supply or connection to the power grid, during natural disasters and world crisis. This sort of office would be similar to the first respond unit, rather than an assist unit for field officers and engineers to deploy at the time of need.

2.2 AutoCAD Designs

AutoCAD have been used to initiate and draw the office space as a typical office or a trailer hauled by a tractor [30]. AutoCAD is a commercial computer-aided design (CAD) and drafting software application, which permits standard 2D drawings, such as lines, circles, walls, doors, windows, elevations and sections with more architectural data designs. The data can be programmed to represent the specific office architectural product used in the construction industry, or extracted into a data file for pricing, materials estimation, and other values related to the objects of civil design. Designers developed additional tools to generate a 3D architectural model with a civil 3D design to draw objects, that have more intelligent data associated with them rather than simple objects. Moreover, civil engineering calculations and representations are easy to facilitated with the software. Figure 2.1 shows the screen capture of the first initial drawing on Autodesk 2015, with implementations of walls, doors, windows, and size.

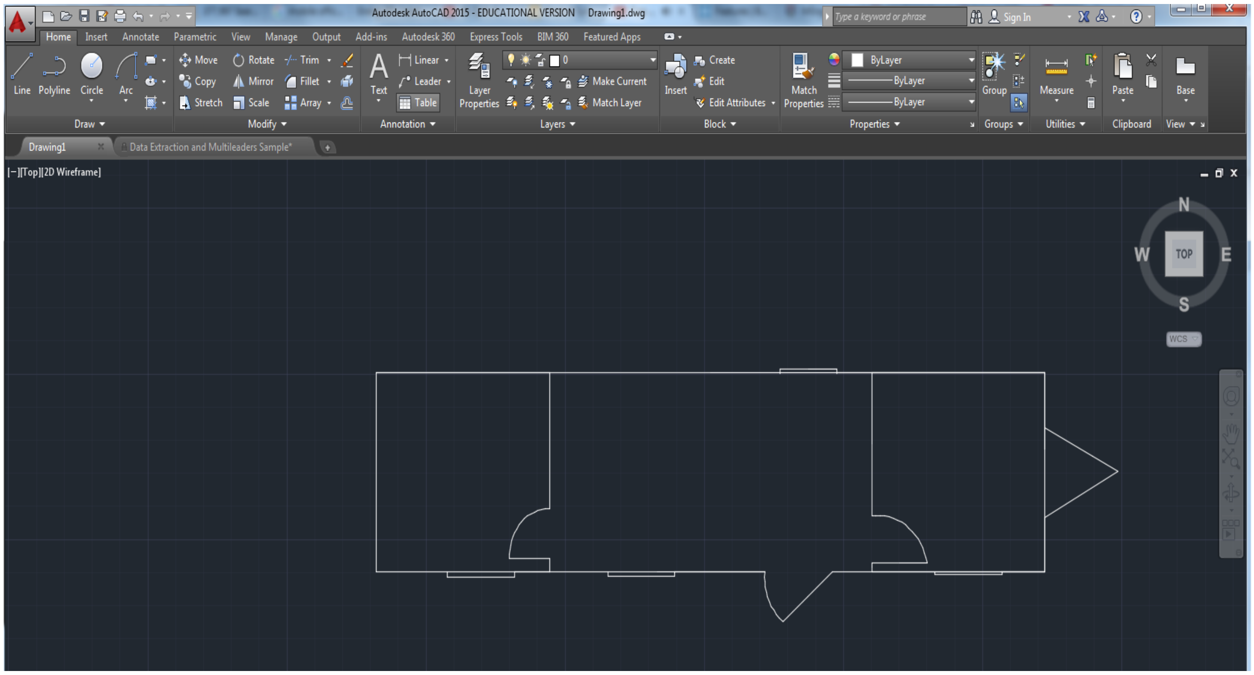


Fig 2.1 AutoCAD front screen capture

After considering multiple mobile office designs around the world, most companies provide a large diesel generator for a mobile office or trailer accompanied by a small power station to measure up to the load needed, all connected internally. Some use the external approach by using a ´tow and go` diesel generator with the mobile office. Such examples are being used at sites across Canada by Alantra-Leasing [31]. Alantra’s products are a state of the art line of offices, lunchroom trailers, office complexes, modular buildings and custom builds that have proven durability even in the most remote locations. Figure 2.2 below shows an examples of a deployed mobile office space at Memorial University’s St. John’s campus, where this study has been conducted. Currently, budget cuts are a major factor for universities adjusting their policies over tuition fees, research funding and projects, while trying to maintain a continuous education for students from around the world. Our part as students and future researchers is to look for the kind of resources surrounding us that can be used for the benefit of the public.

Fig. 2.2 Alantra-leasing offices and trailers

2.3 Mobile Office Design and Drawing

The ultimate ambition is to build a standalone mobile office that is available on site at any time with a zero-dollar utility consumption, no diesel purchases, and no CO2 emission. A renewable mobile office could be a major change in the industry, which could eventually motivate large-scale companies to invest in these offices. Alantra was generous enough to provide us with a drawing of two of their offices that are currently deployed on site. The offices vary in size, “10`x20 `, and 10 `x40`” are shown in the following figures [32].

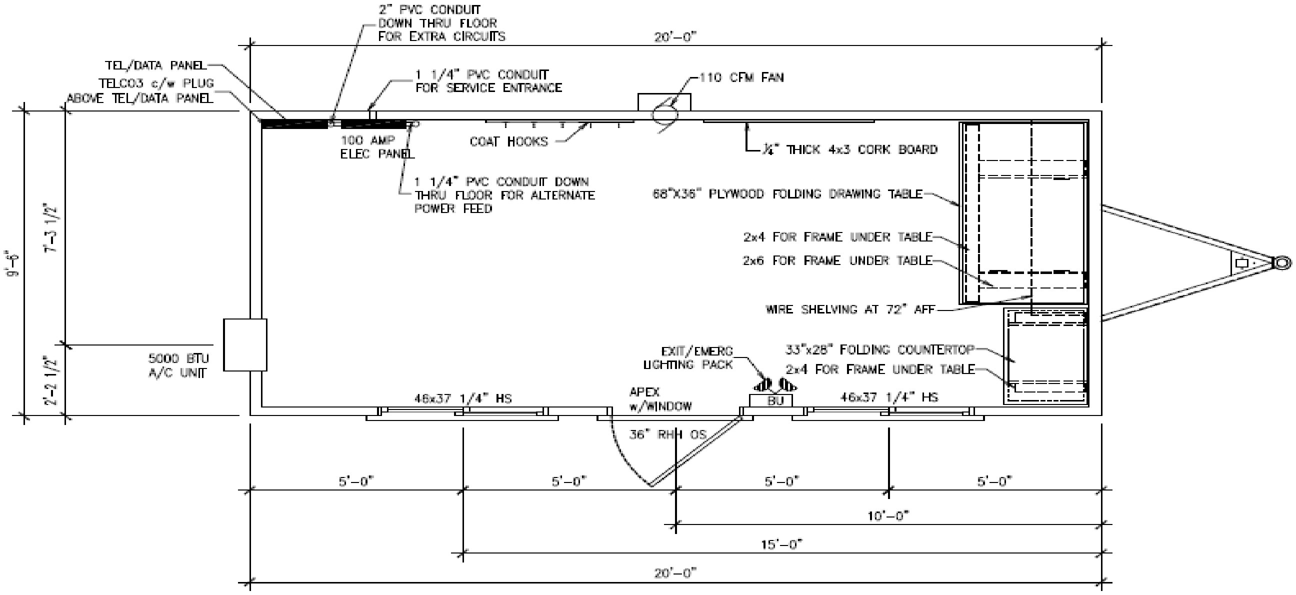


Fig. 2.3 AutoCAD Office Design of 10`x20`

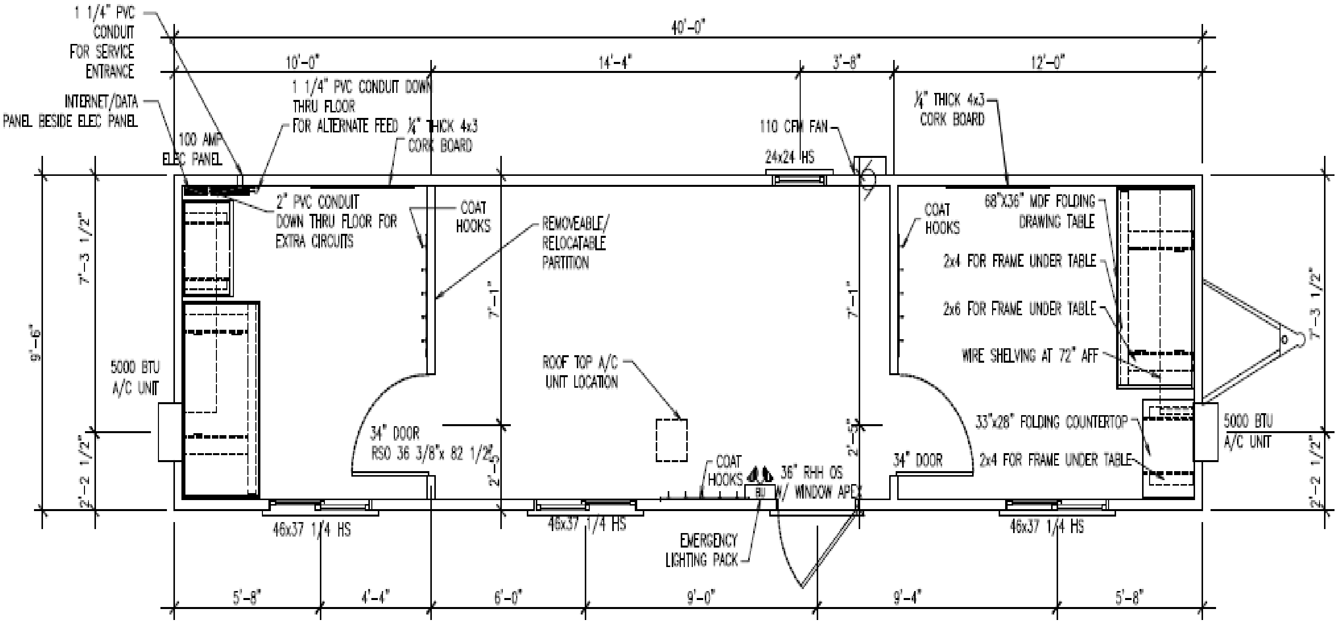


Fig. 2.4 AutoCAD Office Design of 10`x40`

These offices have different features and designs that could be custom made or giving as a standard building design by Alantra. These features are top of the line in the modern engineering society such as: electric heater, A/C, electric mast, fold down drawing tables and counters, a communication panel, emergency and exit lights. Alantra also provides delivery and set up services; this kind of service is the reason Memorial University have leased these offices. The drawing above shows a steel frame constructed with steel beams, steel cross channels, rubber baseboard floor framing, 2 mm sheet vinyl flooring, with R-20 insulation, and 3/8” painted plywood on the underside of floor. There are also interior measures, such as sealing the interior with a polyurethane varnish for easier surface cleaning and protection from damage. As there is a high percentage of traveling and mobility the interior is at risk for distortion, cracking, and peeling, so it is an excellent idea to stain the walls and the interior, however, as a result it could cause paint to crack and peel. Alantra is not the only company that have followed this path of designing mobile offices and portable powered trailers, some have taken the smart mobile office to a whole new level, where it is powered by a complete PV with. There are few of these mobile offices. SunGard for instance, provides a disaster recovery unit and managed IT services and has built over 20 mobile offices and workspace units. The company is currently in a significant expansion mode which is driven by: extreme weather and a desire by employers to keep workers close to home [33]. The proposed hybrid energy system, whether wind turbine or a photovoltaic power supply, will reduce diesel fuel, and has the ability to reduce the impact of the energy service with this configuration. This renewable resource is less environmentally intrusive than the conventional resource it is replacing.

2.4 Energy3D Office Designs

The mobile office designs are implemented in Energy3D, which is a smart CAD software tool that can generate dynamic, adaptive feedback of the design, based on logging and analyzing actions in real time and can calculate properties of the design artifacts using computational physics [34]. On Energy3D, users can sketch a realistic structure similar to the AutoCAD drawing presented earlier, with the Google Map feature superimposing the drawing designs on the Energy3D work platform. Energy3D then evaluates its energy performance for any given day and location. Based on computational physics, Energy3D can rapidly generate time graphs (resembling data loggers) and heat maps (resembling infrared cameras) for in-depth analyses, which is used to generate the load date and the thermal analysis of the mobile office. In the end, engineering design is an extremely sophisticated skill that traditionally requires many years of learning and practice, acquired from hard work and determination. While on the other hand, Energy3D allows users to print out models, cut it out into pieces, and use them to assemble a physical scale model. Energy3D has been primarily developed to provide a simulated engineering design environment that supports science and engineering education. As its simulation results are fairly accurate, it may also be used as an entry-level energy simulation tool by professionals. Energy3d simulates and generates the load data for a “office, house, hospital or structural building”. Also, after adding the exact location of the project, the altitude, and longitude, allows Energy3D to simulate the heat analysis for the building that includes energy usage, season change, and track of temperature. These trailers could be connected according to how many offices need to be deployed, or number of people on site.

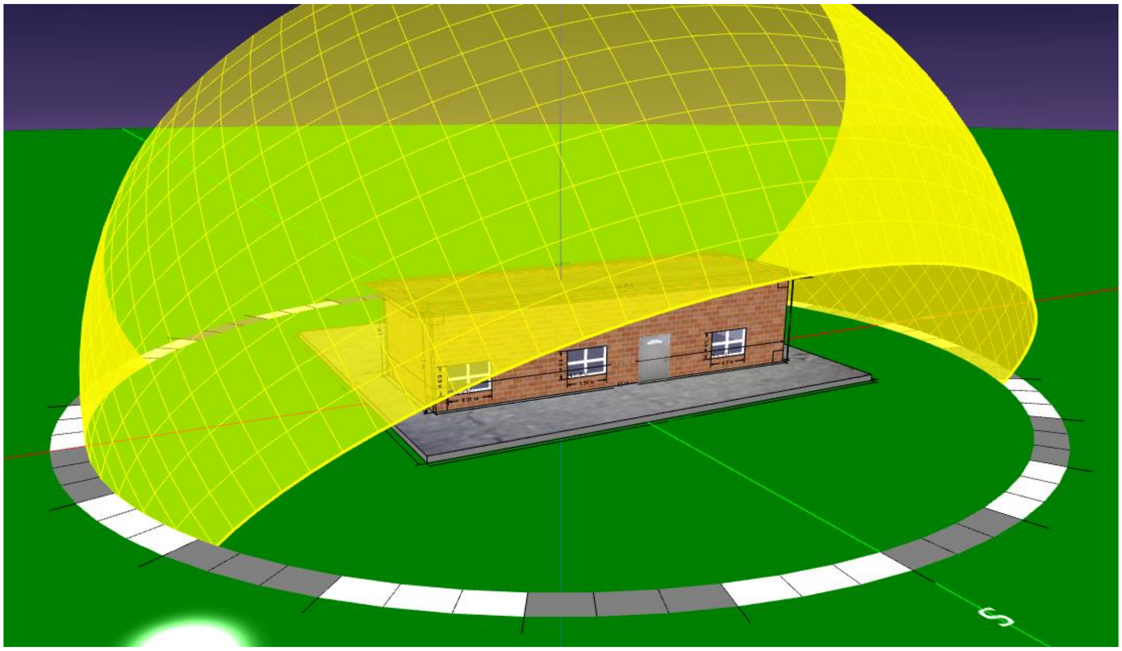


Fig 2.5 Energy3D Design

Design of Renewable Energy System for a Remote Mobile Office in Newfoundland, by Emadeddin Hussein and Tariq M. Iqbal reveals a PV/Wind hybrid system which is being considered for supplying an electrical load to a proposed mobile office along with relevant statistics [35]. Only one container/trailer was presented and wired with solar panels, wind turbines, batteries, convertor, diesel generator, and a battery bank. The design was not connected to the grid, but instead a diesel generator with a battery bank for backups and emergency usage. Figure 2.5, shows the first draft with the use of Energy3D simulation software as simulated in the research paper. Using relatively simple assumptions from a more sophisticated electrical model by calculating the peak electrical demand at a typical office, using time-varying electrical load at a specific location, which is crucial to understanding the costs and benefits associated with installing renewable energy sources in the field to determine the best configuration of a hybrid renewable system. A further drawing has been added and implemented for this study, after considering the size of the building to be 10`x40`, which is almost 3m x12m with a longitude of 47. However, energy3D has a variety of locations that are built into the software, but Newfoundland is not on that list. Thus, the user has to pick the nearest geographical point provided by the software and adjust the longitude and attitude to match that location. Additionally, the drawing reveals that there are four windows, three doors in total, with three windows and one door located at the front side, two internal doors in office, and one window in the middle of the back wall. The total space is almost 40m^2, 12m long by 3m wide, and the height of the office is 3m. A sketch of the Mobile Office is simulated in figure 2.6 below.

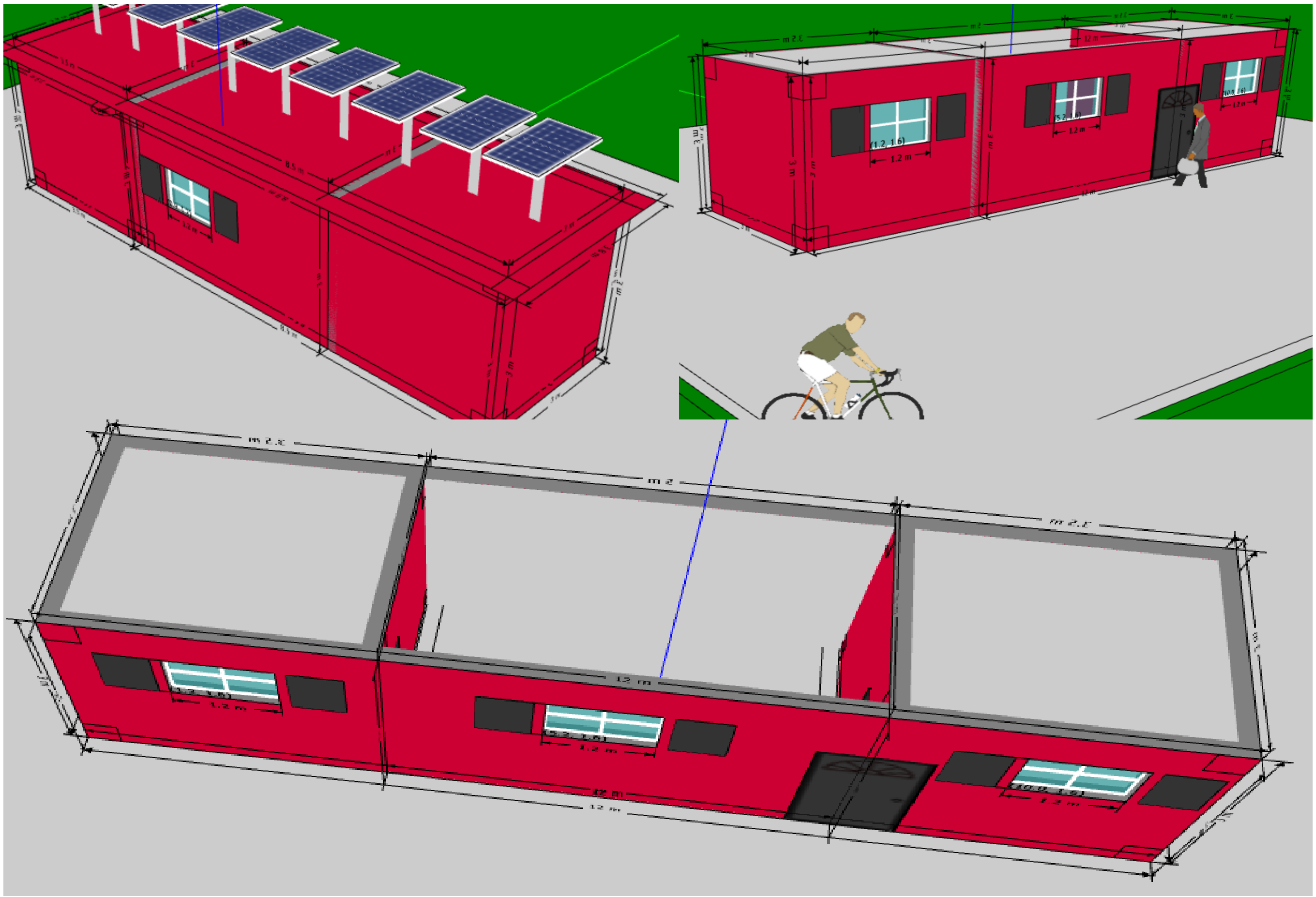
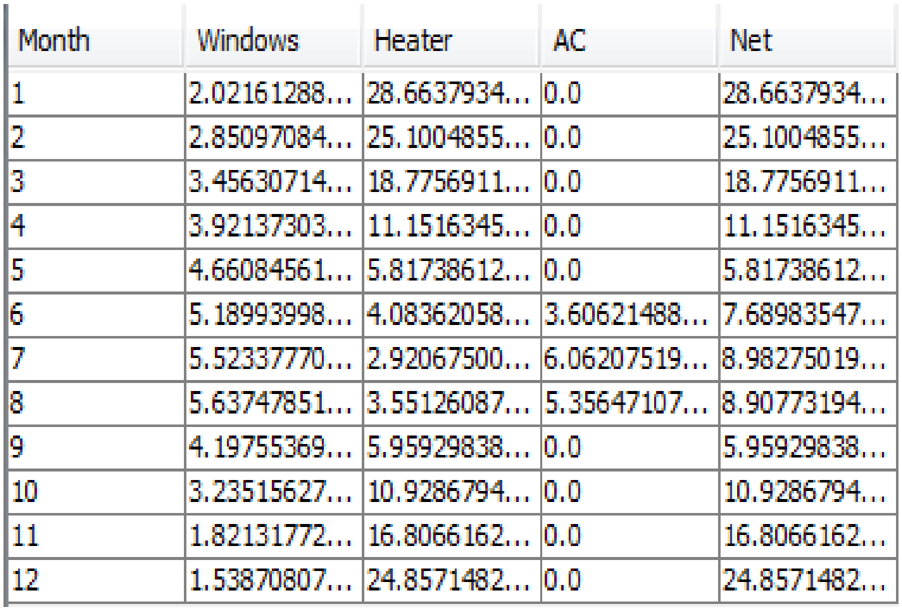


Fig 2.6 Energy3D Drawing of the Mobile Office

The Mobile Office structure is simulated in Energy 3D which allows the use of an hourly data analysis that runs on hour-by-hour readings of the total building and annual energy consumption. The site power consumption is displayed at approximately 5282kWh/year and the energy absorption for the location mentioned below is shown in figure 2.7. The typical load profile is an average monthly estimate produced by Energy3D, varying between 5.8 kWh to 28.66 kWh every day. These results need to be converted to an hourly Txt file data sheet to be readable by HOMER. Excel is a spreadsheet developed by Microsoft for Windows, which includes several features such as calculations tools, pivot tables, and macro programming language [36]. Data conversion could be done using an Excel sheet with detailed hourly variations of load data throughout the year. Dividing the date on daily basis will generate 8760 data points and this data will be used in the proposed software presented in the next chapter.

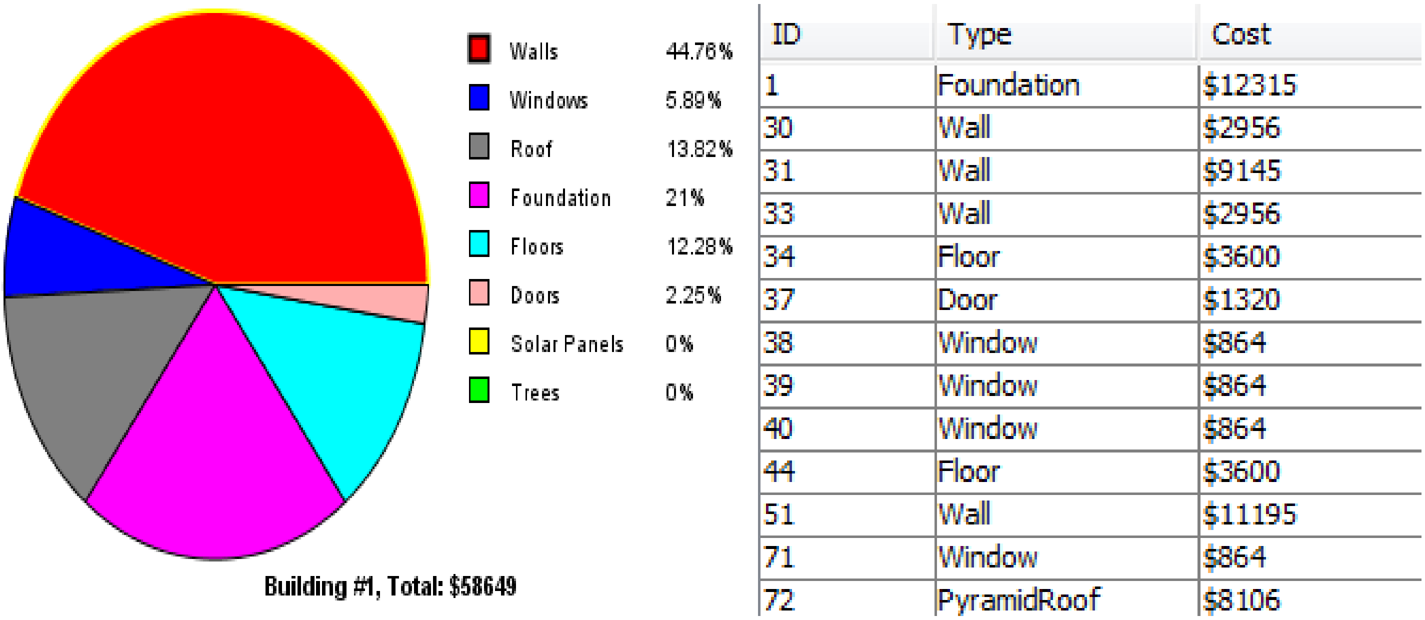


Month	Windows	Heater	AC	Net
1	2.02161288...	28.6637934...	0.0	28.6637934...
2	2.85097084...	25.1004855...	0.0	25.1004855...
3	3.45630714...	18.7756911...	0.0	18.7756911...
4	3.92137303...	11.1516345...	0.0	11.1516345...
5	4.66084561...	5.81738612...	0.0	5.81738612...
6	5.18993998...	4.08362058...	3.60621488...	7.68983547...
7	5.52337770...	2.92067500...	6.06207519...	8.98275019...
8	5.63747851...	3.55126087...	5.35647107...	8.90773194...
9	4.19755369...	5.95929838...	0.0	5.95929838...
10	3.23515627...	10.9286794...	0.0	10.9286794...
11	1.82131772...	16.8066162...	0.0	16.8066162...
12	1.53870807...	24.8571482...	0.0	24.8571482...

Fig 2.7 Monthly Data Consumption

Two readings have been provided regarding the cost of the building and yearly usage. A monthly rent average by Alantra and an itemized annual energy consumption cost is acquired by Energy3D.

According to Alantra a unit rental per month is $700.00 or $8400 year, and adding fire and theft insurance to the unit brings the total to $775 a month, not including the furniture rental costs. Transportation is included by the Rental Company and setup, leveling and jack stands can be provided at an additional cost bringing the total to $920. The annual cost is $10,000 with no power connectivity, which necessitates the use of a diesel power generator. Moreover, diesel costs in Newfoundland are the highest in the country with an average of 1.30 $/L [37]. Assuming this office was connected to the grid while taking readings for the month of March for example, the electricity bill and total net consumption of the site would be 18.7Kwh with an estimate of 9.719 cent per kWh according to Newfoundland Power, the only electricity provider in the province. The monthly bill would be a total of $1,817.50 Canadian dollars [38]. Obviously in this situation going hybrid sounds more beneficial. Energy3D has provided the cost of such an office after inserting the AutoCAD drawing into the design, and running the yearly analysis. The results indicate a minimal material costs of $58,649, which are mostly spent on the construction of the mobile office. Figure 2.8 displays the building material costs such as walls, windows, roof, foundation, doors, and floors combined with an itemized table that illustrate the construction costs of the Mobile Office.



ID	Type	Cost
1	Foundation	$12315
30	Wall	$2956
31	Wall	$9145
33	Wall	$2956
34	Floor	$3600
37	Door	$1320
38	Window	$864
39	Window	$864
40	Window	$864
44	Floor	$3600
51	Wall	$11195
71	Window	$864
72	PyramidRoof	$8106

Fig 2.8 Material costs/Itemized construction costs by Energy3D

In a study on the Design of Renewable Energy Systems for Mobile Clinic that was conducted by the author, a typical Mobile Hospital was designed to be portable while providing maximum comfort, considering the designs as a full medical aid center [39]. With an annual energy consumption of 5200 kWh/year, and 14.3kWh/day, this model produces a minimum cost design at $88.999. A typical Mobile Hospital provided in the field has 100-amp Electrical Panel (38 circuit), electric heat, florescent light fixtures, electrical mast and meter boxes, and emergency lighting/exit signage. Adding details such as size, insulation average, walls, roof, double pane windows and doors, all this data were considered during the system operation as comparable factors in the procedure. Figure 2.9 shows a drawing of the Mobile Hospital design in Energy3D and AutoCAD as was displayed in the journal that was published in 2016. Energy3D supports the design, simulation, analysis, and optimization of both photovoltaic solar power stations and concentrated solar power stations.

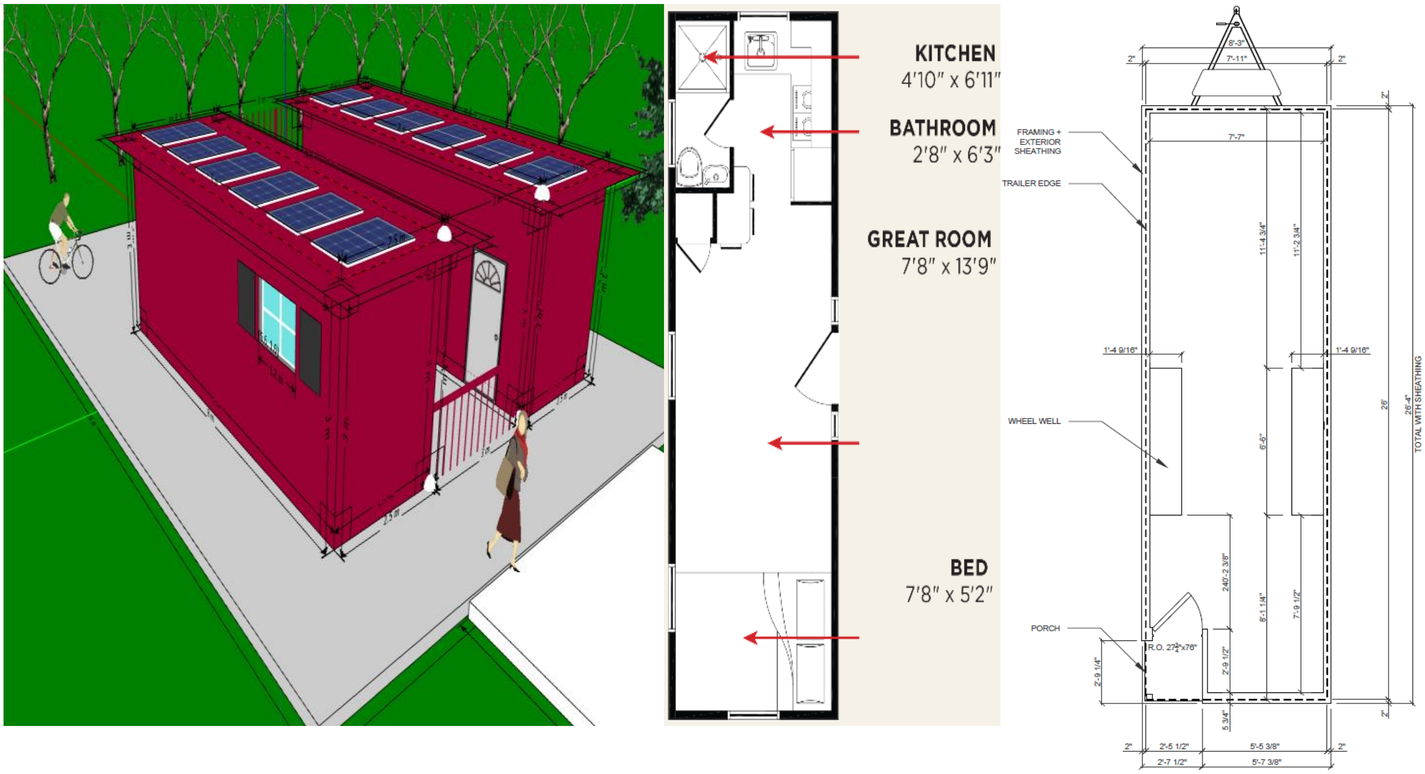


Fig 2.9 Mobile Hospital design

2.6 BEopt Designs

Building Energy Optimization software (BEopt), this software has been developed by the National Renewable Energy Laboratory (NREL), and it provides capabilities to evaluate residential and commercial building designs toward identifying the optimal-cost efficiency packages at various levels of whole-house energy savings along the path to zero net energy [40]. BEopt is used to analyze and estimate both the construction and the existing home retrofits, as well as small detached, multi-usage, and much larger buildings. After the evaluation of each building design, parametric sweeps, and cost-based optimizations, BEopt provides detailed simulation based on specific house characteristics after an excessive analysis on size, architecture, occupancy, location, and utility rates. The exact mobile office drawing design is implemented during the use of the new software to find minimum-cost building designs at different target energy-savings levels.

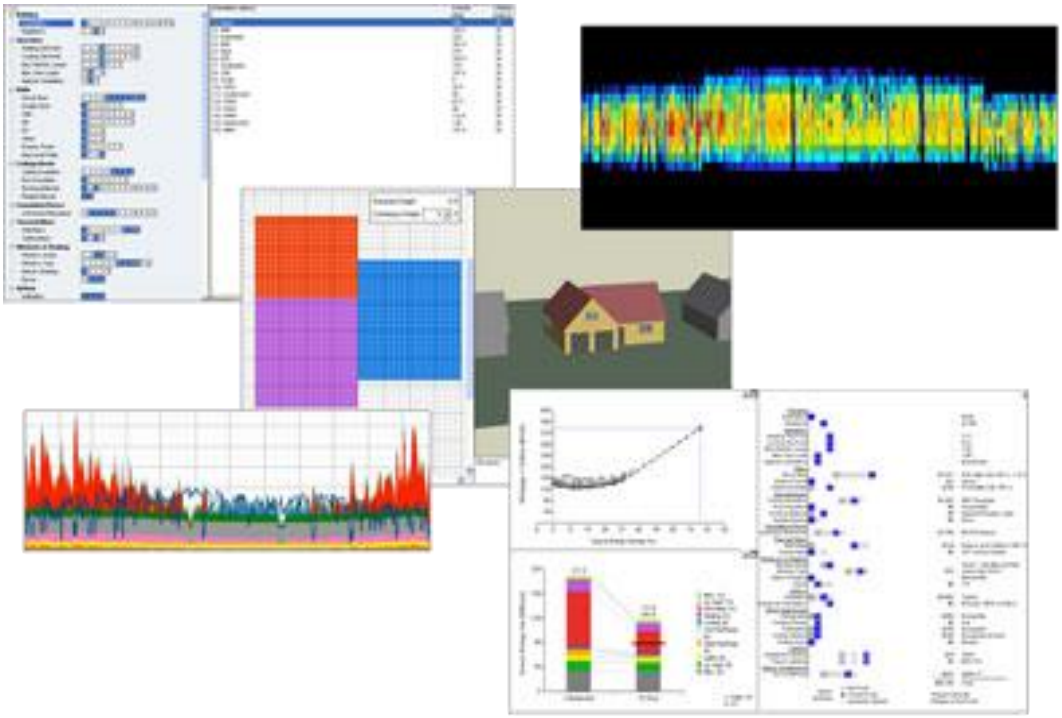


Fig 2.10 General desktop view of designs from BEopt software

Figure 2.10 above shows a general desktop view of the BEopt designs as captured from the official website. Such procedures identify multiple designs that are almost near-optimal along the path, allowing for equivalent solutions based on the builder or contractor preference and equipment's options. The procedures also reflect the realistic construction materials and give a chance for a reasonable practice to be evaluated. At first we need to lay down the building geometry boarder, then make a rapid drawing of a level by level plans of a one floor mobile office. Next, the drawing is automatically converted to a 3D geometry structural design, which can accommodate multiple units according to the needs. Figure 2.11 shows the primary structural drawing of the mobile office in BEopt, in which the geometry screen illustrates the ground floor setting, moving next to the first floor in which defaulted building is shown with the ability to change space and insert suitable structural designs to the file. Many measures are available such as selection and construction tools for the building, equipment, appliances, and occupancy tools, etc.

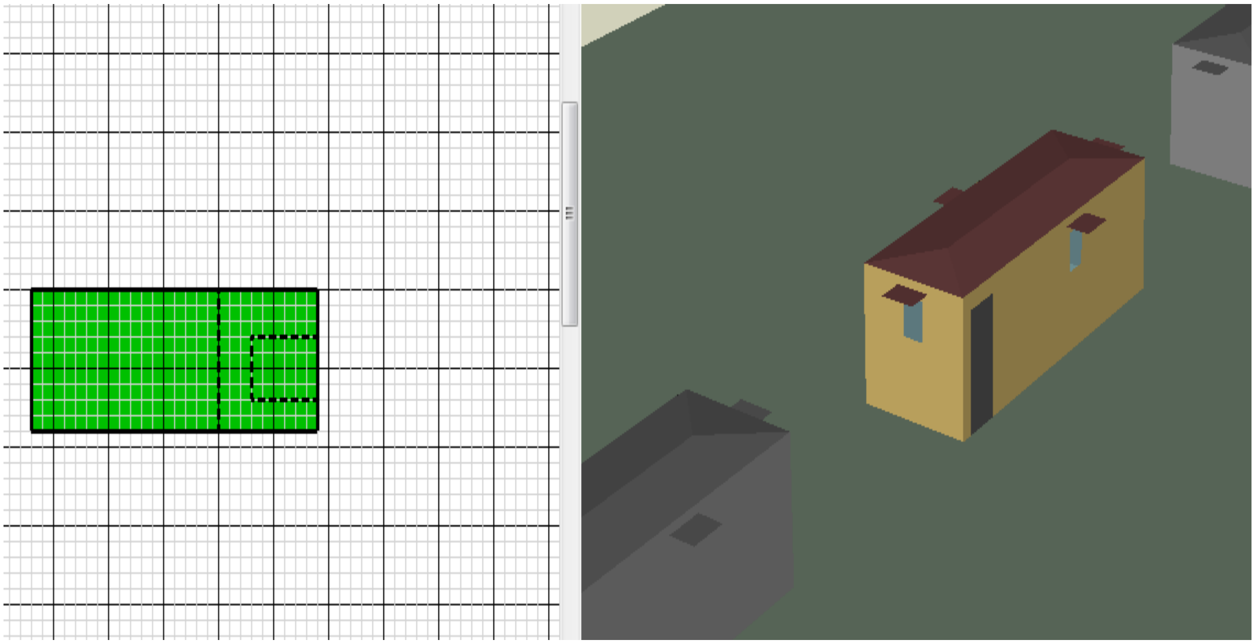
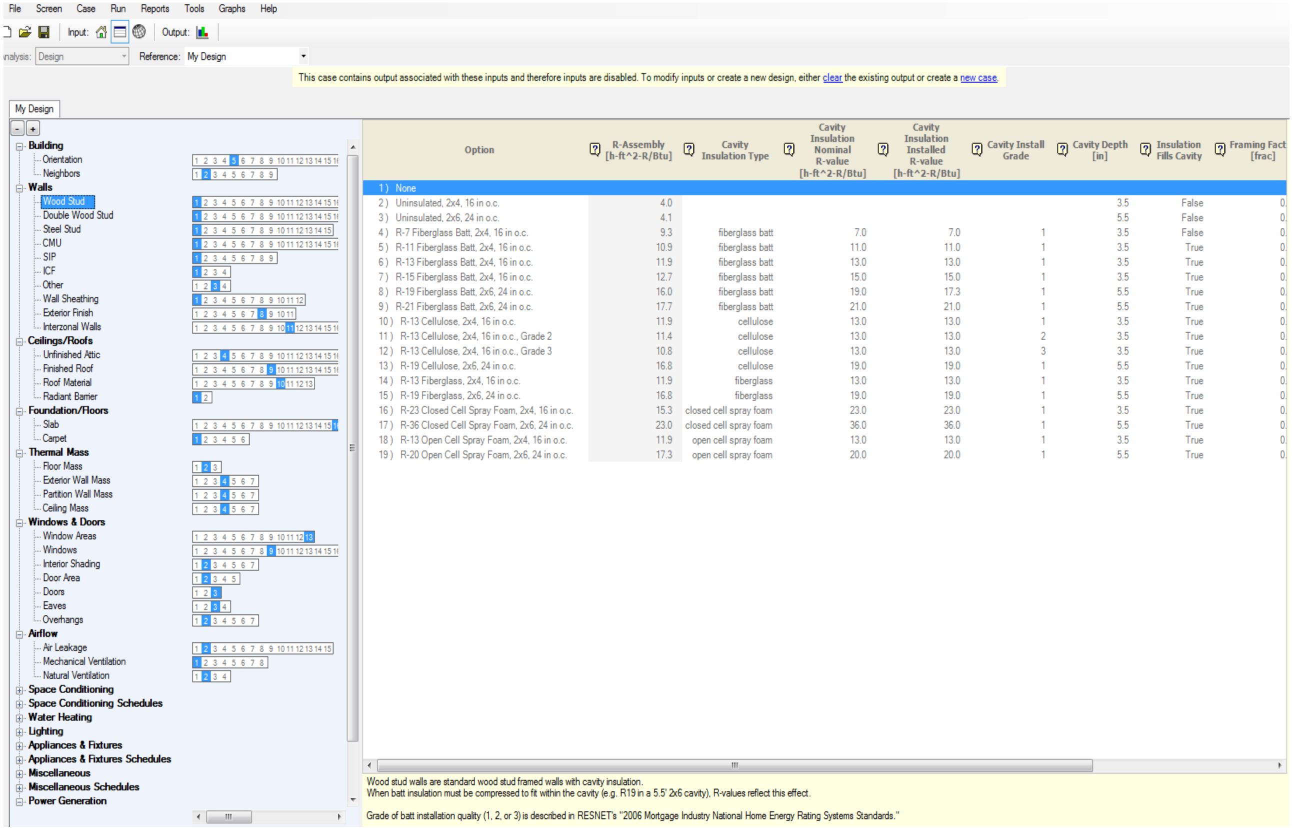


Fig 2.11 BEopt drawing of the Mobile Office

Measures are tailored according to the new construction designs and the applications are retrofit accordingly, since BEopt has the capability to calculate the heat transfer between these different foundations while running the annual energy analysis. This kind of an interface allows analyzing specified building designs or optimizing across a range of possible measures with some additional input depending on each level. At the second level, we can control the type of roofing, a hip or gable, offered by the software. Gable will be our selection due to its capacity which allows more space and access over the roof to install the solar panels on top of the building. BEopt has a specification for the orientations of the building such as the directions the building faces, and where the north arrow angle is displayed. It also has control over shading calculations, whether to add neighbors by replicating the current building geometry or have a single building platform. Figure 2.12 reveals the option screen with its variety of structural and building options.



nalysis: Design

Reference: My Design

This case contains output associated with these inputs and therefore inputs are disabled. To modify inputs or create a new design, either clear the existing output or create a new case.

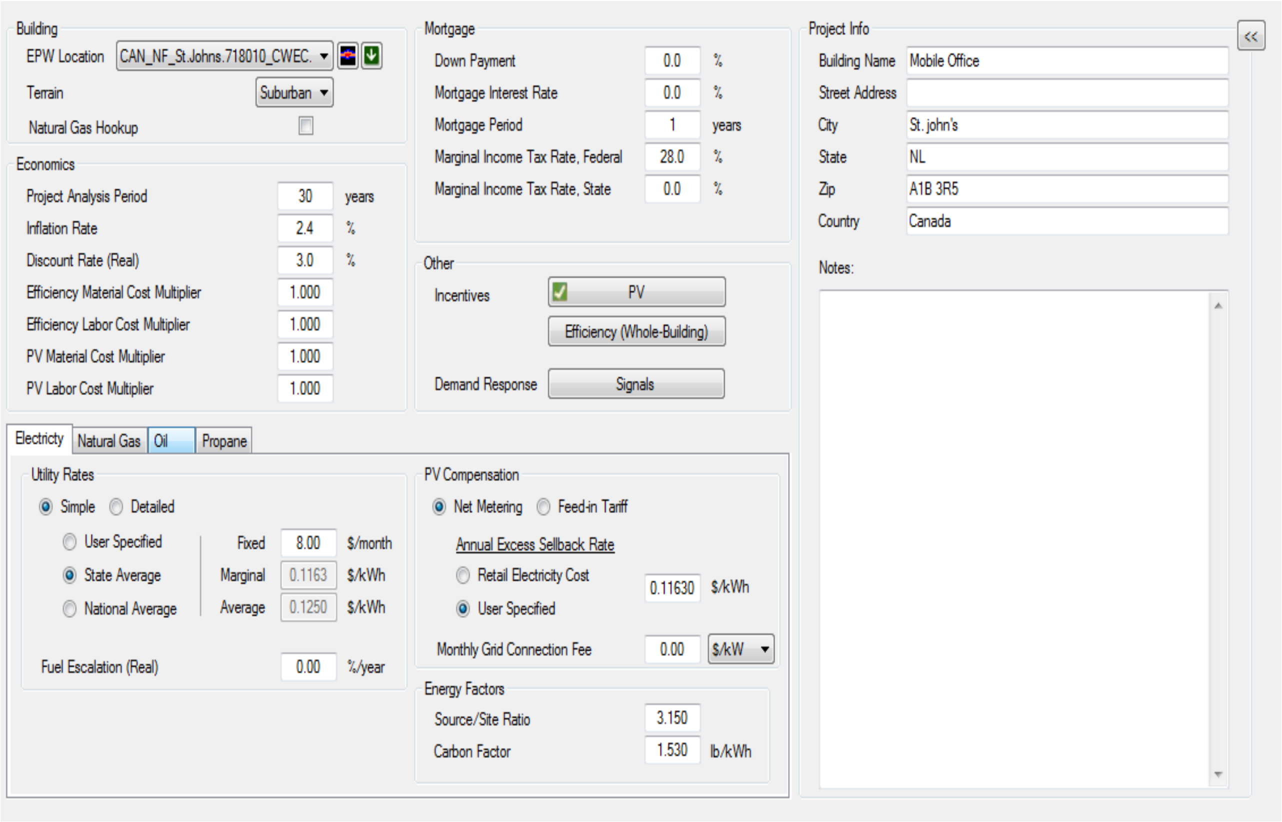
Option	R-Assembly [h-ft^2-R/Btu]	Cavity Insulation Type	Cavity Insulation Nominal R-value [h-ft^2-R/Btu]	Cavity Insulation Installed R-value [h-ft^2-R/Btu]	Cavity Install Grade	Cavity Depth [in]	Insulation Fills Cavity	Framing Fact [frac]
1) None								
2) Uninsulated, 2x4, 16 in o.c.	4.0					3.5	False	0.
3) Uninsulated, 2x6, 24 in o.c.	4.1					5.5	False	0.
4) R-7 Fiberglass Batt, 2x4, 16 in o.c.	9.3	fiberglass batt	7.0	7.0	1	3.5	False	0.
5) R-11 Fiberglass Batt, 2x4, 16 in o.c.	10.9	fiberglass batt	11.0	11.0	1	3.5	True	0.
6) R-13 Fiberglass Batt, 2x4, 16 in o.c.	11.9	fiberglass batt	13.0	13.0	1	3.5	True	0.
7) R-15 Fiberglass Batt, 2x4, 16 in o.c.	12.7	fiberglass batt	15.0	15.0	1	3.5	True	0.
8) R-19 Fiberglass Batt, 2x6, 24 in o.c.	16.0	fiberglass batt	19.0	17.3	1	5.5	True	0.
9) R-21 Fiberglass Batt, 2x6, 24 in o.c.	17.7	fiberglass batt	21.0	21.0	1	5.5	True	0.
10) R-13 Cellulose, 2x4, 16 in o.c.	11.9	cellulose	13.0	13.0	1	3.5	True	0.
11) R-13 Cellulose, 2x4, 16 in o.c., Grade 2	11.4	cellulose	13.0	13.0	2	3.5	True	0.
12) R-13 Cellulose, 2x4, 16 in o.c., Grade 3	10.8	cellulose	13.0	13.0	3	3.5	True	0.
13) R-19 Cellulose, 2x6, 24 in o.c.	16.8	cellulose	19.0	19.0	1	5.5	True	0.
14) R-13 Fiberglass, 2x4, 16 in o.c.	11.9	fiberglass	13.0	13.0	1	3.5	True	0.
15) R-19 Fiberglass, 2x6, 24 in o.c.	16.8	fiberglass	19.0	19.0	1	5.5	True	0.
16) R-23 Closed Cell Spray Foam, 2x4, 16 in o.c.	15.3	closed cell spray foam	23.0	23.0	1	3.5	True	0.
17) R-36 Closed Cell Spray Foam, 2x6, 24 in o.c.	23.0	closed cell spray foam	36.0	36.0	1	5.5	True	0.
18) R-13 Open Cell Spray Foam, 2x4, 16 in o.c.	11.9	open cell spray foam	13.0	13.0	1	3.5	True	0.
19) R-20 Open Cell Spray Foam, 2x6, 24 in o.c.	17.3	open cell spray foam	20.0	20.0	1	5.5	True	0.

Wood stud walls are standard wood stud framed walls with cavity insulation.
When batt insulation must be compressed to fit within the cavity (e.g. R19 in a 5.5' 2x6 cavity), R-values reflect this effect.

Grade of batt installation quality (1, 2, or 3) is described in RESNET's "2006 Mortgage Industry National Home Energy Rating Systems Standards."

Fig 2.12 Option screen on BEopt

It is the second screen of the three input screens provided on the home page, and it includes, but is not limited to, these control option design for walls, doors, floors, type of installations, thickness, air flow, appliances, heat, etc. This screen is also known as the parametric mode screen, that is similar to the design mode but rather more simulated with more options on building designs, structural outlay, external and internal implementation. There is a direct interaction between this screen and the geometry screen which represents in anything that is drawn on the first screen that could affect the features and selections of the exact design, depending on the data acquired during the design mode. It also comes with a hyphenated built in library full of a wide range of categories: airflow, appliances, lighting, equipment, water heating, air condensing, etc. BEOpt aims to detect the most cost effective technique in building design through the selection and combination of multiple possible categories. The software also detects suitable options that could be acquired, adjusted, and customized from these features in order to measure up to the appropriate requirements. Some categories might not need to be included in the simulation designs due to the functionality of these features, such as the heating set point which controls the furnace operation. In a colder climate, the lowest set point will be the optimal point for energy efficiency and minimizing cost. For example, in a mild climate some of the extreme options in wall insulation are not of standard fitting nor in a cold climate are some of the poorly insulated items are not of interest as they do not fit the proper requirements. A third input screen, and one of the BEopt features, is the site screen which is the last input screen. The screen allows the user to specify the location of the building, which opens up a variety of locations across the world that could be added and installed to the site. Also it includes, utility rates and economic properties. Other features, such as directorial locations of the building and surrounding neighbors feature, creates a shading effect on the geometry screen by placing buildings around the design. BEopt performs full life-cycle analysis with costing returns that consist of monthly, daily, and hourly readings. Figure 2.13 demonstrates the input 3 screen as it is shows on BEopt.


Building
EPW Location: CAN_NF_St.Johns.718010_CWEC.
Terrain: Suburban
Natural Gas Hookup ☐

Economics
Project Analysis Period: 30 years
Inflation Rate: 2.4 %
Discount Rate (Real): 3.0 %
Efficiency Material Cost Multiplier: 1.000
Efficiency Labor Cost Multiplier: 1.000
PV Material Cost Multiplier: 1.000
PV Labor Cost Multiplier: 1.000

Mortgage
Down Payment: 0.0 %
Mortgage Interest Rate: 0.0 %
Mortgage Period: 1 years
Marginal Income Tax Rate, Federal: 28.0 %
Marginal Income Tax Rate, State: 0.0 %

Other
Incentives: ☑ PV
Efficiency (Whole-Building)
Demand Response: Signals

Project Info
Building Name: Mobile Office
Street Address:
City: St. john's
State: NL
Zip: A1B 3R5
Country: Canada
Notes:

Electricty | Natural Gas | Oil | Propane

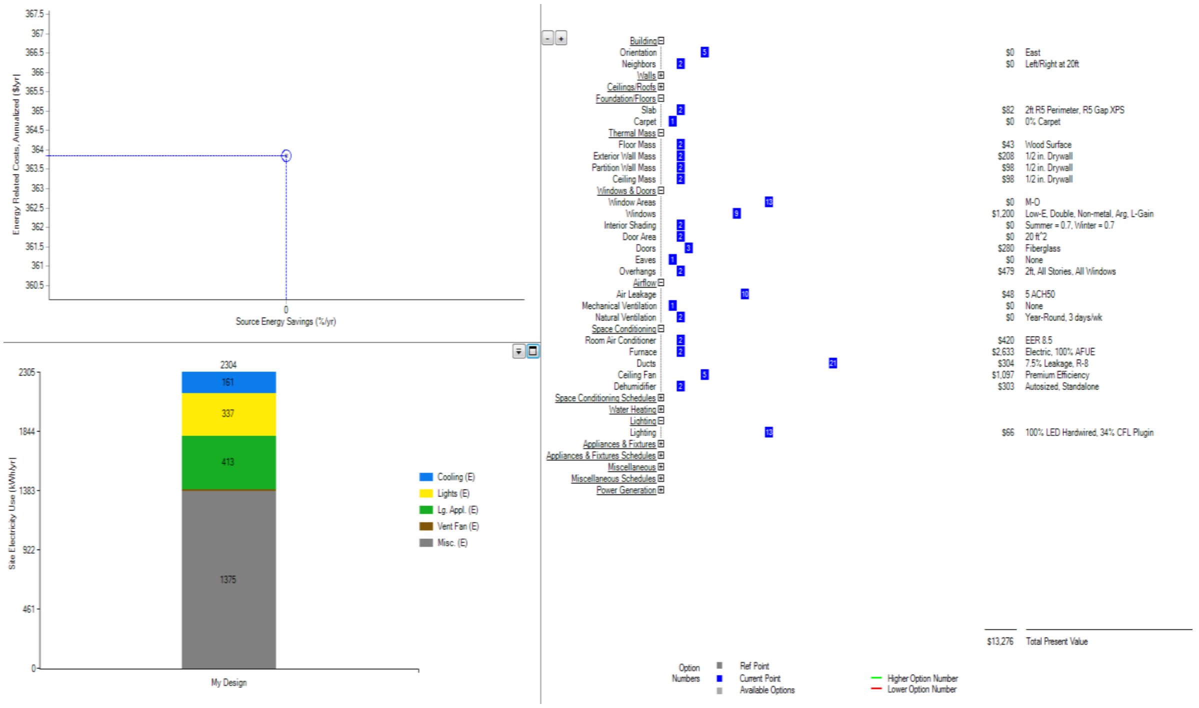
Utility Rates
● Simple ○ Detailed
○ User Specified
● State Average
○ National Average
Fixed: 8.00 $/month
Marginal: 0.1163 $/kWh
Average: 0.1250 $/kWh
Fuel Escalation (Real): 0.00 %/year

PV Compensation
● Net Metering ○ Feed-in Tariff
Annual Excess Sellback Rate
○ Retail Electricity Cost
● User Specified
0.11630 $/kWh
Monthly Grid Connection Fee: 0.00 $/kW

Energy Factors
Source/Site Ratio: 3.150
Carbon Factor: 1.530 lb/kWh

Fig 2.13 location and Site Screen

After constructing of the model and moving over to the analysis procured by clicking on the run button, a small screen will pop up asking to pick the type of viewer that will be used. For example, the viewer "DV" will appear in the D-viewer and it will be selected for this analysis. After that, BEopt will present with three different sample files: (1) designs, (2) parametric cases, and (3) two related optimization and construction sample cases as shown in figure 2.14. Next, multiple points displayed on the output screen including the three show cases of parametric, MU designs, and options.



Building ⊟			
Orientation	5	$0	East
Neighbors	2	$0	Left/Right at 20ft
Walls ⊞			
Ceilings/Roofs ⊞			
Foundation/Floors ⊟			
Slab	2	$82	2ft R5 Perimeter, R5 Gap XPS
Carpet	1	$0	0% Carpet
Thermal Mass ⊟			
Floor Mass	2	$43	Wood Surface
Exterior Wall Mass	2	$208	1/2 in. Drywall
Partition Wall Mass	2	$98	1/2 in. Drywall
Ceiling Mass	2	$98	1/2 in. Drywall
Windows & Doors ⊟			
Window Areas	13	$0	M-O
Windows	9	$1,200	Low-E, Double, Non-metal, Arg, L-Gain
Interior Shading	2	$0	Summer = 0.7, Winter = 0.7
Door Area	2	$0	20 ft^2
Doors	3	$280	Fiberglass
Eaves	1	$0	None
Overhangs	2	$479	2ft, All Stories, All Windows
Airflow ⊟			
Air Leakage	10	$48	5 ACH50
Mechanical Ventilation	1	$0	None
Natural Ventilation	2	$0	Year-Round, 3 days/wk
Space Conditioning ⊟			
Room Air Conditioner	2	$420	EER 8.5
Furnace	2	$2,633	Electric, 100% AFUE
Ducts	21	$304	7.5% Leakage, R-8
Ceiling Fan	5	$1,097	Premium Efficiency
Dehumidifier	2	$303	Autosized, Standalone
Space Conditioning Schedules ⊞			
Water Heating ⊞			
Lighting ⊟			
Lighting	13	$66	100% LED Hardwired, 34% CFL Plugin
Appliances & Fixtures ⊞			
Appliances & Fixtures Schedules ⊞			
Miscellaneous ⊞			
Miscellaneous Schedules ⊞			
Power Generation ⊞			
		$13,276	Total Present Value

Fig 2.14 Output screen

Moreover, the specific metric scene in figure 2.12, where the Y-axis is the cost metric, includes both the utility bills and the cost of the technology itself. On the other hand, the X-axis has an energy saving metric and, in this case, source energy savings.

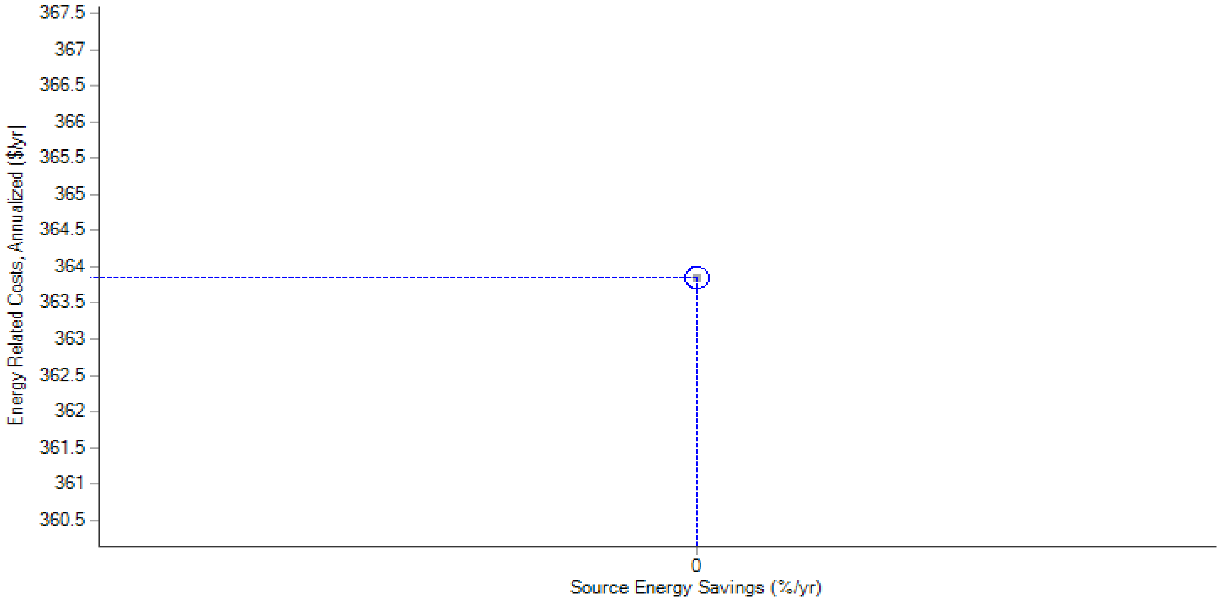


Fig 2.15 Specific Metric Scene

Generally speaking, the base building which is a standard practice building that evaluates a number of possible designs to cut costs by saving on the utility bill. Lowering costs on the utility bill amount to savings that will be greater than the cost of the technology used to lower the contractor costs or the buildings loan payment. All of the related results with fixed points are shown in the other two graphs. The bottom left graph or the MU graph, simulates the relationship between the source energy uses which are desegregated by the different uses in the building. In figure 2.16, lighting banner colored in yellow shows the lighting designs comparing to the base and how much impact it would have on the heating and cooling of the building. Clicking on the options offered on the graph, shows a variety of factors to be considered—instance utility bills, site energy for any of the different fuel types, or even just electricity usage throughout the year in hour by hour readings of the day, or carbon dioxide emissions for the whole building.

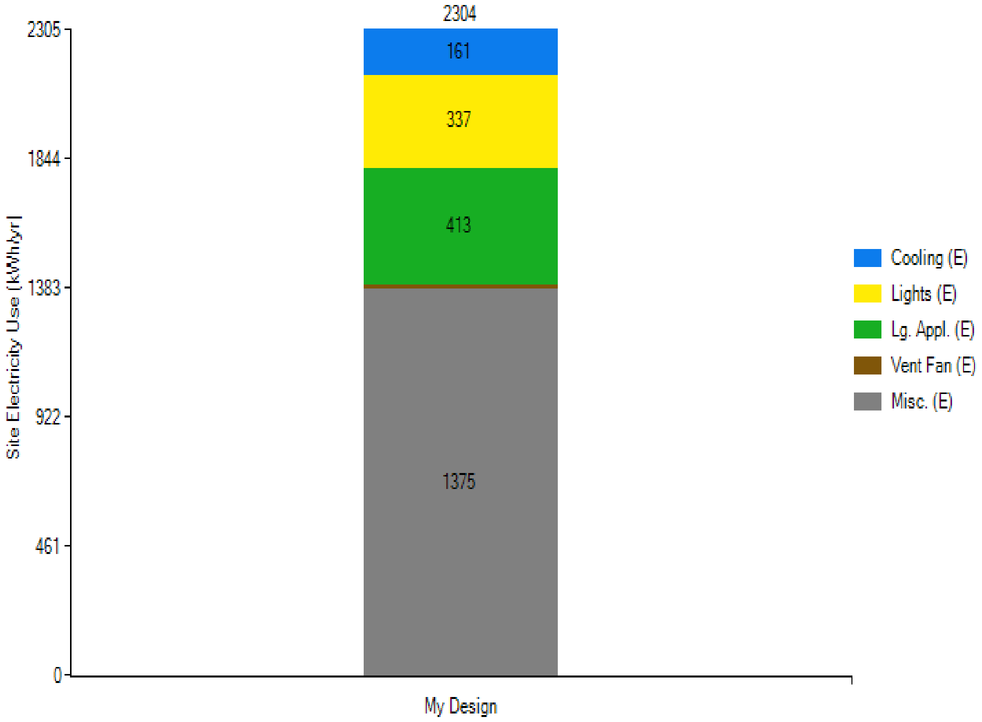
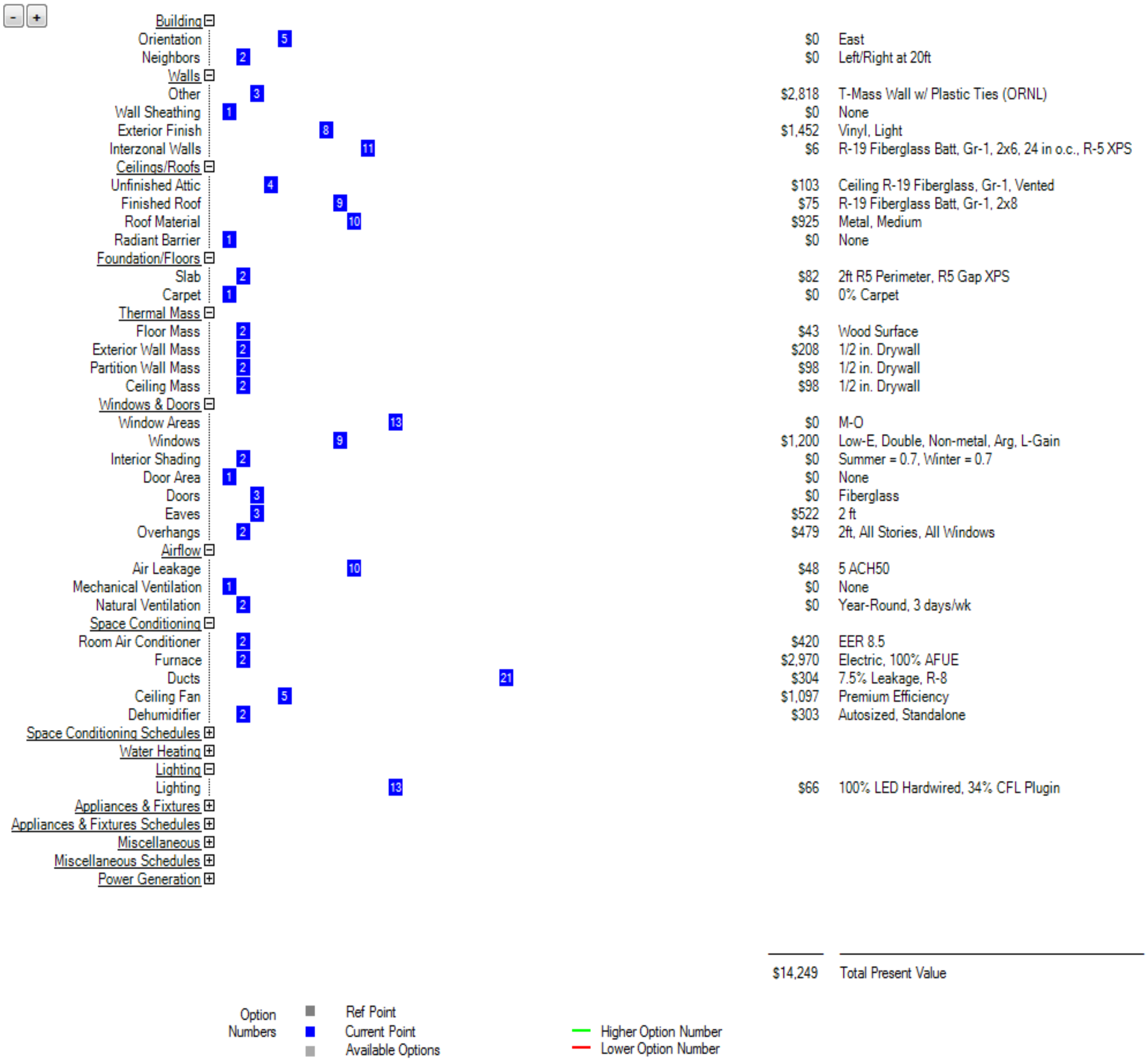


Fig 2.16 Source energy use

One way to compare the energy availability from different resources is to use probability or availability curves, or compare inputs from the screen shown in figure 2.17. Costs and type of building construction range over a variety of directional inputs. For example, $2800 for walls with R-20 insulation 2 x ½ in, fiberglass doors attached to the building with $1452 worth of exterior finishes, $103 of R-19 ceiling fiberglass along with $925 worth of metal roofing of medium hardness, and $335 for whole slab carpet.



Building ⊟			
Orientation	5	$0	East
Neighbors	2	$0	Left/Right at 20ft
Walls ⊟			
Other	3	$2,818	T-Mass Wall w/ Plastic Ties (ORNL)
Wall Sheathing	1	$0	None
Exterior Finish	8	$1,452	Vinyl, Light
Interzonal Walls	11	$6	R-19 Fiberglass Batt, Gr-1, 2x6, 24 in o.c., R-5 XPS
Ceilings/Roofs ⊟			
Unfinished Attic	4	$103	Ceiling R-19 Fiberglass, Gr-1, Vented
Finished Roof	9	$75	R-19 Fiberglass Batt, Gr-1, 2x8
Roof Material	10	$925	Metal, Medium
Radiant Barrier	1	$0	None
Foundation/Floors ⊟			
Slab	2	$82	2ft R5 Perimeter, R5 Gap XPS
Carpet	1	$0	0% Carpet
Thermal Mass ⊟			
Floor Mass	2	$43	Wood Surface
Exterior Wall Mass	2	$208	1/2 in. Drywall
Partition Wall Mass	2	$98	1/2 in. Drywall
Ceiling Mass	2	$98	1/2 in. Drywall
Windows & Doors ⊟			
Window Areas	13	$0	M-O
Windows	9	$1,200	Low-E, Double, Non-metal, Arg, L-Gain
Interior Shading	2	$0	Summer = 0.7, Winter = 0.7
Door Area	1	$0	None
Doors	3	$0	Fiberglass
Eaves	3	$522	2 ft
Overhangs	2	$479	2ft, All Stories, All Windows
Airflow ⊟			
Air Leakage	10	$48	5 ACH50
Mechanical Ventilation	1	$0	None
Natural Ventilation	2	$0	Year-Round, 3 days/wk
Space Conditioning ⊟			
Room Air Conditioner	2	$420	EER 8.5
Furnace	2	$2,970	Electric, 100% AFUE
Ducts	21	$304	7.5% Leakage, R-8
Ceiling Fan	5	$1,097	Premium Efficiency
Dehumidifier	2	$303	Autosized, Standalone
Space Conditioning Schedules ⊞			
Water Heating ⊞			
Lighting ⊟			
Lighting	13	$66	100% LED Hardwired, 34% CFL Plugin
Appliances & Fixtures ⊞			
Appliances & Fixtures Schedules ⊞			
Miscellaneous ⊞			
Miscellaneous Schedules ⊞			
Power Generation ⊞			
		$14,249	Total Present Value

Fig 2.17 Option screen of BEopt simulation results

As insulation is a major concern in these kind of offices due to climate change, a wall mass of ½ in of Drywall with a wood surface on the top costing $360. For the exterior, a metal free doubled low-e windows are installed at the rate of $1200, including a 2 ft overhang for $479. Air exchange is a necessity on site. Room air conditioning costs $420 at the highest temperature of the day. A ceiling fan will cost $1097, and $3653 for a 100% electric furnace. Lighting is an important factor during the day for sites that get darker earlier. 100% LED hardwired and connected for hours in these areas with 34% plugin amounts to $66 each. For utility usage, a cost of $932 for a freezer with 17.6% usage is added for this unit as an essential, not only to optimize the energy efficiency, but also to be economically feasible. Thus, it is necessary to calculate the Net Present Cost (NPC), which roughly estimates the amount of money which must be spent throughout the years, given as:

$C_{NPC} = C_{tot}/C_{RF}$—(1)

C_{NPC}: Net Present Cost, C_{tot}: Total Cost, C_{RF}: Capital Recovery Factor.

The total cost is estimated at $15,727 of the total present value. The system is an energy device that directly converts the power of the feeding fuel into electricity without limitation, and is suitable for stationary and mobile applications. Hybrid renewable systems, including energy storage, are especially suited as an energy supply for isolated area when high feasibility is required. Due to the high conversion efficiencies and the negligible environmental impact, hybrid technology is considered as one of the most promising in contributing to generation of electrical power in the near future [41].

Chapter 3 Sizing of hybrid power system for a mobile office

3.1 Introduction

In this chapter, the author aims to discuss the results of a research study that was published at the 16th annual IEEE Electrical Power and Energy Conference of 2016 (EPEC) in Ottawa, Canada. During the conference, a study was completed at the faculty of Electrical and Computer Engineering at Memorial University in St. John's, it showed the design of Renewable Energy System for a remote Mobile Office in Newfoundland. Renewable Energy Systems are becoming a common choice for small communities in Canada where the cost of diesel fuel is high. The study considered a PV/Wind hybrid system for supplying the electrical load of a mobile office which was proposed and presented along with relevant statistics. Wallis, L. R., "Through the Energy Looking Glass," Vital speeches of the day, vol. LX, pp. 381, 1994, stated in his speech to the American Nuclear Society (ANS) "the world will need to exploit energy resources in increasing amounts if we are to have any hope of bringing people in the developing world up to a reasonable standard of living" [42]. Renewable energy is considered by many as a good field to exploit. For example, the Earth Day Network claims that "Renewable sources of energy are virtually inexhaustible and are naturally and quickly replenished" [43]. Switching to clean, renewable energy will bring us cleaner air and water while improving human health and increasing energy security. However, others claim that renewable energy will never provide us with the energy we require. Others even claim that fossil fuels are the only possible resource for our energy needs and imply that we should not bother looking elsewhere. For example, barring a significant technology breakthrough in either renewable-energy (technology) or cost (of nuclear power), fossil fuels appear to be the only real choice well into the next century. After reviewing renewable energy systems around the world other than hydropower, wind and solar are the most common. Combining both will improve the reliability as compared to using only over the other. For example, it is more practical to use a small solar electric or photovoltaic (PV) system that can be reliable and pollution-free to produce electricity for homes and offices in areas where the radiation of the sun is available, but an optimal configuration of a different renewable energy systems could be determined and obtained by taking the total cost as the objective function. The system optimization is done through optimization features from Energy3D, NREL, HOMER. The results of this study show the hybrid renewable energy system as a cost effective solution. Furthermore, the proposed system it is expected to help companies to provide uninterrupted power for their sites in remote locations.

3.2 Overview of Energy System Configuration

The most important factor in developing a hybrid energy system is the geographical location, in which the available wind and solar data vary significantly. Some resources such as Hydro are consistently available, and some resources are available seasonally such as wind and photovoltaic. During the process, different alternatives were analyzed under the constraint of being 100% renewable. Canada has many renewable energy resources, but at this particular site wind and solar energy are abundantly available. As an overview, the general architecture of conventional grid-connected energy systems is significantly complex from stand-alone renewable energy systems.

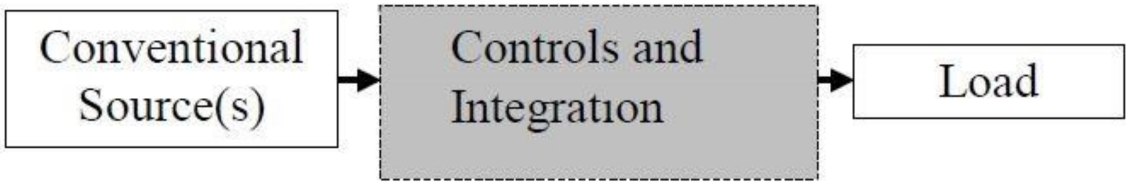


Fig 3.1 Conventional energy system

Energy systems and renewable energy systems models required a consideration of the background of the conventional energy systems in particular, as well a comparison of the different architectures of systems. Figure 3.1 above shows a schematic of a conventional energy system. The resources have the ability to keep up with the demand of the load with a different time constant which controls the systems scale, regardless of whether it is a large or small scale system. Conventional systems generally rely on fossil fuels, such as coal power plants, combined-cycle gas turbines, and diesel generators. Our study suggests that the St. John’s, Newfoundland site has sufficient wind and solar energy for generating acceptable power for this application, in order to be suitable and reliable to power loads. The most popular alternative energy sources are wind and Photovoltaic (PV). However, the seasonal and fluctuating nature of these sources limits their applications for continuous power operations, due to the unpredictability of the weather on an island like Newfoundland. It is suitable to add a conventional generator onto the system as long as the usage of the diesel generator resource does not exceed 15-20% of the load. Below this level, the system can absorb the fluctuations in the load energy by relying on the following characteristics of the hybrid resource.

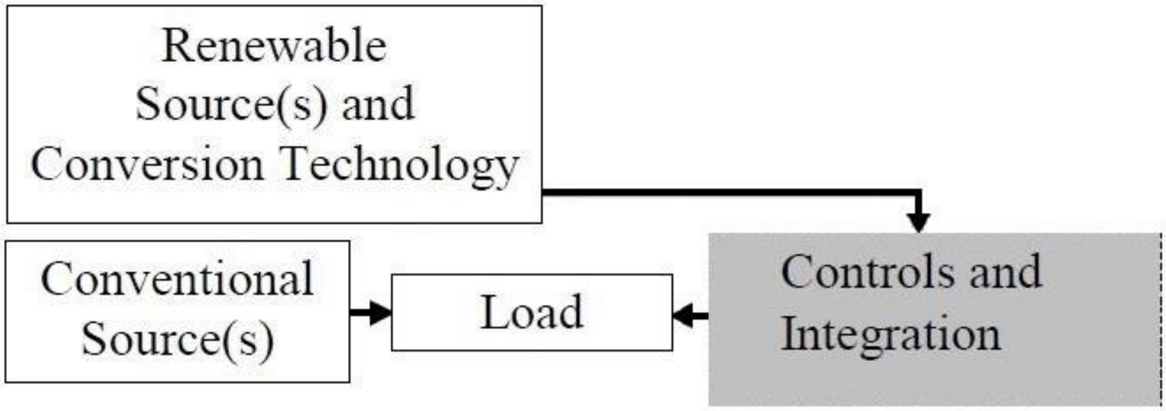


Fig 3.2 Grid-Connected Renewable Energy System

Conversion of wind or solar energy into electricity is more feasible, practical, and easier to do than tide or wave energy. Wind and solar energy, in particular are available in almost every place in the world. Renewable energy is appropriate and economical for generating power for more remote service sites [44]. This system can be developed with either a conventional energy backup system or the system is installed without a backup. However, the lack of energy resources several times during the year for this exact location implies a need for some form of storage, including storage indicated in the energy system diagrams. A schematic of an integrated renewable energy system is shown below in figure 3.3.

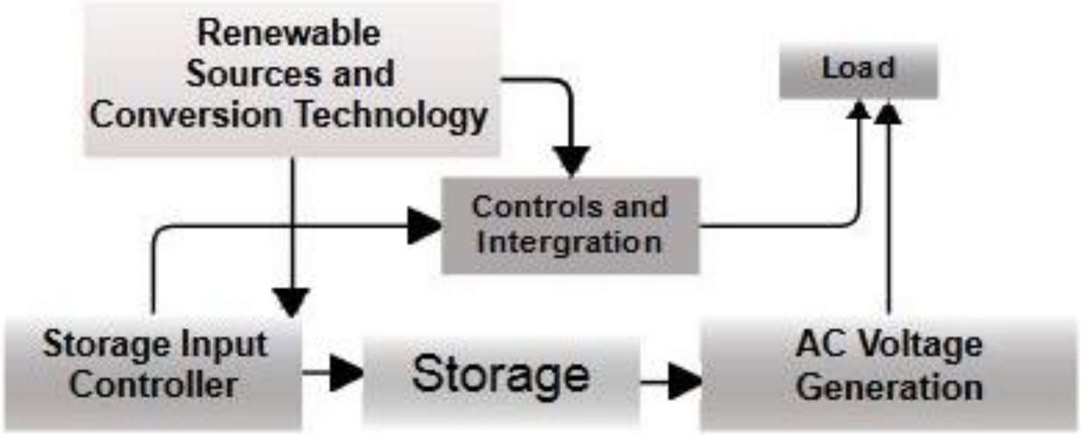


Fig 3.3 Renewable Energy System

3.3 Renewable Energy resources at the location

This section provides a brief review of the two different sources of data used in renewable energy system modeling wind energy and Solar Global Horizontal Irradiance (GHI) resources. Primary energy sources that are infinitely available (such as sunlight, wind or biomass) have less severe environmental consequences. Data was gathered and stochastically modeled from the National Aerodynamics and Space Administration (NASA) website, which include daily and hourly readings of wind speed (m/s) and solar GHI (KWh/m^2/day). NASA is an independent agency of the executive branch of the United States federal government responsible for the civilian space program as well as aeronautics and aerospace research [45]. One technology to generate electricity in a renewable way is to use wind turbines that convert the energy contained by the wind into electricity. The wind is an infinite primary energy source. Furthermore, wind speed, or wind flow velocity is caused by air moving from high pressure to low pressure, usually due to changes in temperature, and it is a fundamental atmospheric quality that affects weather forecasting, aircraft, and maritime operations. One of the main environmental problems associated with wind power are the rotor blades, such as interfering with flight pattern of birds, which is the topic of major debates right now over environmental health and safety, although, many of the turbine’s components can be recycled. Moreover, wind power is a relatively cheap source of renewable energy; therefore, its use is highly promoted and it has strong growing popularity in countries such as Germany, Denmark, and Spain [46]. Figure 3.4 depicts the growth of wind power during the last decade in the US, Europe, and the world.

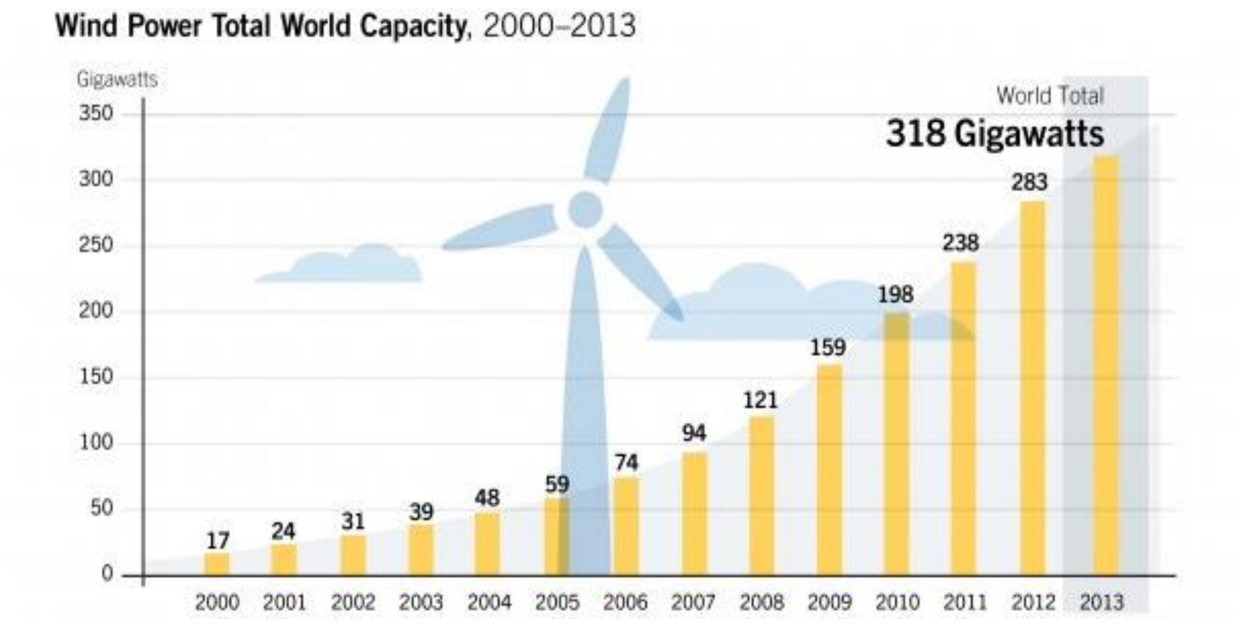
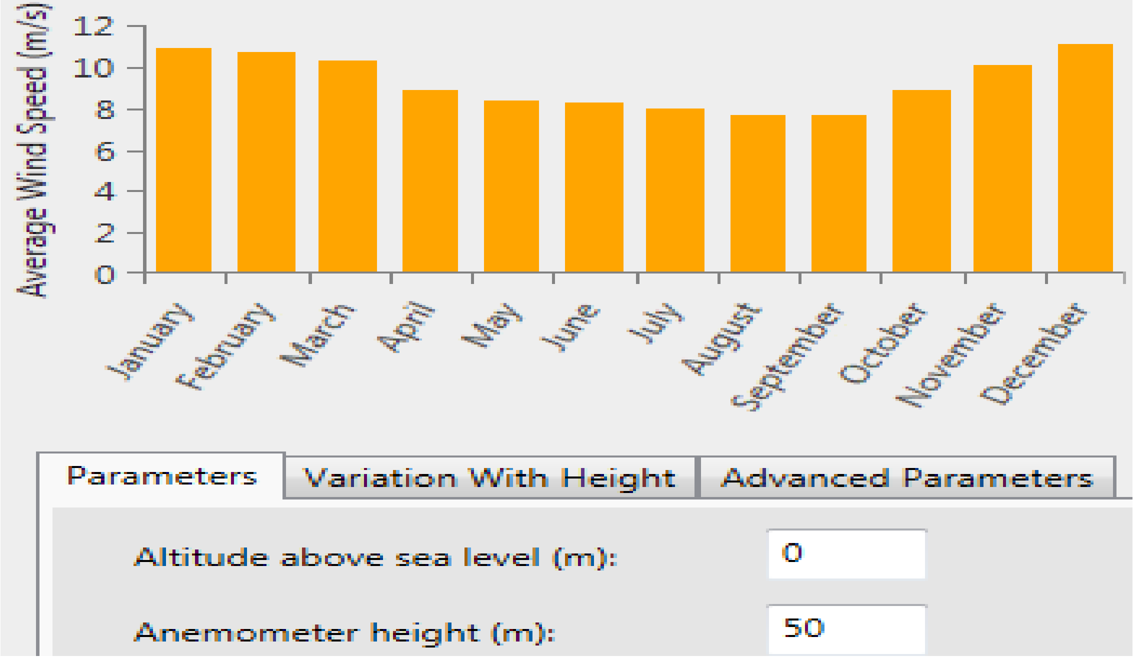


Fig 3.4 Wind Turbines installed across the world [47]

NASA surface meteorology is used to get the approximate wind speed at the sites, downloaded for one year with a 50_m above the surface of the earth for terrain similar to airports, and a monthly averaged values over the year period with 47.5 altitude for the cell point.



Altitude above sea level (m): 0

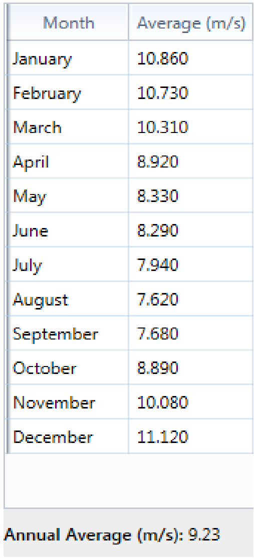
Anemometer height (m): 50

Fig 3.5 Monthly Wind Speed average [48]

Figure 3.5 shows a capture of the monthly average wind data for the year of 2015 with a graph that varies between January and December. Average wind speed is shown on the Y-axis, while months are displayed on the X-axis.

The average wind speed is estimated at 9.23m/s. The highest value was reported in December and the lowest speed was recorded during the summer/beginning of fall. Historically, wind speeds have been reported with a variety of averaging times. Table 3.1 shows annual average included with that monthly data [48]. The extracted months are then combined into a single 'typical' year with 8760 points in one file that is used in the HOMERPRO software which is a newer version of HOMER, which simulates the operation of the system based on the components chosen by the designer. In this process, HOMER will take readings of the hourly data and performs the energy balance calculation based on the system configuration which consists of several numbers and sizes of the component.

Table 3.1 Monthly Wind Data [48]



Month	Average (m/s)
January	10.860
February	10.730
March	10.310
April	8.920
May	8.330
June	8.290
July	7.940
August	7.620
September	7.680
October	8.890
November	10.080
December	11.120

Annual Average (m/s): 9.23

According to the Danish Society of Engineers (IDA), with careful planning and care, it is possible to create a future with sustainable energy by 2030 [46]. In more than one sense, this is a future which is worth investing in. On the other hand, solar energy resources and availability has always been a questionable matter by scientists from around the globe. In fact, solar radiation is available on a daily basis as the sun rising every day for hours, providing light, heat, and electricity. Solar energy is radiant light and heat from the sun that is harnessed using a range of ever-evolving technologies such as solar heating, photovoltaics, solar thermal energy, solar architecture, molten salt power plants, and artificial photosynthesis [47]. Solar power is an important source of renewable energy and its technologies are broadly characterized as either passive or active depending on how it is captured, distributed, and converted into solar power. Photovoltaics, or (PV), are an active solar technique, and as such, it concentrates solar power and converts sunlight into useful outputs. A solar cell is a device that converts light directly into electricity using photoelectric effects. Architectural history has always been influenced by sunlight during both the design and building phases. The proposed system is similar to these systems which are frequently built on residential households with batteries as energy storage (ES). Even during cold nights and stormy weather conditions, they provide the energy to the load. A charge controller is used in the system to prevent overcharging and deep discharge of the batteries. These systems generally include an inverter, which converts the DC voltage of PV modules into AC voltage for direct use with the appliances.

Fig 3.6 PV System with a Battery Energy Storage System

Figure 3.6 shows a typical off-grid PV system with a backup battery energy storage. The photovoltaic flat panel collector receives the energy from the sun and the current generated in the panel is sent through the inverter to the AC bus. The power at the AC bus is fed to the load and the excess will be sent to the battery backup bank. Hourly average global horizontal irradiance models can be broken into a number of different categories. In general, three different components are required to obtain energy from the sun. First, the insulation at a site will obviously have a significant impact on the available energy. Second, the orientation of the collector to this insulation also has a significant effect, since solar insolation is highly directional. Finally, we realize that the actual technology used to convert the insolation to a usable energy form has a significant effect on the amount of energy available. Such data is also acquired from the NASA Surface Meteorology and Solar Energy "Global Data Sets", files provided at no cost free of charge from the agency and give data for typical year data that is taken from a 30-year data set. Each "typical" year is extracted, month-by-month, from the 30-year data set using a number of different statistical criteria that are deemed appropriate for the specific purpose and location that the files are being developed for. The latitude and longitude of the location around Newfoundland can be easily downloaded once it is entered into the software. The graph below shows the hourly solar radiation data that can be collected from NASA's website.

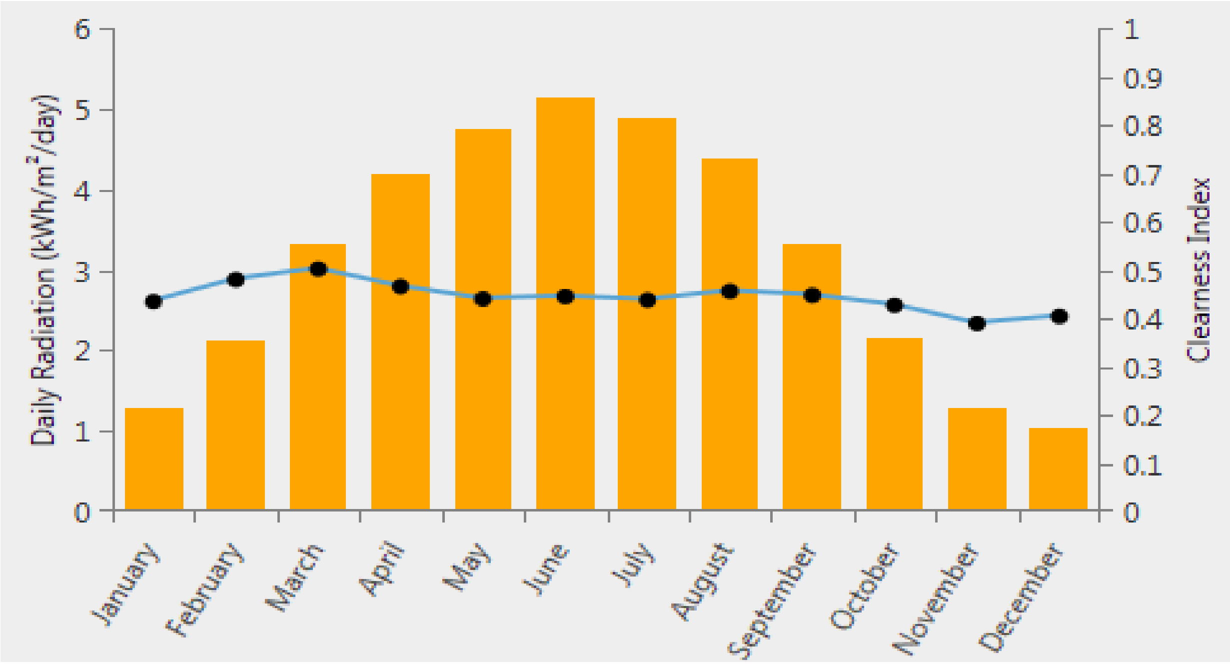
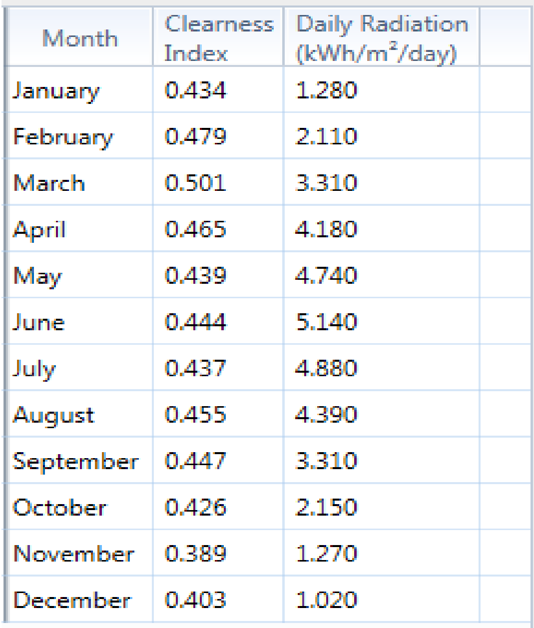


Fig 3.7 Monthly solar radiation and average daily irradiation [48]

With an average solar irradiation of 3.15kWh/m²-d, table 3.2 shows the results for one year of a sensitivity analysis that includes three different values, clearness index, and the average daily radiation [48].

Table 3.2 Monthly average, clearness and daily average of the solar radiation



Month	Clearness Index	Daily Radiation (kWh/m^2/day)
January	0.434	1.280
February	0.479	2.110
March	0.501	3.310
April	0.465	4.180
May	0.439	4.740
June	0.444	5.140
July	0.437	4.880
August	0.455	4.390
September	0.447	3.310
October	0.426	2.150
November	0.389	1.270
December	0.403	1.020

Using the availability of a renewable energy resource, we can calculate a basic installation size required for a specified amount of energy supplied. This calculation, although it can be used to calculate the energy supplied by grid-connected renewable energy, does not take into consideration the unique features of a stand-alone system. The time-dependence of the resource, the non-linearity of the storage system and the efficiency cost of the storage system all have significant effects on the operation of standalone systems. Although renewable energy systems do require a storage system, which has a significant impact on the overall efficiency and cost of the system, they are generally considered to have fewer environmental impacts than conventional energy sources, and definitely produce lower quantities of greenhouse gas during operation.

3.4 System Optimization

The proposed hybrid renewable energy system introduces the working principles of electrical power systems, power generation with wind turbines and photovoltaics. The research looked at the general structure of the electrical power systems and compared wind turbine and Photovoltaic (PV) array systems. Moreover, it discussed electrical power generation, transmission, distribution, and consumption, devoting most of the power generation to the wind turbine indicated by the power curves and speed. Part of the power generation comes from the solar power which includes the control of sensitivity variables and availability of solar irradiance. Also, for backups and emergency load need, a diesel generator is connected to the system with a battery bank and a power converter, and utilized as a storage system for the unit. The transmission of electrical power is carried out at high voltages and often over long distances, and the losses are mainly dependent on the current and the distance to be covered. For practical reasons, this design is specifically for an off-grid system at remote areas. Implementation of this kind of system is shown in the block diagram in figure 3.8. The block diagram illustrates the general structural of a conventional standalone off-grid renewable energy system, which is significantly different from a grid-connected energy system. This overview provides the background required to consider the energy system and renewable energy system models. In particular, the proposed system will reduce fuel consumption and associated operation and maintenance costs [48].

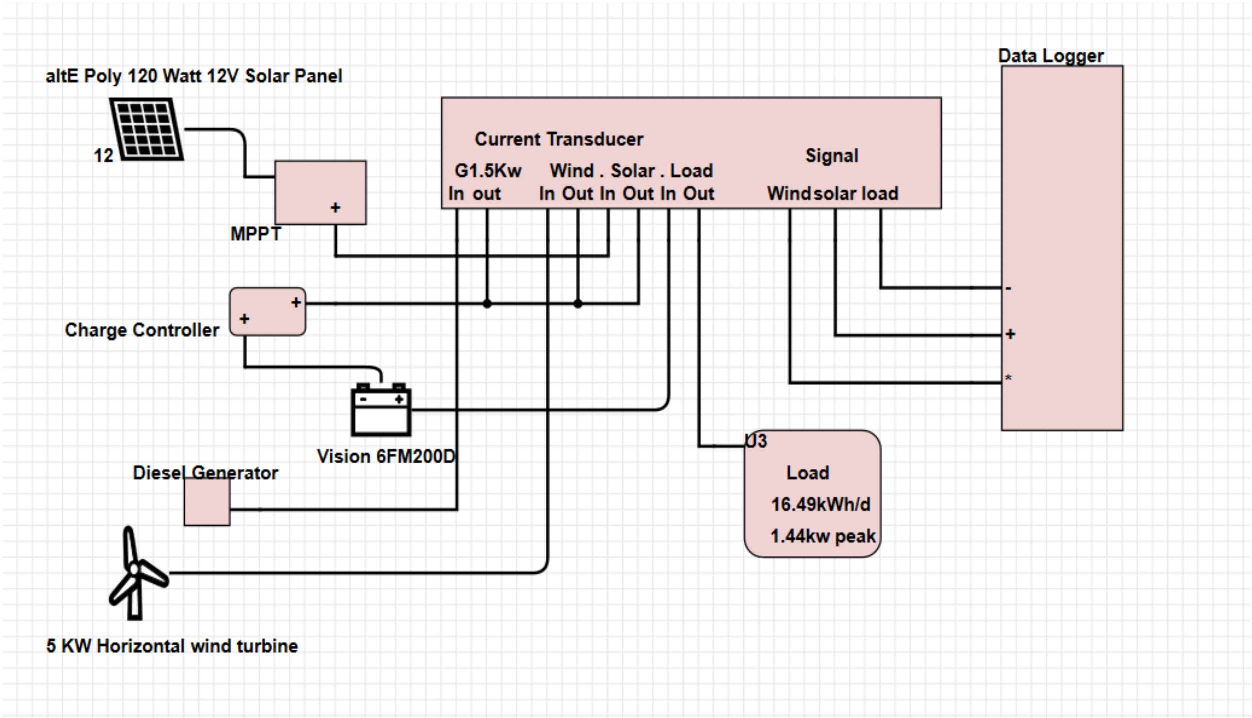


Fig 3.8 System Optimization Simulink Block diagram

The proposed hybrid renewable energy system, shown in figure 3.9, consists of 5kW horizontal wind-turbine, 24, 120W, 12V solar modules, and a 1.5kW generator. In this system, the wind turbines and PV will be the primary power source.

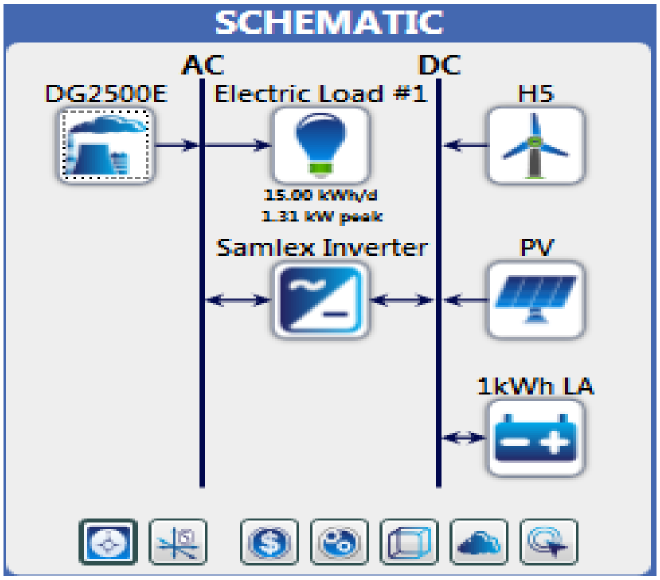


Fig 3.9 System Optimization on HOMERPRO

3.4.1 Wind Turbine

The wind-turbine is characteristic of a typical power output. Depending upon the manufacturer's specifications, the wind turbine starts generating power at the cut-in speed. The power output increases with the variation of wind speed from cut-in speed to rated speed. At wind speeds greater than cut-out speed, the wind turbine shuts down for safety considerations. The rated power output is obtained at the rated wind speed of the turbine [49].

Mathematically, the power output from a wind turbine is given as:

$Pw = 1/2. Pa. A. Cp. V^3$ ——(2)

Where:

Pw: is the power output.

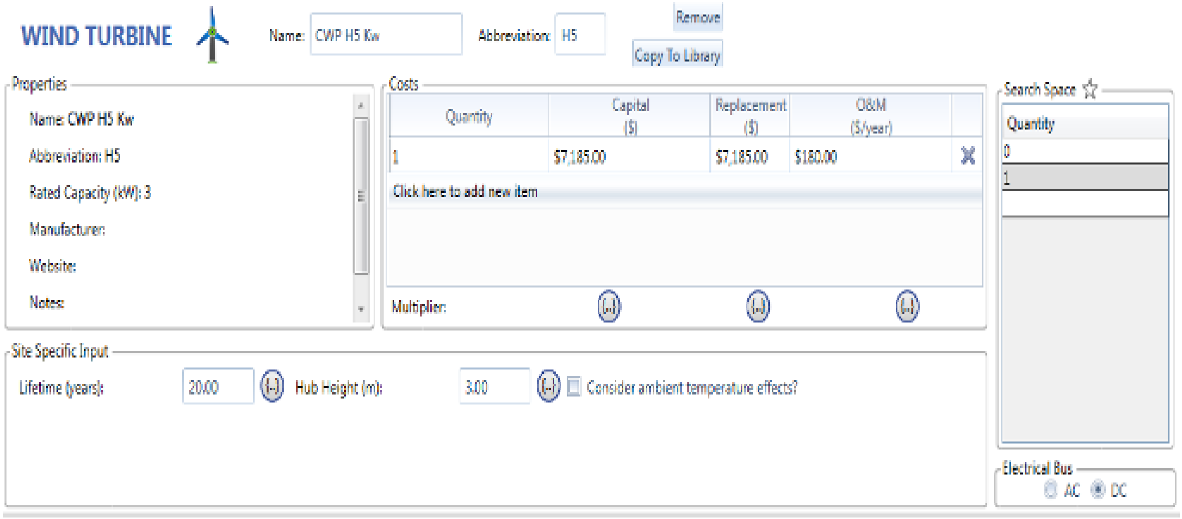
Pa: is the air density.

A: is the swept area.

Cp: is the power coefficient and

V: is the wind-speed.

One horizontal axis H5 wind-turbine is used in this system, with a rated capacity of 5kW and provides 48V DC. The initial capital cost is $7185, the replacement cost is $7185, and the annual operation and maintenance cost are $180 for each turbine. From [50], all the technical parameters of wind turbines were obtained and added, some details are shown in figure 3.10. The blade will not move if the wind speed is below 3m/s, and the blade will automatically stop when the wind speed is above 17m/s. Wind speed kicks in at the cut in speed between 2-3 m/s.



Name: CWP H5 Kw

Abbreviation: H5

Properties:

- Name: CWP H5 Kw
- Abbreviation: H5
- Rated Capacity (kW): 3
- Manufacturer:
- Website:
- Notes:

Costs:

Quantity	Capital ($)	Replacement ($)	O&M ($/year)
1	$7,185.00	$7,185.00	$180.00

Click here to add new item

Search Space:

Quantity
0
1

Lifetime (years): 20.00

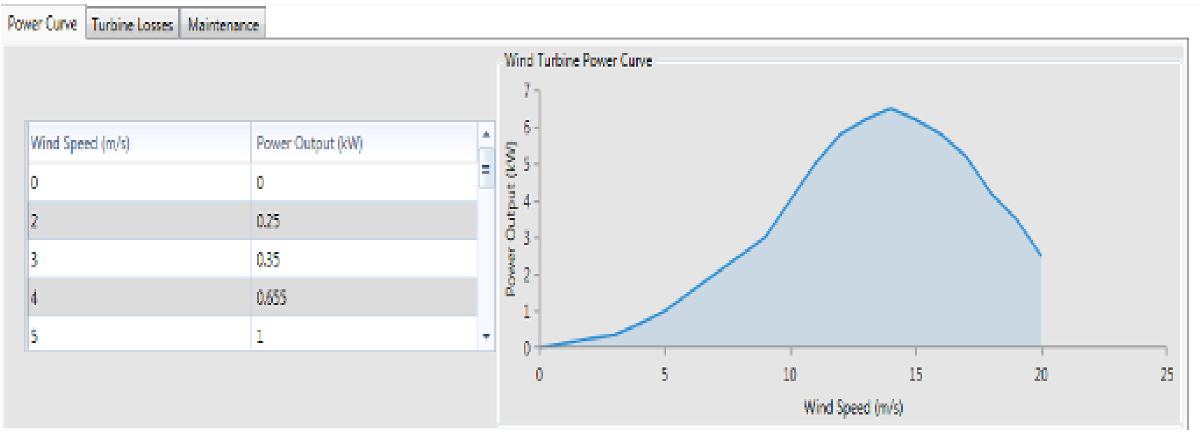
Hub Height (m): 3.00

☐ Consider ambient temperature effects?

Electrical Bus: ○ AC ● DC

Fig 3.10 H5 Horizontal axis 5kW Wind Turbine

The information of average wind speed is shown in the table included with the figure 3.11. The autocorrelation factor of r1=0.85 is measured based on the hour-to-hour randomness of the wind speed. The diurnal pattern strength of δ = 0.26 represents the strength of wind speed and the windiest time is ø = 17.



Wind Speed (m/s)	Power Output (kW)
0	0
2	0.25
3	0.35
4	0.655
5	1

Fig 3.11 Wind turbine Power Curve and table

3.4.2 Solar Panels

It is important to have a proper understanding of a PV module performance under different operating conditions for the appropriate application of PV modules in a stand-alone system. Various parameters that influence the performance of a crystalline silicon PV module are temperature of module, PV module material, and the solar radiance on the PV module surface [51]. A proper understanding of the PV module performance under different operating conditions for an appropriate application of PV modules in a stand-alone system.

Mathematically, from the input solar radiation to the PV system, the total solar radiation on an inclined surface is estimated as:

$I_T = I_{Direct}\, R_{Direct}+I_{Diffuse}\, R_{Diffuse}+R_{Reflected}\, (I_{Direct}+I_{Diffuse})$

where, I_{Direct} and $I_{Diffuse}$ are direct and diffuse solar radiations, $R_{Diffuse}$ and $R_{Reflect}$ are the tilt factors for the diffuse and reflected part of the solar radiations [51]. Hourly power output from the PV system with an area A_{pv} (m^2) on an average day of I_{th} month, when total solar radiation of I_T (kWh/m^2) is evident on the PV surface, which is given as:

$P_{pv} = I_{Ti}\, \eta\, A_{pv}$

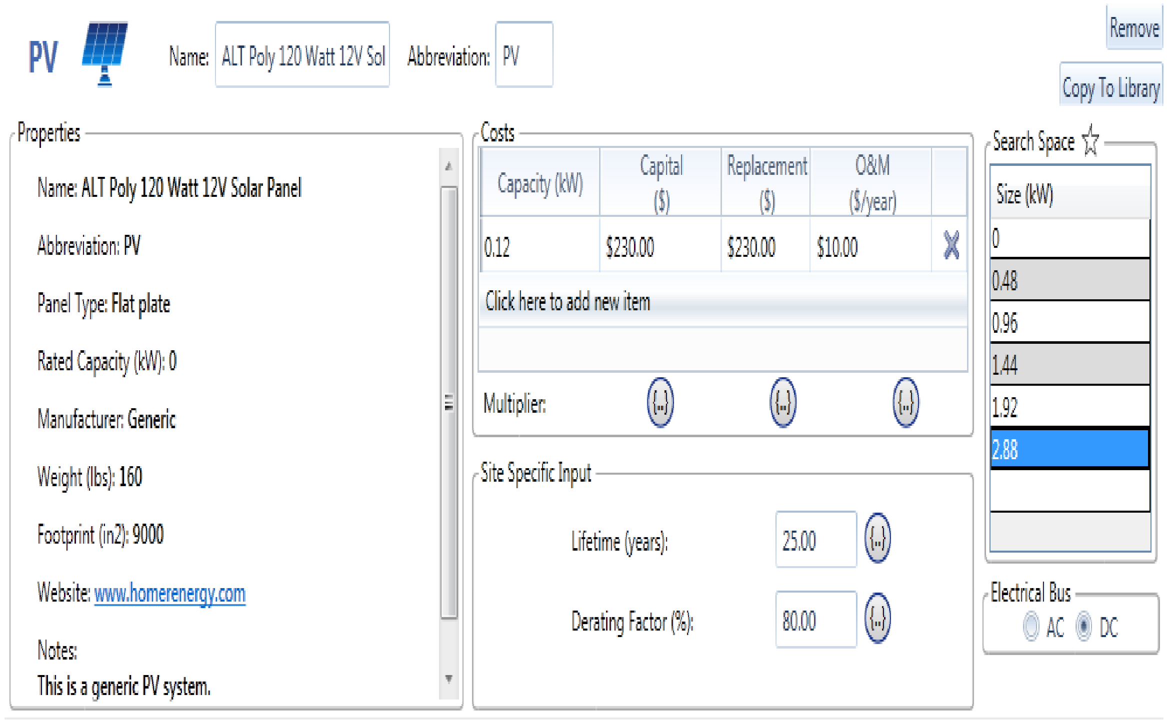
where, system efficiency

$\eta = \eta_{mod}\, \eta_{pc}\, P_f$

and the module efficiency η_{mod} is given as

$\eta_m = \eta_r\, [1 - \beta(T_c - T_r)]$

where, η_r is the module reference efficiency, η_{pc} is the power conditioning efficiency, P_f is the packing factor, β is the array efficiency temperature coefficient, T_r is the reference temperature for the cell efficiency and T_c is the monthly average cell temperature [52, 54]. Various parameters that influence the performance of a crystalline silicon PV module are temperature of module, PV module material, and the solar radiance on the PV module surface [55]. ALTE POLY solar modules are used in this system and each module panel provides 120W with 12V. Therefore, four PV modules are connected in a series to meet the bus voltage which is 48V. In this system, modules are connected in 6 strings. The initial cost of each panel connected in the series is $230, replacement cost is $230, and operational and maintenance cost is $10 [56]. More details are shown in figure 3.12.



Name: ALT Poly 120 Watt 12V Sol

Abbreviation: PV

Properties

Name: ALT Poly 120 Watt 12V Solar Panel

Abbreviation: PV

Panel Type: Flat plate

Rated Capacity (kW): 0

Manufacturer: Generic

Weight (lbs): 160

Footprint (in2): 9000

Website: www.homerenergy.com

Notes:
This is a generic PV system.

Costs

Capacity (kW)	Capital ($)	Replacement ($)	O&M ($/year)
0.12	$230.00	$230.00	$10.00

Search Space

Size (kW)
0
0.48
0.96
1.44
1.92
2.88

Site Specific Input

Lifetime (years): 25.00

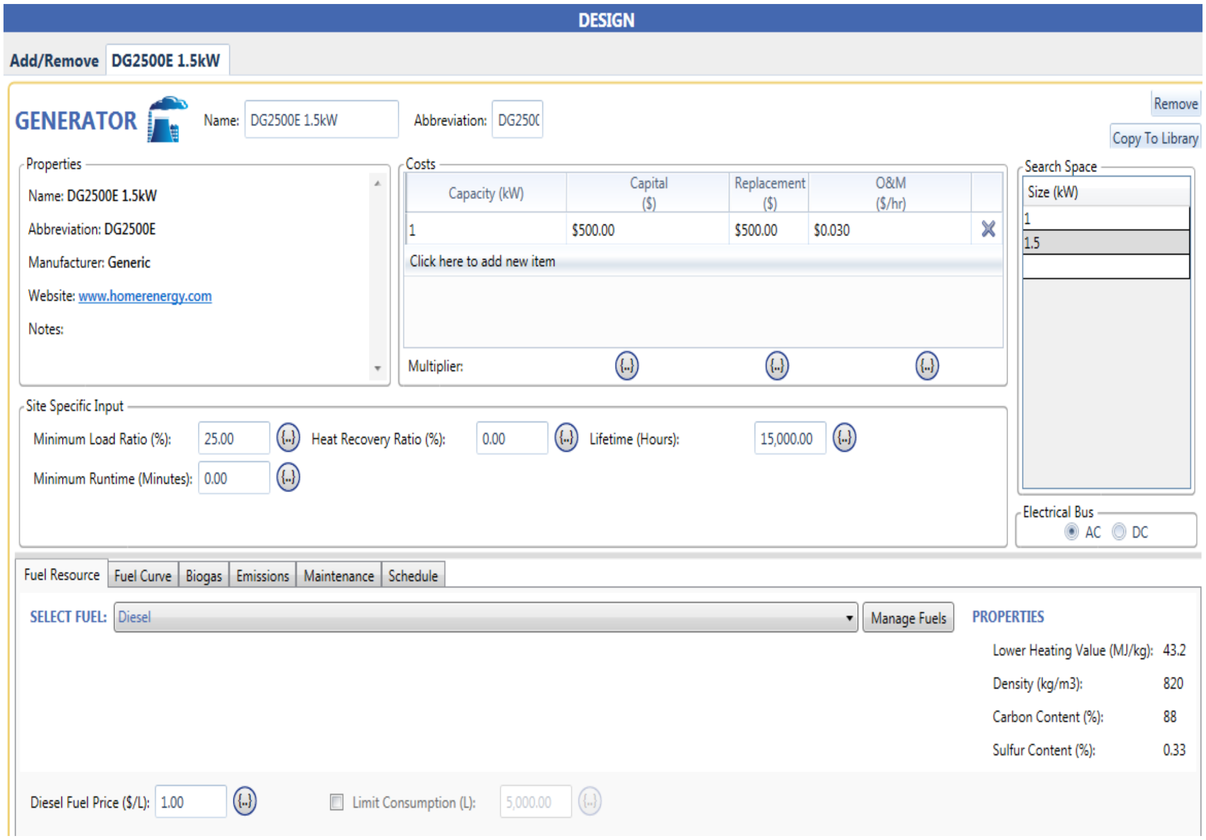
Derating Factor (%): 80.00

Electrical Bus
○ AC ● DC

Fig 3.12 ALTE POLY 12V PV

3.4.3 Generator

The load on the system is considered to be constant through each hourly time step. Although this is not ideal, the model would quickly become overloaded and complex. As to obtaining an accurate model for the loads on remote are sites during winter times, which will cause a significant drop in renewable resources, an electricDG2500E small portable 1.5kW diesel generator is installed and selected based on the electrical load that is intended to supply. The diesel generator engine is insulated at 1200 rpm with 12,000 hours rebuild. This system is a combination of a diesel engine with an electric generator (often an alternator) to generate electrical energy. This is a specific case of engine-generator. A diesel compression-ignition engine often is designed to run on fuel oil, but some types are adapted for other liquid fuels or natural gas. In over loading situations, an emergency stand-by diesel generator preforms the secondary function of compensating the shortage in power supply. It can be up and running in parallel in the site in quickly as two minutes, and does no impact on the site of the office shut down. Whilst diesel is very expensive in fuel terms, they are only used for few hundred hours per year in this capacity, and their availability can prevent the need for a base load station. Figure 3.13 below captures the diesel generator used in the hybrid system, with an initial and replacement cost of $500. The diesel price with four discrete values of 1.00$/L, 1.2$/L, 1.4$/L and 0.9$/L are used for the sensitivity analysis. At present, the diesel price is about 1.41$/L. The diesel generator will supply 17% of the electricity at the time of need during the hours of operation, with an operational and maintenance cost of 0.03$/hr.



Name: DG2500E 1.5kW
Abbreviation: DG250(

Properties
Name: DG2500E 1.5kW
Abbreviation: DG2500E
Manufacturer: Generic
Website: www.homerenergy.com
Notes:

Costs

Capacity (kW)	Capital ($)	Replacement ($)	O&M ($/hr)
1	$500.00	$500.00	$0.030
Click here to add new item			

Multiplier:

Search Space

Size (kW)
1
1.5

Site Specific Input
Minimum Load Ratio (%): 25.00
Heat Recovery Ratio (%): 0.00
Lifetime (Hours): 15,000.00
Minimum Runtime (Minutes): 0.00

Electrical Bus: ● AC ○ DC

SELECT FUEL: Diesel

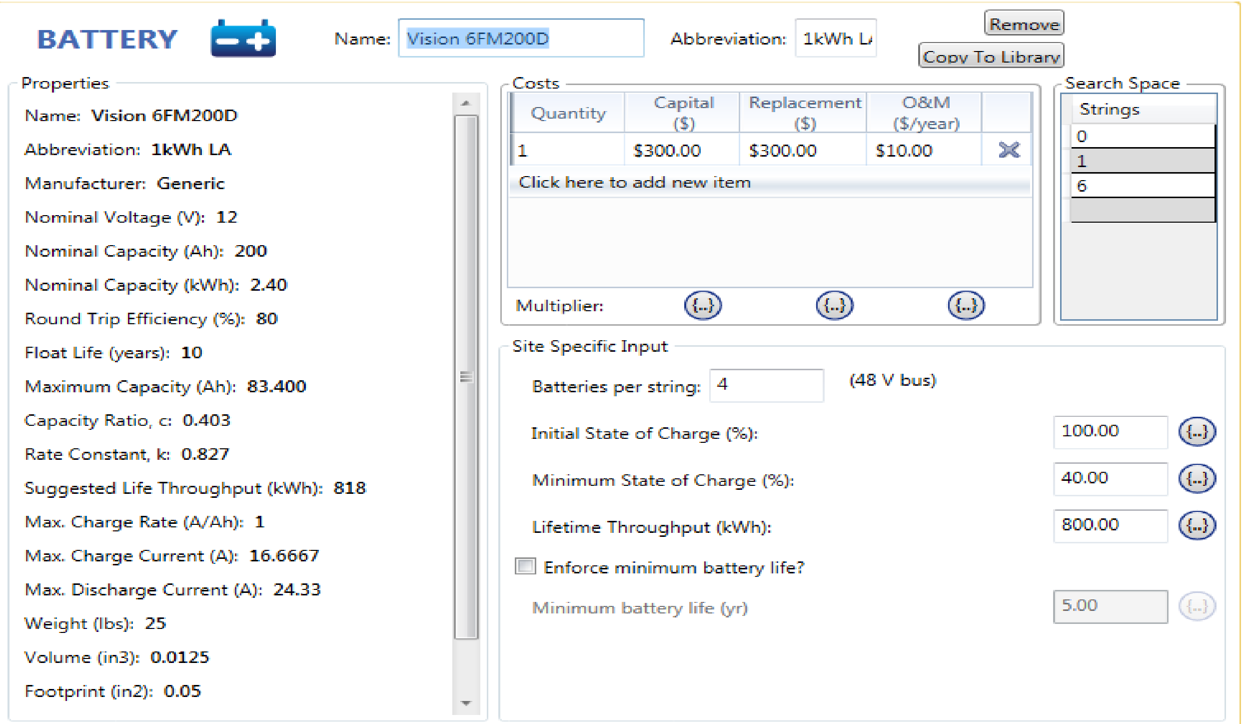
PROPERTIES
Lower Heating Value (MJ/kg): 43.2
Density (kg/m3): 820
Carbon Content (%): 88
Sulfur Content (%): 0.33

Diesel Fuel Price ($/L): 1.00
☐ Limit Consumption (L): 5,000.00

Fig 3.13 DG2500E 1.5kW Generator

3.4.4 Battery

An electric battery is a device consisting of one or more electrochemical cells with external connections provided to power electrical devices. The type of battery used for the system is Vision 6FM200D, 12V, 200AH Battery, with a fast charging and discharging technology. Disposable batteries typically lose 8 to 20 percent of their original charge per year when stored at room temperature (20–30 °C), this is known as the "self-discharge" rate [57]. Figure 3.14 illustrates battery details, which include the cost for one battery, which is $300 with a replacement cost of $290. The battery stack contains several batteries with 48 bus voltage per string, and a maximum capacity of 83.4Ah.



Name: Vision 6FM200D

Abbreviation: 1kWh L

Properties

Name: **Vision 6FM200D**
Abbreviation: **1kWh LA**
Manufacturer: **Generic**
Nominal Voltage (V): **12**
Nominal Capacity (Ah): **200**
Nominal Capacity (kWh): **2.40**
Round Trip Efficiency (%): **80**
Float Life (years): **10**
Maximum Capacity (Ah): **83.400**
Capacity Ratio, c: **0.403**
Rate Constant, k: **0.827**
Suggested Life Throughput (kWh): **818**
Max. Charge Rate (A/Ah): **1**
Max. Charge Current (A): **16.6667**
Max. Discharge Current (A): **24.33**
Weight (lbs): **25**
Volume (in3): **0.0125**
Footprint (in2): **0.05**

Costs

Quantity	Capital ($)	Replacement ($)	O&M ($/year)
1	$300.00	$300.00	$10.00

Search Space

Strings
0
1
6

Site Specific Input

Batteries per string: 4 (48 V bus)
Initial State of Charge (%): 100.00
Minimum State of Charge (%): 40.00
Lifetime Throughput (kWh): 800.00
☐ Enforce minimum battery life?
Minimum battery life (yr) 5.00

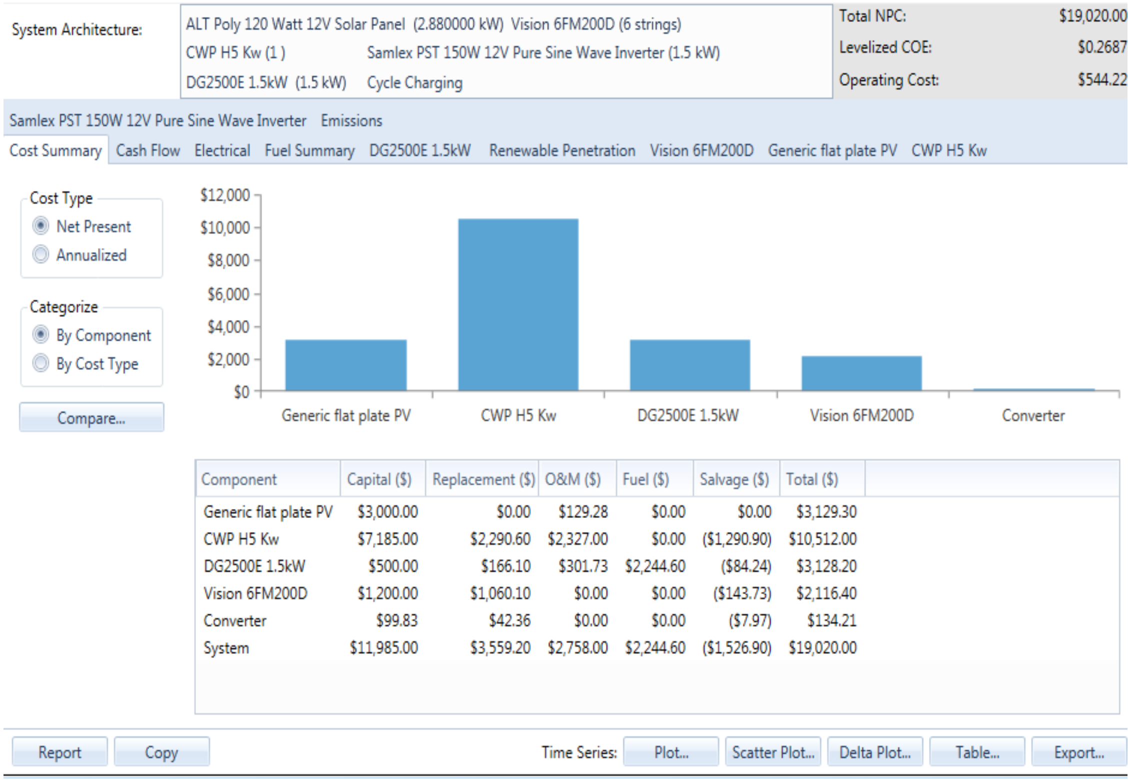
Fig 3.14 Vision Battery

3.4.5 Power Convertor

An electronic power converter is used to maintain the flow of energy between AC and DC components [58]. The size of power converter used in this system is 1.5 kW. The capital and replacement costs for this equipment is $500 and $490, respectively. The lifetime for one converter unit is 15 years with an efficiency of 90%.

3.5 Results and Discussion

The system simulation is done with HOMER software, and the optimal results were obtained for each case. Figure 3.15 shows the optimization result for the renewable energy system. As shown in the figure the total Net Present Cost (NPC) is $19,020. The generator burns 2,153 L of fuel per year and the annual generator run time is 1,095 hours. The total cost calculated with a constant price of fuel is $0.5 per liter. The total fuel cost during a year will be $1,076.5, and the total cost for the whole system will be $19,020.



System Architecture: ALT Poly 120 Watt 12V Solar Panel (2.880000 kW) Vision 6FM200D (6 strings)
CWP H5 Kw (1) Samlex PST 150W 12V Pure Sine Wave Inverter (1.5 kW)
DG2500E 1.5kW (1.5 kW) Cycle Charging

Total NPC: $19,020.00
Levelized COE: $0.2687
Operating Cost: $544.22

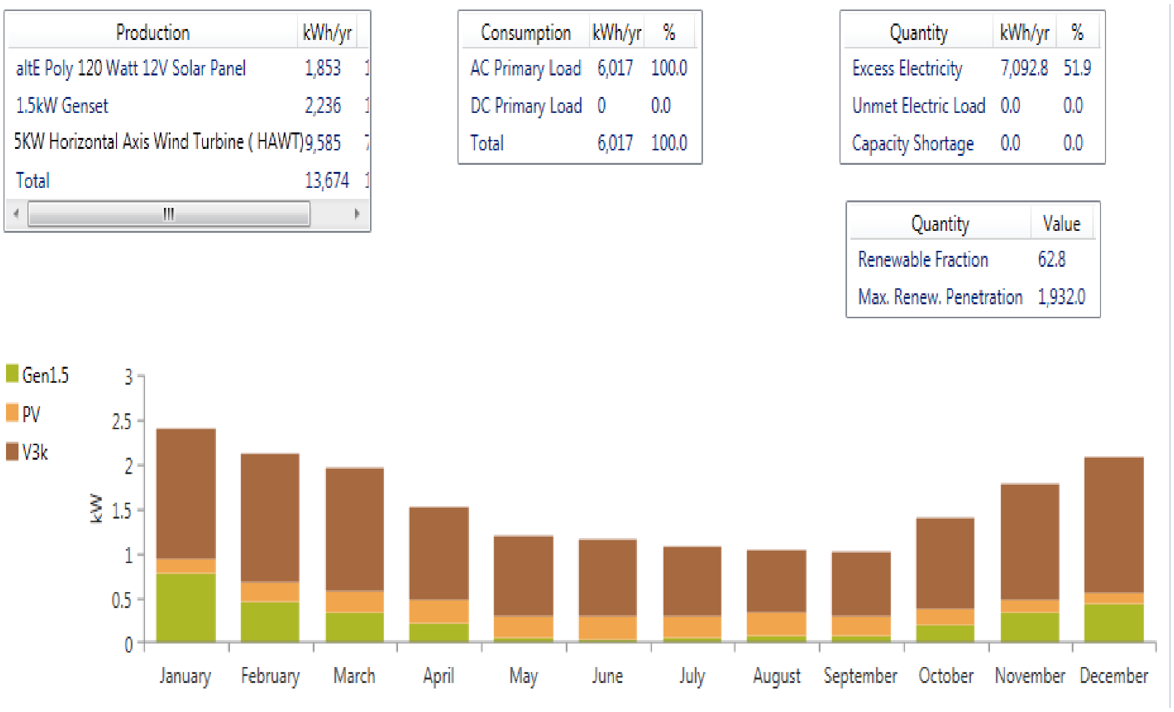
Cost Type: ● Net Present ○ Annualized
Categorize: ● By Component ○ By Cost Type

Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Generic flat plate PV	$3,000.00	$0.00	$129.28	$0.00	$0.00	$3,129.30
CWP H5 Kw	$7,185.00	$2,290.60	$2,327.00	$0.00	($1,290.90)	$10,512.00
DG2500E 1.5kW	$500.00	$166.10	$301.73	$2,244.60	($84.24)	$3,128.20
Vision 6FM200D	$1,200.00	$1,060.10	$0.00	$0.00	($143.73)	$2,116.40
Converter	$99.83	$42.36	$0.00	$0.00	($7.97)	$134.21
System	$11,985.00	$3,559.20	$2,758.00	$2,244.60	($1,526.90)	$19,020.00

Fig 3.15 Result for the Renewable Energy System

The renewable energy based system was also simulated in HOMERPRO software with three sensitivity variables. These variables are wind speed, solar irradiation, load, and diesel price and each of these variables has three different values. Figure 3.16 shows the optimized results for the proposed system, which includes the monthly average electric production of the system. Photovoltaic production is 15% with 1,853kWh/yr. Diesel generator production is 17% with 2,236kWh/yr. Finally, the wind turbine is expected to supply the rest of the load, which is 70% with 9,585kWh/yr. The diesel generator run time is reduced in the proposed system production.

Also, the diesel generator will require less maintenance operation costs and a longer period of service before replacing the system that is combined to reduce the pollution of gas emissions.



Production	kWh/yr
altE Poly 120 Watt 12V Solar Panel	1,853
1.5kW Genset	2,236
5KW Horizontal Axis Wind Turbine (HAWT)	9,585
Total	13,674

Consumption	kWh/yr	%
AC Primary Load	6,017	100.0
DC Primary Load	0	0.0
Total	6,017	100.0

Quantity	kWh/yr	%
Excess Electricity	7,092.8	51.9
Unmet Electric Load	0.0	0.0
Capacity Shortage	0.0	0.0

Quantity	Value
Renewable Fraction	62.8
Max. Renew. Penetration	1,932.0

Fig 3.16 Optimal Electrical Results

3.6 Summary

The main objective of this chapter is to provide the sizing, optimization, experimental setup, and the components of a renewable energy system for a Mobile Office. In addition, the wind energy conversion system, solar energy conversion system, diesel generator, and batteries which are used and employed at the site, are all described in this chapter with simulation results of all system components. It also presents a comparison between the Mobile office design and the Mobile Clinic that will be presented in the next chapter. Wind and solar subsystems are used as primary power source, while a diesel generator is used as backup source for long term with a battery bank for short term storage.

Chapter 4 Design of hybrid power system for a mobile hospital

4.1 Introduction

In this chapter, the author aims to discuss the results of a research study that was published in a Journal of Clean Energy Technologies (JOCET), which is an Electronic Journals Library [59]. The study named "Design of Renewable Energy System for a Mobile Hospital in Libya, Journal of Clean Energy Technologies, 2017" was completed at the department of Electrical and Computer Engineering at the Memorial University of St. John's, it shows the design of a renewable energy system for a remote mobile clinic/hospital in Sabha, Libya. As stated by the UN, "everyone has the right to a standard health care" [60]. According to the Universal Declaration of Human Rights, "the world will need to exploit energy resources in increasing amounts if we are to have any hope of bringing people in the developing world up to a reasonable standard of living". Recently, the United Nation efforts to provide field hospitals and deploy field offices have decreased in areas that lack transportation, power and security. While countering terrorism has been on the agenda of the United Nations for decades, the attacks do not spare hospitals, refugee camps nor military sites. Cases of civilian death increase where there is not enough proper medical care such as a small mobile medical unit or mini hospital that cares for on-site before safe transport to more permanent hospital facilities. During a time of war, natural disasters, or in the case of major accidents, such facilities are not available. A field hospital is supplied with medical staff and equipment that can be transported by an aircraft or a truck and is normally delivered in a standard container. This clinic container can be shipped anywhere and it is easily deployed in remote regions of the world. Containers are ideal because of their inherent strength, wide spread availability and relative low cost. In addition, the clinic is already assembled within the container, and therefore can be operational within days after deployment. In the journal described earlier, a PV hybrid system was considered for supplying an electric load for a mobile hospital in an area where there is no grid connectivity. Renewable Energy Systems are becoming a common choice for small communities around the world. For example, the Earth Day Network claims that renewable sources of energy are virtually inexhaustible and are naturally and quickly replenished [61]. Renewable electricity production, from sources such as wind power and solar power, is sometimes criticized for being variable or intermittent. However, according to the International Energy Agency this only applies to certain renewables, mainly the wind and solar photovoltaics, and its significance depends on a range of factors, such as the penetration of the renewables concerned [62]. Unlike fossil fuel based technologies, solar power does not lead to any harmful emissions during operation. A small solar electric or photovoltaic (PV) system can be a reliable and pollution-free producer of electricity for homes and offices [63]. PV technology uses both direct and scattered sunlight to generate electricity [64].

Africa is often considered and referred to as the "Sun continent" where the Sun's influence is the greatest, since it receives many more hours of bright sunshine during the course of a year. The solar resource across Libya is ample for home solar electric systems [65]. As a place that has long hours of sunshine, dominated by clear skies even beyond deserts. However, the Saharan or northeastern Africa is particularly noted for its world records in sunshine [65]. The idea of solar cells started in 1839. Edmund Becquerel discovered the photovoltaic effect when light was shone on an electrode in an electrolyte solution. Now days, the photovoltaic cell is widely used and considered the fastest growing power generation technology. Declining solar equipment costs are expected to significantly increase solar installations in Africa with an industry projection forecasting that the continent's annual PV market will expand to 2.2 GW by 2018 [66].

According to the Renewables 2014 Global Status Report, a record of more than 39 gigawatts (GW) of solar PV capacity was added in 2013, which brings total (peak) capacity worldwide to 139 GW at the end of 2013. While this is not even enough to generate 1% of global electricity demand, the growth is impressive. Figure 4.1, shows the world total PV cells installed capacity from 2004 to 2013 [67].

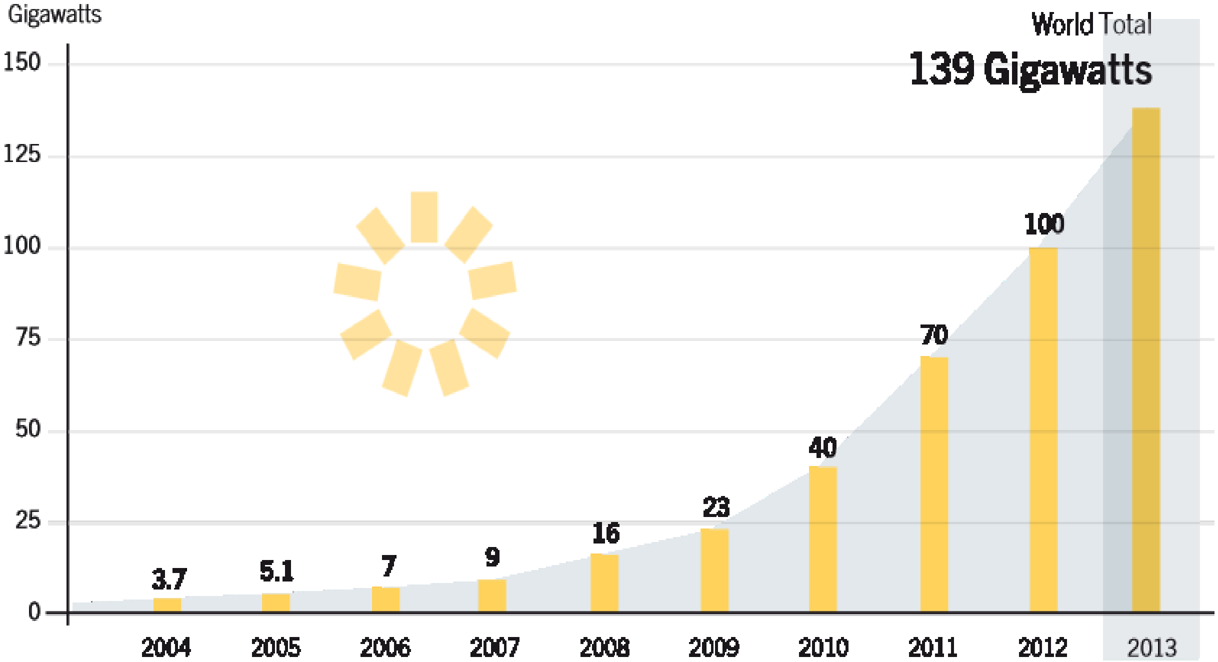


Fig 4.1 The World total PV cells installed capacity [67]

The cost of solar PV has decreased since the manufacturing processes became more efficient, and companies moved production to china. Moreover, if we look at the figure 4.2 below, we see that the decline in cost accelerates sharply from 2009 onwards. This acceleration is the consequences of moving almost the entire PV manufacturers, industry from western countries to Asian countries, where labor and energy are cheaper and less environmental restrictions exist. PV power systems can be designed to meet any electrical requirement, no matter how large or how small, because their modularity can connect them to an electric distribution (grid-connected, or standalone (off-grid) system. Many developing communities are forced to use these systems, as they are too far from electrical distribution.

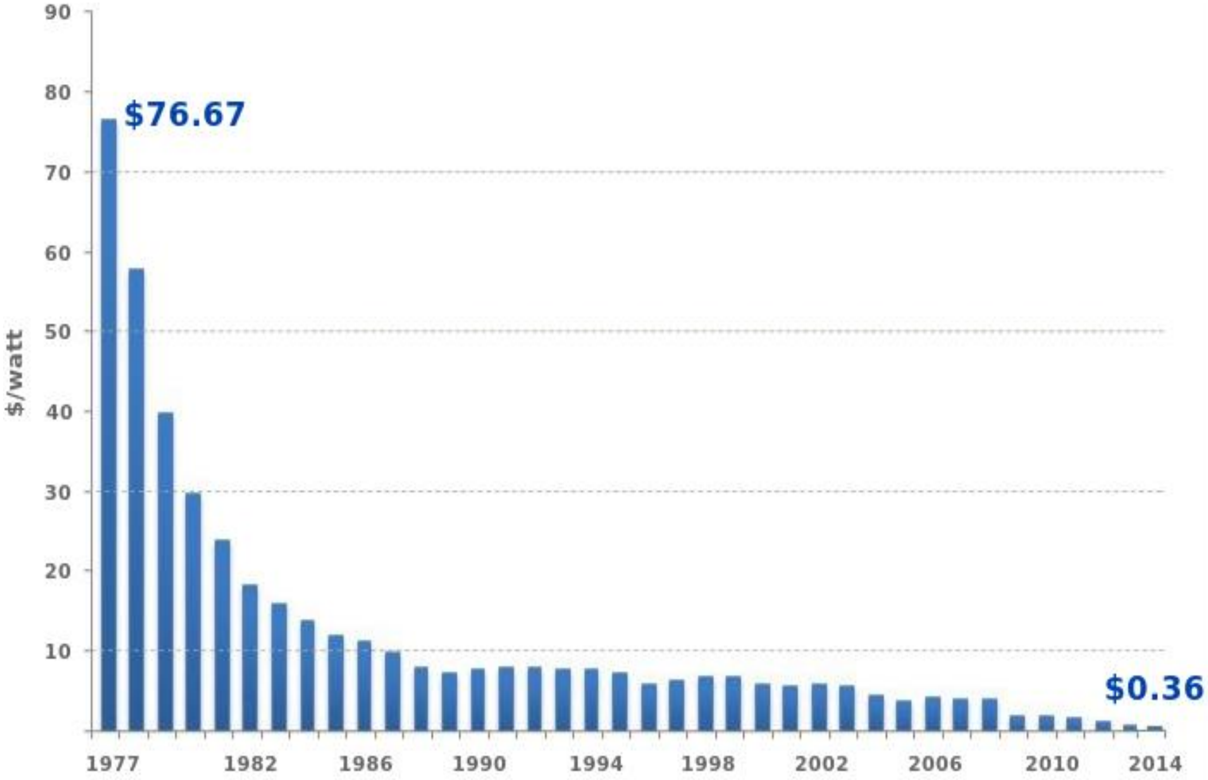


Fig 4.2 Price history of silicon PV cells in $ per Watt [67]

As a result, numerous software models been developed to simulate hybrid renewable energy systems. Several authors have keyed in on a potential solution to the logistical challenge of transporting fuel to mobile hospitals in remote areas. The objective of this paper is to determine the best configuration of a hybrid renewable system for a mobile hospital to help in solving a major crisis. Currently, remote areas are in great need of a small field hospital unit with a doctor and two nurses. What this paper aims to design is the equipping of two containers with a solar panel system, suitable for needs of a mobile hospital. Moreover, the optimal sizing and operational strategy of a combining diesel generator with solar energy that can offer the lowest amount of Total Net Present Cost (TNPC). The hybrid optimization model for electrical renewable software (HOMER) has been used to perform the selection and operational strategy of a generating system in order to obtain the finest solution of hybrid renewable energy with lowest TNPC.

4.2 Location of the Mobile Hospital

The location for which the hospital is set to be deployed is Sabha, Libya. Libya is located in the northern part of Africa, and is the largest country of the continent with 1.8 millions square kilometers of land, and 6 million residents [67]. Figure 4.3 shows a screen capture of the Google maps for the locations mentioned above. Libya has the highest technical and economical potential for solar power exploitation in the Middle East and North African region (MENA).

Fig 4.3 The site location for the Mobile Hospital [67].

4.3 Structural Design of Mobile Hospital

Mobile hospitals are designed to be portable while providing maximum comfort, sizes, full medical aids center with 3 bed, main waiting room and an office that includes a kitchen, bathroom, and a double bed for staff. AutoCAD drawing shows a steel frame constructed with steel beams, steel cross channels, a rubber baseboard floor framing that provides convenient, 2 mm sheet single floor styling without compromise [68]. For the exterior, the walls have to be light weight, resistant to bugs in remote areas, and usable in all climates. To increase longevity, the walls are then finished with a clear sealer. Windows will provide warm light sunshine, and will have a higher protection against weather changes such as a sand storm. R-21 insulation, and 3/8” painted plywood on each side of the floor guarantee the most efficient insulation. Steel doors with U-2.0

W/(m^{2}ċ) take up various temperatures. For interior measures, the walls are painted with two coats of antique eggshell latex paint, and the ceiling is painted with 2 coats of antique latex as well. Batten strips on joints, R-21 batt Insulation due to the rough sand storms, sealing the interior with a polyurethane varnish for easier surface cleaning and protection from damage. Staining the interior is an excellent idea because traveling can cause paint to crack and peel. Lighting in an area where there is lots of sunlight availability should not be an issue, because for long periods of the day it's still bright and illuminate the space with high-quality fixtures. Figure 4.4 shows the structure drawing.

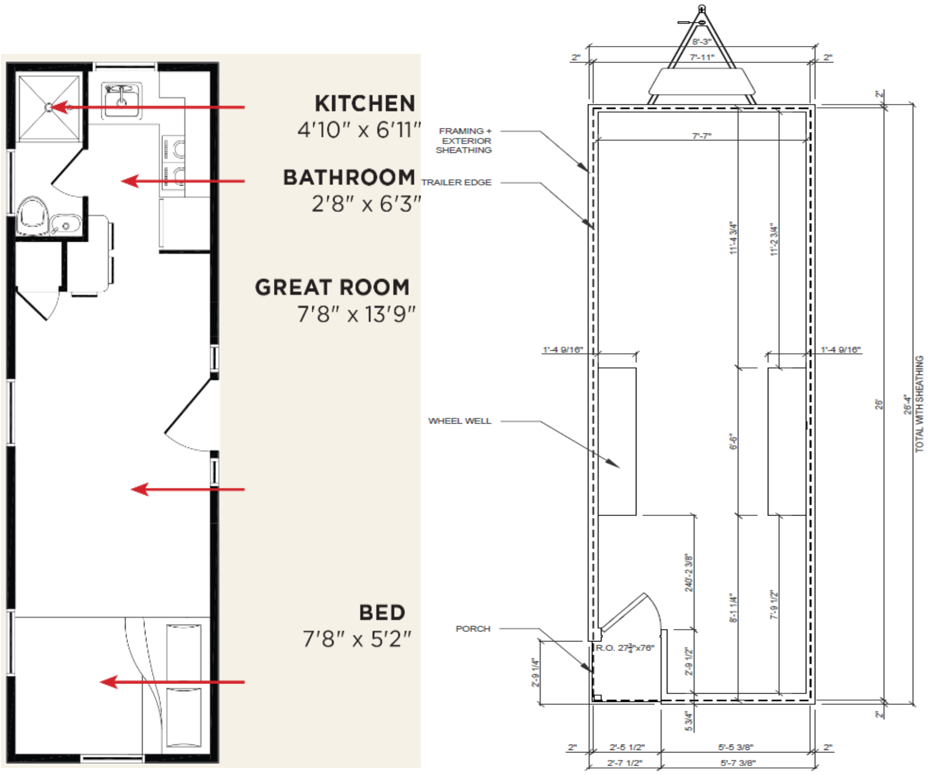


Fig 4.4 Structure Design and Interior

Energy 3D is also used to generate the load data and to simulate the heat analysis for the building which includes energy usage, season change and track of temperature [69]. Two trailers are connected by platform made of wood, with an entrance and a waiting area lounge that connect both the main office/bedroom/bathroom trailer with the medical aid trailer. Figure 4.5 shows the design that forms the shape of the letter H for the word hospital when both trailers are connected. The mobile hospital structure is simulated in Energy 3D and throughout the analysis an hour-by-hour usage data for energy is released, with an annual energy consumption of 18,000 kWh/year. This model produces a minimum cost design of $65,416 in material cost. A typical Mobile Hospital provided at the field has 100-amp Electrical Panel (38 circuit), electric heat, florescent light fixtures, electrical mast and meter box, and emergency lighting and exit signage.

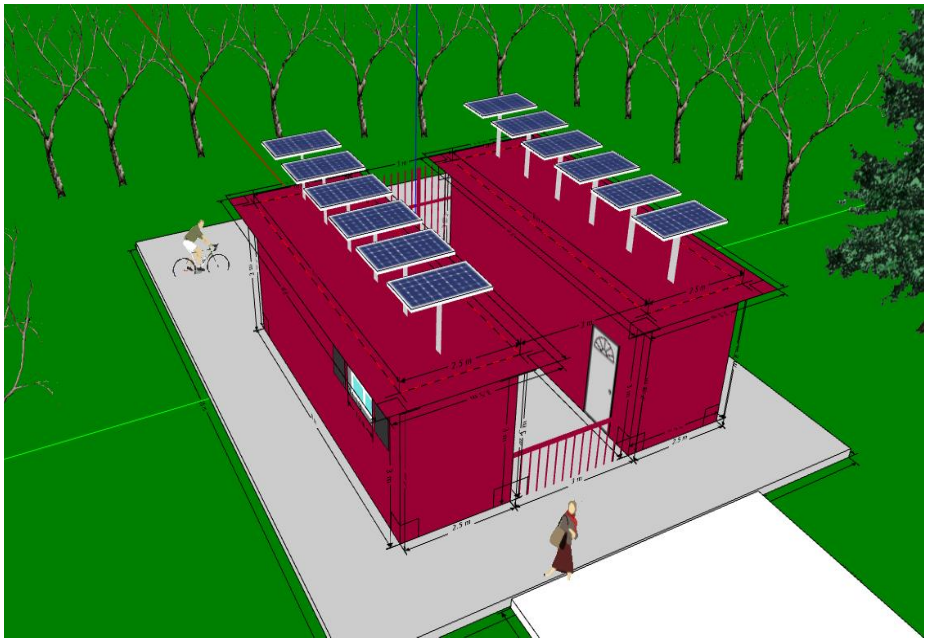


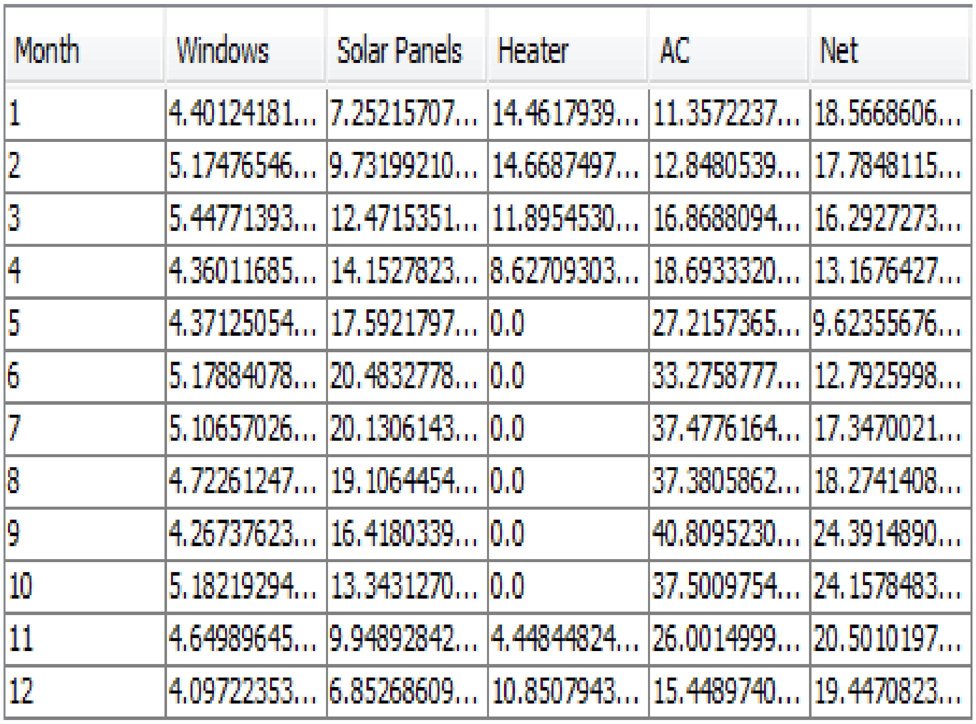
Fig 4.5 Energy3D Design

4.4 Renewable resources in Libya

In recent times, Libya's energy portfolio have moved outside of oil and gas. Since the discovery of oil in 1959, Libya's economic progress has been driven by hydrocarbon profits [70]. Typically, oil and gas wealth has represented up to 90% of Libya's income. Nonetheless, renewable energy has been a part of Libya's energy policy since the 1970's. The department of planning and studies for Renewable Energy was in charge of diversifying Libya's energy production methods, according to Dr. Amin Al-Habibeh of Nottingham Trent University in 2011, "for renewable energy sharing with traditional energy to reach 30% by the year 2030" [70]. In a sense, such projects are not surprising given the strong potential for solar power in Libya a country that is comprised of up to 88% desert, and long hours of sunshine that are evenly distributed throughout the year. Solar power therefore represents an energy source that would be more stable than wind power. For example, a few papers published by the University of Benghazi, about Libya and its potential for generating the electrical power from a nature sources to feed houses loads, government's buildings and street lights. Libya has a very high daily solar radiance rate on a flat coast, with about 7.1kWh/m2/d and in the south region it is around 8.1kWh/m2/d.

4.5 Generation of Load Data

Mobile hospital details such as size, insulation average walls, roof, windows-double pane, and doors all this data were put under consideration in Energy3D. Afterwards, running the thermal simulation indicates the annual energy analysis for the building 17.8kWh/day. From these results, a monthly annual consumption has been acquired as shown below in figure 4.6, and for the analysis in HOMERPRO an hourly load consumption was collected in a txt file format, and 8760 data points are generated in a txt file for this use.



Month	Windows	Solar Panels	Heater	AC	Net
1	4.40124181...	7.25215707...	14.4617939...	11.3572237...	18.5668606...
2	5.17476546...	9.73199210...	14.6687497...	12.8480539...	17.7848115...
3	5.44771393...	12.4715351...	11.8954530...	16.8688094...	16.2927273...
4	4.36011685...	14.1527823...	8.62709303...	18.6933320...	13.1676427...
5	4.37125054...	17.5921797...	0.0	27.2157365...	9.62355676...
6	5.17884078...	20.4832778...	0.0	33.2758777...	12.7925998...
7	5.10657026...	20.1306143...	0.0	37.4776164...	17.3470021...
8	4.72261247...	19.1064454...	0.0	37.3805862...	18.2741408...
9	4.26737623...	16.4180339...	0.0	40.8095230...	24.3914890...
10	5.18219294...	13.3431270...	0.0	37.5009754...	24.1578483...
11	4.64989645...	9.94892842...	4.44844824...	26.0014999...	20.5010197...
12	4.09722353...	6.85268609...	10.8507943...	15.4489740...	19.4470823...

Fig 4.6 Average Monthly energy consumption (kWh/day)

4.6 Electrical Load of the Mobile Hospital

The load profile was used for this study based on the actual imported hourly data to generate the HOMERPRO load, which illustrates the approximate power consumption of the mobile hospital at 17.8kWh/day, with 1kW peak occurs in the morning, and a few hours before noon. The system runs on a 48V DC bus-voltage. Companies are committed to providing uninterruptable service therefore these sites require continuous power throughout the year. The hourly load is almost a constant, as the power consumption remains the same. Figure 4.7 shows load profile of the mobile.

ELECTRIC LOAD

Name: Electric Load #1

January Profile

Hour	Load (kW)
0	.3
1	.33
2	.33
3	.28
4	.32
5	.34
6	.54
7	.74
8	1.07
9	.51
10	.42
11	.72
12	.63
13	.51
14	.47
15	.7
16	.98
17	.86

Time Step Size: 60 minutes

Random Variability
Day-to-day (%): 22.290
Timestep (%): 67.242

Peak Month: January

Metric	Baseline	Scaled
Average (kWh/d)	13.19	17.8
Average (kW)	.55	.74
Peak (kW)	6.66	8.98
Load Factor	.08	.08

Load Type: ● AC ○ DC

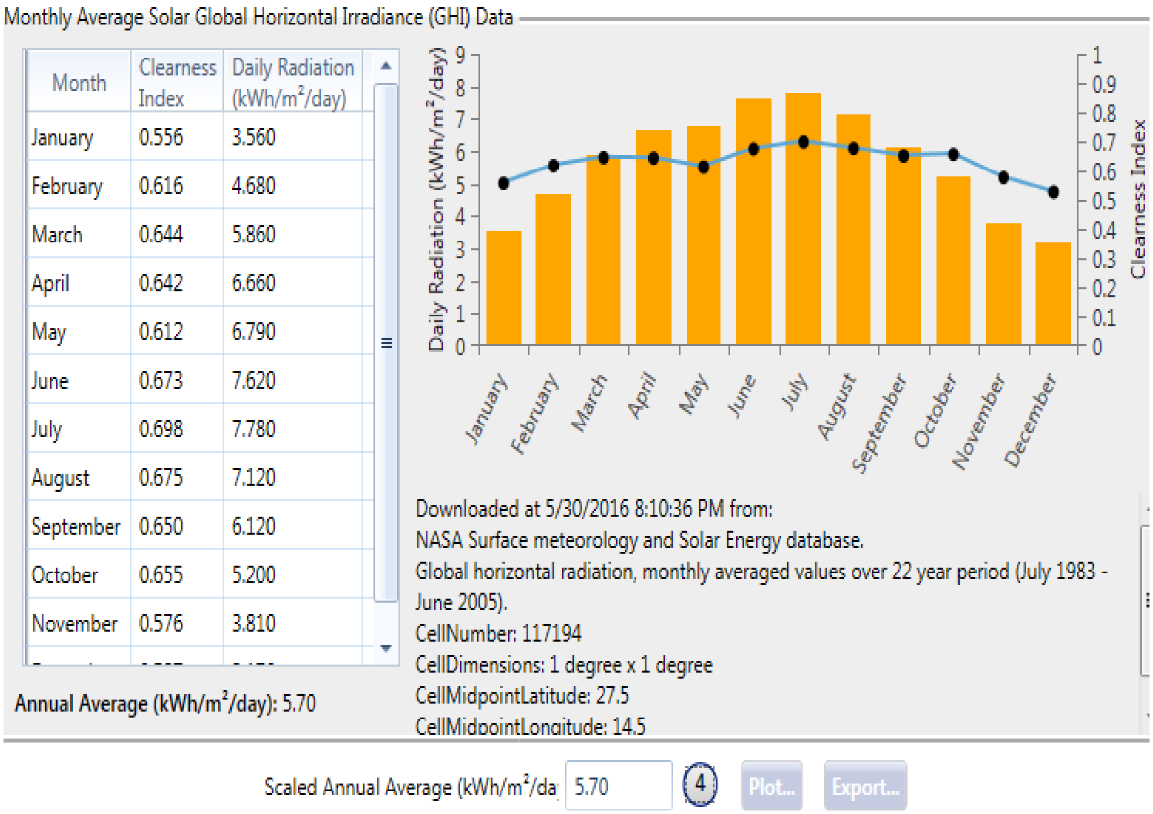
☐ Efficiency (Advanced)
Efficiency multiplier: 1
Capital cost ($): 0
Lifetime (yr): 10

Scaled Annual Average (kWh/d): 17.80

Fig 4.7 Load Profile of the Mobile Office

4.7 Solar Energy Resources

Solar is one of the major renewable sources implemented in the system. Solar data for this site is collected from NASA surface meteorology, which is used to get the approximate solar radiation at different sites. Figure 4.8 below indicates that the applicable renewable sources in that region are solar panels with the latitude and longitude easily downloaded once the location entered in the Homer software. Based on the hourly solar radiation data has been collected for a year from NASA. The average solar irradiation is only 5.7kwh/m²-d and sensitivity analysis is included with three different values. Clearness index and the average daily radiation for a year are added with three values of sensitivity analysis for solar radiation are chosen and added in HOMERPRO.



Monthly Average Solar Global Horizontal Irradiance (GHI) Data

Month	Clearness Index	Daily Radiation (kWh/m²/day)
January	0.556	3.560
February	0.616	4.680
March	0.644	5.860
April	0.642	6.660
May	0.612	6.790
June	0.673	7.620
July	0.698	7.780
August	0.675	7.120
September	0.650	6.120
October	0.655	5.200
November	0.576	3.810

Annual Average (kWh/m²/day): 5.70

Downloaded at 5/30/2016 8:10:36 PM from:
NASA Surface meteorology and Solar Energy database.
Global horizontal radiation, monthly averaged values over 22 year period (July 1983 - June 2005).
CellNumber: 117194
CellDimensions: 1 degree x 1 degree
CellMidpointLatitude: 27.5
CellMidpointLongitude: 14.5

Scaled Annual Average (kWh/m²/da 5.70

Fig 4.8 Monthly Solar Radiation and Average Daily Irradiation

4.8 System Optimization

The proposed hybrid renewable energy system shown in figure 4.9, which consists of a primary load of 17.80 kWh/d, and a 1.1 kW peak connected throw to the AC bus to a 1.5kW diesel generator. On the other side, a 12 PV solar panels, 6FM200D 1 kWh battery, and 1.1 kW power convertor all connect to the DC bus. The proposed system is specifically designed for that site depending on the load and available resources. Additionally, this system produces electrical power to measure up with the estimated load at minimal costs, and will reduce fuel consumption and associate operation/maintenance cost. In this system the PV will be the primary power source and a diesel generator will be used as a backup and batteries for short-term storage system.

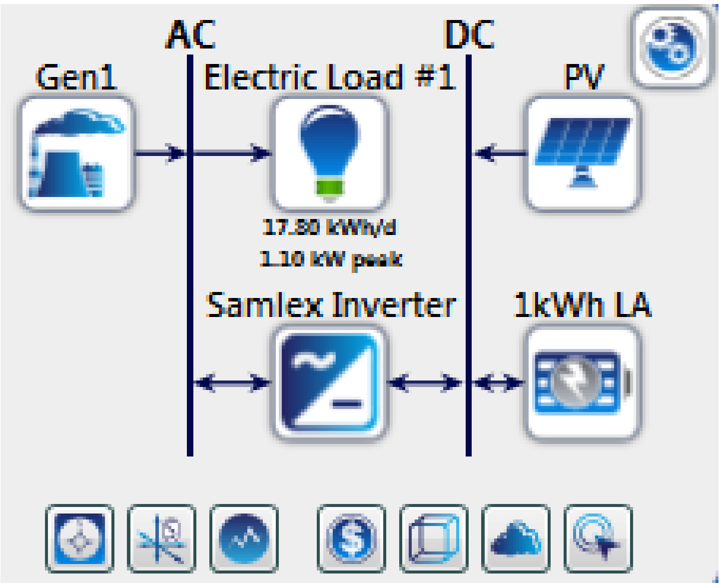
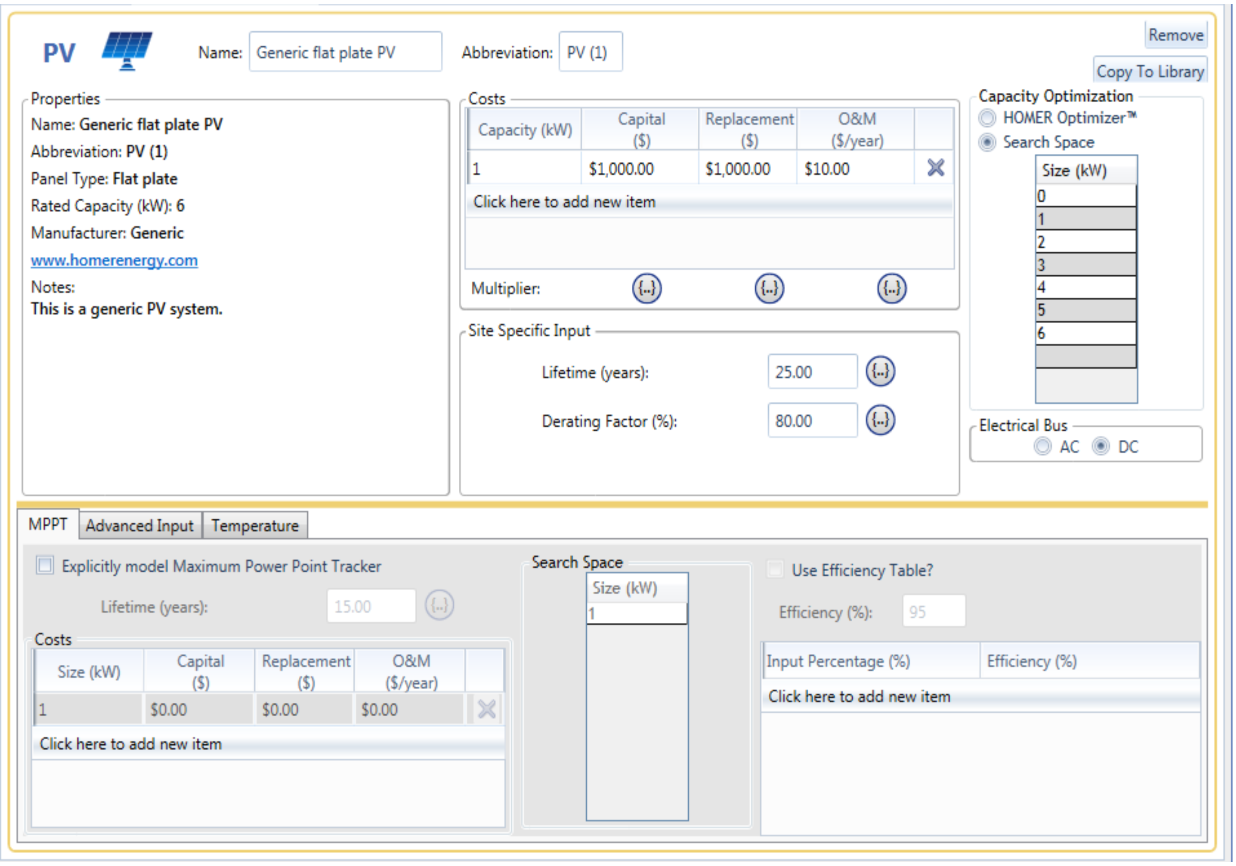


Fig 4.9 System optimization

The data was used in a software that was developed by the National Energy Laboratory, to estimate the designs of an off-grid power system. HOMERPRO uses sensitivity analysis algorithms to make it easier to evaluate the system configurations.

4.8.1 Solar Panels

Solar energy is released to the cosmos mostly by electromagnetic radiation, and approximately one-third of the energy radiated from sun is reflected back. The rest is absorbed and retransmitted to space, while the earth reradiates only as much energy as it received and which creates a sable energy balance at a temperature suitable for life. To get power from the sun, photovoltaic, or PV was selected. It is important to have a proper understanding of PV module performance under different operating conditions for appropriate application of the PV modules in a stand-alone system. PV cells have one or more electric fields that force electrons freed by light absorption to flow in a certain direction, including various parameters that influence the performance of a crystalline silicon PV module such as, temperature of module, PV module material and the solar radiance on the PV module surface [71]. Generic flat plates, or solar modules are used in this system, and 6 strings are connected in parallel in order to produce more current, with each strings containing 4 plates connected in series. The same configurations are also considered for batteries. The initial cost of each panel connected in a series is $1000, the replacement cost is $1000, and the operational and maintenance cost is $10. More details are shown in figure 4.10 [72].



Name: Generic flat plate PV

Abbreviation: PV (1)

Properties

Name: **Generic flat plate PV**

Abbreviation: **PV (1)**

Panel Type: **Flat plate**

Rated Capacity (kW): **6**

Manufacturer: **Generic**

www.homerenergy.com

Notes:

This is a generic PV system.

Costs

Capacity (kW)	Capital ($)	Replacement ($)	O&M ($/year)
1	$1,000.00	$1,000.00	$10.00
Click here to add new item			
Multiplier:	{...}	{...}	{...}

Site Specific Input

Lifetime (years): 25.00

Derating Factor (%): 80.00

Capacity Optimization

○ HOMER Optimizer™

● Search Space

Size (kW)
0
1
2
3
4
5
6

Electrical Bus ○ AC ● DC

☐ Explicitly model Maximum Power Point Tracker

Lifetime (years): 15.00

Costs

Size (kW)	Capital ($)	Replacement ($)	O&M ($/year)
1	$0.00	$0.00	$0.00
Click here to add new item			

Search Space

Size (kW)
1

☐ Use Efficiency Table?

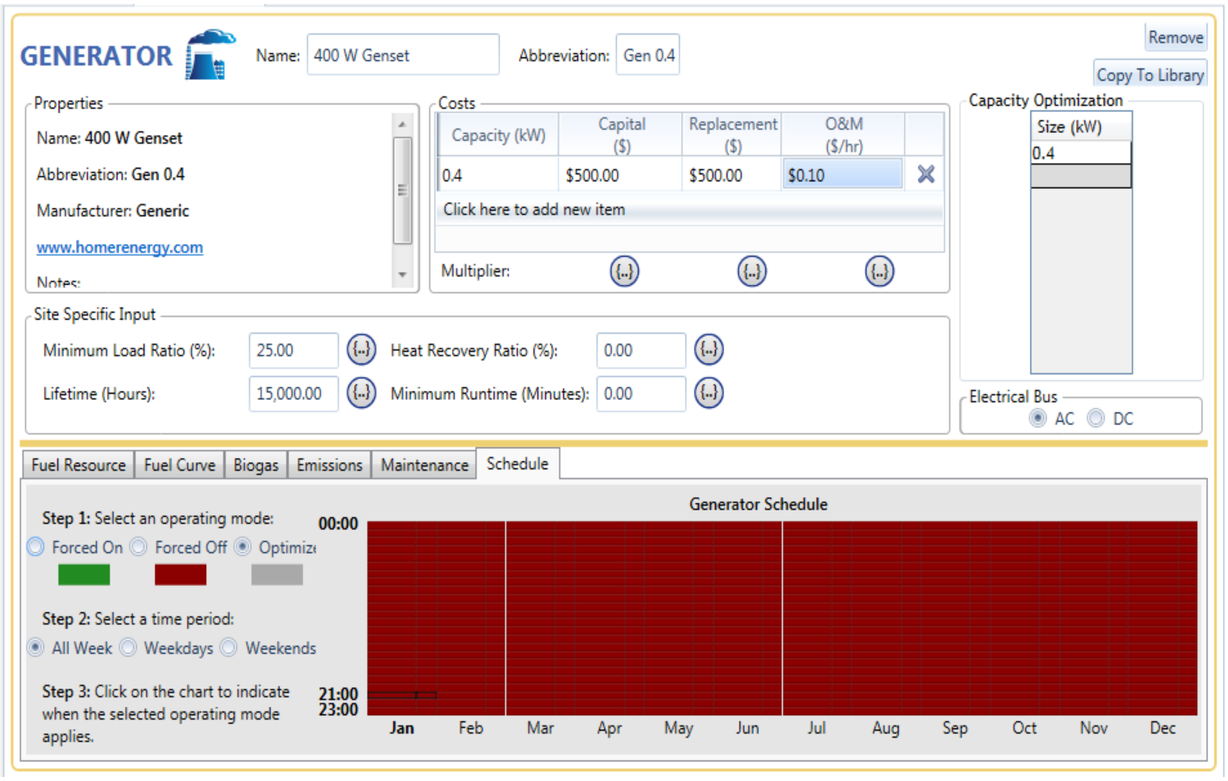
Efficiency (%): 95

Input Percentage (%)	Efficiency (%)
Click here to add new item	

Fig 4.10 Generic Flat Plate *PV*

4.8.2 Generator

During winter, there is a drop in renewable resources, and a surge in heat needed during cold nights, and the opposite during hot summer days. For that reason having an electric DG2500E small portable 400 W Diesel generator with a 400 W at 1200rpm with engine rebuild every 12,000 hours. This generator produces up to 25% of electricity in-time of need during the hours of operation, but as showing in the graph below the generator is forced to a shut-off stage and to be turned on in times of need only. The initial capital cost is $500, the replacement cost is $500, and the operational and maintenance cost $0.03/hr. Figure 4.11 shows the diesel configuration.



Name: 400 W Genset

Abbreviation: Gen 0.4

Properties

Name: **400 W Genset**

Abbreviation: **Gen 0.4**

Manufacturer: **Generic**

www.homerenergy.com

Notes:

Costs

Capacity (kW)	Capital ($)	Replacement ($)	O&M ($/hr)
0.4	$500.00	$500.00	$0.10

Click here to add new item

Multiplier:

Capacity Optimization

Size (kW)
0.4

Site Specific Input

Minimum Load Ratio (%): 25.00

Heat Recovery Ratio (%): 0.00

Lifetime (Hours): 15,000.00

Minimum Runtime (Minutes): 0.00

Electrical Bus

● AC ○ DC

Step 1: Select an operating mode:

○ Forced On ○ Forced Off ● Optimiz

Step 2: Select a time period:

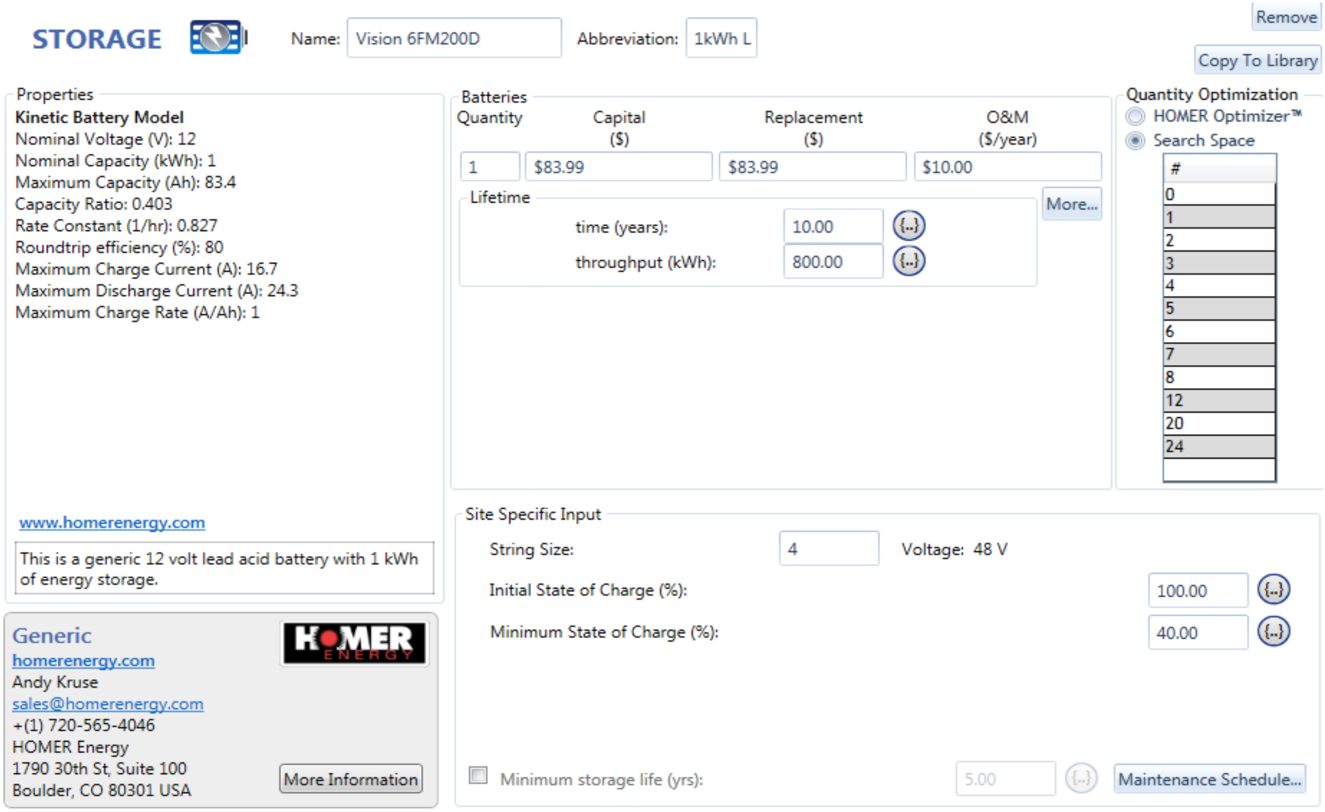
● All Week ○ Weekdays ○ Weekends

Step 3: Click on the chart to indicate when the selected operating mode applies.

Fig 4.11 1.5 kW Generator

4.8.3 Battery

This component is important where the intermittency of solar power require a much larger infrastructure. There are several types of systems for storing the energy, storage technology is pivotal and needed for assuring a continuous supply of power to the load. The type of battery used for the system is Lead Acid 1kWh, 84AH Battery, with the rating of 48V Bus-voltage, 83.333Ah. The general features are Absorbent Glass Mat (AGM) technology for efficient gas recombination of up to 99%, and freedom from electrolyte maintenance or water adding. The cost for one battery is $83.99 with a replacement cost of $83.99. Fig 4.12 below shows few details of an Off-grid hybrid energy system needs a battery bank to keep the system working and more high efficiency. A six string wiring was conducted with 48 bus voltage each and 24 batteries.



Name: Vision 6FM200D

Abbreviation: 1kWh L

Properties

Kinetic Battery Model

Nominal Voltage (V): 12

Nominal Capacity (kWh): 1

Maximum Capacity (Ah): 83.4

Capacity Ratio: 0.403

Rate Constant (1/hr): 0.827

Roundtrip efficiency (%): 80

Maximum Charge Current (A): 16.7

Maximum Discharge Current (A): 24.3

Maximum Charge Rate (A/Ah): 1

www.homerenergy.com

This is a generic 12 volt lead acid battery with 1 kWh of energy storage.

Generic
homerenergy.com
Andy Kruse
sales@homerenergy.com
+(1) 720-565-4046
HOMER Energy
1790 30th St, Suite 100
Boulder, CO 80301 USA

Batteries

Quantity	Capital ($)	Replacement ($)	O&M ($/year)
1	$83.99	$83.99	$10.00

Lifetime

time (years): 10.00

throughput (kWh): 800.00

Quantity Optimization

○ HOMER Optimizer™

● Search Space

#
0
1
2
3
4
5
6
7
8
12
20
24

Site Specific Input

String Size: 4 Voltage: 48 V

Initial State of Charge (%): 100.00

Minimum State of Charge (%): 40.00

☐ Minimum storage life (yrs): 5.00

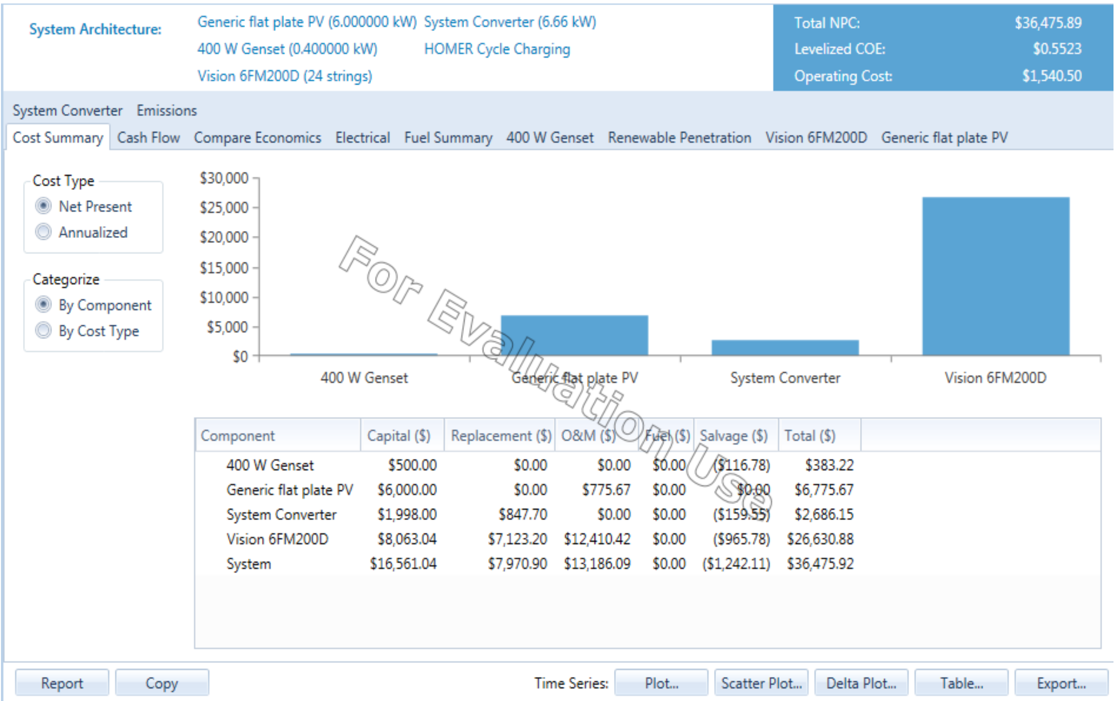
Fig 4.12 Lead Acid Battery

4.8.4 Power Convertor

A power electronic converter is used to maintain the flow of energy between AC and DC components [14-15]. This device is simply a controller and an electric convertor from DC to AC. The size of power converter used in this system is 1 kW. The capital and replacement costs for this equipment is $500. The lifetime for one unit of converter is 15 years with the efficiency of 90%.

4.9 Results and Discussion

The system simulation is done with HOMER software, and the optimal results were obtained for each case. Figure 4.13 displays the optimization result for the renewable energy system, which is a comprehensive series of data providing a high level of detail configuration system. After collecting all the possible configurations and results that can be obtained using the various power resources. As shown below, the cost of units used during operating hours was specified, economic inputs allowing interest rate, project life time, and other inputs.



System Architecture: Generic flat plate PV (6.000000 kW) System Converter (6.66 kW)
400 W Genset (0.400000 kW) HOMER Cycle Charging
Vision 6FM200D (24 strings)

Total NPC: $36,475.89
Levelized COE: $0.5523
Operating Cost: $1,540.50

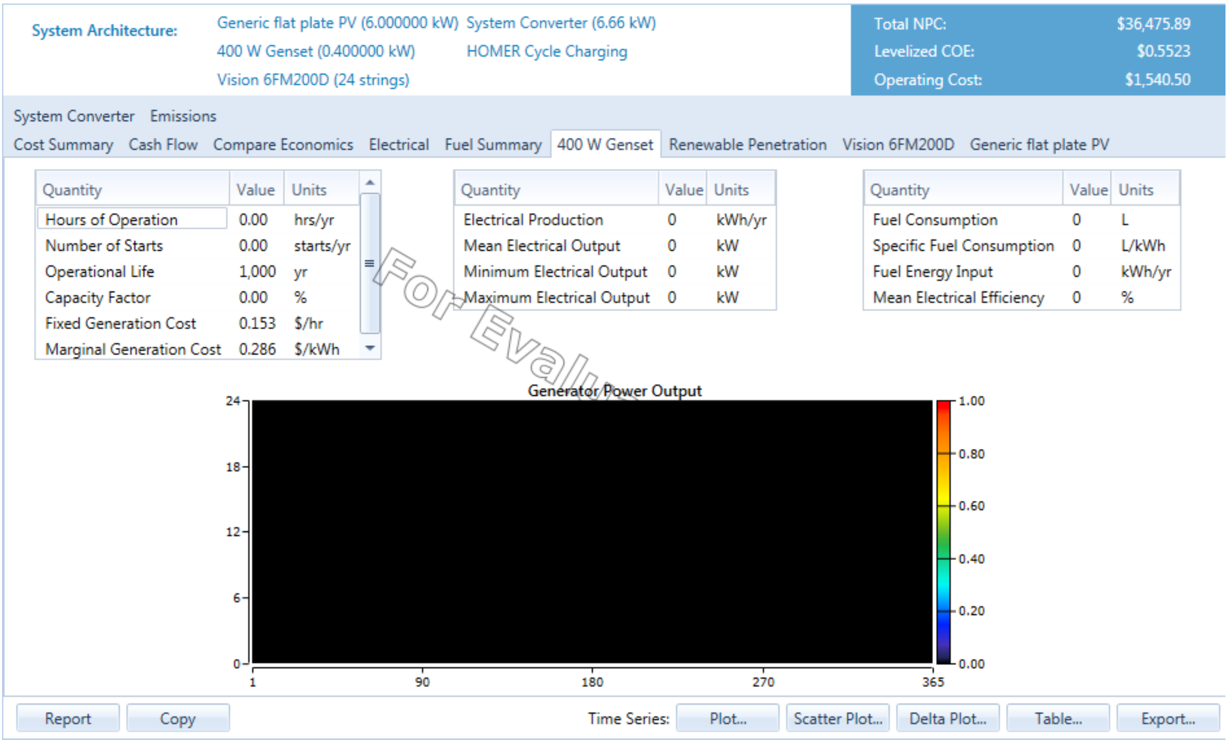
Cost Type: ● Net Present ○ Annualized

Categorize: ● By Component ○ By Cost Type

Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
400 W Genset	$500.00	$0.00	$0.00	$0.00	($116.78)	$383.22
Generic flat plate PV	$6,000.00	$0.00	$775.67	$0.00	$0.00	$6,775.67
System Converter	$1,998.00	$847.70	$0.00	$0.00	($159.55)	$2,686.15
Vision 6FM200D	$8,063.04	$7,123.20	$12,410.42	$0.00	($965.78)	$26,630.88
System	$16,561.04	$7,970.90	$13,186.09	$0.00	($1,242.11)	$36,475.92

Fig 4.13 Simulation Results of the Hybrid Energy System

The total Net Present Cost (NPC) is $36,475.89. When the generator is turned on it burns 545L of fuel per year with an annual generator run time of 8760 hours. The total cost was calculated with a constant price of fuel at $0.153 per hour, and the total fuel cost during a year was $1341. The generator was turned off during this software which resulted to a lower NPC and fuel consumption. The renewable energy based system was also simulated in the software with three sensitivity variables. Solar irradiation, load, and diesel price and each of these variables has three different values. Figure 4.14 shows the simulation results for a 400 W generator.



System Architecture:
Generic flat plate PV (6.000000 kW)
System Converter (6.66 kW)
400 W Genset (0.400000 kW)
HOMER Cycle Charging
Vision 6FM200D (24 strings)

Total NPC:	$36,475.89
Levelized COE:	$0.5523
Operating Cost:	$1,540.50

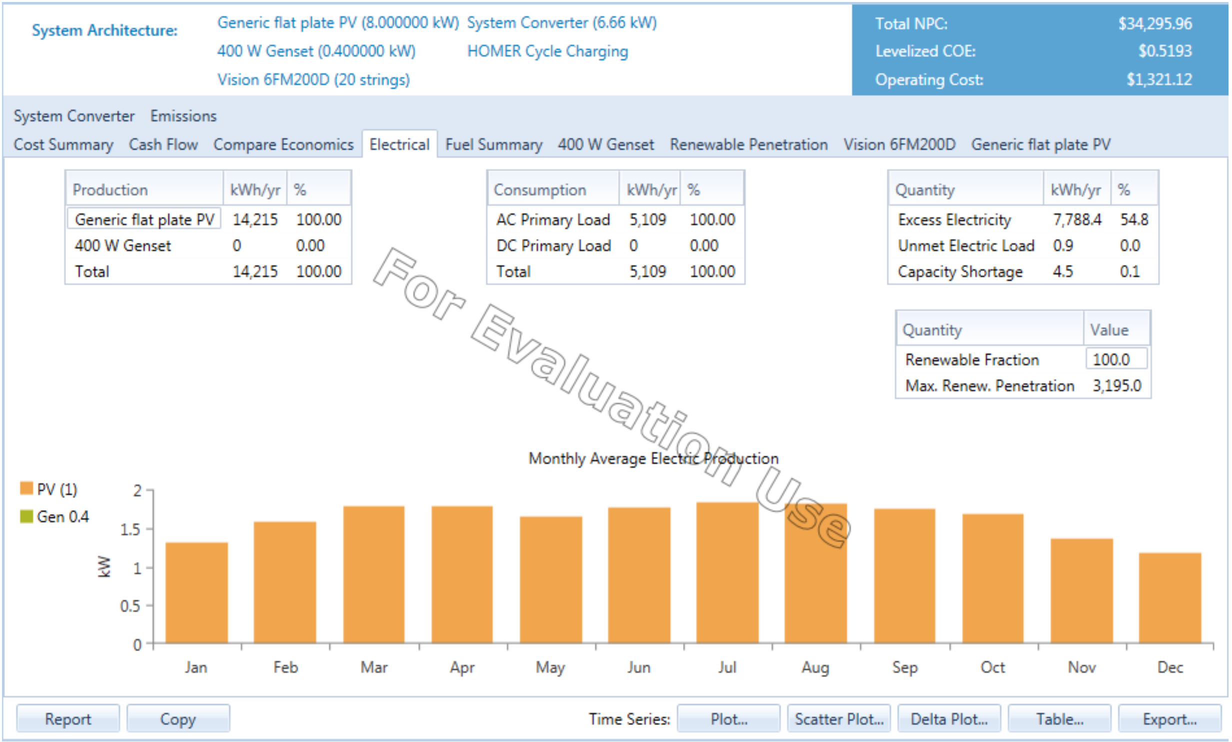
Quantity	Value	Units
Hours of Operation	0.00	hrs/yr
Number of Starts	0.00	starts/yr
Operational Life	1,000	yr
Capacity Factor	0.00	%
Fixed Generation Cost	0.153	$/hr
Marginal Generation Cost	0.286	$/kWh

Quantity	Value	Units
Electrical Production	0	kWh/yr
Mean Electrical Output	0	kW
Minimum Electrical Output	0	kW
Maximum Electrical Output	0	kW

Quantity	Value	Units
Fuel Consumption	0	L
Specific Fuel Consumption	0	L/kWh
Fuel Energy Input	0	kWh/yr
Mean Electrical Efficiency	0	%

Fig 4.14 Simulation Results of a Diesel Generator

A sensitive analysis can result in a large amount of output data, every simulation that homer performs results in many series of output. Figure 4.15 shows the optimized results for the proposed system, which include the monthly average electric production of the system. Photovoltaic production is 100% with 14,215kWh/yr. Diesel generator production during on time would be around 25%, and the run time is reduced in the proposed system production. Also, the diesel generator will require less maintenance and operation costs, yet have a longer period of service before any replacement. In accordance with [16-18], the combination of a PV system and a diesel generator is able to reduce the pollution of gas emissions.



System Architecture:
Generic flat plate PV (8.000000 kW)
400 W Genset (0.400000 kW)
Vision 6FM200D (20 strings)
System Converter (6.66 kW)
HOMER Cycle Charging

Total NPC: $34,295.96
Levelized COE: $0.5193
Operating Cost: $1,321.12

Production	kWh/yr	%
Generic flat plate PV	14,215	100.00
400 W Genset	0	0.00
Total	14,215	100.00

Consumption	kWh/yr	%
AC Primary Load	5,109	100.00
DC Primary Load	0	0.00
Total	5,109	100.00

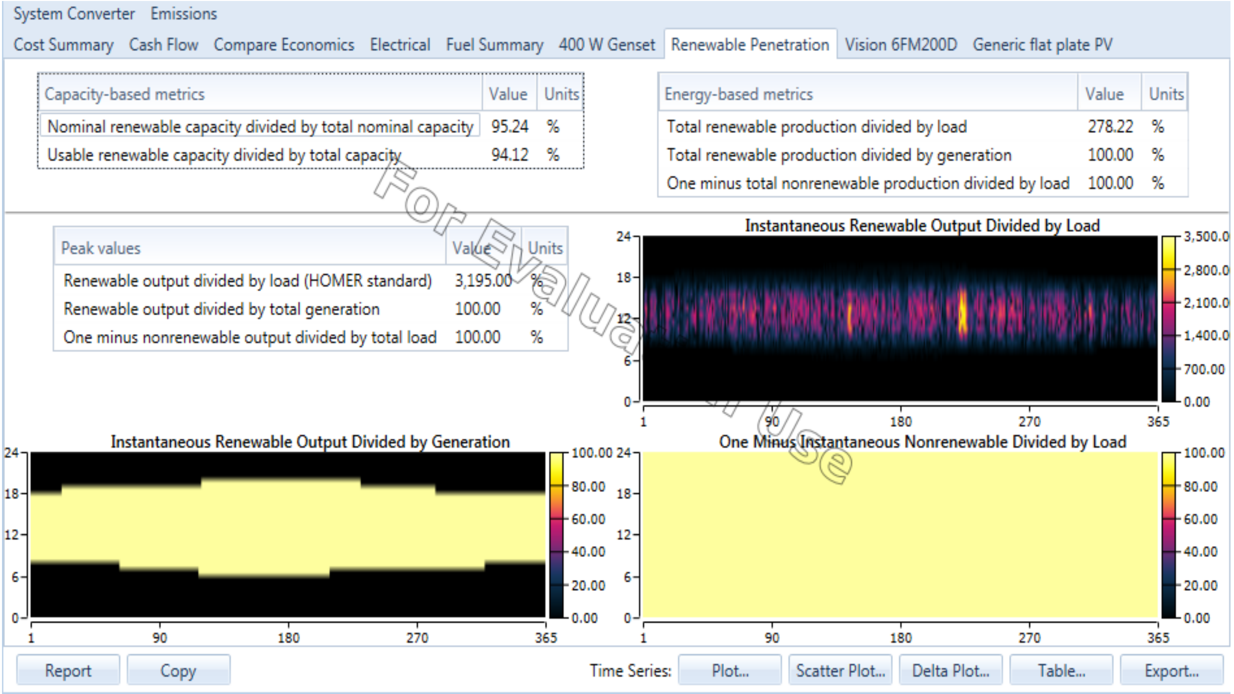
Quantity	kWh/yr	%
Excess Electricity	7,788.4	54.8
Unmet Electric Load	0.9	0.0
Capacity Shortage	4.5	0.1

Quantity	Value
Renewable Fraction	100.0
Max. Renew. Penetration	3,195.0

Fig 4.15 Electric Results for the System

4.10 Conclusion

This chapter discussed the optimization, sizing, and operational strategy of a hybrid renewable energy system, which refers to the minimum cost of Total Net Present Cost (TNPC). The result shows that the PV system, diesel generator, battery storage and converter provides an optimal configuration of hybrid renewable energy system applicable to be used as an off-grid mobile hospital. Figure 4.16 illustrates the system converter emissions which reveals the renewable output divided by load and the total renewable production divided by load.



Capacity-based metrics	Value	Units
Nominal renewable capacity divided by total nominal capacity	95.24	%
Usable renewable capacity divided by total capacity	94.12	%

Energy-based metrics	Value	Units
Total renewable production divided by load	278.22	%
Total renewable production divided by generation	100.00	%
One minus total nonrenewable production divided by load	100.00	%

Peak values	Value	Units
Renewable output divided by load (HOMER standard)	3,195.00	%
Renewable output divided by total generation	100.00	%
One minus nonrenewable output divided by total load	100.00	%

Fig 4.16 System emissions report

The conclusions were drawn from the results obtained from the analysis. There is a high potential of solar radiation resource in Libya, which can be used for supporting the renewable energy especially in terms of solar energy compared to wind turbine. Such a hybrid system for a mobile hospital is recommended for use in remote locations.

Chapter 5 Dynamic Modelling and Control of Designed Hybrid System in Simulink

5.1 Introduction

MATLAB which stand for matrix laboratory is a computer algebra system created in 1964 by Carl Engelman and became rather popular in universities by 1967 [73]. It is also an online system providing machine aid for the hybrid system analysis and is capable of preforming procedures such as simplification, differentiation, indefinite integration, direct and inverse Laplace transforms. Recently, MATLAB —Simulink has become the most used software for modeling and simulation of dynamic systems, where Simulink works as a block diagram for multi-domain simulation and Model-Based Design. It provides a powerful graphical interface for building and verifying new mathematical models as well as new controls strategies, particularly for nonlinear systems. It offers a tight integration with the rest of the MATLAB environment. Simulink can automatically generate C source code for real-time implementation of systems [74]. For production systems, the efficiency and flexibility of the code improves and this is becoming more widely adoptable [75]. An example of such dynamic systems is the study of hybrid renewable energy, containing subsystems with different ranges of the time constants: wind turbine, PV, generator, batteries, converter and AC load. The combination of the sustainable devices like wind and photovoltaic generation has become an attractive source of energy because of their positive impact on the environment. This chapter aims to present an (off grid) hybrid power system model with simulation and analysis of its operation. This system leads to pollution reduction for a standalone, off grid/remote area system. Figure 5.1 shows a simple Simulink model capturing features that are included but not limited to off and on grid connectivity, wind turbine power output, pitch angle, wind speed and direction.

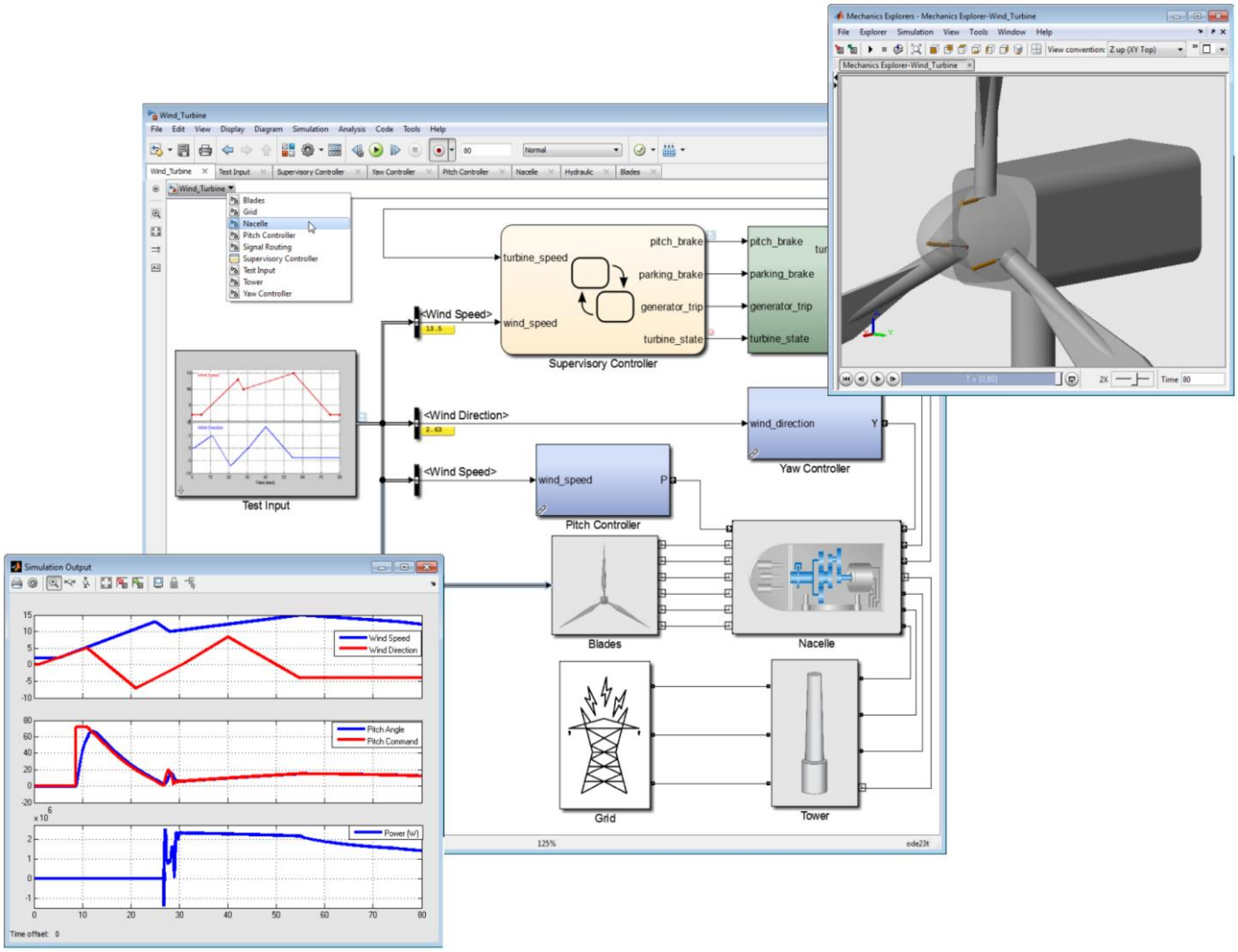


Fig 5.1 Simulink Model of an off-Grid-On-Grid connectivity [75]

5.2 Modeling of a Mobile Office hybrid power system using MATLAB/Simulink

Chapter 3 discussed the results of a research study completed at the Department of Electrical and Computer Engineering at Memorial University in St. John's which showed the design of a Renewable Energy System (RES) for a remote Mobile Office in Newfoundland. As a result of the geographical position and high winds, the average daily wind speed is 9.45 m/s^2 in the central and eastern area. After reviewing Renewable Energy Systems around the world, wind and solar are the most common other than hydropower. Combining wind and solar energy to improve the stability as compared to using only one or the other, is more practical; a small solar electric or photovoltaic (PV) system can be a reliable and pollution-free producer of electricity for homes and offices [75]. This study considered a PV/Wind hybrid system for supplying the electric load of a mobile office where data was gathered and stochastically modeled from the National Aerodynamics and Space Administration (NASA) website, which include daily and hourly readings of wind speed (m/s) and solar GHI (KWh/m^2/day). PV/Wind energy is one of the most universal forms of renewable energy to produce direct current (DC), measured in watts (W) or kilowatts (kW), it is also used to provide electricity to remotely placed stations.

5.2.1 PV/Wind resources

According to the data collected by the National Renewable Energy Laboratory (NREL), our study suggests that the location at the Newfoundland site has sufficient wind and solar energy for generating sufficient power for this application. Collecting weather data is one of the main tasks for this pre-feasibility study for a renewable energy system. In this system, the wind turbines and PV will be the primary power source and a diesel generator will be used as a backup and batteries for short-term storage system.

5.2.2 System optimization

Figure 5.10 illustrates the implementation of this non-grid connected mobile office, in which a screen capture of the Matlab/Simulink design, includes a preview of the DC-Wind Turbine connected to a Boost Converter1, PV Array with a Boost Converter, and a storage unit with a lead-acid battery bank. The storage unit is most suitable for this system which can supply power for longer durations and also can be used up to 80% of its capacity repeatedly, finally a single phase inverter is wired to an off-grid AC-load Mobile Office.

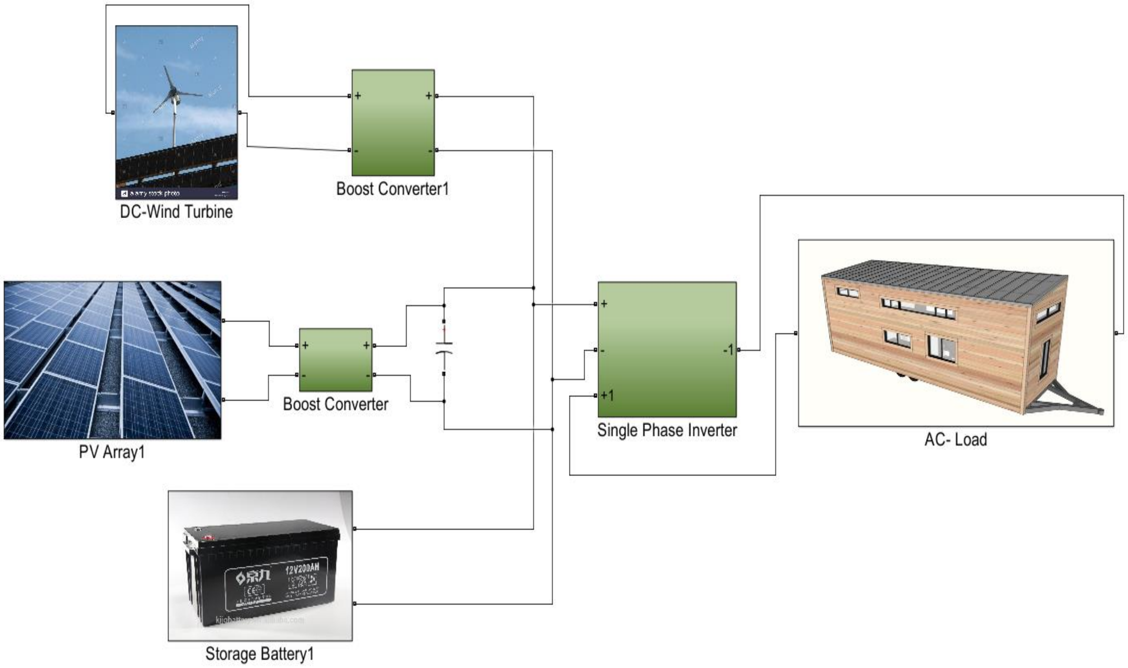


Figure 5.2 Mobile Office design in Matlab/Simulink

Generally, two types of inverters are used in this system, one to modify the sine wave and the other to purify it. The operating cost of a modified sine wave inverter is cheap and less efficient than pure sine wave, which is the most efficient and works without a buzz.

5.2.2.1 Wind Turbine Model

Wind turbines are used to generate electricity from kinetic power of the wind i.e. the generation of wind energy primarily depends on the wind speed [76]. Wind turbine power curves have been collected and installed from the manufacturers' data sheets depending on each's specification. Cut-in and cut-out wind speed, the conditions for which the turbine will initiate generating power and shut-down, have been applied in the wind turbine model. Figure 5.11 illustrates the algorithm at which the wind turbine will generate power or shut down, where U refers to average wind speed.

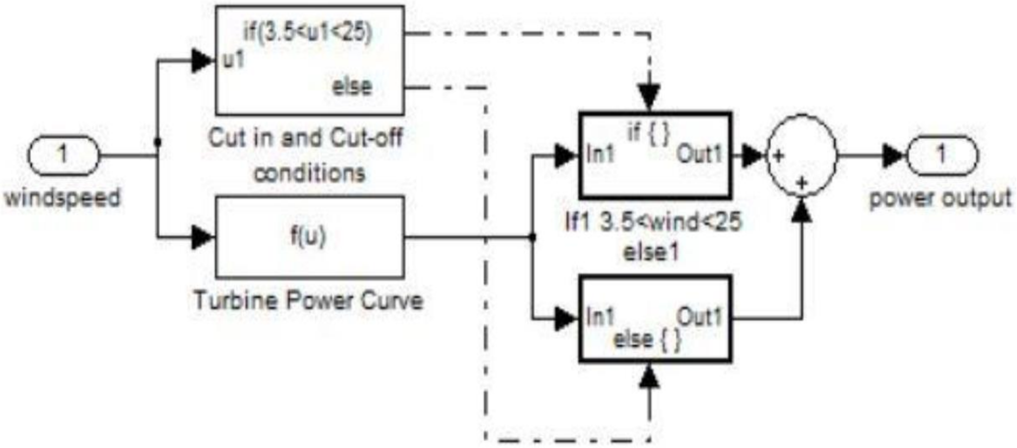


Fig 5.3 Wind Turbine Power Curve and Conditions

Mathematically, the power output from a wind turbine is given by:

Pw = 1/2. Pa. A. Cp. V^3 —(3)

Where;

Pw: is the power output

Pa: is the air density

A: is the swept area

Cp: is the power coefficient

V: is the wind speed.

One horizontal axis H5 wind-turbine is used in this system and it has a rated capacity of 5kW and provides 48 DC voltage. The power produced by the wind generator is a DC voltage, but has variable magnitude and frequency that can then be transformed into DC-DC boost converter to charge the battery. The controller protects the battery from overcharging or deep discharging [77]. The wind turbine is connected to a DC/DC boost converter to charge the battery and the battery connected to DC/AC inverter to feed the required load (Mobile Office). As high voltages can be used to reduce system losses, an inverter is normally introduced to transform the low DC voltage to an AC voltage of 110 V and frequency of 50 Hz. Figure 5.12 display the DC-Wind-Turbine with basic elements-blocks-selected from the Simulink Library that contains models of typical power equipment such as wind turbine, lines, machines, and power electronics.

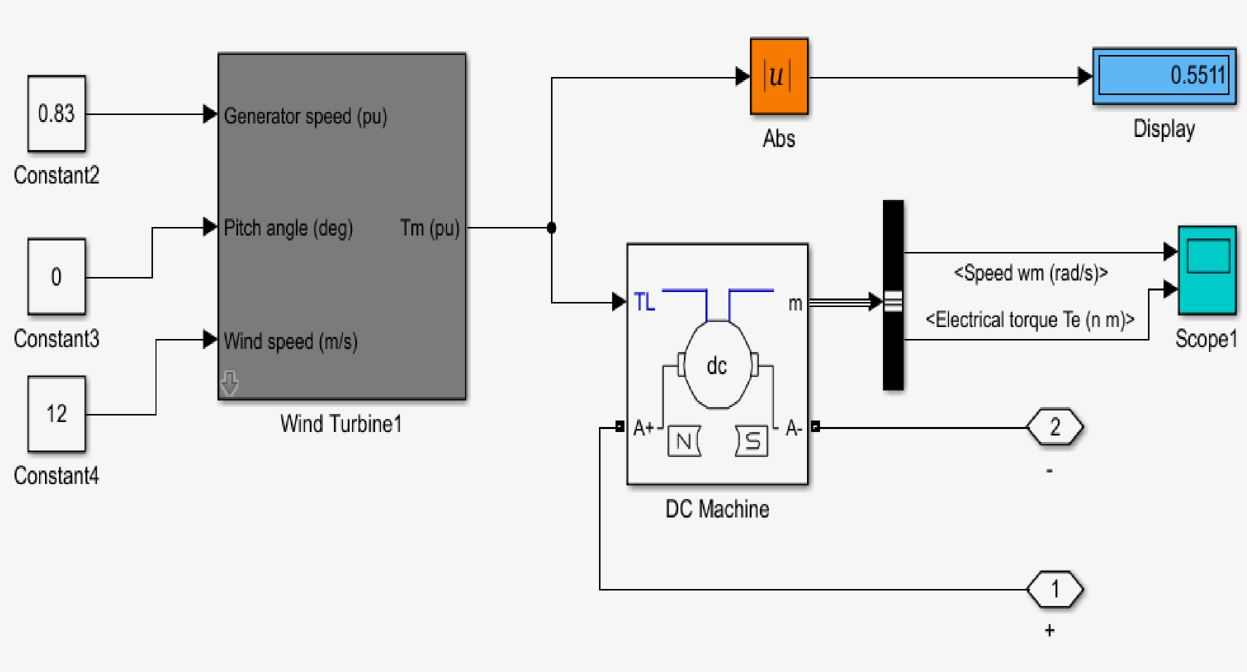
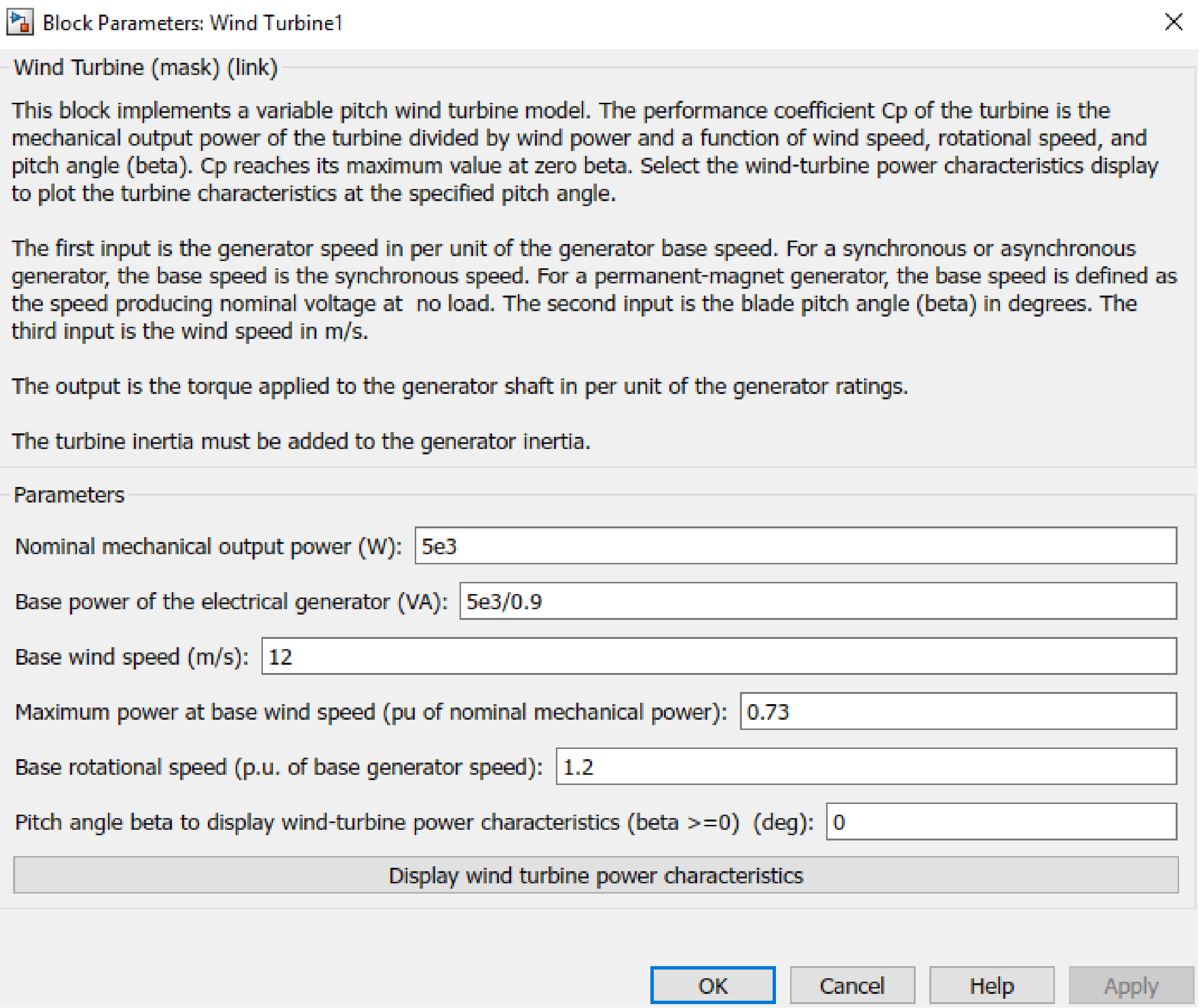


Fig 5.4 Simulink model of the turbine

The base value of the wind speed is expressed in m/s, while the mean value of the expected wind speed is 12m/s. This base wind speed produces a mechanical power which is usually lower than the turbine nominal power. The maximum power at the base wind speed (in pu) of the nominal mechanical power, denotes in a Kp power gain which is defined at 0.73. The rotational speed at maximum power for the base wind speed is 0.83 in pu of the base generator speed. The simulation resulted in the wind turbine produces 0.5511 kW power with a zero degrees pitch angle beta, beta must be greater than or equal to zero. Figure 5.13 illustrates the parameters of the wind turbine.



This block implements a variable pitch wind turbine model. The performance coefficient Cp of the turbine is the mechanical output power of the turbine divided by wind power and a function of wind speed, rotational speed, and pitch angle (beta). Cp reaches its maximum value at zero beta. Select the wind-turbine power characteristics display to plot the turbine characteristics at the specified pitch angle.

The first input is the generator speed in per unit of the generator base speed. For a synchronous or asynchronous generator, the base speed is the synchronous speed. For a permanent-magnet generator, the base speed is defined as the speed producing nominal voltage at no load. The second input is the blade pitch angle (beta) in degrees. The third input is the wind speed in m/s.

The output is the torque applied to the generator shaft in per unit of the generator ratings.

The turbine inertia must be added to the generator inertia.

Nominal mechanical output power (W): 5e3

Base power of the electrical generator (VA): 5e3/0.9

Base wind speed (m/s): 12

Maximum power at base wind speed (pu of nominal mechanical power): 0.73

Base rotational speed (p.u. of base generator speed): 1.2

Pitch angle beta to display wind-turbine power characteristics (beta >=0) (deg): 0

Fig 5.5 Block Parameters of Wind Turbine

5.2.2.2 PV Array System

The energy obtained from the PV-systems can be utilized in different applications. DC power is the direct output of PV-arrays and this DC form of power can be directly used with DC appliances. For AC appliances, this DC power has to be changed into AC form using power electronic inverters. It is important to have a proper understanding of PV module performance under different operating conditions for appropriate application of PV modules in a stand-alone system. Various parameters that influence the performance of a crystalline silicon PV module are temperature of module, PV module material and the solar radiance on the PV module surface [78]. In the stand-alone hybrid power systems, a PV-array system is used in such a way that loads can be supplied any time in an efficient way. ALTE POLY solar modules are used in this system and each module panel provides 120W with 12V. In this system, four PV modules are connected in series to meet the bus voltage which is 48V, therefore modules are connected in 6 strings. The initial cost of each panels connected in series is $230, the replacement cost is $230, and the operational and maintenance cost is $10. Commonly, most appliances and loads are designed to operate on AC. However, the PV-array system only gives DC voltage. Thus, an inverter (DC/AC converter) is a must so that AC loads can be supplied from the PV-system. Figure 5.14 shows the PV-array system, which is a part of the whole system, with a battery bank charging or supplying the AC load. As it is explained in [79], inverters, batteries and the wiring of a well-designed PV-system have typical efficiencies of 85% and 98% respectively. Once the gross energy demand is calculated, the system voltage can be fixed. System voltage is chosen to be 48V if daily energy demand is greater than 1KWh.

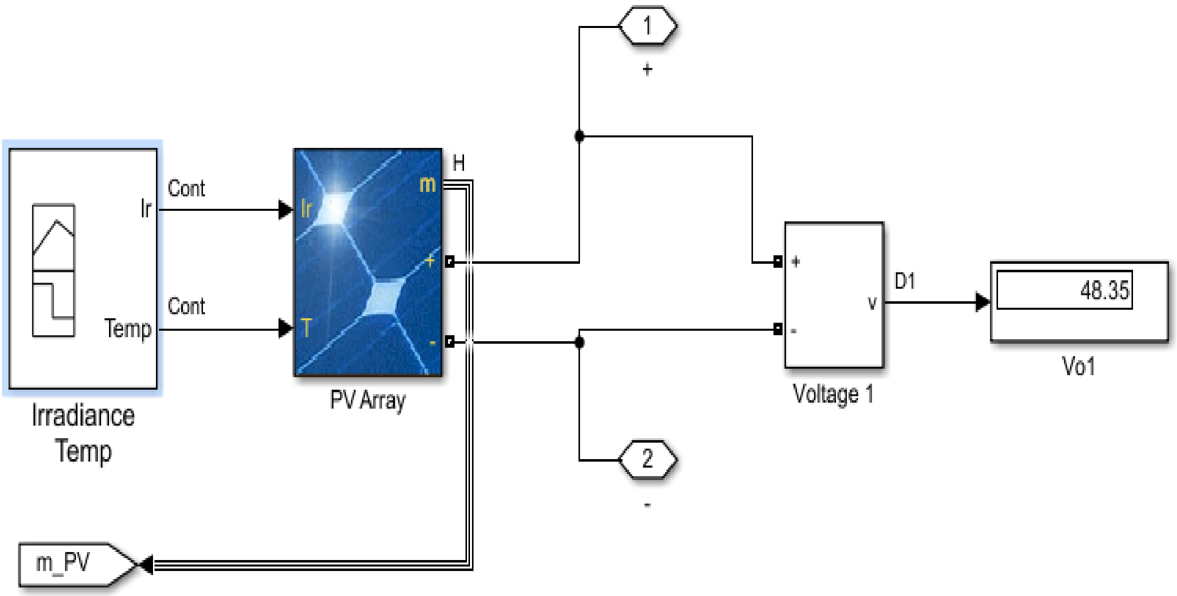
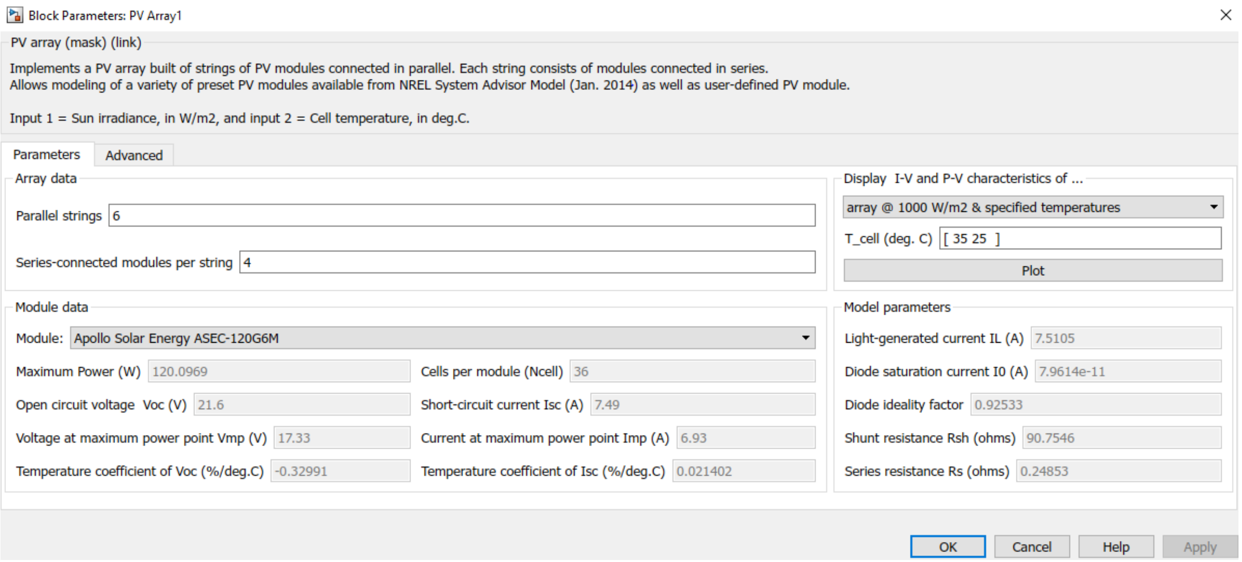


Fig 5.6 PV Array on Simulink

Below in figure 5.15 a dialog box of the PV Array where it shows 6 strings in parallel and 4 series strings modules connected in parallel, giving a total of 2,880 kW.



PV array (mask) (link)

Implements a PV array built of strings of PV modules connected in parallel. Each string consists of modules connected in series.
Allows modeling of a variety of preset PV modules available from NREL System Advisor Model (Jan. 2014) as well as user-defined PV module.

Input 1 = Sun irradiance, in W/m2, and input 2 = Cell temperature, in deg.C.

Array data

Parallel strings: 6

Series-connected modules per string: 4

Display I-V and P-V characteristics of ...: array @ 1000 W/m2 & specified temperatures

T_cell (deg. C): [35 25]

Module data

Module: Apollo Solar Energy ASEC-120G6M

Maximum Power (W)	120.0969	Cells per module (Ncell)	36
Open circuit voltage Voc (V)	21.6	Short-circuit current Isc (A)	7.49
Voltage at maximum power point Vmp (V)	17.33	Current at maximum power point Imp (A)	6.93
Temperature coefficient of Voc (%/deg.C)	-0.32991	Temperature coefficient of Isc (%/deg.C)	0.021402

Model parameters

Light-generated current IL (A)	7.5105
Diode saturation current I0 (A)	7.9614e-11
Diode ideality factor	0.92533
Shunt resistance Rsh (ohms)	90.7546
Series resistance Rs (ohms)	0.24853

Fig 5.7 PV Array dialog box

In the detailed model below, the boost converter boosts DC voltage from 36.19 V to 48.38V. This converter uses a MPPT system, which automatically varies the duty cycle in order to generate the required voltage to extract maximum power.

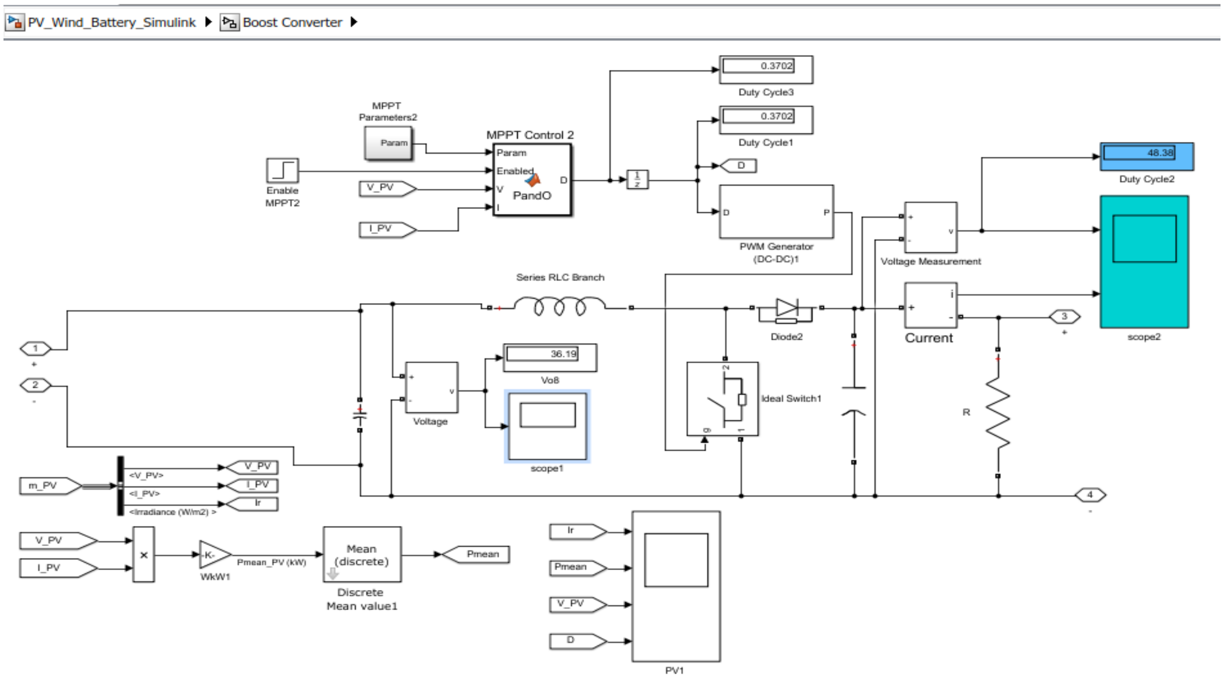


Fig 5.8 Boost converter

5.2.2.3 Storage System

The hybrid system used for a typical mobile office depends mainly on the necessities and the states under which energy is required. This research has considered non-grid connected solar PV and Wind systems, which use a special inverter and battery to store power generated by the PS installed. This will add a major cost and design complexity to the system, as the intensity of solar irradiation and wind speed varies with time and season. So, the most advisable and efficient way of harvesting the energy is by connecting energy storage devices (batteries) in such a way that loads can be supplied at any time, and the battery can store excess supply from the energy system.

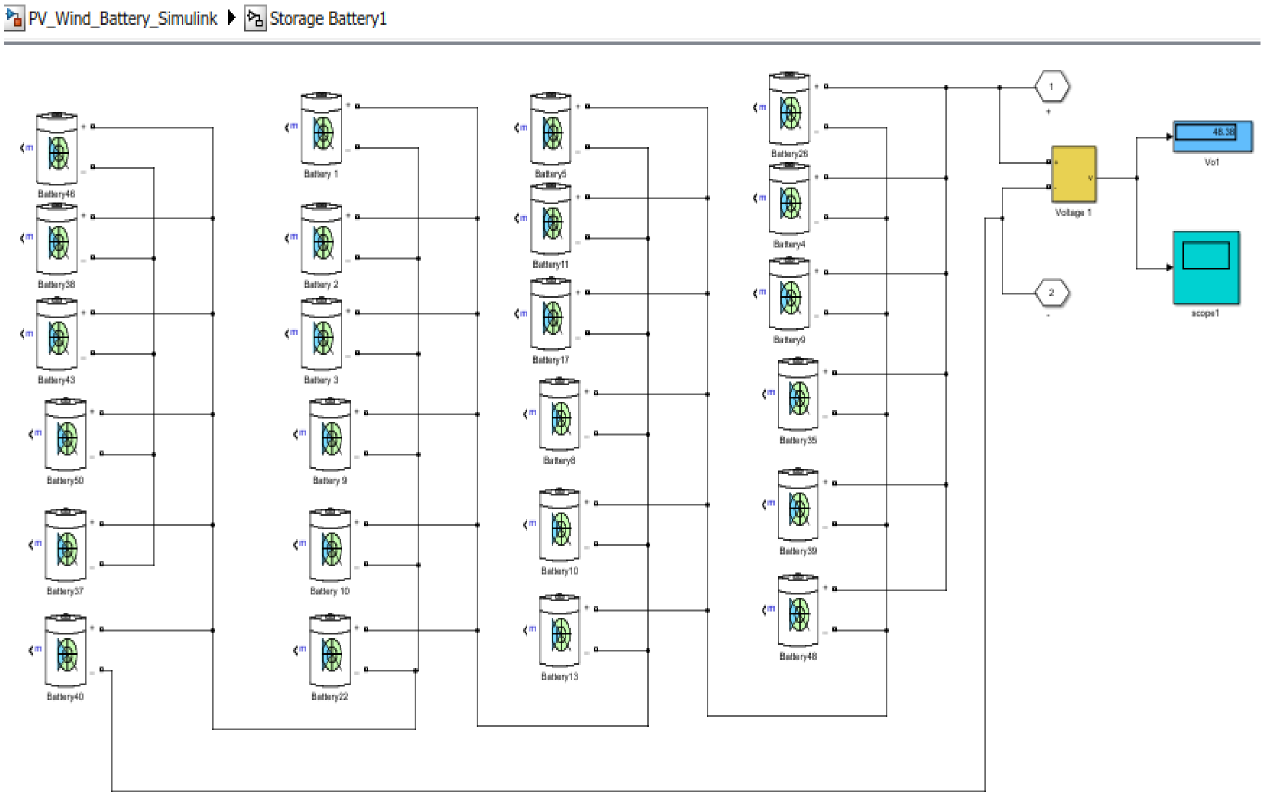


Fig 5.9 Storage Unit (Battery Bank)

Then, the stored energy in the battery can be used during times where there is less supply or there more demand. Figure 5.17 shows a capture demonstrating the battery installation and distribution in Simulink, 4 batteries in series and 6 batteries in parallel connected to a Multimeter known as the volt-ohm-milliammeter (VOM), which displays the bus voltage of the battery bank at 48.35 V. The battery bank is an electrochemical device that uses electrochemical reactions to store electricity in the form of potential chemical energy. The energy storing batteries used with hybrid power systems (HPSs) are rechargeable; they can charge when there is enough supply from the RESs and discharge when there is larger load demand than there is supply. The type of battery employed in this renewable energy system is a 12V Lead Acid Battery (LAB). It is very reliable with a 200AH rated capacity, a 30 second response-time, an initial 70% charge, and 48 Bus-voltage.

5.2.3 Load Profile

For isolated rural areas, solar-wind-diesel hybrid systems are undoubtedly stronger solutions for the electrification. The sizing of system elements is a very important part in which the demand and the supply should be synchronized. For a proper design, the complete load demand profiles and resource profiles of the site have to be known first. In chapter 3, a variety of typical load profiles were considered for the data, respective powers per unit system thus, a developed system was presented HOMERPRO and unutilized in Simulink in this chapter. The data are extrapolated to a 24-hour load profile and averaged into hourly values.

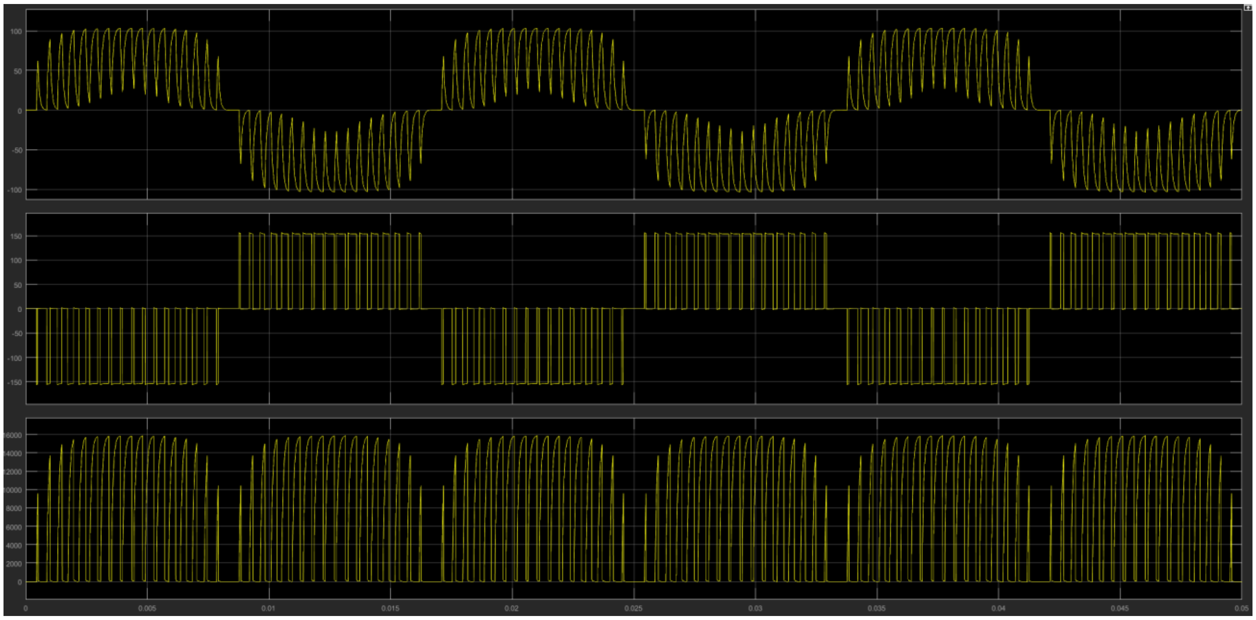


Fig 5.10 Load output scope

Figure 5.18 displays the output of the scope where the load is implemented, power output at 16 kW showing at the bottom of the screenshot, 110 V and 150 Ah as shown in the second and first lines. Figure 5.19 shows the AC-Load design in Simulink with a resistive and inductive components to simulate the mobile office load. Power factor at 0.9997 almost 1, which proves that all the energy supplied by the source is consumed by the load.

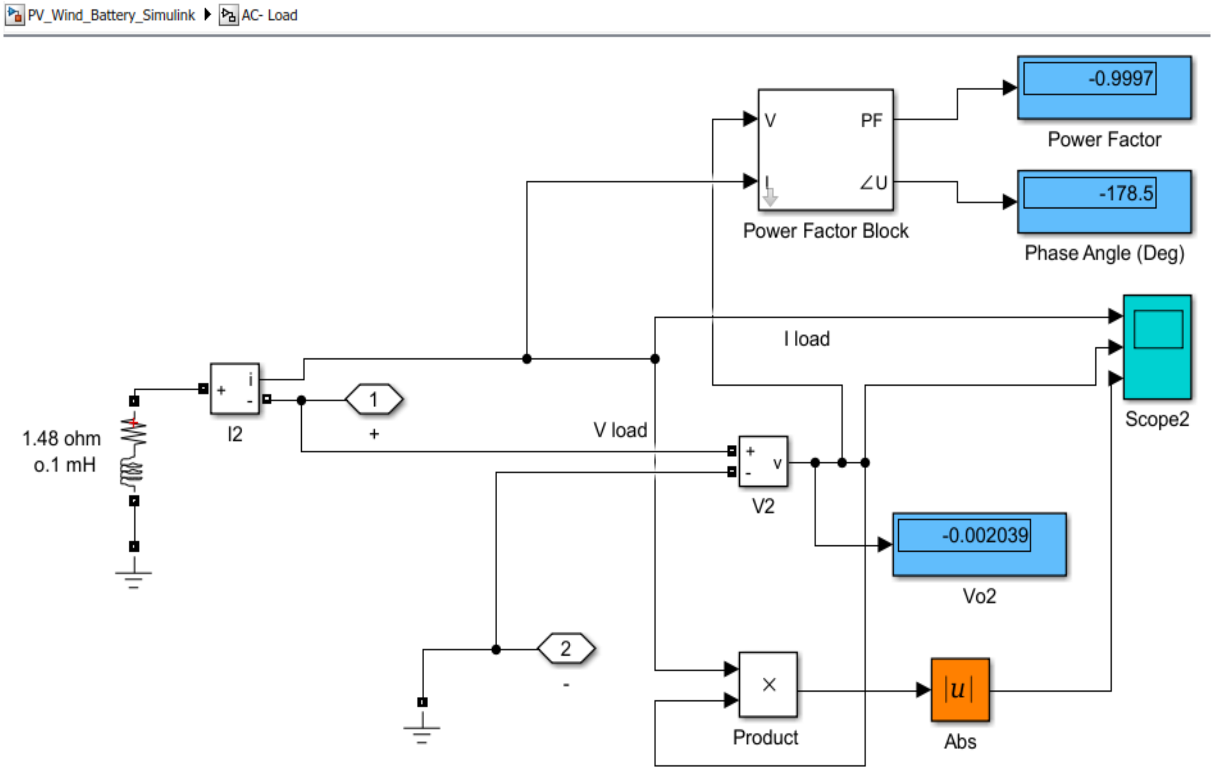


Fig 5.11 AC-Load in Simulink

5.3 Modeling of a Mobile Hospital Hybrid Power System using MATLAB/Simulink

5.3.1 PV Array system

In chapter 4, HOMERPRO was used to simulate a PV hybrid system that was considered for supplying an electric load to a mobile hospital in an area where there is no grid connectivity in the Saharan or northeastern Africa, which are most particularly noted locations for world records in sunshine and long hours of solar irradiation. This design of a Mobile Hospital in HOMPERPRO was implemented in a dynamic model developed with Matlab/Simulink, configured and ran on simulated real time, 24-hour operational period using its library as shown below in Figure 5.2. The system consists of a PV array connected to a storage battery known as the battery bank through a 48-bus voltage, with a capacitor. The capacitor in-between the two is a passive two terminal electrical component that stores electrical energy in an electric field. When weather conditions create low solar irradiance during the day, the capacitor blocks the inverter from consuming the electricity of the PV array and turns on the inverter at discharging phase [80]. The single phase inverter is designed to transfer the voltage from DC to AC where it changes the DC constant signal to an AC variable signal which is ultimately connected to the 17.8 KW AC-load.

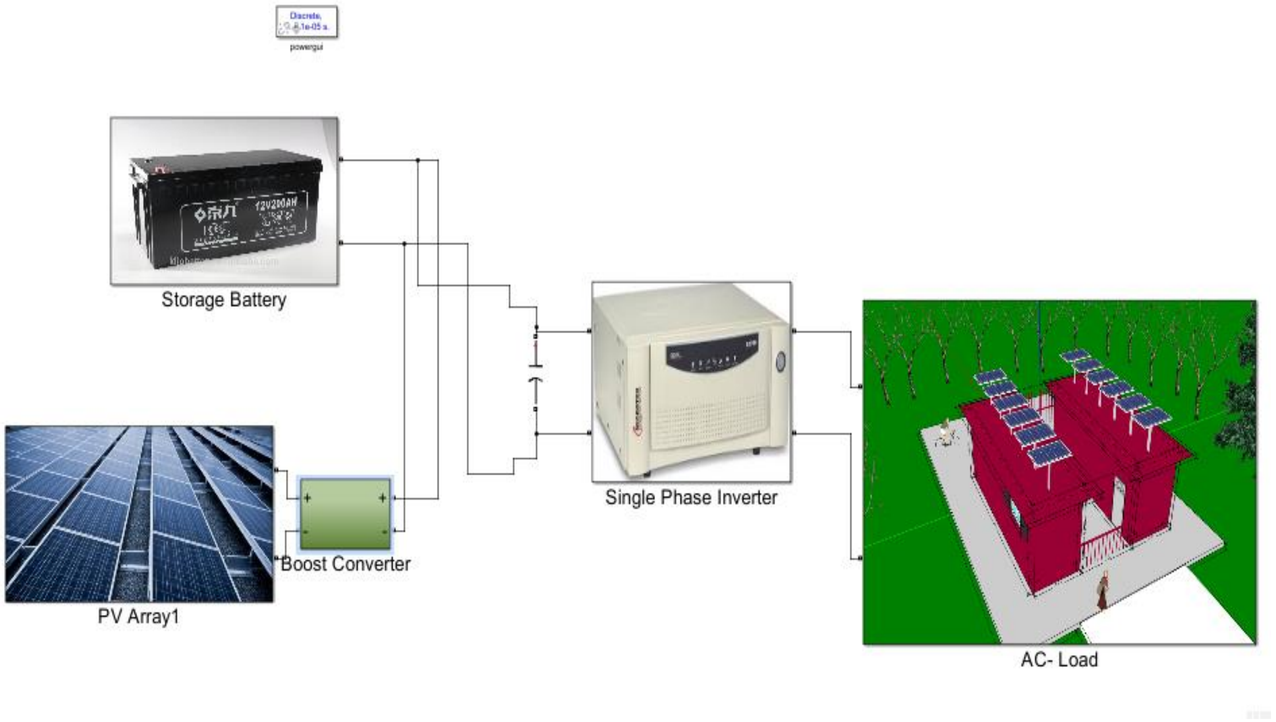


Fig 5.12 PV array module

5.3.2 PV System Model

Generally, a PV module consists of many PV cells wired in parallel to increase current and in series to produce a higher voltage [81]. Based on the electric energy production, the PV modules can be arranged into arrays to increase electric output and the PV systems are generally classified based on their operational requirements. The PV Array block menu allows you to plot the I-V characteristics and implement the input of 3.15 w/m^2 irradiation and a constant 25°C (77 F) temperature. More details from the system are displayed in curves shown in figure 5.3 in which the model specification parameters are 1000(W/M^2), 700(W/M^2), 500(W/M^2) radiation intensity and 25°C ambient temperature. The PV block system in Matlab/Simulink consists of a single PV cell which is a thin semiconductor wafer made of two layers of highly purified silicon combined together and connected in parallel and series.

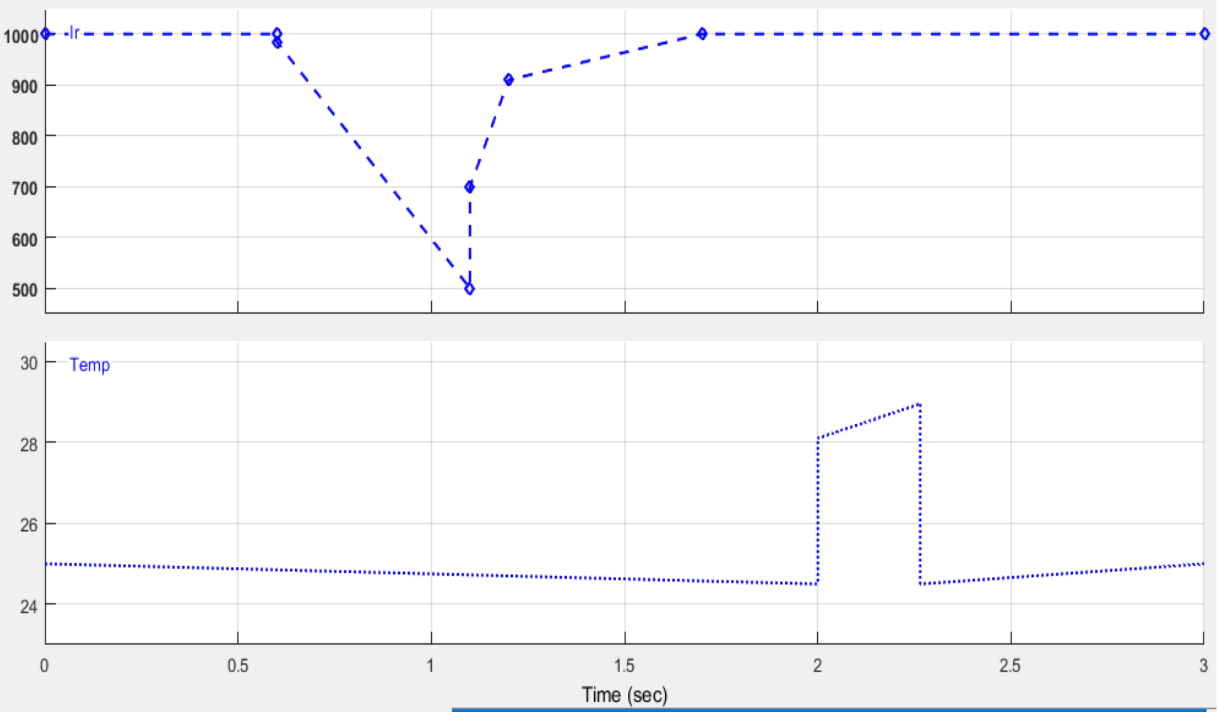


Fig 5.13 Irradiance and Temperature curve

The PV array of the detailed model uses ALTE POLY solar modules and it consists of 24 strings of 4 panels in series modules. Each panel will produce a 12 V, 120 W to the system (6*24*120 W= 17,280 kW), with the amount of current determined by the number of electrons that the solar photon rejects. Figure 5.4 captures the PV array system in Simulink.

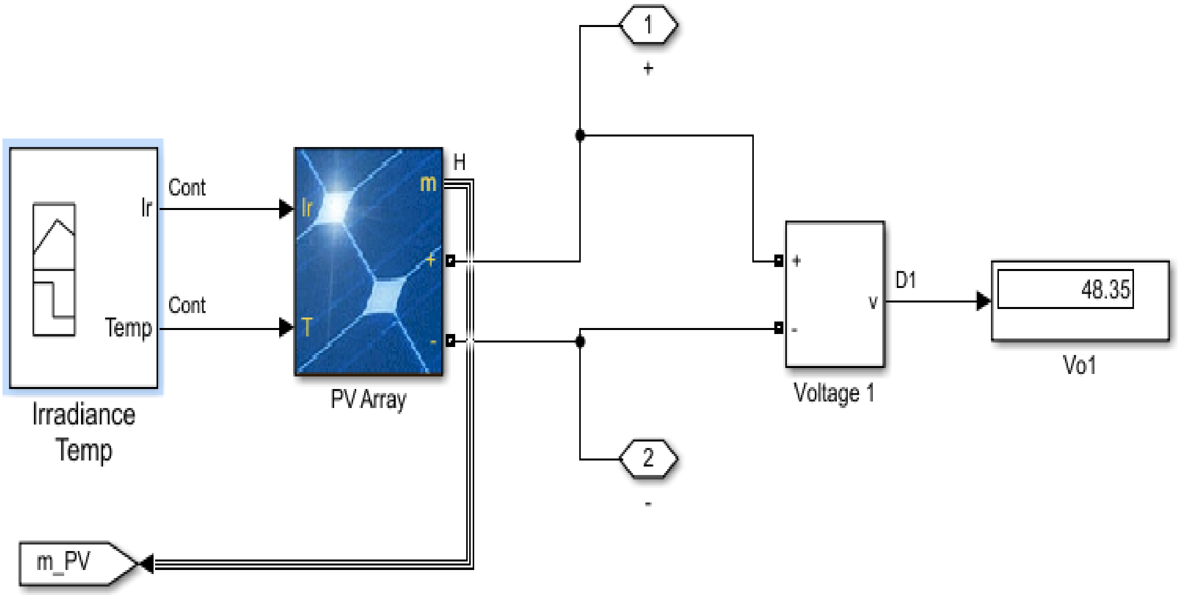


Fig 5.14 PV Array on Simulink

5.3.3 Storage Battery

This component is important in solar applications where the intermittency of solar power requires a much larger infrastructure. There are several types of systems for storing the energy and storage technology is pivotal for assuring a continuous supply of power to the load. There are a variety of battery types fitted for these unique requirements. The type of battery employed in this renewable energy system is a 12V Lead Acid battery. It is very reliable with a 200AH rated capacity, a 30 second response—time, an initial 70% charge, and 48 Bus-voltage. Figure 5.5 demonstrates the battery distribution, 4 batteries in series and 6 batteries in parallel connected to a Multimeter known as the volt-ohm-milliammeter (VOM), which displays the bus voltage of the battery bank at 48.35 V.

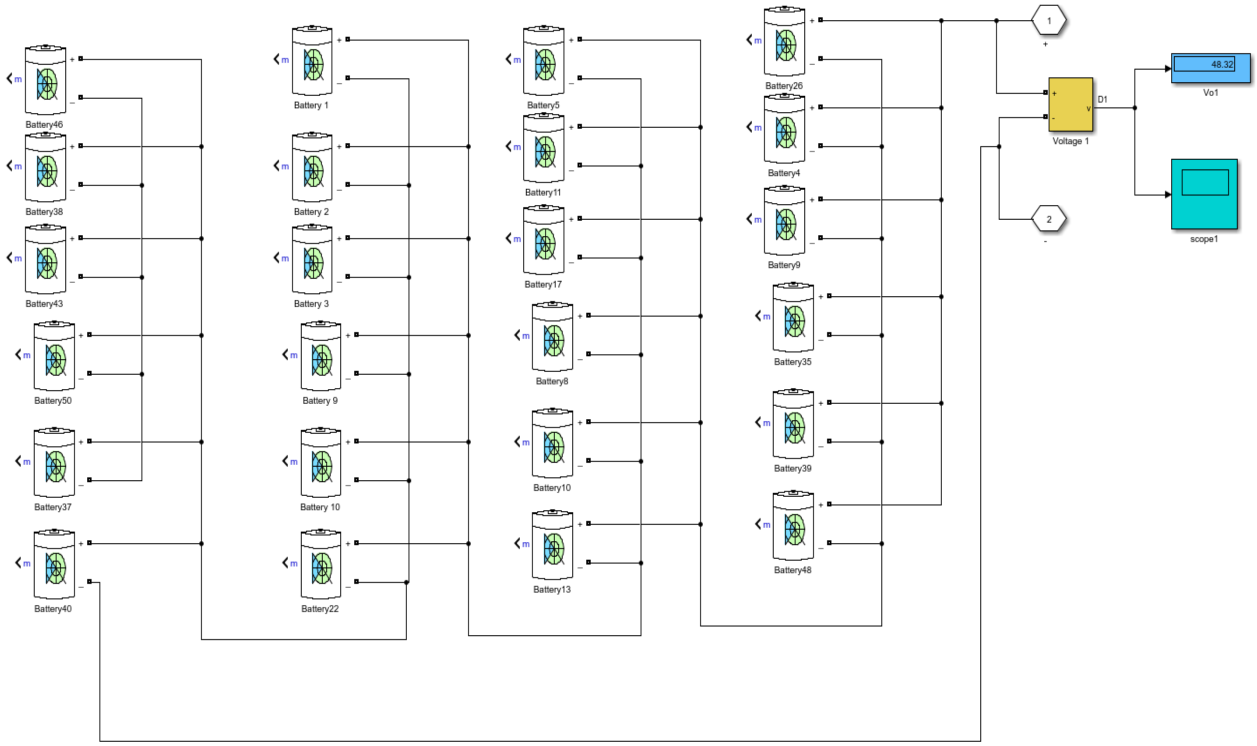


Fig 5.15 Battery Bank Distribution

5.3.4 Single Phase Inverter

An inverter is an electric device that converts direct current (DC) to alternating current (AC), depending on the design of the specific device or the circuit. Also, the inverter has two inputs—frequency and voltage—as illustrated in figure 5.6 with two block parameters at the input known as the physical modeling connection port block. An electric transformer is installed between the inverter and the scope which transfers voltage between two or more circuits throughout an electromagnetic induction [82]. A current goes through coil in winding-1 which produces a magnetic field that induces voltage in the second coil represented in winding-2.

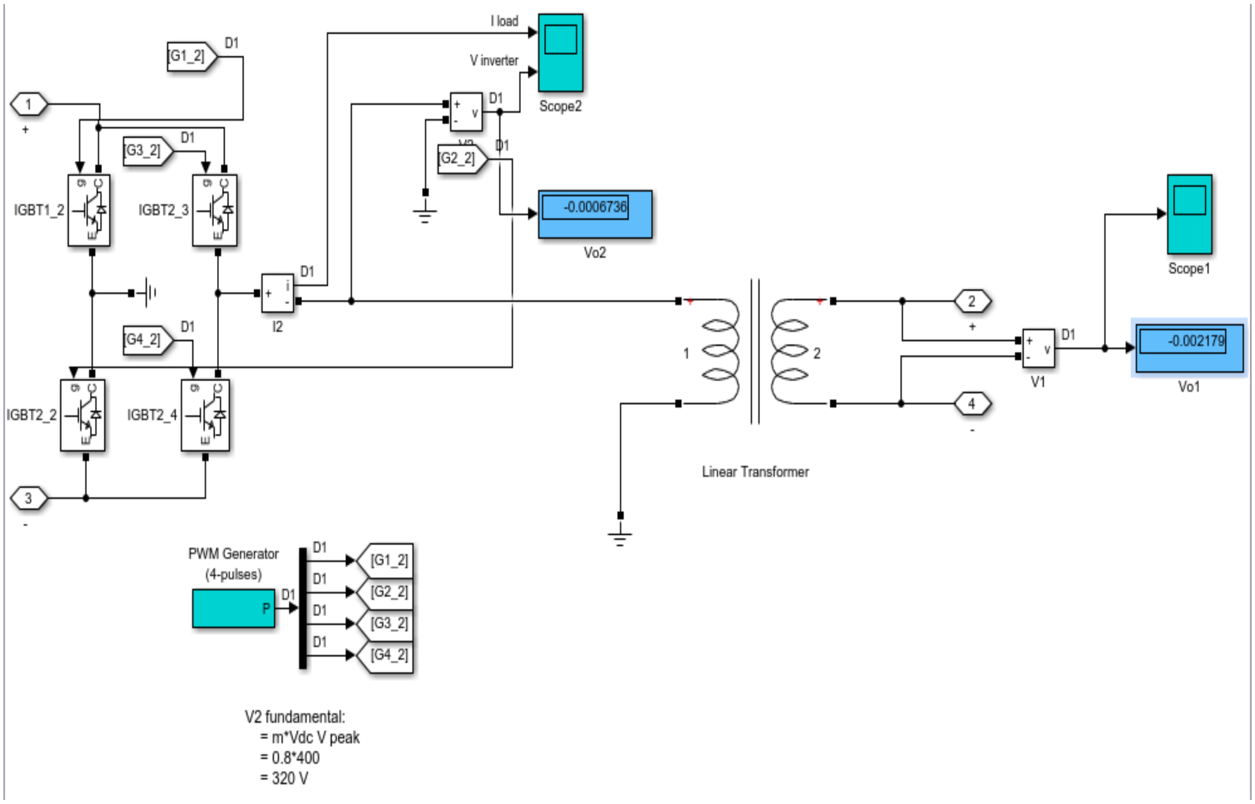


Fig 5.16 Single Phase inverter

Voltage can be transferred between the two coils through the magnetic field without any metallic connection between the two circuits. Moreover, transformers are used to increase or decrease the alternating voltages in electric power applications. The PV array system and the battery bank supply the transformer with a 48 DC voltage that is being converted to a 48 AC voltage which has a positive and negative cycle as shown below. Figure 5.7 is a screen capture of the inverter voltage and load current signal where the inverter voltage is displayed in Green in a semi—sinusoidal wave, and the load is colored in Blue and displayed in the upper wave signal where it has 330 positive and negative values. A linear single phase ideal transformer is implemented at 50 hertz, 1000 watts, 34 Vrms at the primary winding, and 110 Vrms at the secondary winding. Furthermore, due to the inductor use and the electronic switches that interfere with the system, the first harmonic represents a pure sinusoidal waveform, and additional waveforms with higher frequencies produce a distorted waveform that resembles a distorted sinusoidal wave.

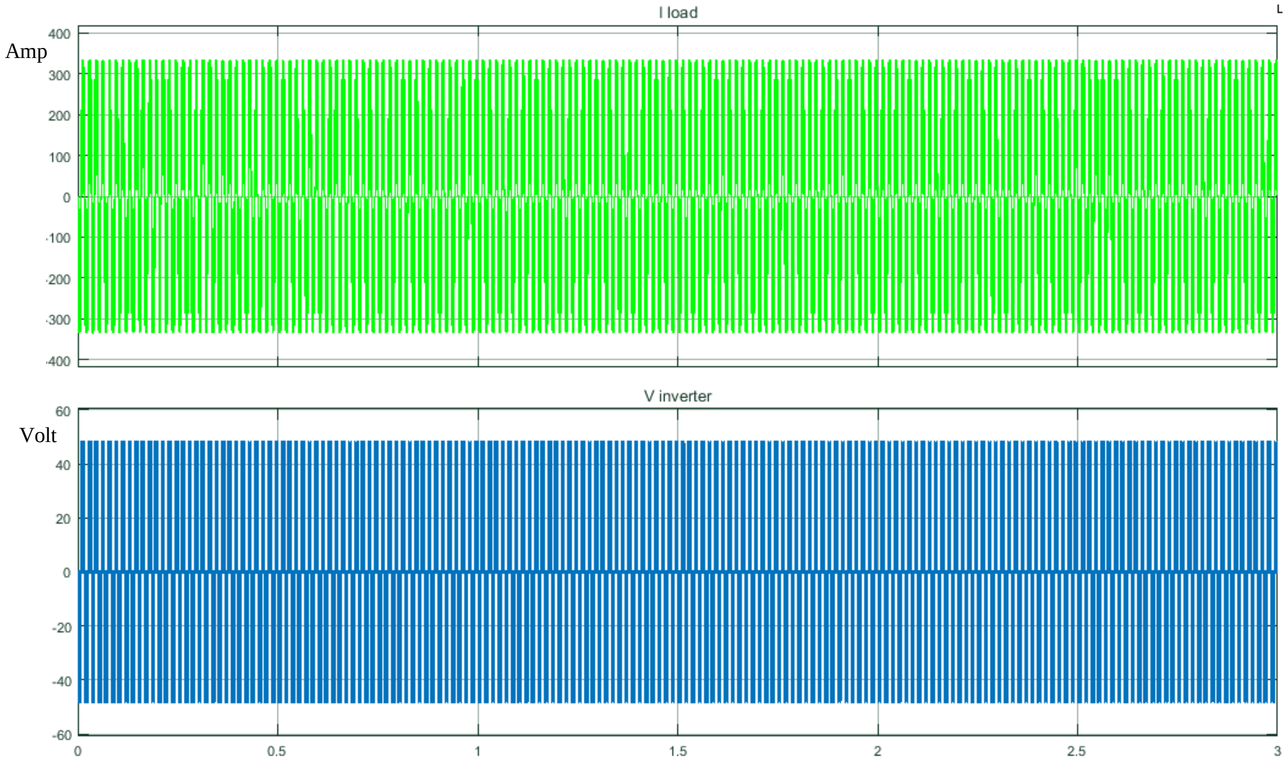


Fig 5.17 Scope 2 shows the 48 AC voltage in a sinusoidal form

5.3.5 AC-Load

Load data for the Mobile Hospital have been collected from HOMERPRO which has been used for simulations in the previous chapters. To implement the load in Simulink an inductor connected in series to a resistance, which represents the electrical appliances and the consumption of the mobile hospital.

For R:

“Total Load (Power) =Resistance (R) * Voltage $(V)^2$” ——(4)

“R = $(17800/(110)^2)$ =1.48 Ω”

With regards to the inductance, an ATV 0.1 mH was used to match the load. Due to the power equipment used in the design such as computers and printers, the designed PV system will assure a match to the load power requirement. Figure 5.8 illustrates the load design in Simulink.

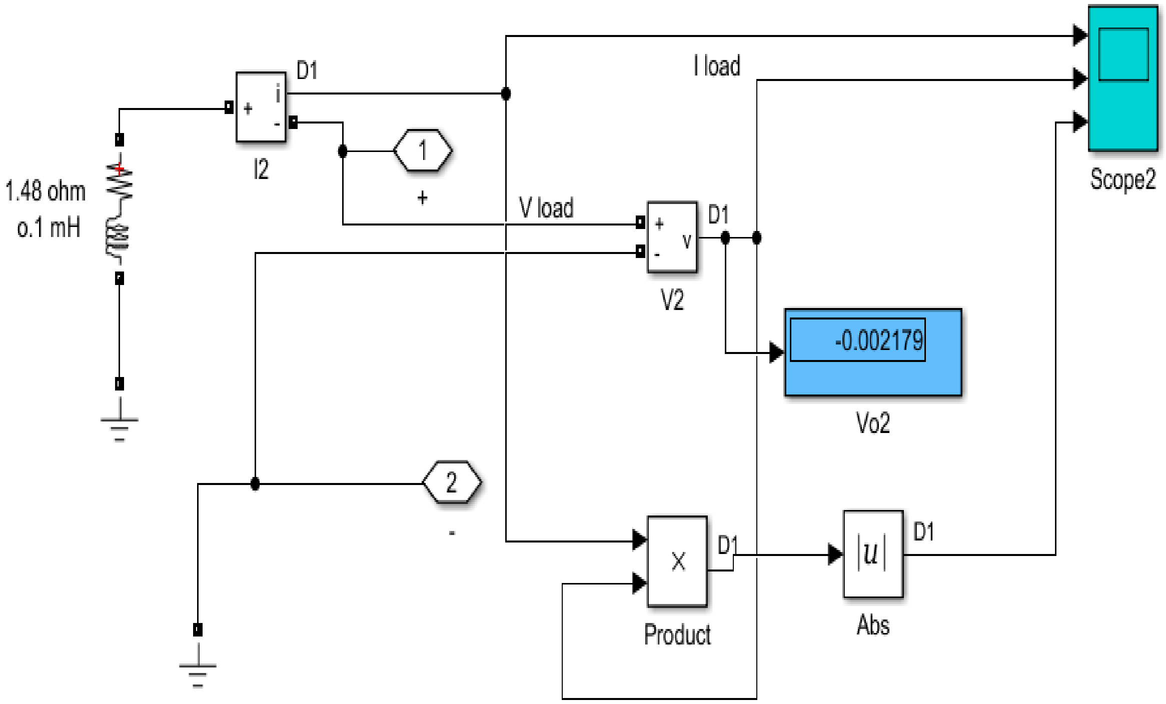


Fig 5.18 Load system design in Simulink

Moreover, the model was designed and developed for the study of the real-time system operation and power quality analysis of the studied system. After running the simulation, power flow graphs among the hybrid system based on renewable resources and instantaneous voltages and currents graphics can be obtained at the scope. In this system, there is no diesel generator added, only in

HOMER simulation a DG forced designed to be turned off and only used during emergency situations. Figure 5.9 presents the optimal results obtained from the scope 2 after collecting all the possible configurations and results that can be obtained using the power source. As shown below the load output signal is 100 A, 100 Vrms, and 17kW which is resulted from the power product block that multiplies the current and voltage signal together.

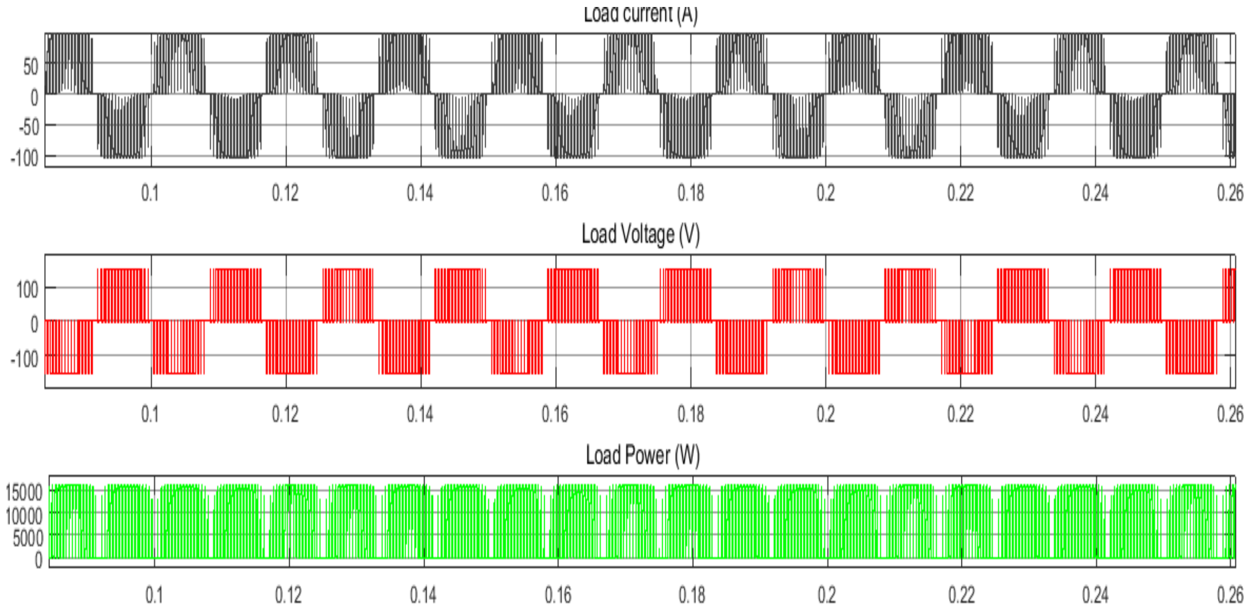


Fig 5.19 System output and Current, Voltage, Power readings

5.4 Summary

A hybrid power system which consists of PV-arrays, and wind turbines with energy storing devices (battery bank) and power electronic devices implemented in Simulink has been discussed in this chapter to achieve an efficient and cost competitive system configuration, so electrification of the rural sites and areas can be done where electricity from the main grid has not reached yet due to capital cost and other limitations. It is found that the best efficiency of power consumption can be achieved when the proposed connecting configurations are Mixed-coupling hybrid power systems (HPSs). Different sizing techniques have been reviewed under classification based on availability of weather data and solar irradiance. As the model is simulated, we got the result which is shown in the figures 5.18-5.19 from the result we can see that wind turbine is producing 4.877 kW power, where the reason for getting this power is due to the wind speed being as desired and mention in the manufacture datasheet (9 – 13 m/s). The system is includes other resources as well such as solar irradiance with scaled annual average of 3.45 kWh/m^2/day hence the system is completely capable of meeting the load demand. The proposed system, including a properly sized battery, leads to a significant reduction of the fuel consumption and a properly designed PV-wind-diesel installation remarkably reduces the required battery capacity, in relation to a PV/wind-only based stand-alone system.

Chapter 6.1 Conclusion, Contribution and future work

6.1 Introduction

This thesis developed an optimal sizing and a pre-feasibility study of the off-grid energy system configurations for powering a renewable Mobile Office/Hospital at sites in remote areas in Newfoundland and Libya. A system model with a generic storage system, generic resource models and generic resource conversion technologies, it also discussed the optimization, sizing, and operational strategy of hybrid renewable energy system. The sizing and prefeasibility are done by HOMERPRO software as shown in chapter three and four.

Mobile offices located in remote areas are generally powered using diesel generators and batteries. However, this study shows a new way to model a hybrid power system with a detailed dynamic simulation model. Diesel generators require maintenance and in-time of need at at locations where it is hard to provide tools, the costs would be catastrophic. Each resource was modelled stochastically using the best models presented in the literature, to verify and investigate the potential of the Mobile Office/Hospital, large number of different possibilities can be examined relatively quickly with the model, which aids in the evaluation of the different possible energy systems.

The proposed system is a combination of renewable and non-renewable power systems. A Horizontal axis H5 wind-turbine with rated capacity of 5kW provides 48V DC, twenty-four SLTR—POLY solar modules provides a 15% of the monthly average electric power production, a DG2500E diesel generator is used with a rated capacity of 1.5kW, and 6 strings of 6FM200D batteries. Each battery is a 12V and has a capacity of 200Ah with 48V total bus voltage. Wind and PV are the primary power source of the system and a diesel generator is used as a backup for short term storage system.

A brief introduction of the hybrid power system has been presented. Moreover, some paper related to renewable energy systems and mobile office, clinics and hospital designs have been presented and published during the course of this research. The results of both the Mobile Office designs in Newfoundland and the Mobile Hospital in Libya are shown in chapter 2, 3 and 4. Both systems are simulated in Energy3D and HOMERPRO, and the optimal results were obtained for each case. From these results it was clear that the installed capacity of a wind/PV energy system at Newfoundland would be significantly lower than that required for either a wind or solar energy system. Also, it was noticed that the required installed capacity of solar panels for the site in Libya was suitable and efficient. It appears that this is related to the availability of renewable energy resources to be used in the evaluations process on the most appropriate system for a specified location. Diesel fuel consumption was reduced, since it has a large impact on the environment and the number of trips needed to fill up the tank at the site will also be reduced. Also less maintenance and operation costs, service period will increase due to less operational hours.

The wind energy system has been simulated with different wind speed during the sensitivity analysis which was performed on the system resources and components to study the effect that this analysis had on the storage efficiency, and to observe the significant affect that it has over the storage size if a system was properly designed. This analysis allows to create a combined system with both wind and solar resources as well as the single-source systems, but at significantly lower installed capacity. A yearly variation in the resources between systems was presented. The combination of a fully developed, integrated, and multiple source renewable energy systems is a move that is being considered by most of the world in 2015 after late world crisis in 2008. For the Newfoundland site, all the results indicate that a hybrid wind/PV energy system would be the most appropriate. However, at the other site in Libya a complete hybrid photovoltaics system was the appropriate approach. Solar energy system has been simulated with different solar irradiance, and power curves have been validated as well.

As the first step, the resource and load potential has been estimated. Based on resource-need matching, a model has been simulated for different combinations of sizes of resources. HOMERPRO has been used as simulation tool that can model both the technical and economic factors involved in the project. The model designed by HOMERPRO refers to the minimum cost of Total Net Present Cost (TNPC). The result shows that the combination of wind turbine, PV system, diesel generator, battery storage and converter brings an optimal configuration of hybrid renewable energy system applicable to be used as an off-grid mobile carrier.

The conclusions drawn from the results obtained during the analysis, there is a high potential of wind resource in Newfoundland, which can be used for supporting the renewable energy especially in terms of wind turbine compared to the solar energy. Libya on the other hand, have an uninterrupted solar irradiance which is the most suitable for a solar power plant, such a PV hybrid system for a mobile clinic is recommended for use in a remote locations of the sub-Saharan desert.

6.2 Contribution

The contribution of this research to the field of renewable energy are:

- AutoCAD and Energy3D are used to provide the most accurate structural drawings, and pre simulation of the total structure of the building.
- HOMERPRO software is used to determine the best optimal sizing and prefeasibility study including the sensitivity analysis, to provide stability and be modified easily for potential future modification to the remote site.
- Considering a mobile office provided by Alantra Leasing at Memorial university St. John's campus, and comparing between a non—renewable energy system and a complete renewable system.
- System have been moduled in Matlab/Simulink and compared between a PV system and a Wind/PV hybrid system.
- Different scenarios and conditions have been taking under consideration for wind and solar systems.
- Three papers has been published from this research. Fourth paper is under preparation and it will be published soon.

6.2.1 Publications

- Design of renewable energy system for a mobile office, Emadeddin Hussein, T. M. Iqbal, presented in NECEC 2015 at the, St. John’s, NL.
- Design of Renewable Energy System for a Remote Mobile Office in Newfoundland, Emadeddin Hussein, T. M. Iqbal, presented at EPEC 2016, Ottawa, Ontario and published at the Canadian Journal of Electrical and Computer Engineering, http://ieeexplore.ieee.org/document/7771678/.
- Emadeddin A. A. Hussein and M. T. Iqbal, "Design of Renewable Energy System for a Mobile Hospital in Libya," Journal of Clean Energy Technologies vol. 5, no. 6, pp.492-495, 2017.

6.2.2 Future Publications

- Dynamic modeling of hybrid power system for a Mobile Hospital using Simulink/Matlab, Emadeddin Hussein, T. M. Iqbal. Location, yet to be decided.

6.3 Future Work

- This system can be developed further by studying the accessibility of such a system in locations around the world by experimenting for other remote hybrid power systems with different ratings and configurations.
- More complicated models may give a better performance of the system and provide opportunity to analysis higher order transient responses.
- Searching for a suitable more compatible wind turbine would be considered.

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