Design of an off-grid hybrid PV/Wind/DG power system for remote mobile base station (Case study around Bale- Robe at Sanate Hill).

Awel Hussein Debo

A Thesis Submitted to

The Department of Electrical Power and Control Engineering

School of Electrical Engineering and Computing

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Electrical Power and Control Engineering (Power System Engineering)

Office of Graduate Studies

Adama Science and Technology University

July, 2022

Adama, Ethiopia

Design of an off-grid hybrid PV/Wind/DG power system for remote mobile base station (Case study around Bale- Robe at Sanate Hill).

Awel Hussein Debo

Advisor: Dr. Molla Biweta

A Thesis Submitted to

The Department of Electrical Power and Control Engineering.

School of Electrical Engineering and Computing

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Electrical Power and Control Engineering (Power System Engineering)

Office of Graduate Studies

Adama Science and Technology University

July, 2022

Adama, Ethiopia

DECLARATION

I hereby declare that this Master Thesis entitled "Design of an off-grid hybrid PV/Wind/DG power system for remote mobile base station (Case study around Bale- Robe at Sanate hill)" is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

Awel Hussein Debo ___________ __________

Name of the student Signature Date

RECOMMENDATION

I, the advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled "Design of an off-grid hybrid PV/Wind/DG power system for remote mobile base station (Case study around Bale- Robe at Sanate hill)" prepared under my guidance by Awel Hussein Debo submitted in partial fulfillment of the requirements for the degree of Mater's of Science in Power System Engineering. Therefore, I recommend the submission of revised version of the thesis to the department following the applicable procedures.

Dr.Molla Biweta	________________________	________________
Advisor	Signature	Date

APPROVAL SHEET

I, the advisor of the thesis entitled "Design of an off-grid hybrid PV/Wind/DG power system for remote mobile base station (Case study around Bale- Robe at Sanate hill)" and developed by Awel Hussein Debo; hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Dr.Molla Biweta ________________ ____________________

Advisor Signature Date

We, the undersigned, members of the Board of Examiners of the thesis by Awel Hussein Debo have read and evaluated the thesis entitled "Design of an off-grid hybrid PV/Wind/DG power system for remote mobile base station (Case study around Bale- Robe at Sanate hill)" and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Power System Engineering.

________________________________ _______________________ _____________________

Chairperson Signature Date

________________________________ _______________________ _____________________

Internal Examiner Signature Date

Dr. Tefera Kitaba ____ TKTefera ____ July 5, 2022 ____

External Examiner Signature Date

Finally, approval and acceptance of the thesis is contingent upon submission of its final copy to the Office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and School Graduate Committee (SGC).

___________________ _____________________ __________________

Department Head Signature Date

__________________ ______________________ __________________

School Dean Signature Date

_____________________ _______________________ __________________

Office of Postgraduate Studies, Dean Signature Date

ACKNOWLEDGEMENT

Primarily my deepest gratitude is extended to the one Almighty Allah, for his infinite grant throughout my life. My advisor Dr. Molla Biweta deserves my strong gratitude for his priceless comments & excellent supervision. My gratefulness is also forwarded to Dr. Teshale who granted & advised me to join this department in the first. My appreciation also extends to Ato Solomon Teshome, Dereje Mekuanint, Usman Ismael and all members of Ethio telecom Bale Robe O&M staffs. My sincere thanks are further offered to my lovely family for their encouragement, appreciation and financial and moral support. My best friends who had supported me throughout all this thesis work in every aspect deserves my heartily acknowledgement. Organizations that I really want to acknowledge for their unlimited support throughout my thesis work are primarily Ethio telecom, Dal Alfiker Ethiopia and Ministry of National Metrological Agency which gave me permission to gather most of the necessary information and data throughout most of its sites. Though not possible to exhaustively mention all friends, relatives and each and every cooperator by name who gave me a hand in some way during this work, I truly would like to say thanks to all.

TABLE OF CONTENTS

CHAPTER PAGE

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS AND ABBREVIATIONS

1G	First Generations
2G	Second Generations
3G	Third Generations
4G	Fourth Generations
5G	Fifth Generations
A	Ampere
AC	Alternating Current
ADSL	Asymmetric Digital Subscriber Line
Ah	Ampere-Hour
ASDC	Atmospheric Science Data Center
BBS	Battery Base Station
BS	Base Stations
BSC	Base Station Controller
BSS	Base Station Subsystem
BTS	Base Transceiver Station
Bc	Battery capacity
BC_n	Net capacity of battery
Bs	Number of series connected batteries
B_p	Battery connected in parallel
Br	Required battery bank capacity
CAPEX	Capital Expense
C_{acap}	Annualized capital cost
CDMA	Code Division Multiple Access
CO	Carbon Monoxide
CO_2	Carbon Dioxide

COE	Cost of Energy
CRF	Capital recovery factor
CPE	Customer Premises Equipment
DC	Direct Current
DG	Diesel Generator
DOD	Depth of Discharge
DSP	Digital Signal Processing
EDGE	Enhanced Data Rate for GSM Evolution
EEU	Ethiopian Electric Utility
$E_{rec-out}(t)$	Hourly energy output from rectifier
$E_{rec-in}(t)$	Hourly energy input to rectifier
$E_{sur-ac}(t)$	Amount of surplus energy from AC sources
$E_{weg}(t)$	Hourly energy generated by wind generator
$E_{cc-out}(t)$	Hourly energy output from charge controller
$E_{cc-in}(t)$	Hourly energy input to charge controller
$E_{rec-out}(t)$	Hourly energy output from rectifier
$E_{sur-dc}(t)$	Amount of surplus energy from DC sources
$E_{bat}(t)$	The energy stored in battery at hour
R	Radius of rotor
$V_{nom,\ bat}$	Nominal battery voltage.
EGPRS	Enhanced GPRS
ETC	Ethiopian Telecommunications Corporation
EVDO	Evolution Data Optimized
FDMA	Frequency Division Multiple Access
GMSC	Gateway MSC
GPRS	General Packet Radio Service

GSM	Global System for Mobile Communication
HES	Hybrid Energy System
HOMER	Hybrid Optimization Model Electric Renewable
HPS	Hybrid Power System
ICT	Information Communication Technology
IEA	International Energy Agency
IMEI	International Mobile Equipment Identity
IMSI	International Mobile Subscriber Identity
IMT	International Mobile Telephone
IRENA	International Renewable Energy Agency
ISDN	Integrated Service Digital Network
ITU	International Telecommunication Union
Kbps	Kilo bit Per Second
Ki	Authentication key
KWh	Kilo Watt hour
LTE	Long Term Evolution
MAP	Mobile Application Part
MCIT	Ministry of Communications & Information Technology
MMS	Multi Media Messaging Service
MPPT	Maximum Power Point Tracker
MS	Mobile Station
MSAG	Multi Service Access Gateway
MSAN	Multi Service Access Node
MSC	Mobile Service Switching Center
MW	Microwave
NASA	National Aeronautics & Space Administration
NOC	Network Operating Center

NPC	Net Present Cost
NSS	Network Switching Subsystem
OPEX	Operational Expense
O&M	Operation and Maintenance
PBC	Power Base Controller
PIN	Personal Identity Number
PSTN	Public Switched Telephone Network
PUK	Pin Unblocking Key
PV	Photovoltaic
RBS	Radio Base Station
RET	Renewable Energy Technologies
RRU	Remote Radio Unit
SIM	Subscriber Identity Module
SMS	Short Message Service
SOC	State of Charge
SSC	System Supervisory Control
STC	Standard Test Conditions
TDMA	Time Division Multiple Access
TWh	Tera Watt hours
V	Volt
VPN	Virtual Private Network
W	Watt
WCDMA	Wideband CDMA
WLAN	Wireless Local Area Network

LIST OF SYMBOLS

ß	The blade pitch angle
ђ	Tip speed ratio
Ƞ	Wind turbine efficiency
ρ	Air density
C	Coefficient of the turbine
G	Global irradiance

ABSTRACT

There is a clear challenge to provide reliable cellular mobile service at remote locations where a reliable power supply is not available. So, the existing Mobile towers or Base Transceiver Station (BTSs) uses a conventional diesel generator with backup battery banks. This paper presents the solution to utilizing a hybrid of photovoltaic (PV) solar and wind power system with a backup battery bank to provide feasible and reliable electric power for a specific remote mobile base station located at Bale Robe. All the necessary modeling, simulation, and techno-economic evaluation are carried out using Hybrid Optimization Model for Electric Renewable (HOMER) software. The best optimal system configurations namely PV/Battery and PV/Wind/Battery hybrid systems are compared with the conventional stand-alone diesel generator (DG) system. Findings indicated that PV array and battery is the most economically viable option with the total net present cost (NPC) and per unit cost of electricity (COE). Simulation results show that the hybrid energy systems can minimize the power generation cost significantly and can decrease CO_2 emissions as compared to the traditional diesel generator only. The sensitivity analysis has been carried out to analyze the effects of probable variation in solar radiation, wind speed, diesel price and average annual energy usage of the system load in the optimal system configurations.

Ethiotelecom tower systems, especially those located in rough terrain, are currently powered by solar and diesel generator sets with battery backup. Diesel power generation is associated with several disadvantages which do not make it the best option. Generally, Ethiopia is blessed with Renewable Energy Resources (RES) which can be utilized at such towers to supply power. This study carried out measurements for wind speeds and solar insolation around Bale Robe, at Sanate site and compared these with data from secondary sources. A HPS system was designed based on the data collected. The design process basically involved selecting the best combination of HPS system components based on their cost and power characteristics. Finally, the study compared the designed power system and the current online system at the site in terms of cost of implementation and running.

Keywords: Diesel Generator(DG); HOMER; Mobile base station; Net Present Cost(NPC); Off-grid system; Photovoltaic (PV); Renewable Energy; Telecommunication

CHAPTER ONE

INTRODUCTION

1.1 Background Information

Stand-Alone Systems are designed and optimized to meet the power demand of remote places are off-grid power systems. An off-grid system does not have a connection to the main grid electricity and vary widely in size and application. Hybrid power systems are designed for the generation of electrical power using number of power generation devices such as wind turbine, PV, micro hydro and/or other conventional generators. In addition, it includes power electronics and electricity storage bank. Some of the advantages of using RESs are gain an immediate access to reliable electricity at any time; reduce the dependency from oil price fluctuations and the transportation costs of fuels; increase economic productivity and fight climate change (Bhandari B, et al. 2015). Telecommunication network have changed the way people live, work and play. Since many people around the world are connected by mobile networks, the challenges to provide reliable and cost effective power solutions to these expanding and remote networks are indispensable for telecom operators. The mobile Industry in Africa faces many challenges to operate the mobile networks in a cost effective manner. Africa has one of the lowest electrification rates in the world with only 43% of the population having access to grid electricity. Wherever there is access to grid electricity, the supply of electricity is highly unreliable with frequent and long outage. Africa is a land of renewable energy source's opportunity. However, currently only less than 2% of the renewable resources (excluding hydro) are exploited for electricity generation across Africa. This presents a huge untapped potential for large scale renewable power projects as well as small scale mini-grids and off-grid power systems. Wherever there is access to grid electricity, the supply of electricity is highly unreliable with frequent and long outage. Despite the fact that around 80% of the population of Ethiopia lives in rural areas, electricity supply from the grid is almost entirely concentrated in urban areas. And limited grid infrastructure and inadequate power generation capacities has greatly affected the availability and quality of electricity supply. Among other things, dispersed demand and very low consumption level of electricity among rural consumers, limited grid electricity penetration to rural population (Olatomiwa L, et al. 2015). The electric power infrastructure is playing a negative role in the growth of mobile telecommunications in terms of network coverage and great impact on the operation cost of running the system due to non-availability of grid power supply. Due to this there is very limited or no coverage of mobile network for the rural population. In the conventional diesel generators with backup battery were used for powering these mobile tower sites (BTS). These off-grid systems, usually located in areas with difficult accessibilities require regular maintenance and are characterized by their high fuel consumption and high transportation and operational cost. Also, due to the increasing demand of clean energy technology to reduce the greenhouse gas emission pressure telecom companies for alternative solution for powering these sites is needed. Therefore, in order to meet the continuous typical load demand of a mobile base station during varying atmospheric conditions, different energy sources need to be integrated for extended usage of alternative energy. This will create a large demand for off-grid power supply in rural areas which renewable energy is best suited to realize ethio-telecom tower site with renewable energy technologies. Solar and wind are available freely and thus appears to be a promising technology to provide reliable power supply in the remote areas and telecom industry of Ethiopia. The project aim to design an off-grid hybrid renewable energy system for Mobile Base Station, so that can generate and provide cost effective electric power to meet the BTS electric load requirement.(Phrakonkham S, Le Chenadec J-Y, Diallo D, et al. 2010)(IFC, GSMA, Green Power for Mobile 2014).

In Ethiopia, Ethio telecom was established in November 2010 by replacing the previous name of the company Ethiopian Telecommunications Corporation (ETC). The operator has passed through different names since 1894 E.C at the governance of Emperor Menelik II when the 407 Km telegraph line between the cities of Harar and the capital Addis Ababa was constructed. Currently Ethio telecom is the sole service provider of telecom technology in the entire country with comprehensive plans in place to meet the requirements set out by the Ministry of Communications and Information Technology (MCIT). The Federal Government of Ethiopia owned and controlled all telecommunications services, except selling of Customer Premises Equipment (CPE). To provide reliable and secured communication services at affordable price throughout the country, the company has developed extensive mixed-capability Information Communication Technology (ICT) infrastructure that provides a blended coverage of 85% of the country's population, with the potential to serve 90% of its population. Recently the telecommunication service was opened for the other telecom operator providers. Mobile service in Ethiopia has existed since 1999 G.C and at that time the network coverage was limited to Addis Ababa with a network capacity not more than

60,000 subscribers. According to September, 2021 press release, the subscription of mobile reached 50 Million at the end of 2020. To provide mobile service, Ethio telecom uses Base Transceiver Station (BTS) that help to connect the service provider with the customer which is placed in access layer of the integrated network structure. It is one of Base Station Subsystem (BSS) element that is used to connect Mobile station (MS) to the network through air interface on one side and Network Switching Subsystem (NSS) on the other side. In providing mobile services throughout the country, Different vendors (ZTE, HUAWEI and ERECSON) signed a contract with Ethio telecom to this end, BTS is installed with the inventory of these companies. Ethio telecom holds a variety of telecom devices that needs consistent power source to be operational. The company got this power mainly from the national grid, and uses this power source alone or with generator and/or batteries as backup. In addition for off grid or remote areas, the company uses commonly generator and battery, but in few places solar power is available (www.ethiotelecom.et. accessed on Jan ,2022).

Although Energy is vital for development of a community and nation as a whole and thus it must be produced and utilized efficiently. It is argued that energy is a basic requirement for the modern life-style. The ever increasing cost and environmental concerns involving conventional sources of electrical energy have increased interest in RES. Technologies should therefore be developed to produce energy in an environmentally friendly manner from all energy sources. Sufficient importance should also be given to the efficient conservation of energy resources. Electrical power requirements for most communication towers installed in rural areas are met by diesel generator sets. The extension of the main grid to low population areas especially those in difficult terrains is associated with high capital outlays (Radicati Group, INC. 2014-2018). The use of a diesel generator however, induces several environmental issues and high Operation and Maintenance (O & M) costs as summarized in Table 1.1

Table 1.1 Comparisons of RES with Diesel Generation (Acharya D, 2013).

Item	RES	Diesel Generation
Cost	Low O&M	High O&M
Pollution	No Emission	Sound & Oil spillage
Dependency	Depends on natural &RES	Depends on oil supply
Fuel Transportation	No transportation cost	Costly to transport using tankers, losses and poor quality due to theft during transportation
Maintenance	Low maintenance	Costly, losses due to theft & oil spillage
Life	Longer useful life	Seven years or shorter
Power Supply	Depends on availability of RES	No guaranteed uninterrupted generation

Sanate Mountain, around Bale Robe (Latitude 6.789; Longitude: 39.775) is hilly with an estimated terrain elevation of 2862.89m above sea level. Electricity consumed by the ethiotelecom tower system in Sanate end is currently supplied by two 10kVA diesel generators, although RES are in abundance. The Capital Expenditure (CAPEX) and annual Operational Expenses (OPEX) for the two diesel generators are approximately ETB 20K and ETB 3.1K respectively. The average power demand for this tower system is approximately 1.5 kW and maximum power demand for the site was between 4 to 6kw. In the current study, the feasibility of replacing diesel power generation at Sanate with solar and wind HPS supplemented with battery bank storage with the use of diesel generation as a back-up source, was investigated. A HPS was then designed based on the solar and wind data collected and economic viability of the investigated system.

1.2 Geographical Site Location

Robe also called as Bale Robe is a town in south central Oromia region of Ethiopia. Located in Bale zone. This town has a latitude and longitude of 7o7'N 40o0'E With an elevation of 2492meters above sea level. It is located about 430 kilometers from the capital Addis Ababa and Sanate hill were far from the Robe town about 25km to the south. Robe shares Robe Airport with neighboring Goba. The notable tourist attractions include the Sof Omar Cave which lie to the east and Bale Mountain national park which include different endemic species like Red Fox, Mountain Nyla etc (Wikipedia).

Figure 1.1 The location of Bale Robe (Google map).

1.3 Problem Definition

Developing countries like Ethiopia have serious energy crisis. Satisfying the power demand of the people for the fundamental necessities by itself is in much a bother situation. Hence, governments and peoples started looking towards permanent and never-ending sources of energy called renewable sources of energy such as solar and wind energy. The positive aspect of use of renewable energy sources in these countries is that they are available in plenty and also pollution free. Although, vendors and operators of equipment for mobile communications in developing countries have been facing difficulty to meet certain challenges such as it costs much, expensive to run, uses much power and is difficult in deploying with limited electricity supply. For instance, many people in emerging markets like Ethiopia live in rural areas with limited access to the electricity grid; it becomes a significant barrier to expanding network coverage in these areas as mobile phone base stations rely on a secure supply of power. Even in areas connected to the grid, the power supply can be unstable and disrupt. And also due to the reach of mobile telephony among the people in remote villages, the service providers are stressed for finding a working solution to the energy crisis. Thus the provision to power the base stations for mobile operators with renewable energy is gaining importance steeply. Like other mobile communication devices, BS devices required power to be operational. In Ethiopia, currently most of the BS gets power from commercial line of Ethiopian Electric Utility (EEU). In addition, these devices were using generator and/or battery as backup in situations when power is disrupted. Although, the national power provider EEU has accelerated its progress in connecting towns and supplying power, electrification rates remain low and are well known in its frequent interruption. The alternative sources, batteries and diesel generators, are unsuitable for long hours and expensive to operate, respectively. On the other hand, if there is no adequate and continuous power supply for the BTS sites, it is difficult to ensure service continuity. As a result, all services supported by the respective devices will automatically be paused. These problems become more challenging in countries like Ethiopia, where power interruption from the grid is more common and where there is lack of reliable power supply for remote locations. Moreover, in rural areas energy consumption contributes most of the total network operating cost. Thus, this expenditure on energy as a result of the lack of grid availability highlights a potential barrier to the growth of the service delivered by the company and ensuring reliable services throughout the country. Fortunately solar wind power is available in almost every location no matter how remote and can be used for low- and medium capacity sites. Apart from having very low environmental impact, solar-wind powered sites have the advantage of being very low maintenance, with a technical lifetime of about 30 years or more. In addition it allows deeper penetration of mobile networks and much more reliable than diesel generator-powered systems. And also it can scales with the load, so the size of the solar installation can be matched to actual needs without unnecessary capacity. However the fact that solar photovoltaic (PV) and wind technology is not yet commercially mature in developing countries. Generally, using these energy sources to power the sites has the potential to resolve the three key needs of the company, namely: reduction in diesel usage; expansion of telecom infrastructure to off-grid areas; and reduction in carbon emissions (Jeannin, L and Jochen H. 2013).

Finally, Electrical power generation using diesel engines is associated with environmental pollution while supplying power from the national grid to remotely located towers is costly.

Therefore, a sustainable power supply system, which is environmentally friendly, cost effective and readily available is required.

1.4 Significance of the study

The significance of this study is to ensure service continuity and reduce dependency on commercial line of Ethiopian Electric Utility (EEU) through an optimal sizing of off Grid-PV and wind hybrid system. In addition, the project shows that availability of alternative PV & wind power source for telecom access layer devices and to minimize the power cost. Furthermore, this project encourages further studies that can be done to utilize available alternative power sources for other network equipment's. Finally, the findings of this study will serve as a reference for other studies and decision makers for planning.

1.5 Objective of the study

1.5.1 General Objective

The main objective of this study is to model and develop alternative power source for ethio telecom mobile base station, using off Grid connected PV/Wind/DG hybrid power system and size the system using proper optimization method.

1.5.2 Specific objectives

The specific objectives to be undertaken to reach at the general objectives are to:

- Assess the solar radiation and wind speed of Bale Robe area
- Design and optimize a HPS for Mobile base station system
- Develop a model and formulate objective function & constraints
- Determine the economic feasibility of the proposed system

1.6 Limitation of the study

The fact that the study was done only in Bale Robe area it may limit its generalization of using the alternative power source nationally. The proposed model of alternative hybrid power system for remote mobile station was modeled only for simulation due to high cost for individual, but it's prefer to fabricate and install its prototype at the site for actual implementation and investigation.

CHAPTER TWO

LITERATURE REVIEW

2.1 Background of the Study Area

2.1.1 Renewable energy sources (RES)

The International Renewable Energy Agency (IRENA) has a statutory definition, "renewable energy includes all forms of energy produced from renewable sources in a sustainable manner, including bioenergy, geothermal energy, hydropower, ocean energy, solar energy and wind energy" (Jochen H. Schiller, 2003).

The International Energy Agency (IEA) defines renewable energy resources as those "derived from natural processes" and "replenished at a faster rate than they are consumed". The IEA definition of renewable energy includes the following sources: "electricity and heat derived from solar, wind, ocean, hydropower, biomass, geothermal resources, and biofuels and hydrogen derived from renewable resources" (IEA 2002).

Renewable energy comes from the sun and can be used directly as the case with solar heating systems or indirectly as with hydroelectric power, wind power and power from biomass fuels. RES includes solar energy, wind energy, hydroelectric power, geothermal energy, bioenergy, ocean energy, etc. There are other alternatives to sources of energy that are not renewable in nature. Although these are "alternative energy" rather than "renewable energy", they use the existing energy more efficiently than older technologies. The use of renewable and alternative energy sources can save funds, conserve energy, save the environment and reduce overdependence on energy supplies outside the country borders (Jochen H. 2003).

2.1.2 Hybrid Power Systems

Hybrid power system involves a combination of two or more modes of electricity generation devices or sources such as wind turbines, PV, micro-hydro and/or fossil fuel generators. They are generally independent of centralized power grids and can be used in remote/rural area. The use of RES in hybrid power generation systems reduces the reliance on expensive fuels while allowing for a cleaner generation of electrical power. HPS addresses limitations in terms of fuel flexibility, efficiency, reliability, emissions and/or economics as well as elimination of fuel transportation costs. Figure 2.1 shows the schematic diagram of a basic HPS involving various sources.

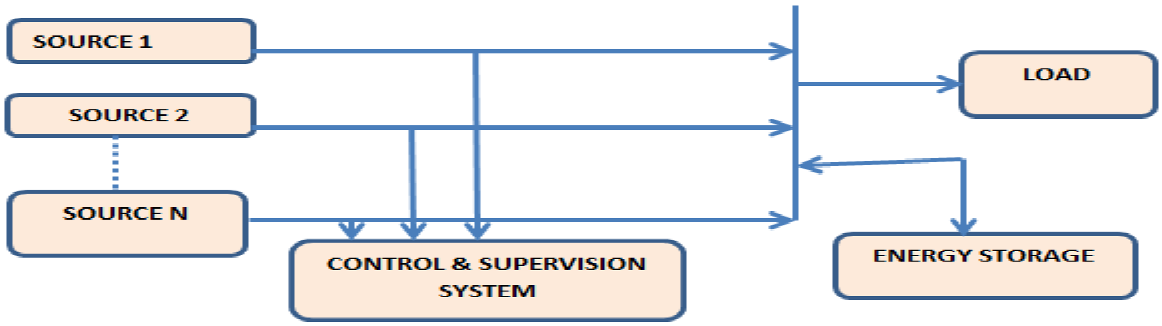


Figure 2.1 Basic hybrid power systems (Bhandari B & Lee K-T, et al. 2015)

In a HPS, a diesel power generator acts as a back-up system in circumstances which may render RES capturing components unavailable. The system is usually modified so that the diesel generator is not always required, but in that case other components must be added. There are a number of wind turbines that supply DC power as their principal output. These machines are typically in the smaller size range of 10kW or less. With suitable controls or converters they can support both AC and DC loads. PV panels represent a useful complement to wind turbines in some hybrid power systems. PV panels inherently generate DC power and therefore usually operate in conjunction with storage and a separate DC bus. There are two types of power conversion functions of particular significance for hybrid power systems: rectifying and inverting, to charge batteries from AC sources or supply AC loads from DC sources, such as batteries and photovoltaic panels. Some control functions are carried out by dedicated controllers that are integral to the system components. Overall system control is accomplished by the system supervisory control (SSC). A stand-alone HPS consisting of wind and solar PV is a suitable hybrid combination for most applications, taking care of seasonal changes. They also complement each other during lean periods in that they are both seasonal in nature. Figure 2.2 shows a HPS consisting of wind and solar PV and other components.

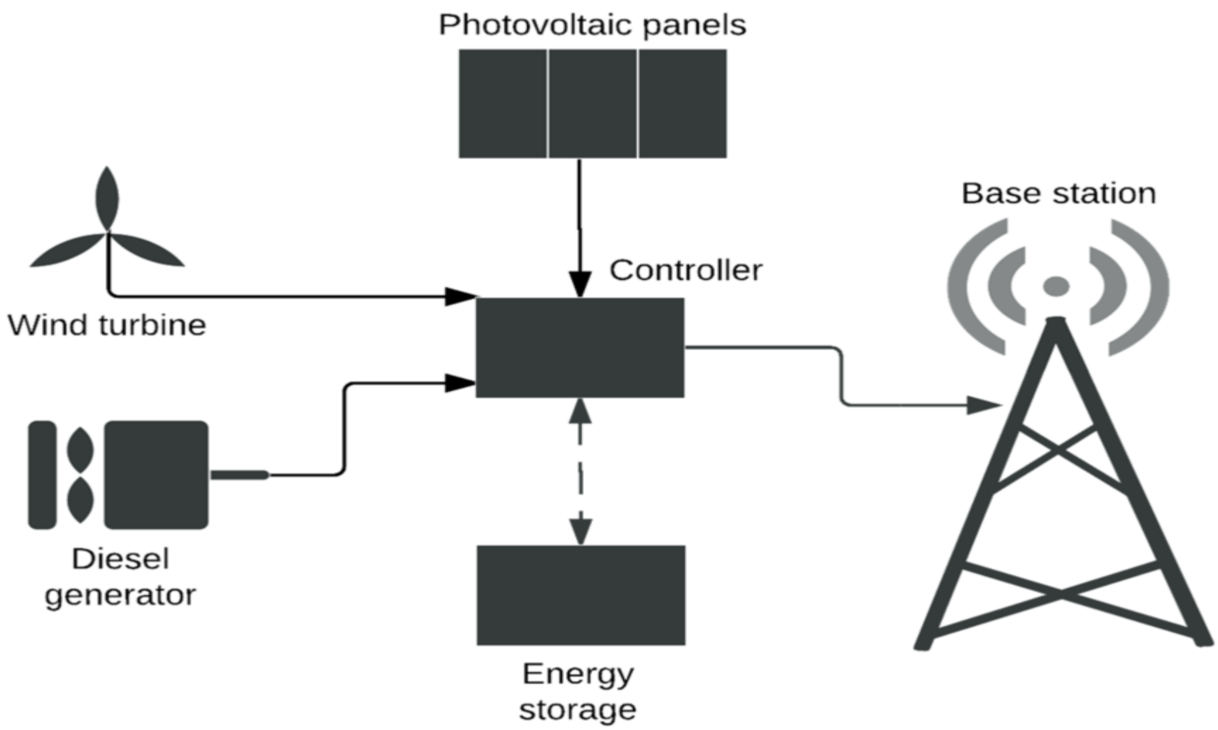


Figure 2.2 PV- Wind-DG Hybrid power systems (Chaouchi.H & Laurent.M, 2009)

2.2 Mobile Telephony Network

Consumers seek communication at home or in the street, always using the mobile phone beyond the limitations imposed by cables. However, in order to be able to use a mobile phone at least one telephone wireless network is required. The network shown in Figure 2.3 required different network devices to get the desired communication (accessed from ipcisco on May, 2022).

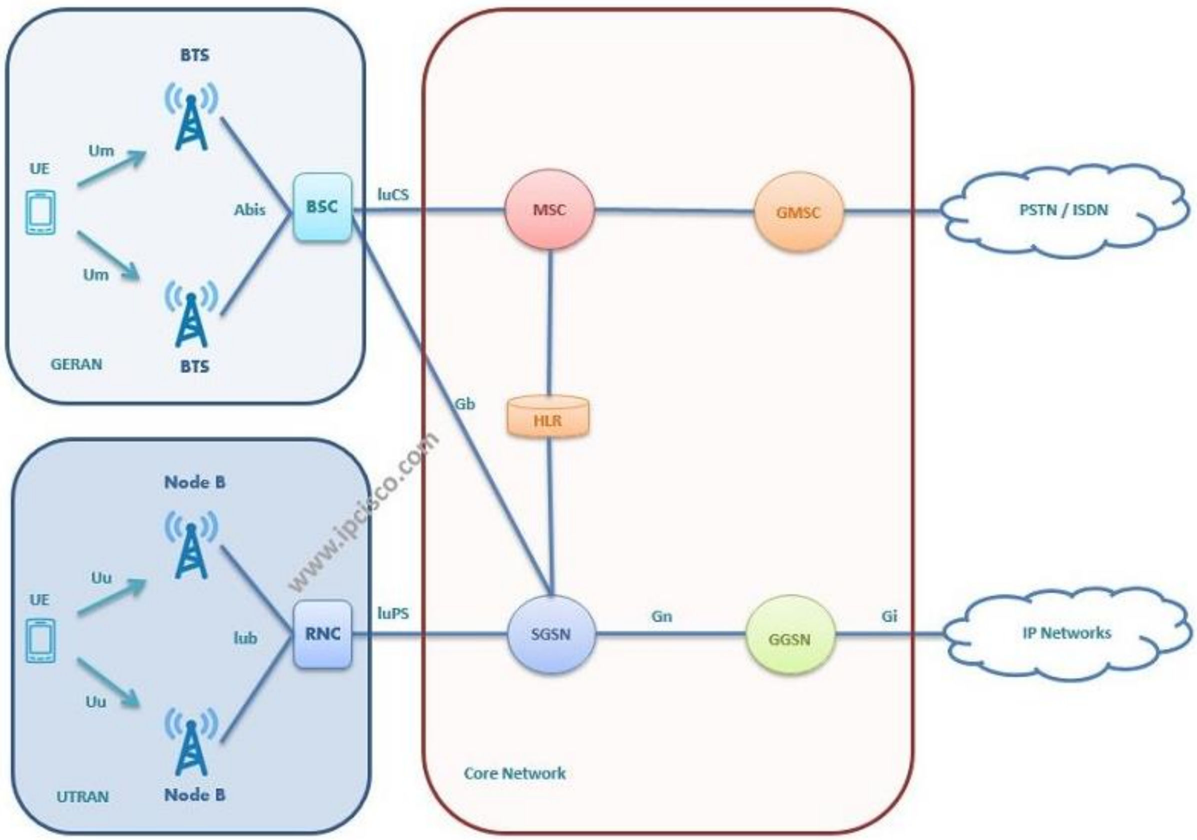


Figure 2.3 Structure of Mobile Network (ipcisco accessed on May, 2022)

A GSM mobile telephony network is generally composed of the following:

Mobile station (MS): The MS includes all user equipment and software needed for communication with network. It consists of the subscriber identity module (SIM), which is a data base on the user side that stores all user-specific data. It contains many identifiers and tables, such as card-type, serial number, a list of subscribed services, a personal identity number (PIN), a PIN unblocking key (PUK), an authentication key (Ki) and the international mobile subscriber identity (IMSI). And MS can be identified via the international mobile equipment identity (IMEI), a user can personalize any MS using his or her SIM, i.e., user-specific mechanisms like charging and authentication are based on the SIM, not on the device itself (Heine, Gunnar, 1999).

Base transceiver station (BTS): A BTS comprises all radio equipment, i.e., antennas, signal processing, amplifiers necessary for radio transmission. Also it provides the physical connection of

MS to the network through Air-interface. On the other side, it is connected to the Base Station Controller (BSC) via the Abis-interface (Heine, Gunnar, 1999).

Base station controller (BSC): is a small digital exchange its function is to switch the incoming traffic channels through A-interface from the Mobile service Switching Center (MSC) to the correct Abis-interface channels. In addition it manages BTS's, reserves radio frequencies, handles the handover from one BTS to another within the Base Station Subsystem (BSS) and performs paging of the MS (Heine, Gunnar, 1999).

Mobile services switching center (MSC): MSCs are high-performance digital integrated service digital network (ISDN) switches. They set up connections to other MSCs and to the BSCs via the A-interface, and form the fixed backbone network of a system. Typically, an MSC manages several BSCs in a geographical region. It also handles all signaling needed for connection setup, connection release and handover of connections to other MSCs (Heine, Gunnar, 1999).

Gateway MSC (GMSC) has additional connections to other fixed networks, such as public switched Telephone network (PSTN) and ISDN (Heine, Gunnar, 1999).

2.2.1 Mobile Base Stations

A base station is a wireless system situated at the heart of the cell (The area covered by base station signals); it includes an antenna, a controller and a number of transmitters and receivers.

Usually, three antennas with hundred and twenty degrees are mounted on the top of the metallic tower to cover the specified region and connected to Remote Radio Unit (RRU) with cables. Though these antennas are operated at different frequencies they are well separated from each other to avoid interference of emitted power from each other. Also at the bottom of the tower a small house of electronic circuits often called a shelter is found, contained power amplifiers that are used to generate strong signals and they are connected to RRU with fiber. The base station also has additional components within a shelter include digital signal processing unit, microwave link, rectifier, air conditioning elements (for indoor base station) and lighting. Also many base stations have a Direct Current (DC) power back up system in the form of batteries connected either in series or parallel (Pande.G, Sept,2009).

2.2.2. Mobile Base Station Load

The main electrical and electronics equipment of this mobile network site are Radio Base Station (RBS), Power Base Controller (PBC) including Rectifier, Battery Base Station (BBS) and Diesel Generator (DG) with Fuel Tank. Typically, a conventional BTS site load consists of BTS equipment load as well as air conditioner and lighting loads. So A second-generation GSM System mobile base station consisting of a single RBS 6101 with three RF Antenna at angle of 120; with one MW Antenna, with Lighting Rod and Aviation Light; one PBC 05 with 3 Rectifier of 2 KW Power rating; BBS 6101 with 8 Battery per two battery Strings and DG with Rating of 10 KVA and Fuel tank with 1000L Capacity was considered in this study. This equipment's are outdoor Material. Diesel generator is scheduled to operate accordingly for the whole day throughout the year. Weather it is high or low traffic demand, DG is scheduled to run in optimal conditions for the rest of hours. Most of the radio transceiver appliances employed in mobile network site use DC power to operate. There AC power supply from the DG to the AC input terminal of rectifiers to convert in DC power and transfer to the DC loads. The DC load components are connected to −48 V DC power supply. More power is consumed by the radio equipment and amplifiers; the left is consumed by the DC power system and by the cooling equipment, an air conditioning unit. An individual mobile phone tower, the BTS can account for approximately 4 kW–6 kW of total energy consumption. Comprising BTSs (the primary radio equipment), an air conditioner (if required), antennas and lighting are the largest energy consumers at a tower site (CSC 249, Cellular Technology 2014).

2.2.3. Power consumption for Mobile Base Station

The base station's power consumption can be determined by the sum of the power consumption of all those components. The load represents the number of active users or the number of calls at that time and the requirements of the services they use in the base station cell, the higher the load, the higher the base station's power consumption. The Load estimation is assumed based on the electric and electronic appliances used in the mobile network site and usage of the electrical energy; because the power consumption pattern of a BTS depends up on the number of subscribers, the area to be covered, the topography of this area, and the technology used(IFC, Green Power for Mobile 2014). Typically, a conventional BTS site load consists of BTS equipment load (base station RBS and microwaves) as well as air conditioner and lighting loads. A second-generation GSM mobile base station consisting of one number BTS with three transceivers was considered in this study. The maximum power consumption of air conditioner is considered as 1.8 kW, whereas the BTS equipment's power and miscellaneous loads (battery charging load and lighting) are 1.5kW and 0.5k W, respectively. Although, measured hourly load data for the considered site are not available, however it is important to note that, the stated rating of BTS equipment (base station RBS and microwaves) will not be loaded to full capacity at all times due to the variability in operating hour of the equipment which often depends on the level of usage by the mobile subscribers. This load is therefore classified into three categories according to the level of usage, namely; low hour, medium hour and busy hour load. Based on the first category, it is assumed that the subscriber utilized only 10% of the total BTS load, this usually occurred during 12PM to 6 AM in the morning, whereas in the second category is considered 30% usage, this occurred between 7 AM and 10 AM in the morning and between 6 PM and 11 PM in the night. Finally the third category is taking as 50% and usually occurs during the business hours of the day (10 AM to 6 PM). It should also be noted, that the air conditional is considered to only operate during the business hour (sunshine hour) of the day when high power is expected to be demanded from the BTS equipment, whereas the miscellaneous loads (lighting) is operated only in the night hours (6 PM to 6 AM). Therefore, mobile base station is operated at busy load and low load condition under maximum and minimum traffic. It should also be noted, that the air conditional is considered to only operate during the business hour (sunshine hour) of the day when high power is expected to be demanded from the BTS equipment, whereas the miscellaneous loads (Aviation lighting & florescent lamp) is operated only in the night hours. The mismatch in the peak value and value shown in Figure below is due to the scaling process and the random variability introduced in HOMER to make the load pattern unique.

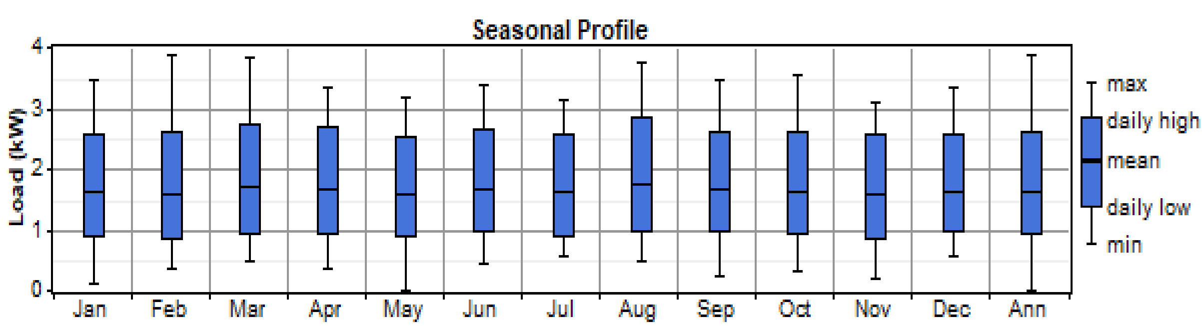


Figure 2.4 Seasonal Load Profile of the site

To synthesize data in HOMER, we have to enter at least one load profile, which is a set of 24 hourly values of electric load, one for each hour of the day. You can enter different load profiles for different months and for weekdays and weekends too. But if you only enter one load profile it will be used throughout the year. HOMER adds randomness according to the values you enter for daily noise (5% for day to day Variation) and hourly noise (10% for hour to hour Variation) and calculates the average 24-hour load profile for the whole year.

2.2.4 Power Sources for Base station

BS primarily powered by electrical power from the grid in urban areas with a back-up by battery and/or a diesel generator. The grid power must be available for 24 hours a day to give reliable service for the customers. But electrical grids are not available or are unreliable in most locations of developing countries; therefore cellular network operators rely on diesel powered generators to run a base station. The idea of using diesel generators as a primary or back-up power supply has become less favorable due to the challenges linked to their reliability, high operational and maintenance costs and their considerable environmental impacts. Therefore adding several base-stations for service providers can only multiply this destructive environmental impact, unless these base-stations are supported by a sustainable alternative energy sources. Hence renewable energy sources such as solar, wind and fuel cell energy or hybrid solution seem to be more practicable options to reduce the overall difficulties. These solutions have been strong choices for powering BSs due to their abundant availability in a wide range of geographical locations around the world. Additionally, the components in solar and wind-based systems are usually modular, which makes the design, expansion, and installation of these types of systems for the BS sites very practical and feasible. However, due to the unpredictable and irregular nature of wind and solar, the systems running on these sources typically need to be integrated with other means of renewable or non-renewable power supply and/or energy storage solutions in order to ensure the continuity of power supply in a BS site . The relative characteristics, advantages and limitations of solar photovoltaic technology are discussed below. The hybrids system Enabling distributed power generation and emission-free power source makes solar photovoltaic and wind technology a desired option for backup power. In addition detailed evaluation of the load profile of the site, weather conditions at the site throughout the year, solar radiation, wind speed, battery efficiency, charge controller efficiency, power loss due to dust accumulation and available area for installation of the solar photovoltaic panels should be considered (Dan Chiras, 2020).

2.2.4.1 Factors Affecting Power Requirement of Base Stations

Base stations represent the main contributor to the energy consumption of a mobile cellular network. Several factors can affect the base station power consumption. These include the traffic load (which varies as a function of time), the density of population and building of an area that is morphology, the type of technology or combination of technology used at the base station, number of hub linked to a specific base station, availability of microwave link, normally the BS is linked to the respective backbone through fiber link; however, some BSs may not have access to fiber link, as a result microwave connection will be used. In some cases, both may occur at a time. The other factors are configuration and whether the site is indoor (BTS housed in a shelter) or outdoor.

2.3 Energy Potential of the Study Area

The mobile telecom base station considered for this hybrid system project is located in Oromia Region around Bale Robe area at sanate hill, with Geographical coordinates of latitude 7.03 and longitude 39.899. Here, the mobile telephony base station is taken from ethio telecom site; the global system for mobile (GSM) network system base station is considered. Wind and Solar resource raw data input to the HOMER software is the average global horizontal radiation and wind speed obtained for the site from Atmospheric Science Data Center (ASDC)-NASA surface meteorology and solar energy database which attached in appendix A.

Table 2.1 Average monthly global solar radiation and wind speed of Bale Robe area at Sanate hill (data was accessed from nasa.gov on March, 2022).

Parameter	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
Surface Pressure(kpa)	2020	72.65	72.71	72.62	72.62	72.68	72.58	72.46	72.49	72.52	72.58	72.61	72.62	72.6
Temperature at 2M(^{0}C)	2020	11.23	11.87	13.22	13.15	13.05	12.55	11.9	12.29	12.1	11.16	10.44	9.57	11.87
Wind speed at 2M(m/s)	2020	1.71	1.93	2.05	2.02	1.72	1.75	2.58	2.49	1.86	1.92	1.89	1.8	1.98
Wind Speed at 10M(m/s)	2020	2.62	2.86	3	2.98	2.56	2.66	3.72	3.57	2.74	2.89	2.92	2.85	2.95
Wind speed at 50M(m/s)	2020	3.59	3.74	3.95	4.06	3.46	3.84	4.94	4.7	3.73	3.94	3.94	3.91	3.98
Solar radiation (kwh/m^2/day)	2020	6.02	6.51	6.29	5.77	6.08	5.4	4.14	4.63	4.98	5.65	6.05	6.2	5.64
Clearness Index_	2020	0.66	0.663	0.61	0.55	0.59	0.54	0.41	0.45	0.48	0.57	0.65	0.7	0.57

From Table 2.1 it can be seen that the monthly average solar energy resource is well distributed in the site with average monthly solar radiation of 5.64 kWh/m^2 /day and average daily sunshine hours of 11 hr. The maximum solar radiation is for the month of February having daily radiation of 6.51 kWh/m^2 /day; February was the sunniest month of the year, whereas the minimum value is occurred during the peak rainy season months July in the area, particularly in the month of July with radiation of 4.14kWh/m^2 /day. It also depicts the clearness index of the site obtained after HOMER simulation. The clearness index tells about the clearness of the sky from the latitude and longitude of the site considered. Here in this study the clearness value varies from 0.41 in July to 0.66 in February. Note that HOMER assumes the output of the PV array is linearly related to the solar radiation incident on the PV array and also ignores the effect of ambient temperature on the performance of the PV array. The nominal operating cell temperature is the surface temperature that the PV array would reach if it were exposed to 0.8 kW/m$^{\mathbf{2}}$ of solar radiation, an ambient temperature of 20 °C and a wind speed of 1 m/s. The clearness index in HOMER tells about the clearness of the sky of the site meaning the transmission of the radiation directly from sky to earth's surface. The clearness index value is dimensionless and varies from 0 to 1 representing the cloudiest and sunniest months respectively and there is an average daily sunshine hours of 11 hrs. as shown in Figure 2.5.

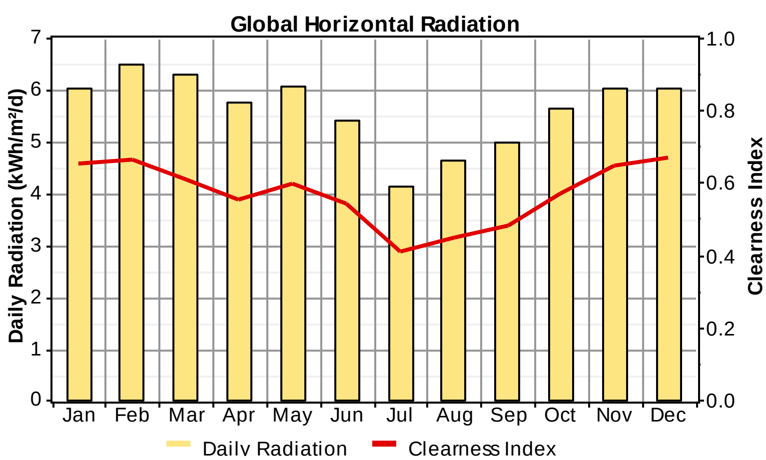


Figure 2.5 Global Horizontal Solar Radiation Source

Normally from end of June till end of August is summer season in region which means it is rainy time but the solar radiation is enough and a substantial amount of electricity could be generated, thus the considered site in this study has shown excellent solar energy sources to be exploited to generate electricity. From HOMER analysis, it can be seen that the considered site has enormous potentials for PV applications. Monthly mean wind speed resources of the site are obtained from

NASA surface meteorology and solar energy database. NASA has estimated the annual average wind speed of the location to be 2.95 m/s at an anemometer height of 10 m as shown in Table 2.1.

Generally it shows the wind speed data of the site is not that much satisfactory for power generation since it has a very small cut-in wind speeds. So, wind speed extracted from NASA is simply taken to assess wind energy potential of the selected site (resource assessment). This data can be extrapolated to the designated wind turbine height of 50 m. Tables summarize the monthly wind speed variation of the site at 50 m heights where the average wind speed found to be 3.98m/s. The lowest wind speed profile is indicated in the months of January, February & May; Whereas, April, July and August are the windiest months. As wind turbine height increase length from ground the wind speed also increase and hence, power production also rises. The wind speed at any height above ground level can be interpolated either in exponential function or logarithmic function forms (Pramod Jain, 2011).

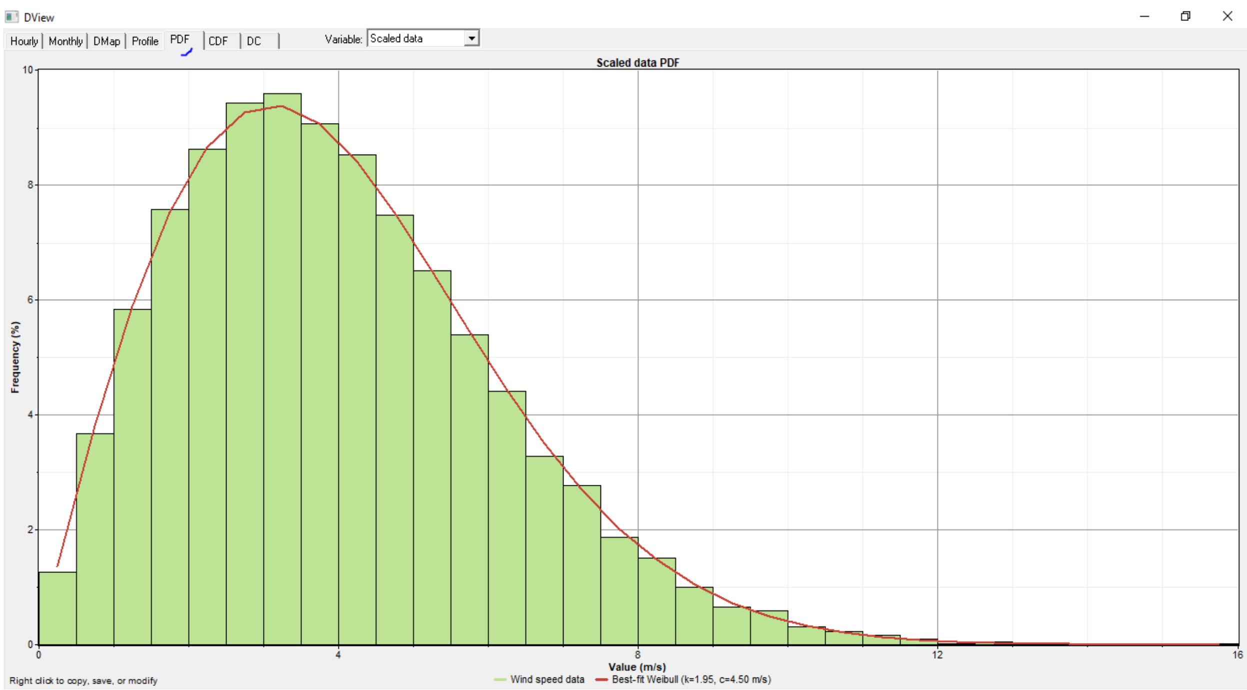


Figure 2.6 Probability Distribution Function of Wind speed data of Bale Robe

From this Figure it can be seen that the most probable wind speed range 2.0–3.5 m/sec occurs approximately 25%, and the wind speed above 3.5 m/s is occurred around 67% of the time. Thus this shows that some of the wind energy could be exploitable. The characteristic curve of Bergey wind turbine, which exhibits wind turbine power output variation with wind speed, the cut out wind speed is around 8 m/sec and cut in speed is more than 4 m/sec at hub height as shown in Figure 2.7.

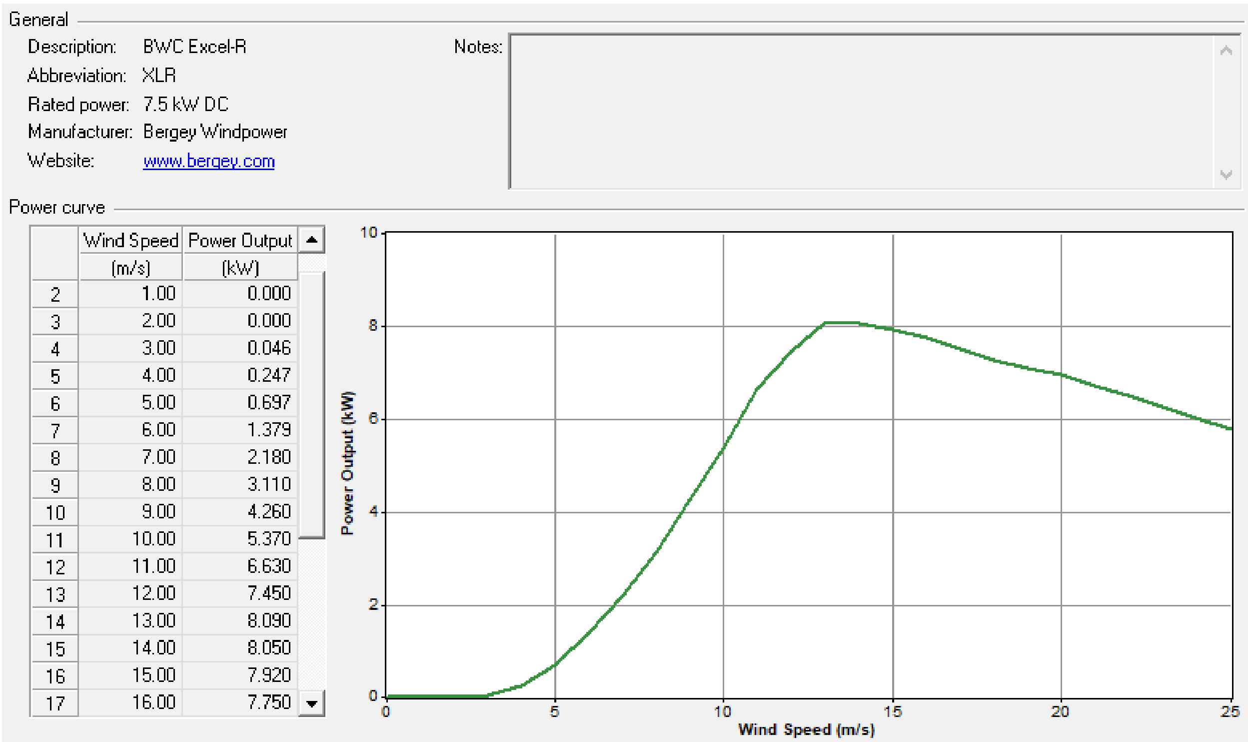


Figure 2.7 Power Curve of Bergey Wind Turbine

2.4 Components Used in Hybrid Model

Photovoltaic Cells, Panels and Arrays

A PV cell is a semiconductor device that can convert solar energy in to DC electricity through the photovoltaic effect. The PV generated electricity is ‘silent’, low in maintenance and does not need fuel or oil supplies. However, PV energy is only available when enough radiation is accessible. A PV panel consists of several connected PV cells. The power rating of a panel is specified at standard test conditions (STC) which include a defined cell junction temperature, (usually 25^0 C) and irradiance (usually $1000W/m^2$) and is the maximum power output in this state expressed in peak watt (Wp), also it depends on its cell area and efficiency. PV panels are available in wide variety of ratings, in some cases up to 500Wp each are manufactured. If higher voltages or currents are required from a single module voltage and current, modules must be connected into arrays. Series connections result in higher voltages, while parallel connections result in higher currents. When modules are connected in series, it is desirable to have each module’s maximum power production occur at the same current. When modules are connected in parallel, it is desirable to have each module's maximum power production occur at the same voltage. Since PV arrays produce power only when illuminated, PV systems often employ an energy storage mechanism so the captured electrical energy may be made available at a later time. Most commonly, the storage mechanism consists of rechargeable batteries. When a battery storage mechanism is employed, it is common to also incorporate a charge controller into the system, so the batteries can be prevented from reaching either an overcharged or over discharged condition.

It is also possible that the PV system will be interconnected with the utility grid. Such systems may deliver excess PV energy to the grid or use the grid as a backup system in case of insufficient PV generation. Energy Storage Battery Bank now a day's energy storage system has taken a huge part in case of power generation including hybrid power system. It makes the system much more reliable and efficient. Energy storage system has dual advantage; (i) whenever power deficit occurs; it helps to transfer the stored energy to the system. (ii) In case of excess energy supply from resources, the system will store the surplus energy in the storable form of energy. To this end, storage system has remarkable importance in renewable energy sources, wind and Solar PVs in particular; as they are intermittent sources. (Baron.D, 2010)(Acharya D, 2013).

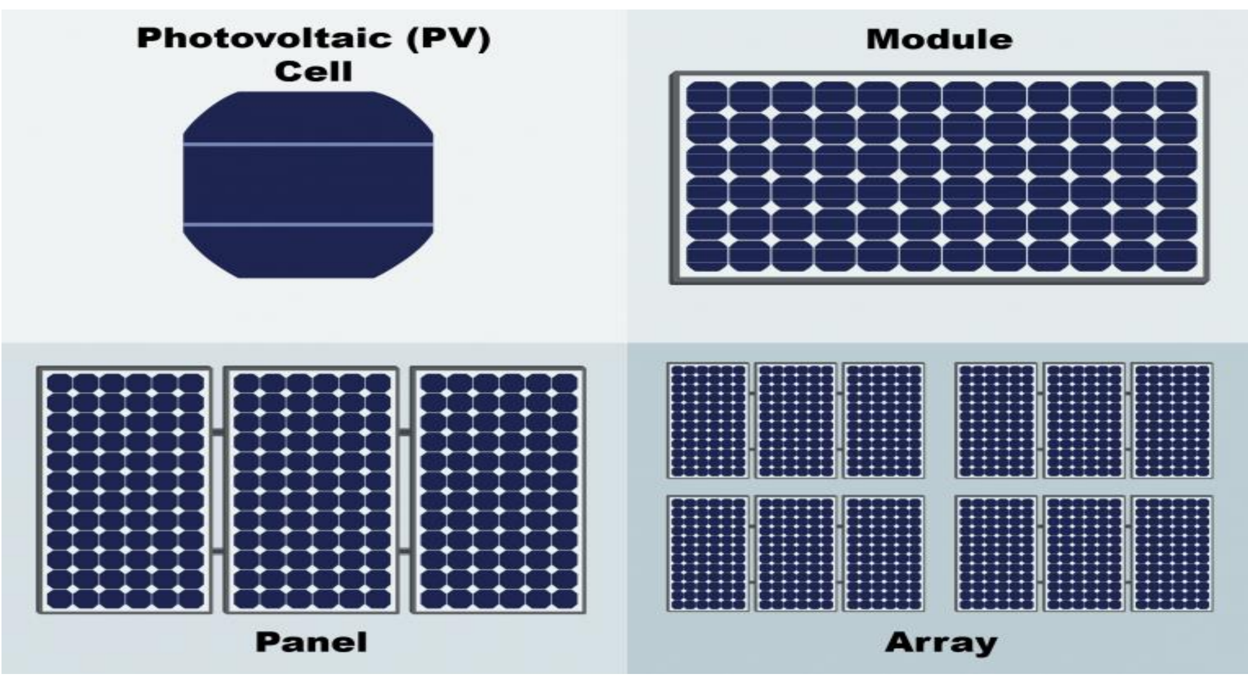


Figure 2.8 Buildup of a solar PV array from cell to array (Acharya D, 2013)

Batteries (Storage)

A battery bank is used as a backup system and it also maintains constant voltage across the load. Classic OPzS batteries have been proven energy suppliers for decades, which captivate in robustness, extreme long design life and reliability Very high operationally reliability under rough operating conditions Low maintenance due to reduced antimony in the alloy and high electrolyte reserve.

Classic OPzS batteries are robust energy storage solutions, with proven technology that has been relied upon for decades in applications such as telecommunications, power supply and power distribution, data, alarm security systems and emergency lighting as well as all other power supplies for safety systems. The battery pack consists of 4(12), 48V, 150Ah, 1.83kWh batteries connected in series / parallel configuration, two parallel sets of 4 batteries in series.

Figure 2.9 Storages Batteries (Industrial batteries-OPzS)

Battery is described in terms of four main characteristics: Battery capacity, Battery voltage, Cycle depth and autonomy.

Battery capacity: is the amount of energy, the battery can store. Temperature, rate of discharge, battery age and battery type determines the amount of energy extracted from a fully charged battery. The three main ratings to specify the capacity of a battery are:

(1) Ampere hour (Ah): the amount of current at which the battery can discharge their stored energy over a fixed interval of time.

(2)Reserve capacity: the time length in minutes when the battery can manage to produce a specified level of discharge.

(3)KWh capacity: the amount of energy required to charge a depleted battery (not fully discharged batteries).

Battery voltage: is that of a fully charged battery. It depends up on the number of cells and voltage per cell.

Cycle depth: Fully discharging batteries can cause an adverse effect regarding to the life of the battery. Deep cycle batteries can discharge up to 15%-20% of their capacity. This gives a depth of discharge (DOD) of 85% - 80%.

Autonomy: the ratio of restorable energy capacity to the maximum power discharge. It indicates the maximum amount of time in which the system can extract its energy.

Wind turbine: Unlike windmills which are used directly to do work such as water pumping or grain grinding, wind turbines are used to convert wind energy to electricity. The first automatically operated wind turbine in the world was designed and built by Charles Brush in 1888. This wind turbine was equipped with 144 cedar blades having a rotating diameter of 17 m. It generated a peak power of 12 kW to charge batteries that supply DC current to lamps and electric motors. Today, modern wind turbines in wind farms have typically three blades, operating at relative high wind speeds for the power output up to several megawatts.

Wind energy is a converted form of solar energy which is produced by the nuclear fusion of hydrogen (H) into helium (He) in its core. The H → He fusion process creates heat and electromagnetic radiation streams out from the sun into space in all directions. Though only a small portion of solar radiation is intercepted by the earth. Wind results from the movement of air due to atmospheric pressure gradients. Wind flows from regions of higher pressure to regions of lower pressure. The larger the atmospheric pressure gradient, the higher the wind speed and thus, the greater the wind power that can be captured from the wind by means of wind energy-converting machinery. Wind speed is one of the most critical characteristics in wind power generation. In fact, wind speed varies in both time and space, determined by many factors such as geographic and weather conditions. Because wind speed is a random parameter, measured wind speed data are usually dealt with using statistical method (Pramod Jain, 2011).

Charge Controller: A charge controller is required in most PV systems that use battery storage to regulate battery state of charge, optimize battery and system performance and help prevent damage to the batteries or hazardous condition resulting from the charging process. A typical charge controller consists of 5 basic features:

1. Low voltage protection
2. over voltage protection
3. Battery cut off circuit
4. Back current protection
5. over discharge protection

The first part of our charge controller is N-channel MOSFET in forward bias condition to stop the flow of current to battery from the solar panels. During the sunrise whenever the panel voltage reaches 10v and the wind system also provides an output of 10v then ultimately the 10v zener diode starts conducting thus turning on the MOSFET which ultimately turns on the relay and the battery starts charging. This is known as low voltage protection. Whenever the current reaches 15V the other zener diode turns on thus brings the MOSFET to change in conducting state, negative voltage flows through it thus turns off the MOSFET. Then the battery is not being charged, which leads the current flows through the battery to zero. Now the case of over charge protection here, when the battery is fully charged less current flows through it; which ultimately turns off the second MOSFET and then it trips the second relay. This cycle repeats whenever the battery reaches to a minimum value. So this is how a solar and wind charge controller actually works (Acharya D, 2013).

Converter: The 2000W high-efficiency eSure solar MPPT converter (model S48-2000e3) is designed to convert solar DC supply voltages into nominal -48 V DC voltages that are adjustable to application needs. The S48-2000e3 is a constant power converter designed with the latest patented switch mode technology, using DSP (Digital Signaling Processor) functionality for efficient operation. For a higher load capacity, converters can be connected in parallel, and intelligent control can be added with the help of a separate controller (Acharya D, 2013).

Figure 2.10 Solar MPPT Converters (Acharya D, 2013).

2.5 Related Works

Different research is carried in the field of renewable energy; applications of stand-alone power system and hybrid renewable energy systems have been conducted for the maximum usage of the resource potential.

The study (Huda ASN, et al. 2015) presents the result of techno-economic analysis of hybrid system comprising of solar and wind energy for powering a specific remote mobile base transceiver (BTS) in Kaduna state, Nigeria. But the optimal system configurations obtained through simulation in HOMER. Two best optimal system configurations namely PV-Diesel-Battery and PV-wind-diesel-battery system are compared with the conventional stand-alone diesel generator (DG) system. Finding indicated that PV array (10KW)-DG (5.5KW)-Battery (64 units Trojan L16P) is the most economically viable option with the total net present cost of $69,811 and per unit cost of electricity of $0.409. The simulations indicate that a hybrid system option, compared to a diesel only system, is feasible for each of the three villages.

In the paper (Nikum, K. and Wagh, A. 2016) they are proposed a hybrid system cost analysis which has wind generation, solar system, and storage battery system and diesel generator using efficient optimization tool HOMER for obtain the optimal cost of the hybrid system. Determine the optimal combination of solar, wind and diesel based hybrid system to fulfill the load requirement and minimize the cost of telecommunication site in BSNL Bhopal, India.

In paper presents a solution utilizing a hybrid of solar and wind power systems with a portable generator to provide reliable power for a mobile base station located behind the Himalayas of south Asia. The meteorological data including solar sunshine hours and hourly wind speed are taken for a site in Mustang district at 3444 m altitude. The power consumption pattern of a mobile base station depends up on the traffic pattern of the mobile users. The cost of the hybrid system is also estimated as $81,512.04 Canadian dollars. The proposed system ensures the reliability of power supply to run the 24/7 cellular mobile services at an extremely remote site of Nepal. Thus, based on the literature reviews, HOMER modeling software is taken for the purposes of this study to carry the feasibility analysis. When compared with other software's HOMER creates a list of feasible system configurations sorted according to cost effectiveness and presents the optimal configuration based on the lowest net percent cost (NPC) the supply in order to design system.

Solar power for powering BS There is several works which have used solar power energy for powering base stations that are on or off grid sites. A study conducted in West Arsi, Oromia region presented the solution to utilizing a hybrid of photovoltaic (PV) solar and wind power system with a backup battery bank to provide reliable electric power for a specific remote mobile base station. The result indicated that the hybrid energy systems can minimize the power generation cost significantly and can decrease CO2 emissions as compared to the traditional diesel generator (Yeshalem, M. & Khan, B. 2017).

In (Salih, et al. 2014) a study was done based on minimized capital and operation costs of system components without compensation of meeting the load demand. The study used three different system configurations (system efficiency and performance, Cost of Energy (COE) and environmental emissions) for assessment and comparison; and the analysis was carried out by HOMER software. Generally, the study showed the use of a PV/wind/Diesel and battery hybrid system for powering remote BTS sites. Subodh Paudel et al.

C.S. Supriya et al.2017 conducted a research on the optimal design of a hybrid wind-solar power system for either autonomous or grid-linked applications. The study was designed to accomplish minimum cost, reliable source for the load and to reduce the power purchased from the grid. This was achieved by finding the optimum number of PV modules and wind turbines using quadratic programming techniques. The result showed that the hybrid systems had considerable reductions in carbon emission and cost of the system.

The most related study done by Nikum et al. Presented techno-economic analysis of hybrid power system with cost minimization. The renewable sources, wind and solar energy connected with battery, grid and diesel generator, which are used as backup in the study, and their economic feasibility was compared. The data from location of Mumbai, Maharashtra assessed and calculated by HOMER. The result showed that the cost with highest renewable fraction to reduce the emission and fulfill the load demand significantly. Finally the study concluded that the grid plays an important role of power backup component in the hybrid system, when the renewable energy resources are not enough to meet the load. Here some of the above studies used the PV hybrid system for other purpose other than powering base stations; while this study employed it for base stations. Moreover, in some of the studies, the PV hybrid system included diesel generator where it doesn’t allow excluding the effect of diesel generator such as cost and environmental pollution.

CHAPTER THREE

METHODOLOGY

3.1 Description of Ethio-telecom (Study Company)

Ethio telecom was established in November 2010 by replacing the previous name of the company ETC, owned and monopolized by government. All telecommunication services are provided by this company. Among others, internet, mobile, fixed line telephone, data communication, e-video, international connectivity and teleconferencing are the services provided by the telecom. To delivering these aforementioned services, the company uses diverse communication equipment's including BTS, media gateway devices, wireless antennas, Microwaves, routers, switches and etc. BTS is the device used to link the provider (Ethio-telecom) with the customers (SIM cards). All telecom base stations are connected to national as well as local networks either through fiber and/or microwave links. Each base station serves the entire customers that are found in the surrounding area. Telecom BS has similar design, principle of work, and equipment that it consists of; however, it is broadly categorized in to two based on the equipment placement:

(1) indoor position – where the tower is situated in the compound of around 150 square meter area of green field and all other telecom equipment, electrical boards, racks, air conditioners and batteries are placed in room next to the tower.

(2) Outdoor position –as the name implied, the towers, all telecom equipment, battery banks and etc. are outside of the shelter (Room). See Figure 3.1 and Figure 3.2, respectively.

Figure 3.1 Existing Indoor Equipment pictures taken from Site 211367 & 211562, March 2022

Figure 3.2 Existing Outdoor picture taken from site 211275 & 211367, March 2022

3.1.1 Existing Base Stations Electrification in Ethio-telecom

Base station equipment needs stable electric source to be operational. They are categorized in to three based on their power configuration or the type of electric supply system; described under here:

Main sites: these sites are usually either VIP sites such as sites connected to Minister Offices, Embassies, Security Offices or sites which have linkage with other towers. Continuous power supply is mandatory for this category; as a result these sites are supplied by three alternative sources:

(1) The main source is AC power from grid networks;

(2) First backup system from diesel generator

(3) Battery system as second backup system.

Tower serving small areas: usually it is the dead end which doesn't have linkage with other towers. It is supplied by two power sources with main source of AC power from grid networks and backup of battery system.

Towers in remote (off grid) areas: are sites that are far from utility grids. Its main source is diesel generator and/or with additional solar source in some areas and battery system as backup.

3.2 Hybrid Power System Design

There are different configurations of renewable and conventional energy sources being deployed for telecommunication purposes: Diesel-Battery; Solar-Diesel Battery; Diesel-Battery-Wind; Solar-Diesel-Battery-Wind or Solar-Battery. The configuration of a HPS depends on three factors namely, RES availability, load, and costs (i.e. CAPEX and OPEX). Thus, the HPS is selected to optimize the available resources various constraints to improve performance, economy and reliability (Acharya D, 2013).

3.3 Metrological data

One year hourly metrological data specifically global horizontal radiation, diffuse solar radiation, wind speed and average temperature, were collected from National Metrological Agency; sample hourly collected data and monthly average data are annexed in Appendix A. The hourly data was used to simulate hourly DC power output generated by a single.

3.4 Estimation Primary load of the site

Primary load is the load that should meet by the energy providing system as it requires immediately which includes RBS,RRU, Antenna, PBC, micro wave ,air conditioner, Aviation light and lightening. The electricity load consumption in each site is considered to be the same and constant through the year. During load estimation the nature of the load has been thoroughly analyzed to come up with sustainable energy demand satisfaction since electric load is vary hourly daily and monthly base. The electricity load estimation is made according to the following approach.

Annual Energy Consumption (Kwh) = [(number of appliance used* power rating of each appliance (w)*hours of operation*number of days)/1000]

Table 3.1: Mobile Base station Electric load consumption characteristic for GSM technology

Appliance	Power Rating(w)	Quantity	Hours usage per day	Power(w)	Energy (kwh/day)
Txn Radio	100	3	24	300	7.2
RF Antenna	100	3	24	300	7.2
Sector	100	3	24	300	7.2
1800MHz RRU	100	3	24	300	7.2
900MHz RRU	100	3	24	300	7.2
Lighting Lambs	36	2	12	72	0.9
Aviation light	25	1	12	25	0.3
Rectifier	100	3	24	300	7.2
Air Conditioner	1.8k	1	1	1800	1.8
Total				3697	46.2

3.5 Mathematical model of the system

3.5.1 Mathematical modeling of PV system

The models describing the pv models maximum power output behaviors are more practical the pv system assessment. Using the solar radiation available on the tilted surface, The ambient temperature and the manufacturer data for the pv modules, The power output of the pv generator (Pgv) can be calculated as;

$P_{pv}=n_g N A_m G_t$ (3.1)

Where n_g- The instantaneous pv generator efficiency

Am- The area of single module in (m^2)

Gt- Global irradiance incident on the titled plane (kw/m^2) and N- Number of modules

All the energy loss in pv generator including connection losses, wiring losses and other losses are assumed to be zero.

3.5.2 Mathematical modeling of wind energy

Energy generated by wind generator (E_{weg}) with rated power output (P_{weg}) is defined by the following expression

$P_{weg}= ½\ \rho_{wind}\ AV^3 Cp(ђ,ß)*\eta_t*\eta_g$ (3.2)

$E_{weg}=P_{weg}*t$ (3.3)

Where ρ_{wind} =air density in 1.22kg/m3

A= The swept area (m^2)

V-Wind speed (m/s)

Cp- Performance coefficient of the turbine

ђ-Tip speed ratio of rotor blade tip speed to wind speed

ß-The blade pitch angle (deg) as 0^0

Ƞt- Wind turbine efficiency

$Ƞ_g$- The generator efficiency

The power density of wind = P/A = ½(PV^3) (3.4)

$A=\Pi r^2$ (3.5)

Where A- swept area and

r – Radius of rotor

3.5.3 Mathematical model of converter

In the proposed system a converter contains both rectifier and chopper. PV and Battery system are connected with DC bus while Wind turbine and diesel generator is connected with AC bus. The rectifier used to transform the surplus AC power from the wind turbine & Diesel generator to DC power constant voltage. The wind turbine and DG will powering the load and at the same time charging the battery and modeled equation below

$$E_{rec-out}(t)=E_{rec-in}(t)*\eta_{rec} \tag{3.6}$$

$$E_{rec-in}(t)=E_{sur-ac}(t), \tag{3.7}$$

at any time t,

$$E_{sur-ac}(t)=E_{weg}(t)-E_{load}(t) \tag{3.8}$$

Where, $E_{rec-out}(t)$-Hourly energy output from rectifier , in KWh

$E_{rec-in}(t)$-Hourly energy input to rectifier , in KWh

η_{rec}-Rectifier efficiency

$E_{sur-ac}(t)$-Amount of surplus energy from AC sources, KWh

$E_{weg}(t)$-Hourly energy generated by wind generator

According to the proposed scheme the converter work for both direction of power flow

3.5.4 Mathematical model of charge controller

To prevent overcharge or discharge of battery a charge controller is used to sense when the batteries are fully charged and to stop or reduce the amount of energy flowing from the energy source to the batteries. The model of the charge controller rating is given below

$$\text{Solar charge controller rating}= (Isc*\text{total number of modules}*1.3) \tag{3.9}$$

Where, 1.3 charge controller oversizing factor, Isc-Total short circuit current of PV array

The energy of charge controller is given by

$$E_{cc-out}(t)=E_{cc-in}(t)*\eta_{cc} \tag{3.10}$$

$$E_{cc-in}(t)=E_{rec-out}(t)+E_{sur-dc}(t) \tag{3.11}$$

Where, $E_{cc-out}(t)$-hourly energy output from charge controller, kwh

$E_{cc- in}$ (t)-hourly energy input to charge controller, kwh

ηcc: efficiency of charge controller

$E_{rec-out}(t)$-hourly energy output from rectifier, kwh

$E_{sur-dc}(t)$-amount of surplus energy from DC sources kwh

3.5.5 Mathematical model of battery bank

The state of charge, SOC is the cumulative sum of the daily charge or discharge transfer. The battery serves as an energy source entity when discharging and a load when it charging.at any time t the state of battery is related to the previous state of charge and to energy production and consumption situation of the system during the time from t-1 to t. The net capacity that the battery can store in Ah/day must be;

$$BC_n=E_{tot}/V_{nom,\ bat} \tag{3.12}$$

Where, BC_n-Net capacity of battery

E_{tot}-Total energy

$V_{nom,\ bat}$- Nominal battery voltage. i.e. 48VDC

To calculate the number of batteries connected in parallel to reach the Ah required by the system

$$Bp = \frac{Bc}{Br} \tag{3.13}$$

Where B_p-battery connected in parallel

Bc-battery capacity

Br-required battery bank capacity, Ah

To calculate the number of battery connected in series to reach the required voltage for the system,

$$Bs = \frac{Vnbat}{Vbat} \tag{3.14}$$

Where, Bs-Number of series connected batteries

V_{nbat}-nominal battery voltage (48vdc)

V_{bat}-Battery voltage (12vdc)

During the charging process when the total output energy of all generators exceeds the load demand the available battery bank capacity at time t can be described by using

$$E_{bat}(t)= E_{bat}(t-1) - E_{cc-out}(t)*\eta_{chg} \tag{3.15}$$

Where $E_{bat}(t)$- The energy stored in battery at hour in kwh

$E_{bat}(t-1)$- The energy stored in battery at hour t -1 ,kwh

η_{chg}- Battery charging efficiency

On the other hand, when the load demand is greater than the available energy generated the battery bank is in discharging state. Therefore the available battery bank capacity at time t can be expressed as.

$$E_{bat}(t)=E_{bat}(t-1)-E_{needed}(t) \tag{3.16}$$

Where $E_{needed}(t)$-The hourly load demand at a particular period of time. Let d be the ratio of minimum allowable SOC voltage limit to the maximum SOC voltage across the battery terminals when it is fully charged. So the depth of discharge (DOD) can be calculated;

$$DOD= (1-d)*100 \tag{3.17}$$

DOD is a measure of how much energy has been withdrawn from a storage device expressed as a percentage of full capacity. The maximum value of SOC is 1, and the minimum SOC is determined by maximum DOD,

$$SOC_{min}=1-DOD/100 \tag{3.18}$$

Total hybrid power generated at any time t is given by

$$P(t) = \sum_{weg=1}^{Nw} Pw + \sum_{pvg=1}^{Np} Ppv + \sum_{g=1}^{Ng} Pg \tag{3.19}$$

Where Nw- The number of wind generators unit

Np is the number of PV module cell units

Ng is the number of diesel generator

Pg- Power generated by diesel generator at t, time

This generated power will feed to the loads. When this generated power exceeds the load demand then the surplus of energy will be stored in the battery bank. This energy will be used when deficiency of power occurs in order to meet the load demand.

3.5.6 Mathematical cost model of energy systems

The Annualized Cost of a Component: - the annualized cost of a component includes annualized capital cost, replacement O&M cost. Operation cost is calculated hourly on daily basics.

Annualized Capital Cost: - The annualized capital cost of component is equal to the total initial capital cost multiplied by the capital recovery factor. Annualized capital cost is calculated by using eqn.

$C_{acap} = C_{cap}$*CRF (i, Rproj) (3.20)

Where, C_{acap}-Annualized capital cost,

CRF (I,R_{proj})-Capital recovery factor ,

i- Interest rate

R_{proj}- Project lifetime,

C_{cap} - Initial capital cost of the component

Annualized operating cost (Caop): The operating cost is the annualized value of all costs and revenues other than initial capital costs and is calculated by using

$C_{aop}=\sum_{t=1}^{N} Coc(t)$ (3.21)

Where, C_{aop}-Annualized operating cost

C_{oc}-Operating cost

Total cost of component=Economic cost + Environmental cost (3.22)

Where, Economic cost=Capital cost + replacement cost + O&M cost (3.23)

Environmental=Emissions cost=0

Therefore annualized total cost ($C_{ann,totc}$) of a component is calculated using eqns(3.24):

$C_{ann,totc} = \sum_{c=1}^{Nc}(Cacap,c + Carep,c + Caop,c)$ (3.24)

Where, $C_{acap,c}$- Annualized capital cost of a component

$C_{arep,c}$- Annualized replacement cost of component

$C_{aop,c}$- Annualized operating cost of a component

3.6 Hybrid System Designing and Sizing

In this thesis the main system design methods based on the daily energy demand assessment of Sanate Hilly that is the peak load of 3.697kw/day and total energy 46.2kwh/day were estimated. The work also dealt with the sizing and specifying of PV array, wind energy blade radius, battery bank and converter

3.6.1 Designing and sizing of solar photovoltaic

Based on above data about the system at peak time the total power supplied by solar PV to the site by neglecting losses in the energy and delivery system. The design requirements were;

Selection of PV module to be used

Module type: 200W

Number of cells per module: 72

Life time: 90% power output over 20year

De rating factor	95%
Tracking system	No tracking
Slope	4-15
Azimuth	0
Ground reflectance	20%

Specifications of considered PV system under standard test condition (STC)

V_{oc}=25V

I_{sc}=10.39A

Voltage (V_{mp}) =20.27V

Current (I_{mp}) =9.87A

PV system for 3.697kwp, the calculation of the number of modules

Total number of panels= Peak power/rating per panel=3697w/200w=18.4~18panels

0.5 fractional powers are not possible so panels rounded up to 18

Total number of panels=18

3.6.2 Designing and sizing of wind turbine power rating

Based on given data above the daily energy requirement of the sanate site supplied by wind energy, calculate the size of wind turbine i.e required to be installed to meet the energy requirement. The parameters were given below which determine wind energy.

One bergey wind turbine consider for the system analysis (small dc output load)

Coefficient of performance-0.4

Annual average wind speed (m/s) at 50m/s is 3.98m/s

Density of air ρ=1.22kg/m3

Capacity factor- 0.3(i.e. 30%) of the time wind machine is producing energy at rated power

Number of hours in a day 24hrs

The power density of wind (power per unit area)

$$=\frac{P}{A}= 1/2(\rho V^3) =0.5*1.22*(3.98)^3=38.46w/m^2$$

Actual power density= Power density of wind *Number of hours per day

$$= 38.46*24=0.923kwh/m^2$$

The rotor size and wind turbine power rating equation

$$A= \frac{\text{Total daily energy required}}{\text{Useful energy density}} = \frac{46.2}{0..923} = 50.5\ m^2$$

Radius of the rotor blade,(R)

$$A=\Pi R^2 =50.5m^2$$

$$R=3.987m= 4m$$

Power rating of the turbine = actual power density * area of the rotor

$$= 38.46w/m^2*50.5m^2=1.94kw$$

Actual rated power of the turbine rating should be = $\frac{\text{Power rating}}{\text{Capacity factor}}$

$$= \frac{1.94kw}{0.3} = 6.5kw$$

Therefore around 6.5kw rated power wind turbine was providing for the desired daily energy under the given situation.

3.6.3 Battery sizing and specifying

The final battery capacity will depend on the following

1. The total energy that the battery bank must supply to loads
2. Maximum power demand
3. Maximum deptAh of discharge

4. System voltage
5. Charge current and recharge time

Determining the required battery capacity:- Batteries used in a solar system are sized in Ah under STCs (temperature 25^0C). Battery manufactures usually specify the maximum allowable DOD for their batteries. The DOD is a measure of how much of the total battery capacity has been consumed. For most batteries the maximum allowable DOD is about 60% based on the above equation the net capacity that the battery can store in Ah/day must be

$$BC_n = \frac{\text{Etot}}{\text{Vnom,bat}} = \frac{46.2kwh/day}{48\text{v}} = 962.5\text{Ah/day}$$

The net capacity of the battery depends on the DOD of the battery and the DOD determines the life cycle of the battery. Taking an assumption of DOD=80% then total commercial capacity of the battery is calculated as;

$$BC = \frac{\text{BCn}}{\text{DOD}} = \frac{962.5\text{Ah/day}}{0.8} = 1{,}203\text{Ah/day}$$

Considering the battery must be at least to be big because of cloudy day's shadows on solar PV and low speed on wind case

Therefore, BC= 1203Ah/day ~1200Ah/day.

Hence the capacity of the battery is taken as 2400Ah. And also selected battery Ah rating =150Ah. To calculate the number of the batteries connected in parallel to reach the Ahs required by the system

$$B_p = \frac{1200\text{Ah/day}}{150\text{Ah/day}} = 8 \text{ batteries}$$

And also calculate the number of batteries to be connected in series to reach the voltage required by the system

$$B_s = \frac{\text{Vnbat}}{\text{Vbat}} = \frac{48\text{v}}{12\text{v}} = 4 \text{ batteries}$$

The total number of batteries required by the system is

$$= B_p * B_s = 8*4 = 32 \text{ batteries}$$

3.6.4 Charge controller sizing and specification

The solar charge controller is typically rated against amperage and voltage capacity. The size of the controller depends on the total PV input current which is delivered to the controller and PV panel configuration. Solar charge controller rating =Isc*Total number of modules*1.3

$$= 10.39*18*1.3= 243.12\text{A} \sim 243\text{A}$$

3.6.5 Converter sizing and specification

Based on the above equation maximum power of ac loads supplied by the system 3.697kw,

Converter size (kw) = maximum power of Ac loads * 1.3(oversize factor)

= 3.697kw*1.3 = 4.8kw

3.7. Model Design of the Proposed System

Towards overcoming the national power shortage and ensuring service continuity, a model was proposed in this study. The proposed hybrid model comprises of PV-Wind-DG-Battery as shown Figure 3.3. The main components to supply the demand are the Wind and PV module; while the DG and battery are used as a back-up energy source. This is due to the fact that, normally PV is not reliable as the solar irradiance is intermittent in nature and the Wind will also be interrupted due to wind speed variation; therefore battery is used as a storage device that can deliver power at the time of shortage in energy for load. The Wind Turbine, PV module and batteries are giving the DC power output which is going to the DC link. While DG is produced AC Power output which is converted to DC power by using rectifiers (AC to DC).

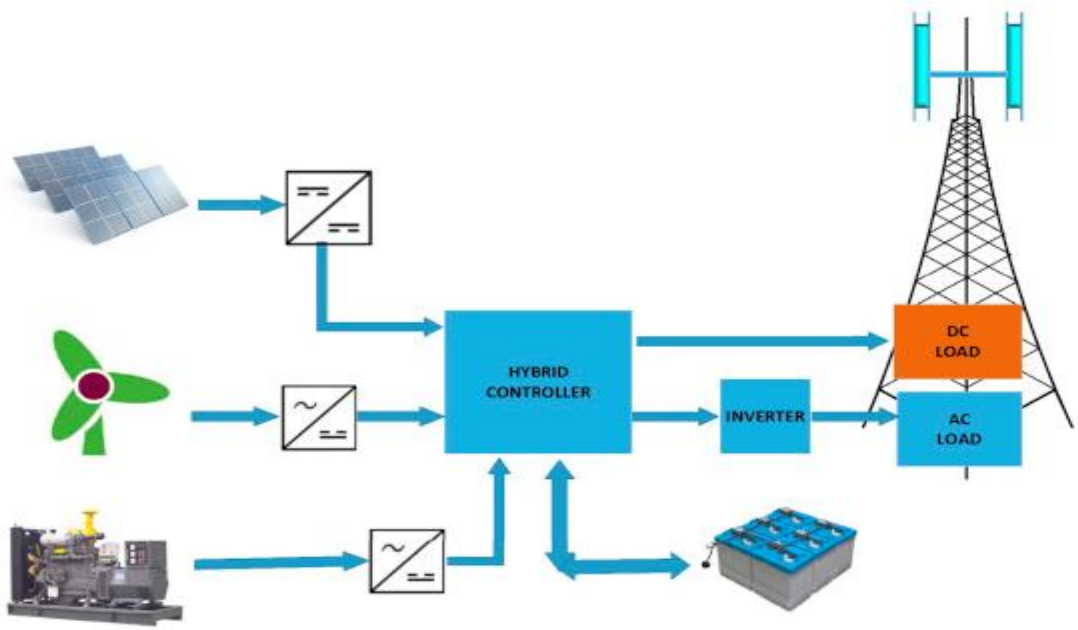


Figure 3.3 Block Diagram of Proposed Model

When the proposed system starts to operate, to fulfill the power demand the Wind, PV array, DG and battery are working in one of the following ways: When the total power generated by PV arrays and wind turbine are greater than the load demand, the surplus energy will be stored in the batteries. However, when the battery becomes full, the remaining energy will be either dumped or can be sold to the utility. When the total power generated by PV arrays and/or Wind Turbine are less than the load demand, the DG and battery will be used as a backup source.

3.8 HOMER Software

Hybrid model for electric renewable (HOMER) is the micro power optimization model simplifies the task of evaluating designs of both off-grid and grid connected power systems for a variety of applications. Hybrid Optimization Model for Electric Renewables (HOMER) software has been developed and is continually improved from time to time by National Renewable Energy Laboratory (NREL). HOMER is primarily an optimization software package which simulates various RES system configurations and scales them on the basis of NPC. HOMER calculates the available renewable power and compares it to the required electrical load.

Incorrect power system design can lead to shorter life battery increase cost of energy production insufficient supply of electricity demand. It has different energy generating component s in its library. The users select the components from the library to represent the architecture considered. HOMER simplifies or helps the designer to compare various power systems options based on technical and economic aspects (HOMER NREL, 2009).

The proposed energy system should meet the load demand of the site. The main renewable sources of energy considered in this project are solar and wind. The diesel generator produces AC type voltage as backup, whereas the PV panels and wind turbine output is DC type. The converter is added to maintain the flow of energy between the AC and DC components, whereas the battery is employed as energy storage systems in order to ensure uninterrupted power and to maintain the desired power quality at the load point because of unpredictable variation in the climatic condition affect nature of the renewable sources. Hybrid model of these three energy sources in parallel with battery storage make the hybrid power system more reliable, efficient and provides a smooth and uninterrupted power supply. Figure 3.4 presents the schematic representation of HOMER simulation model considered.

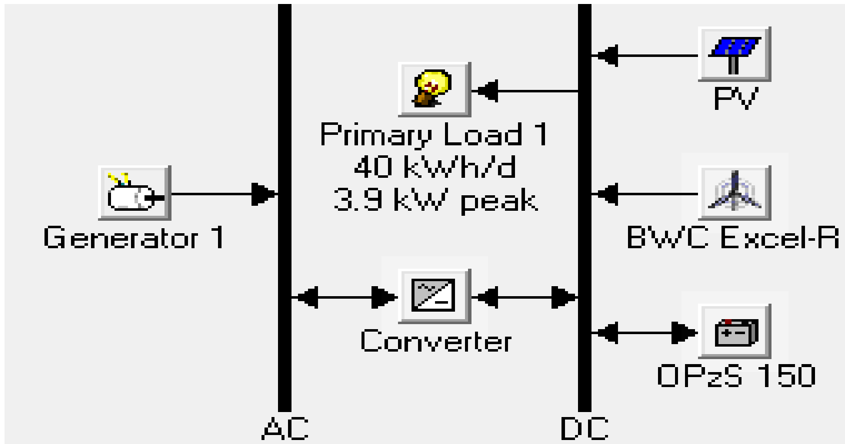


Figure 3.4 Designed Model Schematic Representation by HOMER Software

The Bergey wind turbine (BWC EXCEL-R) generator has a permanent magnet alternator and the turbine generate 3 phase AC output and the rectifier was linearly attached on the system to produce the overall system DC output (48VDC) nominal according to our model. See the further specification with appendix C. The designed model schematic representation by HOMER software indicate that the BWC Excel-R, the Photo Voltaic(PV) and OPzS 150 battery Bank which connected to DC Bus produce the total system DC output while the Diesel Generator connected with AC Bus produce AC output and the converter between two bus makes a conversion from AC to DC and vice versa.

In the proposed system, dispatch strategies are considered which means HOMER will simulate each optimal system to determine to charge/discharge of batteries and control the operation of the diesel generator. In such a system, the battery bank absorbs energy when the renewable energy output exceeds the load and discharges energy when the load exceeds the renewable output and one of the Constraint inputs assumed in HOMER are the system select the large amount of energy from renewable fraction and compare with diesel generator based on the cost.

CHAPTER FOUR

MATERIALS COST AND SIZE SPECIFICATION

4.1 Materials Specification

Wind turbine, PV module, DG and battery should be selected for the system simulation. To select these equipment local markets were surveyed. The selection criteria were availability, cost of equipment and existence of full data sheet. Based on the criteria, 200Wp module, 7.5kw DC wind turbine, Perkins 10kva DG and a solar battery with 150Ah and 12V have been selected. The data sheets for the selected equipment are annexed in Appendix B-F.

The HOMER software is used to determine the best optimal sizing and feasibility study of the system. The initial choice of the components size is based on the site load profile. Some of the input values into the software are expressed in size and in quantity. Wind turbines, batteries are the power system components which vary in quantity and solar PV, diesel generator and converter are other components that vary in size. The main purpose of the work is searching the optimum power system configuration that would meet the load demand with minimum NPC and COE. The brief description of the main components of the proposed hybrid system is summarized in Table 4.1. The basic criterion related to the selection of the power system components are the overall cost of individual materials. So we use the current cost of all the necessary components from different companies around the end of 2021.

Table 4.1 Summary of cost and size of components

No	Component	Size(kw) Qty.(No)	Capital cost($)	Replacement Cost($)	O&M Cost ($/yrs.)	Consider Size(kw)	Lifetime(yrs.)
1	Solar PV	1kw	1500	1200	15	0,1,…,10	20
2	Wind Turbine	7.5kw	20000	18000	400	0,1,…5	20
3	DG	8kw,10kva	6500	6000	0.35/hr	0,3,5,8	15000hr
4	Battery	12v,150Ah 1.8kwh	700	700	70	4,8,…24	15
5	Power Converter	4kw	650	650	10	0,2,4,…,8	10

4.1.1 Solar PV Size and Cost

In this project the solar panel considered was a 1 kW, capital cost and replacement cost for 1 kW of PV array are taken as $1500 and $1200, respectively. The operation and maintenance cost would be 1% per year. In this case, 15 different types of PV arrays are considered to get the optimal size (0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 and 15 kW). The lifetime of PV arrays was taken as 20 years and no tracking system was considered. The following default parameters were considered for modeling of the power system like; the de-rating factor was taken as 90%, ground reflectance was also considered as 20%, slope 7.2 and azimuth 0 (south orientation). The PV de rating factor is a scaling factor that HOMER applies to the PV array power output to account for reduced output in real-world operating conditions for such factors as ambient temperature, soiling of the panels, wiring losses, shading, snow cover, aging and so on.

4.1.2. Wind Turbine Size and Cost

The wind turbine is manufactured by Bergey Wind Power having the model BWC Excel-R with a rated capacity of 7.5 kW and provides DC is used in this project. The initial cost of one unit in the current market price is considered as $20000. Replacement and annual operational maintenance costs were assumed as $18000 and $400year, respectively. Replacement cost of the wind turbine considered in this case is about 70% of capital cost after 20 year service life. In order to find an optimal size, five different wind turbine options were analyzed: 0, 1, 2, 3, 4, and 5 turbines. The operational lifetime of a turbine is considered as 20 years and Hub height is 30m. As we know the advantage of Bergey wind turbines is easy to install particularly in remote telecom sites and the tower height can be adjusted to the required hub height because the tower is metal most of the time so that makes good to construct & mount the mobile tower mechanically.

4.1.3. Diesel Generator Size and Cost

The cost of diesel generators available in the market varies but the DG used in the particular Ethio-telecom BTS site is Perkins DG with rate output power of 8 kW and 10 kVA with the initial cost of $6500 and the fuel consumption at full load is less than 3 litters. The initial capital cost of the DG is assumed $800/kW. Replacement and operational costs were assumed $800/kW and $0.35/h, respectively. The operating lifetime was also considered 15,000h. Currently, per liter price of diesel in Ethiopia is around $0.8. In this study, 0, 3, 5, 8 and 10 kW sizes of DGs were also considered for simulation. The minimum load ratio was set at 10%.

4.1.4. Battery Size and Cost

The Classic battery of OPzS 150 LA model battery with 12 V cell, 150 Ah, and 1.8 kWh is selected in the proposed system, since this type of battery used in the selected Ethio-telecom BTS site with 4 batteries in one string of 48V. The initial cost of one unit is considered as $700. Replacement and operational maintenance costs were assumed as $700 and $70/year, respectively. In order to find an optimal configuration, the battery bank was assumed to consist of any number of batteries (0, 8, 12, 16, 20, 24, and 28). Each battery string contains four batteries.

4.1.5. Power Converter Size and Cost

The initial capital cost and replacement cost and operation-maintenance cost of the convertor that is considering in system 4 kW are $650, $650 and $10/year respectively. The efficiency of the converter is assumed to be 90% and the lifetime is considered as 10 years. Different sizes of converters (0, 2, 4, 6, and 8 kW) are considered during analysis using HOMER.

CHAPTER FIVE

RESULTS AND DISCUSSION

5.1. Optimization and Simulation Results

After introducing all of the input variables, the HOMER software is run repeatedly to get the feasible system configuration component sizes that meet the load requirement and the inputs constraints at the lowest NPC and then presents the results of the simulation in terms of optimal systems and sensitivity analysis. The Optimization result displays ten different configurations according to the lowest NPC for further analysis and to increase the chance of finding most optimized system. Hybrid system with less NPC, less COE, higher renewable fraction, less capacity shortage and minimum fuel consumption would be suggested as optimum system. HOMER simulates every system in all set of component combination (search space) and ranks all the feasible systems according to increasing net present cost. In the case of this paper it has 4 sensitivity performing 6720 simulations.

PV (kW)	XLR	DG (kW)	OPzS 150	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)	Batt. Lf. (yr)
10		3	16	4	$ 29,288	2,620	$ 62,782	0.339	0.92	477	497	15.0
10	1	3	16	4	$ 49,288	2,481	$ 81,006	0.437	0.98	105	109	15.0
15	1		16		$ 53,700	2,429	$ 84,744	0.458	1.00			15.0
15			48		$ 56,100	4,671	$ 115,806	0.625	1.00			15.0
	2	3	16	4	$ 54,288	9,040	$ 169,846	0.917	0.44	3,229	3,263	15.0
		3	16	4	$ 14,288	13,237	$ 183,500	0.991	0.00	5,900	5,960	15.0
10	1	3		4	$ 38,088	14,685	$ 225,805	1.219	0.71	4,177	8,760	
4		5		4	$ 10,713	22,659	$ 300,368	1.622	0.37	6,391	8,760	
		5		4	$ 4,713	23,647	$ 307,004	1.657	0.00	7,766	8,760	
	1	5		4	$ 24,713	23,564	$ 325,945	1.760	0.22	6,922	8,760	

Figure 5.1 Categorized Optimization Results of the system

PV (kW)	XLR	DG (kW)	OPzS 150	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)	Batt. Lf. (yr)
10		3	16	4	$ 29,288	2,620	$ 62,782	0.339	0.92	477	497	15.0
15		3	16	2	$ 36,463	2,070	$ 62,926	0.340	0.99	119	149	15.0
15		3	16	4	$ 36,788	2,050	$ 62,996	0.340	0.99	116	121	15.0
10		3	16	6	$ 29,613	2,634	$ 63,281	0.342	0.92	477	497	15.0
10		3	16	2	$ 28,963	2,695	$ 63,416	0.342	0.93	468	583	15.0
15		3	16	6	$ 37,113	2,064	$ 63,495	0.343	0.99	116	121	15.0
10		3	16	8	$ 29,938	2,647	$ 63,781	0.344	0.92	477	497	15.0
15		3	16	8	$ 37,438	2,077	$ 63,995	0.345	0.99	116	121	15.0
10		3	16	10	$ 30,263	2,661	$ 64,280	0.347	0.92	477	497	15.0
15		3	16	10	$ 37,763	2,091	$ 64,494	0.348	0.99	116	121	15.0
10		5	16	6	$ 31,238	2,620	$ 64,728	0.349	0.92	478	305	15.0
10		5	16	4	$ 30,913	2,658	$ 64,887	0.350	0.92	491	327	15.0
15		5	16	4	$ 38,413	2,076	$ 64,957	0.351	0.98	138	92	15.0
10		5	16	8	$ 31,563	2,634	$ 65,228	0.352	0.92	478	305	15.0
15		5	16	6	$ 38,738	2,079	$ 65,317	0.353	0.98	136	87	15.0
10		5	16	10	$ 31,888	2,647	$ 65,727	0.355	0.92	478	305	15.0
15		5	16	8	$ 39,063	2,093	$ 65,816	0.355	0.98	136	87	15.0
15		5	16	2	$ 38,088	2,173	$ 65,868	0.356	0.99	143	149	15.0
15		5	16	10	$ 39,388	2,106	$ 66,315	0.358	0.98	136	87	15.0
15		8	16	6	$ 41,175	2,117	$ 68,233	0.368	0.98	165	73	15.0
15		8	16	4	$ 40,850	2,147	$ 68,301	0.369	0.98	157	90	15.0
10		8	16	8	$ 34,000	2,689	$ 68,371	0.369	0.92	519	212	15.0
15		8	16	8	$ 41,500	2,107	$ 68,435	0.369	0.98	162	66	15.0
10		8	16	6	$ 33,675	2,740	$ 68,702	0.371	0.92	526	232	15.0

Figure 5.2 Overall Optimization Results of the system

The two best optimal hybrid system configurations PV/DG/Battery/Converter and PV/WT/DG/Battery/Converter which ranks first and second by the net present cost (NPC) with leveled cost of energy (LCOE), will be compared with the conventional DG/Battery/Converter system rank in six. The performance analysis of the two selected hybrid systems configuration and standalone DG system are discussed in the proceeding sections. The parameters used for the comparison and analysis of hybrid power systems are NPC, COE, Renewable fraction, fuel consumption, Capacity shortage and excess electricity generation as shown in table 5.1. It can be seen from this table below that the site can adequately rely on the RE source to power the remote telecom BTS towers equipment due to presence of solar radiation and wind speed at the site.

Table 5.1 Performance parameters of three different system configurations.

Model Parameters	PV/DG/BB/Conv 1st Choice	PV/WT/DG/BB/Conv 2nd Choice	DG/BB/Conv Existed system
PV Size (kw)	10	10	0
Wind Turbine(Quantity)	0	1	0
Generator Size(kw)	3	3	3
Battery bank(quantity)	16	16	16
Converter size(kw)	4	4	4
Dispatch strategy	CC	CC	CC
Initial capital cost($)	29288	49288	14288
M&O Cost ($/yrs.)	2630	2483	13237
Diesel Fuel Used(L)	483	106	5900
DG Running hours (hrs.)	502	110	5960
Renewable fraction (%)	92	98	0
Capacity shortage (%)	0	0	0.024
Excess Electricity (kwh/yrs.)	2225	5183	0
Unmet load (kwh/yrs.)	0	0	1.25
Total electricity production (kwh/yrs.)	18051	20688	17878

5.1.1 PV/ DG/Battery/Converter Configuration

The best optimal combination comprised of 10 kW PV array and 16 units power safe classic OPzS 150LA battery at 5.64 KWh/m^2 per day average global solar radiation, 3.98 m/sec annual average wind speed and 0.8/L diesel price. It has a renewable fraction of 92% solar energy without inclusion of wind. The cost summary of this system has a total net present cost of $62,782 leveled cost of energy of $0.339/kWh and operating cost of $2,620 per year. The total NPC for the stand-alone diesel system is $183,500 which is 3 times higher than PV/DG/Battery configuration. The simulation result recommends that even a Solar-Battery System is enough to fulfill the demand for basic telecom load profile with excess of electricity 2,268 kWh/year. It can be seen that the site can adequately rely on solar energy to power the BTS loads due to high presence of solar radiation at the site as shown in Figure 5.3.

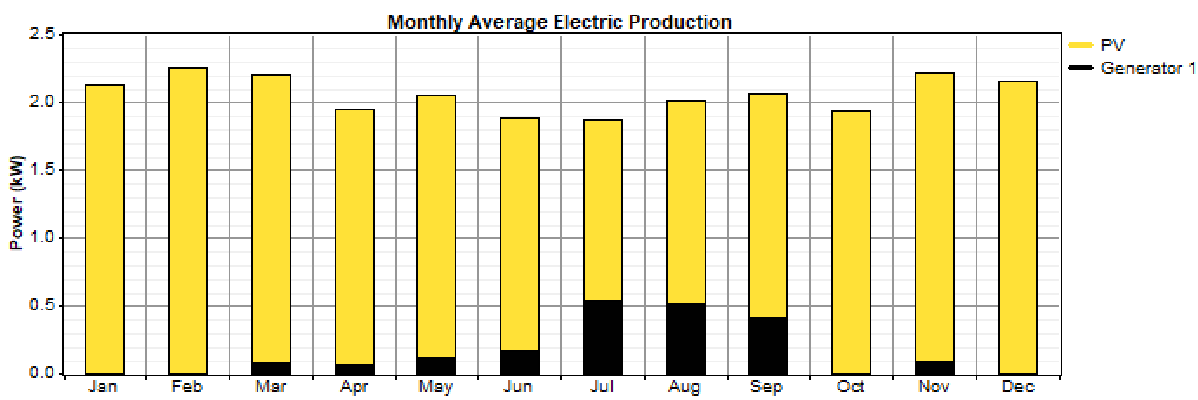


Figure 5.3 Monthly average electricity production of PV/DG/Battery system

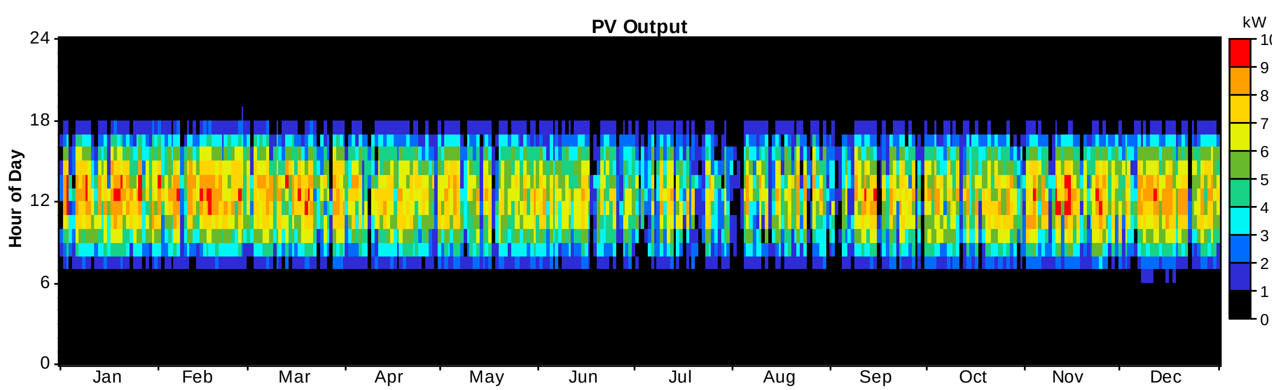


Figure 5.4 Solar PV power productions

5.1.2. PV/Wind/DG/Battery Configuration

The next optimal combination consists of 10kW PV array, one 7.5kW BWCXL-R wind turbine and 16 units Energy's power safe OPzS 150LA battery with converter because DG produced AC. The result is based upon the system with 40 kWh/day telecom load at 5.64 KWh/m^2 of solar radiation, 3.98m/s of wind speed and \$0.8/L diesel price. The COE of this hybrid system is \$0.437/kWh and the total NPC and Operating cost of the system were found to be \$81,006 and \$2,481 respectively. On the other hand, NPC of the stand-alone diesel system is more than 2 times higher than this configuration. The total average electric production of the hybrid system is found to be 20,744kWh per year, of which PV array contribute 80% and wind turbine provides 18% of the total annual production. But the consumption as per the dc telecom load is found to be 14491 kWh per year resulting excess electricity of 5239kWh per year with unmet electric load of 0 kWh per year and capacity shortage of 0.0 kWh per year.

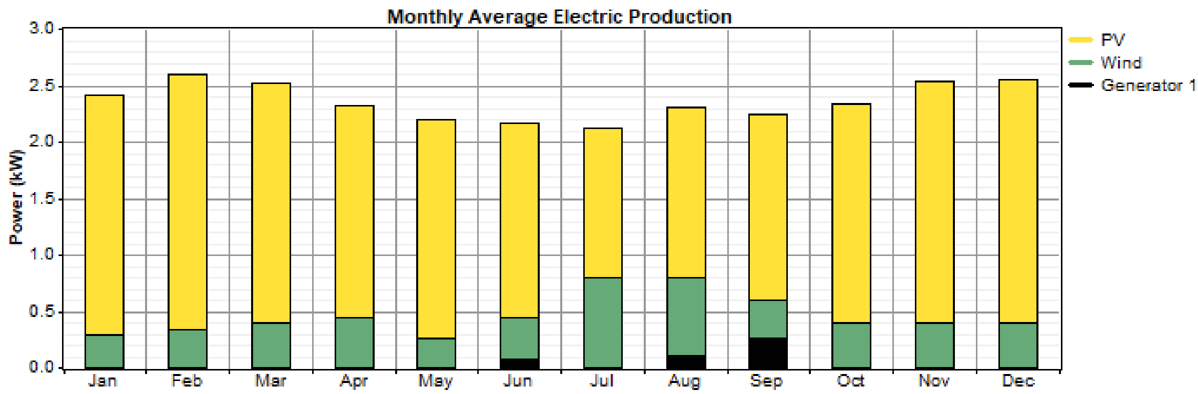


Figure 5.5 Monthly average electricity production of PV/Wind/DG/Battery hybrid system

As Figure 5.5 shows the PV system will operate more compared to the wind turbine, which means the PV array serves the base load. The electricity production from the wind turbine is limited due to the lower wind speed at the site, although the renewable energy fulfills the telecom load demand 98%.

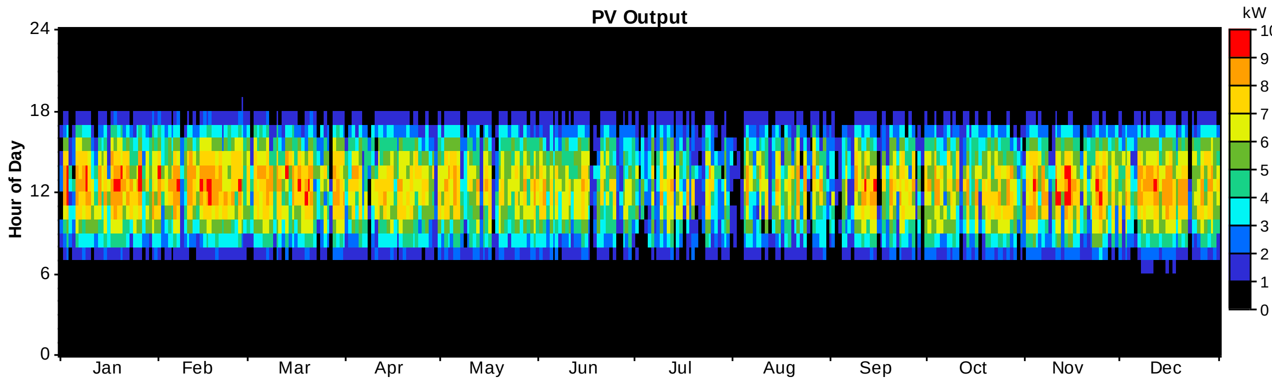


Figure 5.6 Solar PV power productions for optimal system

5.1.3. DG/Battery/Converter Configuration

The conventional standalone generator system consists of 3KW DG, 16 unit battery and 4KW converter. This project reveals that DG-Battery System is very costly with cost of energy (COE) $0.991/kWh and takes large total NPC of $183,500 due to the huge operation cost of $13,237 per year when compared with other hybrid system. So, the DG NPC cost takes more than 85% of the total NPC cost and the NPC cost of the battery and the converter are around 10% and 5% of the total NPC cost respectively. The reason is the cost of Fuel and O&M are very large. On the other hand, the standalone diesel system consumes a total of 5900 L/year and run for 5,960hr/year. The total electrical energy production from the DG system is found to be 17,878 kWh/year and DC primary load consumption of 14489 kWh per year; approximately resulting no excess electricity production, no capacity shortage and zero unmet electric loads. CO2 emission is found to be 15,537 kg per year followed by 38.4 kg/year of CO emission per year.

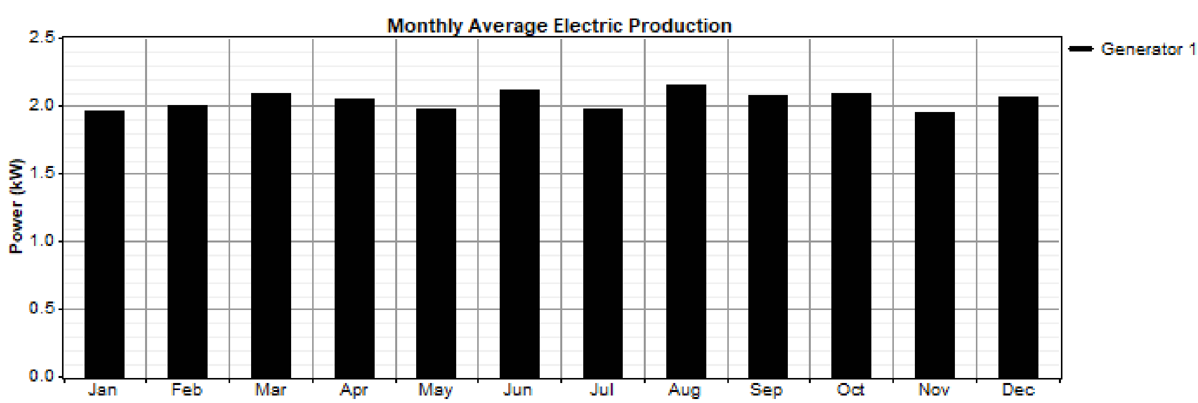


Figure 5.7 Monthly average electricity production of DG/Battery system

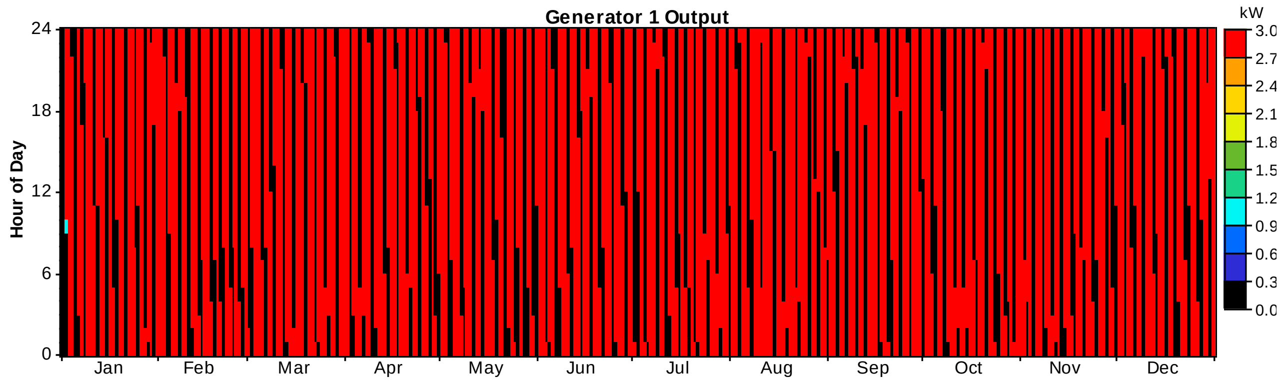
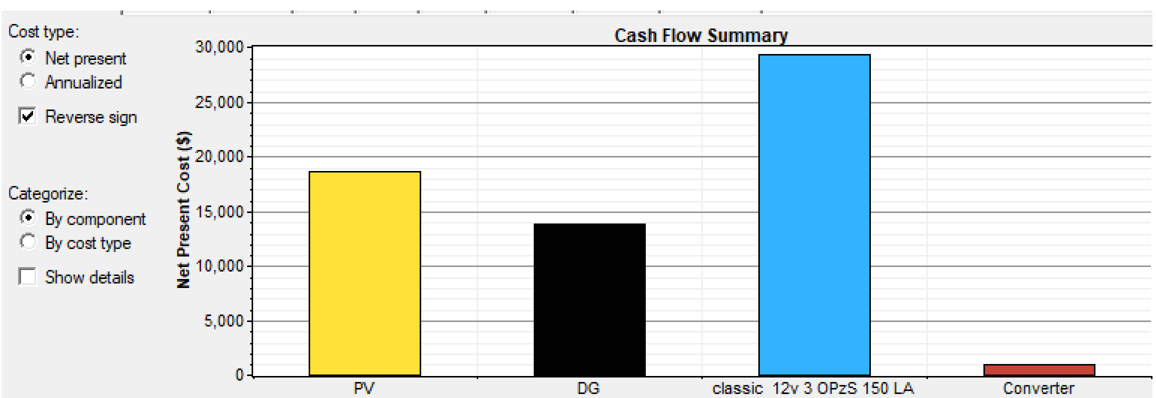


Figure 5.8 Generator power productions

5.2 Summary in terms of NPC by component type

The cost summary in terms of NPC by component type which were the system set up in the below figure. It shows graphical representation of each component and the required materials NPC as shown figure below.



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	15,000	3,742	1,918	0	-2,097	18,562
Generator 1	2,438	0	6,671	4,882	-90	13,900
classic 12v 3 OPzS 150	11,200	4,673	14,317	0	-870	29,321
Converter	650	271	128	0	-50	999
System	29,288	8,686	23,034	4,882	-3,107	62,782

Figure 5.9 Summary of NPC by component type

5.3 Sensitivity Result

Sensitivity analysis helps in exploring the effect of the changes (uncertainty dynamic change like, increasing or decreasing demands, renewable and non-renewable resources fluctuations) in the available resource and economic condition. This analysis shows the power system sensitive for each change of the input variables. Four sensitivity parameters were considered in this study, namely: solar radiation (3, 5.64 & 8 kWh/m2/day), wind speed (2, 3.98 & 6 m/sec), annual average energy (20, 40 & 60 kWh/day) and diesel price (0.4, 0.8 & 1.5$/L). There are six different sensitivity results scenarios for the Optimal System Type (OST) they are: Variation in wind speed and solar radiation, Variation in wind speed and diesel price, Variation in solar radiation and diesel price, Variation in solar radiation and Load average energy, Variation in diesel price and Load average energy and Variation in load average energy and wind speed.

Sensitivity variables

Primary Load 1 (kWh/d) 39.7 Global Solar (kWh/m²/d) 5.64 Wind Speed (m/s) 3.99 Diesel Price ($/L) 0.8 DG O&M Multiplier 8

Double click on a system below for simulation results. Categorized Overall Expo

PV (kW)	XLR	DG (kW)	OPzS 150	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	DG (hrs)	Batt. Lf. (yr)
10		3	16	4	$ 29,288	2,620	$ 62,782	0.339	0.92	477	497	15.0
15		3	16	2	$ 36,463	2,070	$ 62,926	0.340	0.99	119	149	15.0
15		3	16	4	$ 36,788	2,050	$ 62,996	0.340	0.99	116	121	15.0
10		3	16	6	$ 29,613	2,634	$ 63,281	0.342	0.92	477	497	15.0
10		3	16	2	$ 28,963	2,695	$ 63,416	0.342	0.93	468	583	15.0
15		3	16	6	$ 37,113	2,064	$ 63,495	0.343	0.99	116	121	15.0
10		3	16	8	$ 29,938	2,647	$ 63,781	0.344	0.92	477	497	15.0
15		3	16	8	$ 37,438	2,077	$ 63,995	0.345	0.99	116	121	15.0
10		3	16	10	$ 30,263	2,661	$ 64,280	0.347	0.92	477	497	15.0
15		3	16	10	$ 37,763	2,091	$ 64,494	0.348	0.99	116	121	15.0
10		5	16	6	$ 31,238	2,620	$ 64,728	0.349	0.92	478	305	15.0
10		5	16	4	$ 30,913	2,658	$ 64,887	0.350	0.92	491	327	15.0
15		5	16	4	$ 38,413	2,076	$ 64,957	0.351	0.98	138	92	15.0
10		5	16	8	$ 31,563	2,634	$ 65,228	0.352	0.92	478	305	15.0
15		5	16	6	$ 38,738	2,079	$ 65,317	0.353	0.98	136	87	15.0
10		5	16	10	$ 31,888	2,647	$ 65,727	0.355	0.92	478	305	15.0
15		5	16	8	$ 39,063	2,093	$ 65,816	0.355	0.98	136	87	15.0
15		5	16	2	$ 38,088	2,173	$ 65,868	0.356	0.99	143	149	15.0
15		5	16	10	$ 39,388	2,106	$ 66,315	0.358	0.98	136	87	15.0
15		8	16	6	$ 41,175	2,117	$ 68,233	0.368	0.98	165	73	15.0
15		8	16	4	$ 40,850	2,147	$ 68,301	0.369	0.98	157	90	15.0
10		8	16	8	$ 34,000	2,689	$ 68,371	0.369	0.92	519	212	15.0
15		8	16	8	$ 41,500	2,107	$ 68,435	0.369	0.98	162	66	15.0
10		8	16	6	$ 33,675	2,740	$ 68,702	0.371	0.92	526	232	15.0

Figure 5.10 Overall Sensitivity Optimization Results of the system

5.2.1. Varying average wind speed and average solar radiation value

In this sensitivity analysis, Optimal system types are investigated for three different values of load average energy of BTS and diesel prices as presented in above of Sensitivity analyses that means we have a total of nine combinations for Optimal system types graph for which the wind speed range 3.0 and 6 m/sec in the X-axis and solar radiation range 4.0 and 7.0kWh/m^2/day as shown

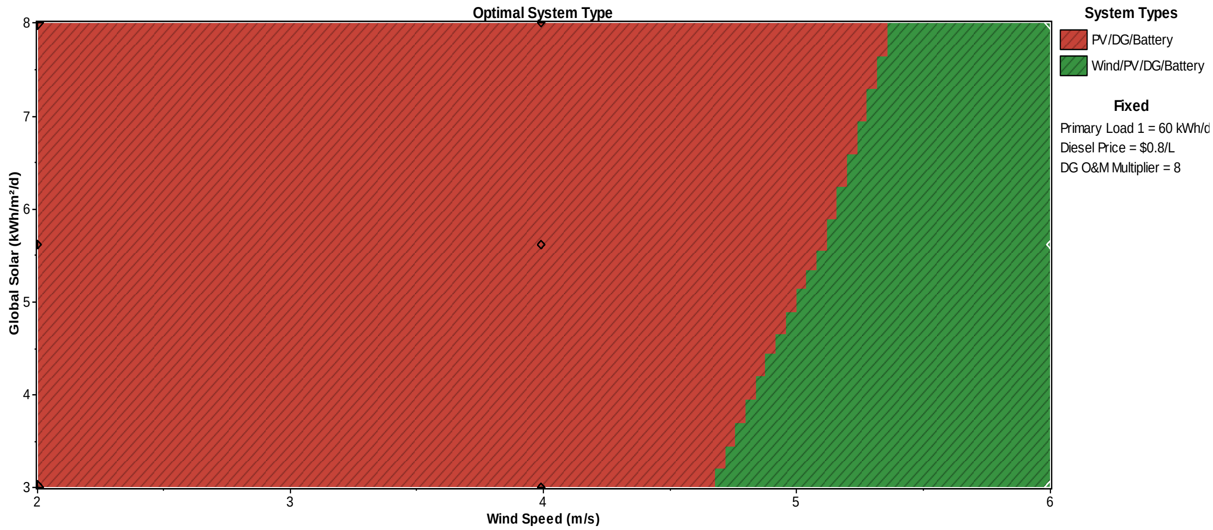


Figure 5.11 optimal system types for varying solar radiation and wind speed values

Figure 5.11 shows that Sensitivity result for the specified values of Primary load (40kWh/day) and diesel price ($0.08/L) there are two best optimal configurations PV/DG/Battery and Wind/PV/DG/Battery at the considered site is more economical.

In the remaining sensitivity values it can be observed that there are different configurations for the system. The sensitivity analysis showed that almost the same configuration was obtained except in some case there are quantity and size change of the components. The different setups resulted in this paper could be appropriate in areas that have the same climatic resources.

6. CONCLUSION AND RECOMMENDATION

6.1 Conclusion

In Ethiopia more than 60 million peoples are mobile user. To provide better network services mobile operator installed new mobile base stations. Power is main issue for remote or isolated areas base station, because grid extension is not feasible. This project assessed for off grid mobile base station sites that are found around bale robe, with the aim of developing alternative power source for the remote or off grid Ethio telecom sites.

The paper indicates that the site is blessed with annual average global solar radiation of 5.64 kWh/m^2 /day and average wind speed of 3.98m/s at 30 m height. Therefore; there is a potential site for installation of PV/DG/Battery hybrid system and PV/Wind/DG/Battery hybrid system. The simulation results from HOMER show that the most economically feasible configuration for the site load is composed of 10 kW PV array, 3 kW DG and 16 units of batteries of which each has a nominal voltage of 12 V and capacity of 150 Ah and that the most economically feasible configuration for the site; both configurations have a renewable penetration of 92% and 98%. However, the conventional standalone diesel configuration is not economically due to the high cost of fuel consumption and O&M.

Overall the simulation result showed that the proposed model has lower life time cost as compared to the existing standalone Diesel Generator system. Beyond cost, the use of PV and wind will contribute for the reduction of the negative effects of DG such as environmental pollution and emission through minimizing the number of DG implementation. This will save the extra budget. Additionally this will reduce dependency on commercial line of Ethiopian Electric Utility (EEU) and ensure continuous power supply. It will also contribute to reduce the national energy crisis as well. Due to powering the base station by hybrid renewable energy system, it will reduce the carbon and other harmful gases emission in environments.

Alternate power solutions are not commonly used in mobile telecommunication system today but are actively evaluated for remote and isolated areas over worldwide. With the help of above pre-feasibility study the solar and wind hybrid energy system are most viable power solution for mobile base station in Ethiotelecom sites over conventional diesel generator. Thus the Base stations powered by the solar wind hybrid energy system with diesel and battery backup are proving to be the most environmentally friendly and cost effective solutions.

6.2 Recommendation

Finally the following points are recommended:

- The proposed model will be beneficial if it can be implemented in off grid BTS sites particularly for 2^{nd}, 3^{rd}, 4^{th} & 5^{th} generation technologies.
- This project consider 200wp module for assessment, but using higher watt peak modules will decrease the number of module needed for the system and also minimize space constraints.
- In this project, the model is designed only for mobile base station. It is suggested to assess and design hybrid power source for other telecom devices such as Multiservice Access Gateway (MSAG), Multi-Service Access Node (MSAN), Transport network device & etc.
- The project was undertaken around Bale Robe, where its context is different from other towns especially considering weather condition; therefore, it will be good if further assessment is done in other areas.

REFERENCES

Bhandari B, Lee K-T, Lee G-Y, et al. (2015) Optimization of Hybrid Renewable Energy Power Systems: A Review. Int J Precis Eng Manuf-Green Tech 2: 99-112.

Olatomiwa L, Mekhilef S, Huda ASN, et al. (2015) Techno-Economic analysis of hybrid PV diesel-battery and PV-Wind-Diesel-Battery power system for mobile BTS: the way forward for rural development. Energ Sci Eng 3: 271-285.

Phrakonkham S, Le Chenadec J-Y, Diallo D, et al. (2010) Reviews on Micro-Grid Configuration and Dedicated Hybrid System Optimization Software Tools: Application to Laos. Eng J 14:15-34.

IFC, Green Power for Mobile (2014) Tower Power Africa, Energy Challenges and Opportunist for Mobile Industry in Africa.

GSMA, Green Power for Mobile (2014) The Global Telecom Tower ESCO Market Overview of The Global Market For Energy To Telecom Towers In Off-Grid And Bad-Grid Areas.

Jeannin, L., and de Givry, S. (2003, October). Network planning with constraint programming. In International Network Optimization Conference (INOC), Evry/Paris, France.

Jochen H. Schiller (2003). Mobile Communications (second Edition). ADDISON-WESELY.

Ericson AB 2015/ MOD RSM Low Level Design pdf and Site Installation documentation, SID NSB ASP 222626 SR REV, ERICSSON, ethio-telecom.

The Radicati Group, INC. (2014-2018). Mobile Statistics, Technology Market Research Firm. PALO ALTO, CA, USA and Goggin, G. (2012). Cell phone culture: Mobile technology in everyday life. Routledge

Acharya D (2013) Solar and Wind Hybrid Power for an Extremely Remote Mobile Base Station. Guelph Eng J 1-10.ISSN: 1916-1107.

Jochen H. Schiller (2003). Mobile Communications (second Edition). ADDISON-WESELY[10]

Heine, Gunnar (1999). GSM Network: Protocols, Terminology and Implementation. Artech House Mobile Communication Library. ISBN 0-89006-471-1

Chaouchi, H. and Laurent-Maknavicius, M. (2009). Wireless and Mobile Network Security. John Wiley and Sons, Inc. Optimal Sizing of Grid-PV Hybrid System for Ethio telecom Access Layer Devices and Its Economic Feasibility 2017 53

Pande, G. (2009, September). A Case Study of Solar Powered Cellular Base Stations. (Master Thesis in Energy System, University of GAVLE).

Cellular Technology (2014, December). CSC 249

Aris, A. M., and Shabani, B. (2015). Sustainable Power Supply Solutions for Off-Grid Base Stations. Energies, ISSN 1996-1073

Dan Chiras (2010) Wind Power Basics: a Green Energy Guide. New Society Publishers.

Baron, D. (2010). The Impact of Telecommunications Services on Doing Business in Ethiopia. Addis Ababa Chamber of Commerce and Sectoral Associations.

Pramod Jain (2011) Wind Energy Engineering. McGraw-Hill

Girma Z (2013) Technical and Economic Assessment of solar PV/diesel Hybrid Power System for Rural School Electrification in Ethiopia. Int J Renew Energ Res 3

Industrial Batteries – Network Power Classic OPzS Energy storage for economical safety

Lambert T, Gilman P, Lilienthal P (2005) Micro power system modeling with HOMER. Integration of Alternative Sources of Energy, F. A. Farret, M.G. Simoes, John Wiley & Sons, 379-416.

Yeshalem, M. T., & Khan, B. (2017). Design of an off-grid hybrid PV/wind power system for remote mobile base station: A case study. AIMS ENERGY, 5(1), 96-112

Salih, T., Wang, Y., and Ahmed Adam, M.A. (2014). Renewable Micro Hybrid System of Solar Panel and Wind Turbine for Telecommunication Equipment in Remote Areas in Sudan. Energy Procedia 61, 80 – 83.

C.S. Supriya and M. Siddarthan (2011, May). Optimization and Sizing of a Grid Connected Hybrid PV-Wind Energy System. IJEST, ISSN: 0975-5462

Nikum, K., Saxena, R., and Wagh, A. (2016, February). Cost Optimization of PV-Wind- Battery Grid Connected hybrid system. SSRG-IJEEE – volume 3.

HOMER, the Micro-Power Optimization Model; ver.2.68Beta, NREL; 2009.

http://www.ethiotelecom.et. (Accessed on Jan ,2022)

http://eosweb.larc.nasa.gov/sse(Accessed on Mar ,2022)

http:// www.ipcisco.com/ (Accessed on May, 2022

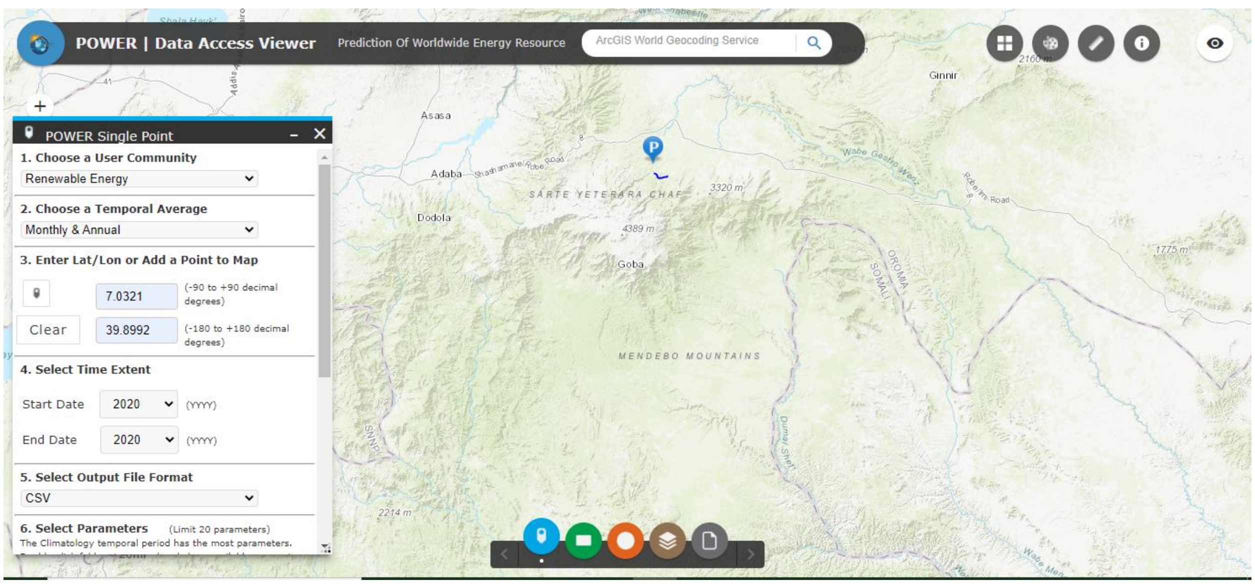
APPENDIX

Appendix A: NASA & National Metrological Agency

A1 NASA/POWER CERES/MERRA2 Native Resolution Monthly and Annual

NASA/POWER CERES/MERRA2 Native Resolution Monthly and Annual
Dates (month/day/year): 01/01/2020 through 12/31/2020
Location: Latitude 7.0321 Longitude 39.8992
Elevation from MERRA-2: Average for 0.5 x 0.625 degree lat/lon region = 2862.89 meters
PS MERRA-2 Surface Pressure (kPa)
T2M MERRA-2 Temperature at 2 Meters (C)
WS2M MERRA-2 Wind Speed at 2 Meters (m/s)
WS10M MERRA-2 Wind Speed at 10 Meters (m/s)
WS50M MERRA-2 Wind Speed at 50 Meters (m/s)
ALLSKY_KT CERES SYN1deg All Sky Insolation Clearness Index (dimensionless)
CLRSKY_KT CERES SYN1deg Clear Sky Insolation Clearness Index (dimensionless)
ALLSKY_SFC_SW_DWN CERES SYN1deg All Sky Surface Shortwave Downward Irradiance (kW-hr/m^2/day)
CLRSKY_SFC_SW_DWN CERES SYN1deg Clear Sky Surface Shortwave Downward Irradiance (kW-hr/m^2/day)
ALLSKY_SFC_SW_DIFF CERES SYN1deg All Sky Surface Shortwave Diffuse Irradiance (kW-hr/m^2/day)

PARAMETER	YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
PS	2020	72.65	72.71	72.62	72.62	72.68	72.58	72.46	72.49	72.52	72.58	72.61	72.62	72.6
T2M	2020	11.23	11.87	13.22	13.15	13.05	12.55	11.9	12.29	12.1	11.16	10.44	9.57	11.87
WS2M	2020	1.71	1.93	2.05	2.02	1.72	1.75	2.58	2.49	1.86	1.92	1.89	1.8	1.98
WS10M	2020	2.62	2.86	3	2.98	2.56	2.66	3.72	3.57	2.74	2.89	2.92	2.85	2.95
WS50M	2020	3.59	3.74	3.95	4.06	3.46	3.84	4.94	4.7	3.73	3.94	3.94	3.91	3.98
ALLSKY_KT	2020	0.66	0.66	0.61	0.55	0.59	0.54	0.41	0.45	0.48	0.57	0.65	0.7	0.57
CLRSKY_KT	2020	0.76	0.77	0.76	0.75	0.75	0.73	0.73	0.73	0.74	0.74	0.76	0.77	0.75
ALLSKY_SFC_SW_DWN	2020	6.02	6.51	6.29	5.77	6.08	5.4	4.14	4.63	4.98	5.65	6.05	6.2	5.64
CLRSKY_SFC_SW_DWN	2020	6.93	7.5	7.8	7.85	7.69	7.33	7.3	7.56	7.59	7.33	7.03	6.88	7.4



Appendix B: PV Model Specification

200w Mono Crystalline Solar Panel specification

200 Watt

Electrical parameters at standard test conditions
(STC:AM=1.5, 1000W/m2, Cells Temperature 25°C)

Model type	200W
Peak power(Pmax)	200W
Weight	11.7kg
Dimensions(mm)	1500*675*35
Max Power voltage(Vmp)	20.27
Max Power current(Imp)	9.87
Open circuit voltage(Voc)	25V
Short circuit current(Isc)	10.39A
Module Efficiency(%)	20.25%
Max system voltage	DC 1500V
Maximum Series Fuse Rating	20A
Front glass	3.2mm tempered glass
Output cables	4mm² Symmetrical lengths 1100mm
Connectors	MC4 compatible IP68
Cell type	Mono-Crystalline Silicon
Normal operating cell temp.	45± 2°C
Power tolerance	0±3%

Appendix C: Wind Turbine Specification

7.5kw Bergey Wind Turbines Specification

Wind Generator Specifications	
Rated Power Output	7,500 watts at 29 mph (13.0 m/s)
Cut-in Wind Speed	7.0 mph (3.1 m/s)
Start-up Wind Speed	7.5 mph (3.4 m/s)
Cut-out wind Speed	none
Furling Wind Speed	35 mph (15.6 m/s)
Maximum Design Wind Speed	120 mph (53.6 m/s)
Type	3 Blade Upwind
Rotor Diameter	23.0 ft (7.0 m)
Weight	1050 lbs (477 kg)
Gearbox/Belts	none, direct drive
Temperature Range	-40C to +60C
Generator	Permanent Magnet Alternator
Turbine Output Form	3 phase AC, variable frequency
System Output Form	120VDC, 240VDC, 48VDC nominal (with included battery charge controller)

Appendix D: Diesel Generator Specification

10KVA Perkins new DG specification

kVA(ESP):	10
kVA(PRP):	9
kW:	8
Hz:	50
Amps:	14
RPM:	1500
Voltage:	415/240
Phase:	3
Engine:	Perkins
Alternator:	Brushless
Controller:	Deepsea
Battery Charger:	Yes
Jacket Water Heater:	Yes
Fuel Tank:	Yes

Appendix E: Battery Storage Specification

Classic OPzS 150LA Battery Specification

Classic OPzS blocks / 12V 3 OPzS 150 LA

INDUSTRIAL BATTERIES / NETWORK POWER

Classic OPzS batteries have been proven energy suppliers for decades, which convince in robustness, reliability and extremely long design- or cycle life.

Part Number: NVZS120150WC0FB

APPLICATIONS

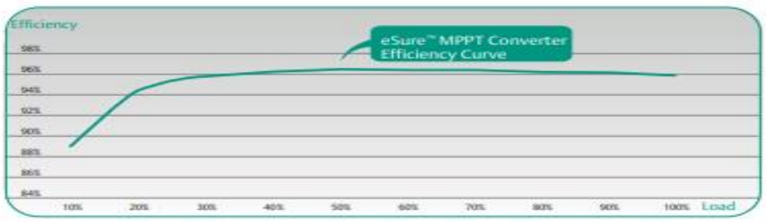
SPECIFICATIONS

- Very high operational reliability under rough operating conditions
- Low maintenance due to optimised alloy and large electrolyte reserve
- 20 years design life at 20 °C ambient temperature (80 % remaining capacity from C_{10})
- Container made from high quality translucent plastics
- Also available in dry charged condition with separate electrolyte
- Low gassing acc. to EN 50272-2 thanks to the low antimony alloy (< 3%)
- Designed in accordance with IEC 60896-11, DIN 40736 and DIN 40737 T3
- Electrolyte: diluted sulphuric acid dN = 1.24 kg/l
- Manufactured in Europe in our ISO 9001 certified production plants

Design life | Block battery | Tubular plate | Recyclable | Low

Appendix F: Converter Specification

S48-2000e3 Converter Specification



Key Features

- ✓ High efficiency, above 96.2%
- ✓ Highest MPPT precision exceeds 99%
- ✓ Very high power density, occupies minimum space
- ✓ Compliant with global standards – delivers quality, performance and reliability no matter what the application or location demands
- ✓ Interchangeable with R48-2000e3 Net Sure rectifiers, occupying same slots for ultimate system flexibility
- ✓ Wide operating temperature range (-40C to +80C) for the most demanding environments
- ✓ Wide input voltage range (120VDC to 420VDC) allows for a wide range of solar panel configurations
- ✓ Hot pluggable – facilitates future expansions and easy maintenance