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Research article

Design of an off-grid hybrid PV/wind power system for remote mobile base station: A case study

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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 feasibility and reliable electric power for a specific remote mobile base station located at west arise, Oromia. 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) of $57,508 and per unit cost of electricity (COE) of $0.355. 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 is also carried out to analysis 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.

Keywords: Base Transceiver Station (BTSs); photovoltaic (PV); wind power system

1. Introduction

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 [15].

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[16–19].

Telecommunication network have changed the way people live, work and play. Since many people around the world are connected by mobile networks, the challenge to provide reliable and cost effective power solutions to these expanding and remote networks is 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 [1].

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 [20].

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 [20,21].

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.

The latest national energy balance indicates that Ethiopia consumed 1.3EJ of energy in 2010. This was derived from biomass fuels (92%), hydrocarbons (7%), and electricity (1%). The main consumers of energy were the residential and service sector (93%) and transport (5%) with the remainder going for industrial and other applications [6].

In Ethiopia, the mobile phone ownership/ mobile network coverage has reached 24.7% of households in 2011—65.2% of households in urban areas and 12.8% of households in rural areas. In contrast rural household electricity connection was only 4.8% in 2011. Mobile phone owning households in rural areas had already reached 1.75 million in 2011. Rural mobile ownership can be expected to reach 45% (this is the planned mobile network coverage for 2015) or 6.8 million households by 2015. Since the electrification rate is going much slowly than mobile phone network coverage more than two third of rural mobile phone owners (or more than 4 million households in 2015) would not be connected to electricity [6]. 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 [10,11]. 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 Base Transceiver Station (BTS), so that can generate and provide cost effective electric power to meet the BTS electric load requirement.

1.1. Literature review

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.

A case study [7] in the Somalia region of Ethiopia, The remote rural village called Werder district (6050'N 45030' E) have an average wind speed of 5m/s at 10m elevation and an average daily solar radiation of 7.5kwh/m2/day. Extension of national grid is not economically feasible and the electrical load density in the village is low. The techno economic analysis of this option has been done using HOMER software and hybrid PV/wind/diesel generator system became economically feasible for the proposed site based on some important parameters such as high renewable penetration, less annual diesel consumption, less carbon dioxide emission and less cost of energy.

The study [10] 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 [14] 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 this paper [11] 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 design is based on the local mobile subscribers with 350 capacities with 51mE per subscriber traffic and the peak load capacity of 750 W. 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 patter 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 [23]. This paper also used the same software to design and optimize the off-grid hybrid power system to be provided electricity requirement of the remote telecom site in Ethiopia.

To improve the communication infrastructure of the rural community the ethio-telecom must use Hybrid RES to provide electrical power depending on the geographical area and the resource availability of the area. Here in this site, it uses Hybrid Battery and Generator, but power supply is not continuous. However this paper differs from the related studies in terms of application, load demand, climatic data, and location of the study area.

2. Background of the Study Area

2.1. Energy Potential of the Study Area

The mobile telecom base station considered for this hybrid system project is located in Ethiopia in Oromia Region of West Arsi, with Geographical coordinates of latitude 7.20592 and longitude 38.60801. Here, the mobile telephony base station is taken from ethio telecom site; the global system for mobile (GSM) and code division multiple access (CDMA) network system base station is considered. Since Ethio telecom is the only operating companies in Ethiopia.

Ethiopia is located near the equator, there is a significant potential of solar resource. Solar resource raw data input to the HOMER software is the average global horizontal radiation obtained for the site from Atmospheric Science Data Center (ASDC)-NASA surface meteorology and solar energy database [12].

Table 1. Average monthly global solar radiation of West Arsi, Oromia region of Ethiopia.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave.
Solar radiation (kWh/m2/day)	6.02	6.41	6.35	6.04	5.95	5.42	4.83	5.01	5.64	6.04	6.25	6.10	5.83
Clearness index	0.652	0.652	0.614	0.577	0.581	0.541	0.479	0.486	0.547	0.609	0.669	0.677	0.588

From Table 1 it can be seen that the monthly average solar energy resource is well distributed in the site with average monthly solar radiation of 5.834 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 6.41 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 and August) in the country, particularly in the month of July with radiation of 4.83 kWh/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 0.479 in July to 0.677 in December.

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^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 hr as shown in Figure 1.

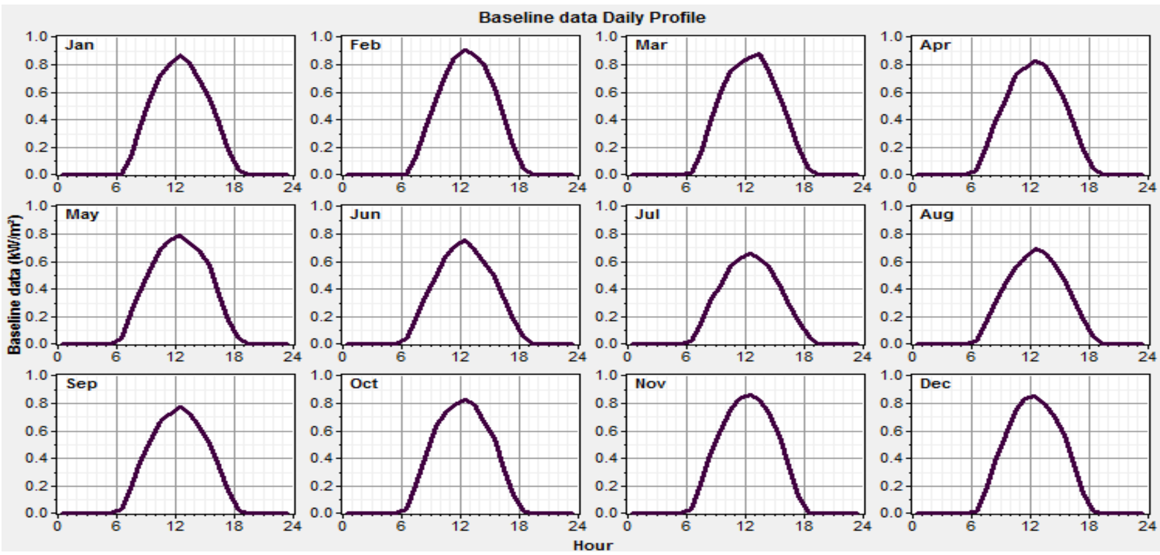


Figure 1. Diurnal Variation of Global Horizontal Solar Radiation Source.

Normally from middle 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.

There are two basic windy areas in Ethiopia located alongside the main East African Rift Valley, the North Eastern highlands of the country near Tigray regional state, the southern part of Ethiopia near the Kenyan border, the central Ethiopia and eastern lowlands part of Ethiopia, however, a significant amount of it had not been harnessed yet throughout the county [7,8].
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 2.97 m/s at an anemometer height of 10 m [9,12] as shown in Table 2.

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 30 m. Tables 2 summarize the monthly wind speed variation of the site at 30 m heights where the average wind speed found to be 3.687 nm/s. The lowest wind speed profile is indicated in the months of July, August and September; Whereas, November, December and January 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 [24]. In this paper the logarithmic function used that the logarithmic profile (or log law) assumes that the wind speed is proportional to the logarithm of the height above ground. The following equation therefore gives the ratio of the wind speed at hub height to the wind speed at anemometer height:

$$\frac{V_2}{V_1} = \frac{In(\frac{h_2}{z_0})}{In(\frac{h_1}{z_0})}$$

Where: Zo: Surface roughness length factor [m]; Surface roughness length describes the roughness of the surroundings terrain in this case few trees, having a value of 0.01. h1: Reference height above ground level [m], h2: Hub height [m].

Table 2. Average monthly wind speed at 10m and 30m Height of West Arsi, Oromia region of Ethiopia.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave.
Wind Speed (m/s) at 10m	3.55	3.21	3.03	3.10	2.94	2.90	2.52	2.34	2.41	2.89	3.32	3.53	2.97
Wind Speed (m/s) at 30m	4.397	3.976	3.753	3.636	3.840	3.592	3.121	2.898	2.985	3.579	4.112	4.372	3.687

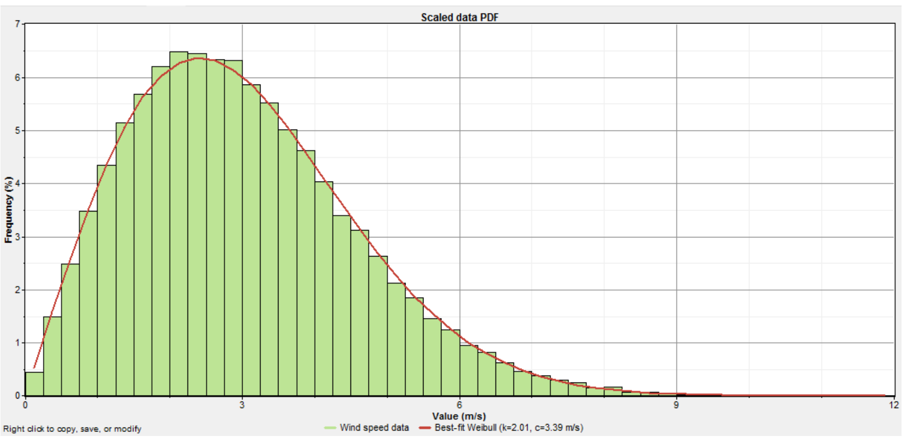


Figure 2. Probability Distribution Function of Wind Speed data of West Arsi, Oromia region of Ethiopia.

From this Figure 2 it can be seen that the most probable wind speed range 2.0–3.5 m/sec occurs approximately 35%, and the wind speed above 3.5 m/s is occurred around 45% 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 3.

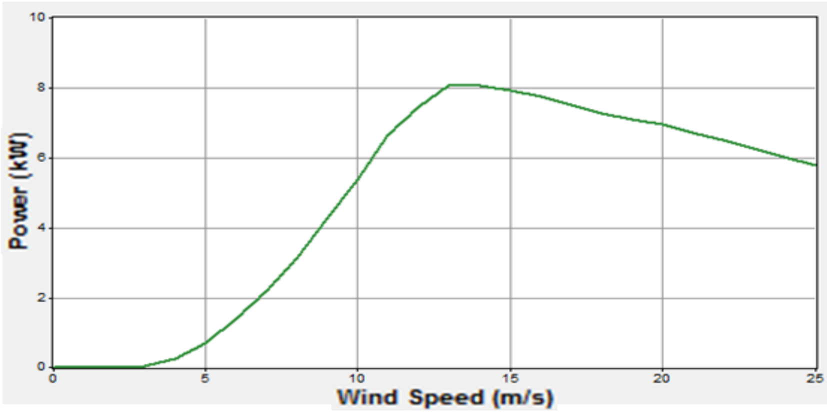


Figure 3. Power Curve of Bergey wind turbine.

2.2. Analysis of The BTS Electricity 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 [2,3]. Typically, a conventional BTS site load consists of BTS equipment load as well as air conditioner and lighting loads. So A second-generation GSM & WCDMA System mobile base station consisting of a single RBS 6101 with three RF Antenna at angle of 120 at 29 m height; with one MW Antenna at 36.6 m high, with Lighting Rod and Aviation Light at 40 m high; 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 1000 L Capacity was considered in this study [4,5] 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 than 60% of the power is consumed by the radio equipment and amplifiers, 11% is consumed by the DC power system and 25% by the cooling equipment, an air conditioning unit [5]. 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) and antennas and lighting, are the largest energy consumers at a tower site.

2.3. Load Pattern for Mobile Base Station

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.

Although, measured hourly load data for the considered site is difficult to find the exact hourly load usage data. However, it is important to note that, the stated rating of BTS equipment will not be loaded to full capacity at all times due to the variability in operating hour of the equipment.

Normally, the mobile network load requirement to be the same for entire days of the year and there is low variation in the energy load profile requirements of a BTS across the day. The load can be classified into two categories. The load is low throughout the night till morning, whereas in the busy category occurred usually occurs during in the day time particularly the business hours of the day around lunch time took the maximum power demand. Therefore, BTS 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 hourly load profile of the site for a typical day (1 January) is shown in Figure 4 from where scaled average energy consumption per day, scaled daily peak demand, and daily average demand are found to be approximately 41.4 kWh, 3.01 kW, and 1.72 kW, respectively. The mismatch in the peak value and value shown in Figure 4 is due to the scaling process and the random variability introduced in HOMER to make the load pattern unique. Based on this variation, a day-to-day random variability of 5% and hour-to-hour random variability of 10% was specified in HOMER so as not to underestimate the peak load the proposed system can serve.

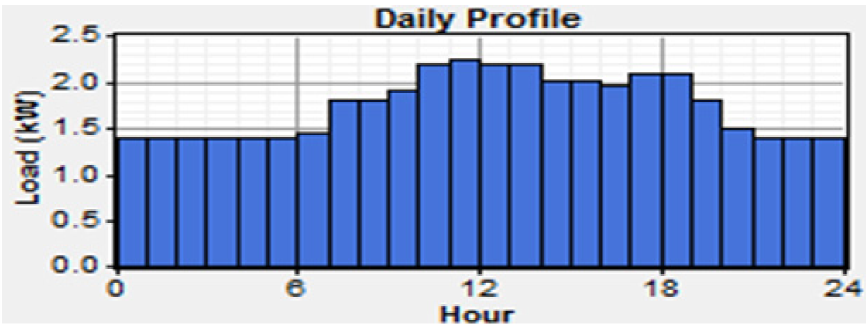


Figure 4. Daily load profile of the site.

To synthesize data in HOMER, you must 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.

3. Design of the Proposed System

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 5 presents the schematic representation of HOMER simulation model considered.

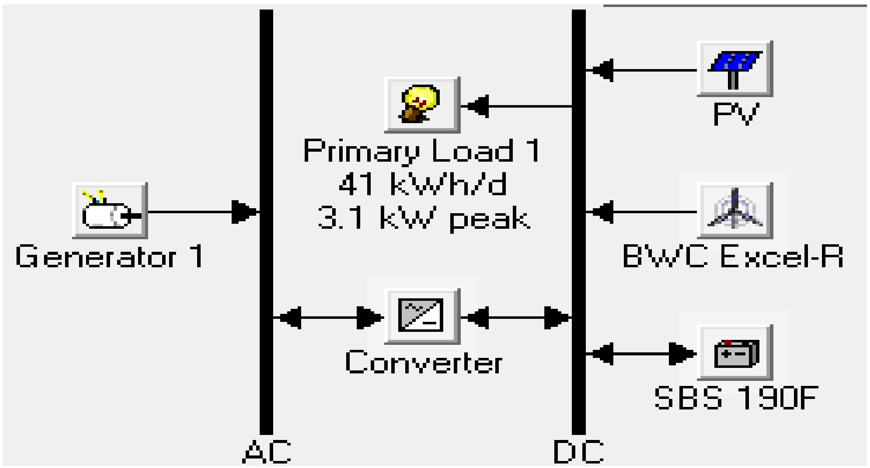


Figure 5. The proposed hybrid system produced by HOMER.

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 energy from renewable fraction compare with diesel generator based on the cost.

4. Materials Cost and Size Specification

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 3; 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 2015.

Table 3. Summary of cost and size of components.

No	Component	Size(KW) Qty. (No.)	Capital Cost($)	Replacement Cost ($)	O&M Cost ($/Year)	Consider size(kW)	lifetime
1	Solar PV	1kW	$2500	$2000	25	0, 1, 2, 3, 4, 5, 6, 7, 8, 9,10	20 year
2	Wind Turbine	7.5kW	$16870	$11809	$337	0, 1, 2, 3, 4, 5	20 year
3	Diesel Generator	8kW and 10kVA	$5700	$570/ kW	$0.35/h	0, 3, 5, 8 10	15,000 hr.
4	Battery 4batteries in one string	6 cells, 12V, 190Ah, 2.3 kWh	$300	$300	$10/year	0, 8, 12, 16, 20, 24, and 28	1000 kWh
5	Power Converter	1kW	$650,	$650	$10/year	0, 2, 4, 6, and 8 kW	10 years

4.1. 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 $2500 and $2000, respectively. As the installation cost is taken as 60% of the PV price and the operation and maintenance cost would be 1% per year [10]. In this case, 10 different types of PV arrays are considered to get the optimal size (0, 1, 2, 3, 4, 5, 6, 7, 8, 9, and 10 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 derating 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.

4.2. 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 $16870. Replacement and annual operational maintenance costs were assumed as $11809 and $337year, respectively. O&M cost of wind turbine was proposed about 2% of its initial capital cost as given in [13]. 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 good to construct and mount the mobile tower mechanically.

4.3. Diesel Generator Size and Cost

The cost of diesel generators available in the market varies but the DG used in the in particular Ethio-telecom BTS site is Deutz air cooled DG with rate output power of 8 kW and 10 kVA with the initial cost of $5700 and the fuel consumption at full load is less than 3 litters. The initial capital cost of the DG is assumed $570/kW. Replacement and operational costs were assumed $570/kW and $0.35/h, respectively. The operating lifetime was also considered 15,000 h. 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%.

4.4. Battery Size and Cost

The lead acid battery of EnerSys SBS model battery with 6 cells, 12 V, 190 Ah, and 2.3 kWh is selected in the proposed system, since this the type of battery used in the selected Ethio-telecom BTS site with 4 batteries in one string of 48V and total of 3 stings. The initial cost of one unit is considered as $300. Replacement and operational maintenance costs were assumed as $300 and $10/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 and the lifetime throughput of each battery is estimated to be 1000 kWh.

4.5. Power Converter Size and Cost

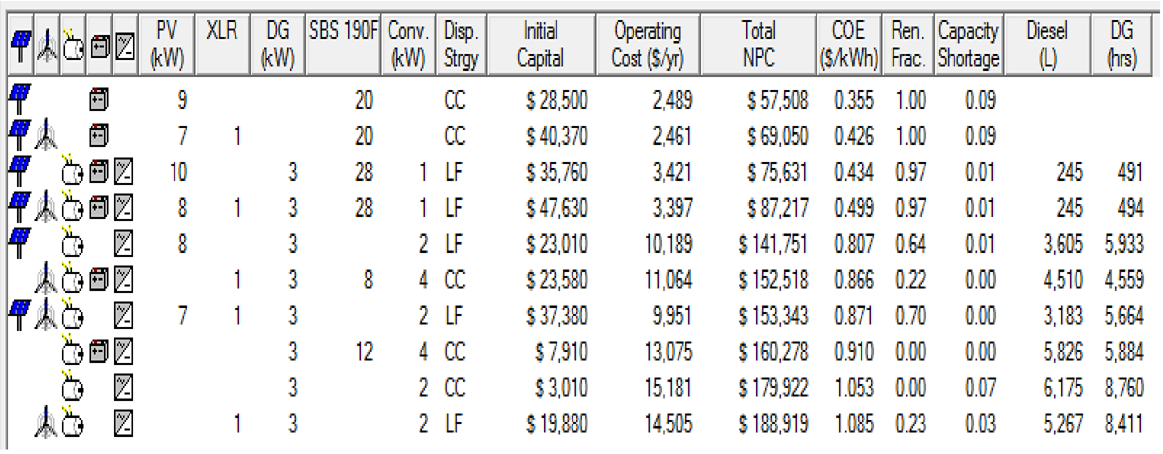
The initial capital cost and replacement cost and operation-maintenance cost of the convertor that is considering in system is 1 kW are $650, $650 and $10/year respectively. The efficiency of the converter is assumed to be 90% and the lifetime is considered as 10 years. Different sizes of converters (0, 2, 4, 6, and 8 kW) are considered during analysis using HOMER.

5. 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 81 sensitivity performing 23760 simulations.



PV (kW)	XLR	DG (kW)	SBS 190F	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Diesel (L)	DG (hrs)
9			20		CC	$ 28,500	2,489	$ 57,508	0.355	1.00	0.09		
7	1		20		CC	$ 40,370	2,461	$ 69,050	0.426	1.00	0.09		
10		3	28	1	LF	$ 35,760	3,421	$ 75,631	0.434	0.97	0.01	245	491
8	1	3	28	1	LF	$ 47,630	3,397	$ 87,217	0.499	0.97	0.01	245	494
8		3		2	LF	$ 23,010	10,189	$ 141,751	0.807	0.64	0.01	3,605	5,933
	1	3	8	4	CC	$ 23,580	11,064	$ 152,518	0.866	0.22	0.00	4,510	4,559
7	1	3		2	LF	$ 37,380	9,951	$ 153,343	0.871	0.70	0.00	3,183	5,664
		3	12	4	CC	$ 7,910	13,075	$ 160,278	0.910	0.00	0.00	5,826	5,884
		3		2	CC	$ 3,010	15,181	$ 179,922	1.053	0.00	0.07	6,175	8,760
	1	3		2	LF	$ 19,880	14,505	$ 188,919	1.085	0.23	0.03	5,267	8,411

Figure 6. Optimization results of the system.

The two best optimal hybrid system configurations PV/Battery and PV/WT/Battery which ranks first and second by the net present cost (NPC) with levelized cost of energy (LCOE), will be compared with the conventional DG/Battery/Converter system rank in eight. 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 4.

It can be seen from this table 4 below that the site can adequately rely on the RE source to power the remote telecom BTS towers equipment due to high presence of solar radiation and wind speed at the site.

Table 4. Performance parameters of three different system configurations.

Models / Parameters	PV/BB System (First Choice)	PV/WT/BB Systems (Second Choice)	DG/BB/Converter System (Existed system)
PV size (kW)	9	7	0
Wind Turbine (quantity)	0	1	0
Generator Size (kW)	0	0	3
Battery Bank (Quantity)	20	20	12
Converter Size (kW)	0	0	4
Dispatch Strategy	CC	CC	CC
Initial Capital cost ($)	28,500	40,370	7910
M&O Cost ($/year)	2,489	2,461	13,075
Total cost of Fuel ($/year)	0	0	4,660
Diesel Fuel Used (L)	0	0	5,826
DG Running hours (hrs.)	0	0	5,884
Renewable fraction (%)	100	100	0
Capacity Shortage (%)	9	9	0
Excess Electricity (KWh/year)	2,405	2,512	0
Unmet load (kWh/year)	1,207	1,189	0
Total electricity production (kWh/year)	17,436	17,357	17,652

5.1.1. PV/ Battery configuration

The best optimal combination comprised of 9 kW PV array and 20 units EnerSys power safe SBS 190F battery at 5.83 kWh/m^2 per day average global solar radiation, 3.687 m/sec annual average wind speed and 0.8/L diesel price. It has a renewable fraction of 100% solar energy without inclusion of wind. The cost summary of this system has a total net present cost of $57,508, levelized cost of energy of $0.355/kWh and operating cost of $2,489 per year. The total NPC for the stand-alone diesel system is $160,278 which is 3 time higher than PV/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 2,405 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 7.

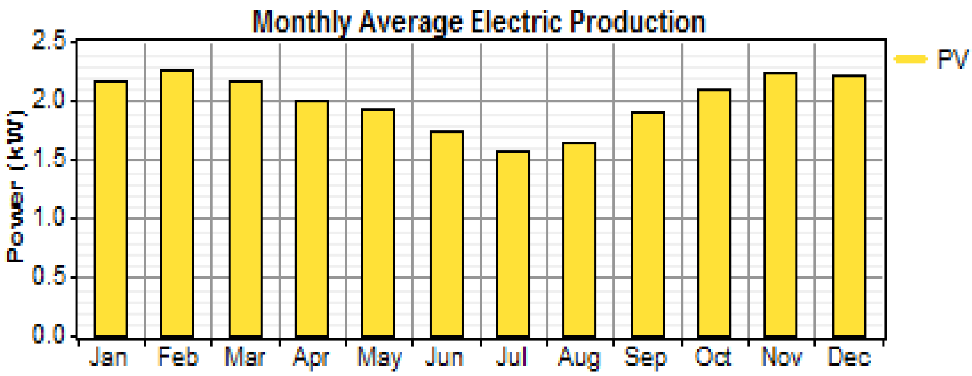


Figure 7. Monthly average electricity production of PV/Battery hybrid system.

5.1.2. PV/Wind/Battery configuration

The next optimal combination consists of 7 kW PV array, one 7.5 kW BWCXL-R wind turbine and 20 units EnerSys power safe SBS 190F battery and no converter because all electricity produced are DC. The result is based upon the system with 41.4 kWh/day telecom load at 5.83 kWh/m^2 of solar radiation, 3.687m/s of wind speed and $0.8/L diesel price.

The COE of this hybrid system is $0.426/kWh and the total NPC and Operating cost of the system were found to be $69,050 and $2,461 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 17,357 kWh per year, of which PV array contribute 78% and wind turbine provides 22% of the total annual production.

But the consumption as per the dc telecom load is found to be 20,344 kWh per year resulting excess electricity of 3969 kWh per year with unmet electric load of 1556 kWh per year and capacity shortage of 1825 kWh per year.

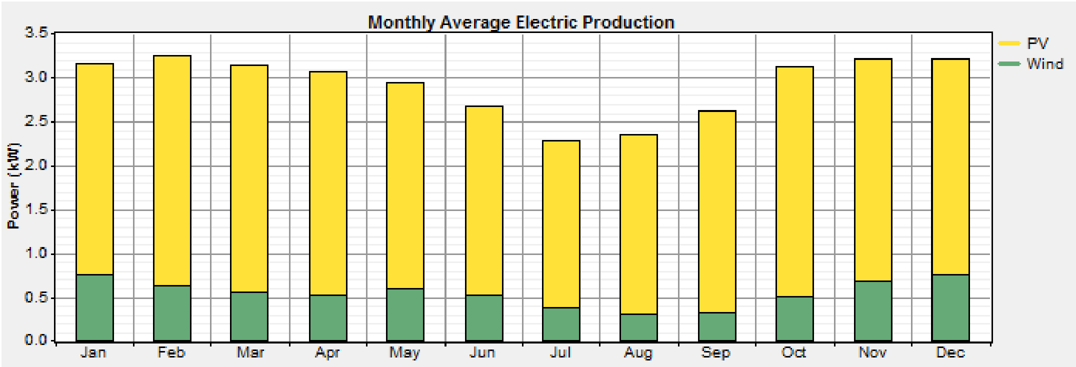


Figure 8. Monthly average electricity production of PV/Wind/Battery hybrid system.

As Figure 8 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 100%.

5.1.3. DG/Battery/Converter configuration

The conventional standalone generator system consists of 3KW DG, 12 unit battery, and 4KW converter. This project reveals that DG-Battery System is very costly with cost of energy (COE) $0.910/kWh and takes large total NPC of $160,278 due to the huge operation cost of $13,075 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 5,826 L/year and run for 5,884hr/year. The total electrical energy production from the DG system is found to be 17,652 kWh/year and DC primary load consumption of 15111 kWh per year; resulting no excess electricity production, no capacity shortage and zero unmet electric loads. CO2 emission is found to be 15,341 kg per year followed by 37.9 kg/year of CO emission per telecom tower.

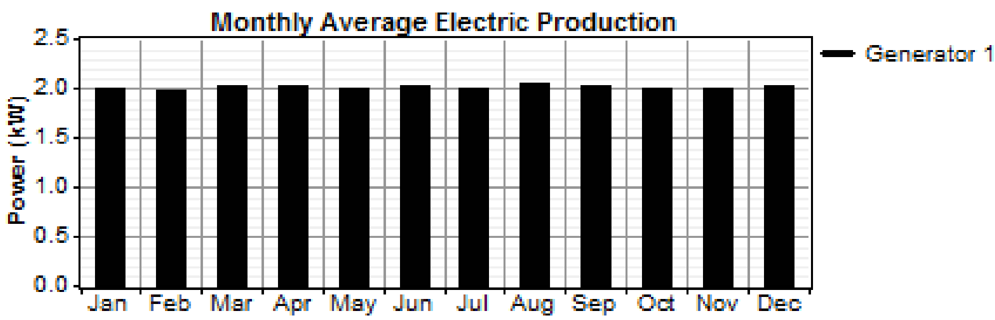


Figure 9. Monthly average electricity production of DG/Battery system.

5.2. 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, 5.83 & 8 kWh/m2/day), wind speed (2, 3.687 & 6 m/sec), annual average energy (20, 41.4 & 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.

5.2.1. Varying average wind speed and average solar radiation value

In this sensitivity analysis, OSTs 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/m2/day as shown in Figure 10.

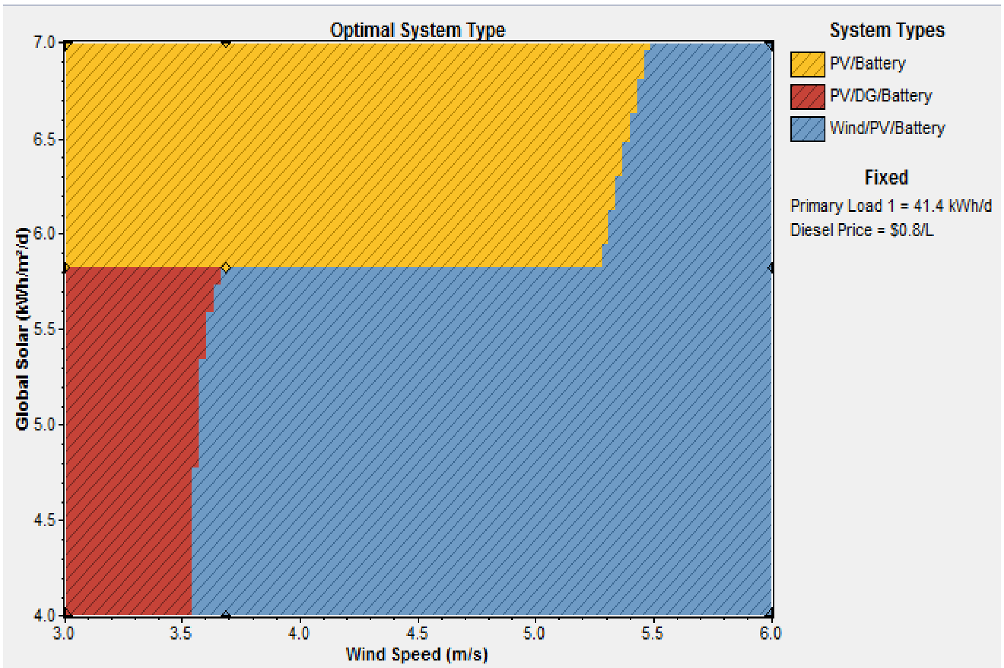


Figure 10. Optimal system types for varying solar radiation and wind speed values.

It is obvious from this Figure 10 that for the specified values of Primary load (41.4 kWh/day) and diesel price ($0.08/L) there is three best optimal configurations PV/Battery, Wind/PV/Battery and PV/DG/Battery at the considered site, therefore it 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

The paper indicates that the site is blessed with considerable annual average global solar radiation of 5.83 kWh/m^2/day and average wind speed of 3.69 m/sec at 30 m height. Therefore; there is a potential site for installation of PV/Battery hybrid system and PV/Wind/Battery hybrid system. The simulation results from HOMER show that the most economically feasible configuration for the site; both configurations have a renewable penetration of 100%. However, the conventional standalone diesel configuration is not economically due to the high cost of fuel consumption and O&M, which might have significant effect on the operating cost of the mobile telecom operation and also environmental impact due to high CO_2 & CO emission from the system.

Therefore, utilizing renewable-energy based hybrid system for powering BTS sites will decrease the operating cost of the telecom company which has direct impact on the low-income rural telecoms subscriber, but also eliminate the diesel fuel usage, thereby bring low greenhouse gas emission to the environment. Finally, the information gained from the entire project can be applied in the design, execution, or development of HRES for any mobile tower applications in other locations in the country.

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Conflict of Interest

All authors declare no conflict of interest in this paper.

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