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Published in:
Energy Conversion (CENCON), 2014 IEEE Conference on

Date of Conference:
13-14 Oct. 2014

Page(s):
243 - 247

Conference Location :
Johor Bahru, Malaysia

DOI:
10.1109/CENCON.2014.6967509

Publisher:
IEEE

Optimal Sizing of Hybrid Energy System for a Remote Telecom Tower: A Case Study in Nigeria

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***Abstract*— Hybrid energy systems are becoming attractive for providing electricity in remote areas due to excessive expenditure of grid extension, increase in oil price and advances in renewable energy technology. Optimal sizing of components can reduce the cost of hybrid systems. This article illustrates the size optimization of solar-wind-diesel generator-battery hybrid system designed for a remote location mobile telecom base transceiver station in Nigeria. Different energy combinations have been analyzed using HOMER 2.81 (Hybrid Optimization Model for Electric Renewables) in order to determine an optimal model. 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.**

Keywords— hybrid energy system; HOMER; telecom tower; off-grid remote electrification; Nigeria

I. Introduction

In Nigeria, about 11,692 mobile sites are connected to the national grid, out of which only 9% have up to 6 hours grid outage/day, 10% have 6-12 hours outage/day and 81% have more than 12 hours outage per day, while about 12,560 site are completely off-grid [1]. This uncertainty in availability of grid connected electricity compels telecom operators in Nigeria to the use of diesel generator for proving uninterrupted power supply to the telecom equipment. Annually, more than 500 million litres of diesel are consumed by telecom sites in Nigeria, resulting in CO_2 emission of about 1.3 million metric tonnes. The utilization of diesel generators as the main power generation for off-grid and back-up for grid connected telecom tower sites comes with its implicit disadvantage in terms of high cost of diesel based power generation as well as having a negative environmental impact due to high CO_2 emission per kWh consumed [2].

Renewable technologies offer clean, sustainable, green and reliable power generation as well as low operating and maintenance cost of power supply [3,4]. In Nigeria, both solar and wind are ubiquitously available sources of clean energy, bring power generation to where it is needed and thus being suitable for the telecom industry. However, independent solar photovoltaic (PV) and wind turbine generator alone cannot provide reliable power supply due to the intermittent nature of the resources (variation in solar irradiation, wind speed) because of changes in atmospheric conditions [5]. The combination of different energy resources allows improving the overall system efficiency, reliability of the power supply and reduces the energy storage requirements compared to the systems comprising only one renewable energy source [6].

This paper presents the results of technical and economic feasibility studies of employing hybrid renewable energy system (HRES) to power a remote location mobile telecom base transceiver station (BTS) in Nigeria. The stand-alone solar-wind with diesel backup hybrid system is an economically attractive alternative for mobile telecom sector over the conventional diesel generator standalone system [7]. A hybrid renewable energy system with diesel generator offers several advantages which include reduction in operating cost by decreasing operating time of the generator, reduction of environmental pollution and lower maintenance costs, etc. The inclusion of battery storage reduces the number of start/stop cycle of the generator and thus minimizes oil consumption considerably. The complementary nature of solar and wind resources combined with a storage system significantly increases the reliability of system [8].

The paper is organized as follows: Section 2 gives a brief description of the renewable energy resources potential of the study area, while section 3 presents the load demand profile of a typical rural site telecom base station. Section 4 discusses the required components for hybrid system modelling with their technical specification and cost summary. Section 5 presents the simulation result of HOMER software used in determining the optimal system design. Section 6 shows the environmental benefit of the proposed system and finally, concluding remarks are included in Section 7.

II. Solar and Wind Energy Potential in the Site

The telecom tower considered in this study is located at Doka-Sharia nature reserve, in Kaduna State, northern region of Nigeria with latitude (9^0 47'N) and longitude (7^0 20'E). The weather in the northern part of Nigeria can be characterized as hot and humid, and there are two major seasons, wet and dry seasons. Each season lasts roughly six (6) months. People living in this area are highly dependent on wood for cooking, gas lamps for lightings and the electrical equipment in most cases are powered by diesel generators. The fuel supply is very difficult due to an extremely bad state of road access to the area.

The country is endowed with abundant renewable energy resources due to its coordinate position; its lies within a high sunshine belt and thus have enormous solar energy potential.

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Table I shows the monthly variation of solar radiation and clearness index in the site as obtained from NASA surface meteorology and solar energy database [9]. These data serve as inputs to the HOMER (Hybrid Optimization Model for Electric Renewable) for economic modeling of energy systems. Solar radiation is well distributed with average solar radiation of about 5.75 kWh/m^2/day and average daily sunshine of 6 hours.

TABLE I. AVERAGE MONTHLY SOLAR RADIATION AND CLEARNESS INDEX PROFILE

Month	Clearness Index	Daily Radiation (kWh/m2/d)
January	0.568	5.72
February	0.573	5.95
March	0.605	6.36
April	0.628	6.41
May	0.637	6.15
June	0.613	5.7
July	0.529	4.99
August	0.487	4.83
September	0.532	5.5
October	0.596	6.17
November	0.603	6.09
December	0.584	5.79

On the other hand, wind energy is available at annual average speed of about 2.0 m/s in the coastal region and 4.0 m/s in the far northern region of the country [10]. With an air density of 1.1 kg/m3, the wind energy intensity perpendicular to the wind direction ranges between 4.4 W/m^2 at the coastal areas and 35.2 W/m^2 at the far northern region or the country [11]. Fig. 1 shows the monthly wind speed variation of the site, where the average wind speed is found to be 3.2m/s.

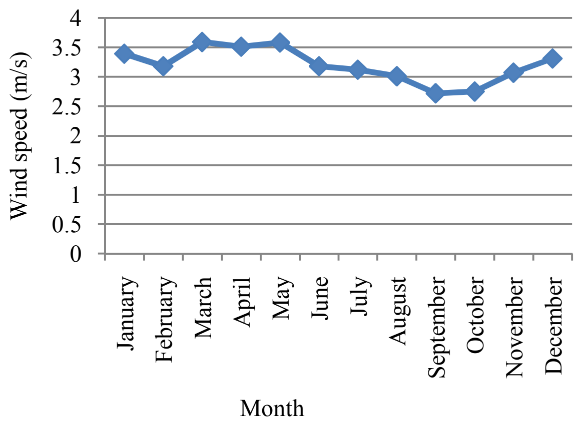

Fig.1. Average monthly wind speed (m/s) in the site

III. ELECTRICAL LOAD VARIATION IN THE SITE

Typically, a conventional BTS shelter load contains BTS equipment load, power unit (mini-link) load as well as air conditional and lighting loads. A 2nd generation (2/2/2) GSM mobile base station consisting of one BTS with three transceivers was considered in this study. The maximum power consumption of air conditioner is 1.8kW, while the BTS equipment power and miscellaneous load (battery charging load, fans and lights) are 800W and 480W respectively [12]. Normally, the full load will be constant to the BTS equipment load, miscellaneous load and the air conditioning system, but when the temperature goes low, the air conditioner can be configured to switch off automatically, thereby only the BTS equipment and the miscellaneous load will be powered. Fig. 2 shows the hourly load profile of the site, where average energy consumption per day and the peak demand is found to be approximately 37kWh and 3.3kW respectively.

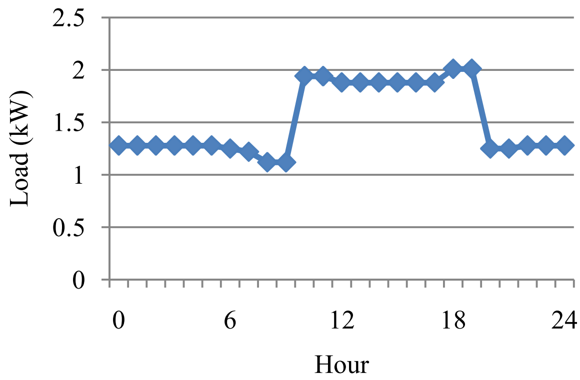

Fig.2. Daily load profile of the site

IV. HYBRID SYSTEM COMPONENTS AND CONTROL PARAMETERS

In this study, PV-wind-diesel-battery system is proposed for the site. The solar PV, wind and diesel generator components are integrated together to harness the output power of the system as well as to compensate for the unpredictable variations in the climate. The converter is added to maintain the flow of energy between the AC and DC components, while the battery is employed as a backup in order to ensure uninterrupted power and to maintain the desired power quality at the load point. The use of these three energy sources in parallel with battery storage provides a smooth and uninterrupted output which makes the hybrid system more reliable and efficient. Table II and III shows the control parameters and technical and study assumption data of different components used in this study respectively.

TABLE II. CONTROL PARAMETERS

Simulation time step	60 minutes
Dispatch strategy	Load-following and cycle charging strategies
project lifetime	25 years
Annual interest rate	6%
Maximum renewable fraction	0-100%
Maximum unserved energy	0%
Maximum annual capacity shortage	0, 4, 6 and 10%

The simulation time step is the time step that HOMER uses to simulate the operation of each system configuration. In the proposed system, the duration of simulation is set to 60 minutes. A dispatch strategy is a set of rules that controls the function of the generator(s) and the battery bank. In the proposed system, both load-following and cycle charging strategies are considered which means HOMER will simulate each system using both dispatch strategies and finally will determine the optimal configuration. All economic factors are calculated in constant dollar (US$) terms.

TABLE III. TECHNICAL DATA AND STUDY ASSUMPTIONS OF DIFFERENT COMPONENTS

PV array	
Capital cost	$2.5/W
Replacement cost	$2.0/W
Sizes consideration	0, 0.25, 2, 5, 7 & 8 kW
Lifetime	20 years
De-rating factor	90%
No tracking system	
Wind turbine	
Model	BWC WL.1
Rated capacity	1 kW
Initial cost per unit	$6760
Replacement cost	$4595
Maintenance cost	$25/year
Units consideration	0, 1 and 2 turbines
Lifetime	20 years
Battery	
Model	Trojan T-5
Rating	6V, 225 Ah, 1.35 kWh
Initial cost per unit	$174
Replacement cost	$174
Maintenance cost	$5/year
Units consideration	0, 16, 32, 48, 64, 80, 96 & 112
Battery string	8 batteries
Lifetime	845 kWh
Converter	
Capital cost	$200/kW
Maintenance cost	$10/year
Sizes consideration	0, 2, 4, 6 & 8kW
Lifetime	10 years
Efficiency	90%
Diesel generator	
Rating	5.5 kW, 22.6 A
Maximum load ratio	10%
Initial cost per unit	$1262/kW
Replacement cost	$1100/kW
Operational cost	$0.5/hour
Lifetime	15000 hours
Diesel price	$1.1/L
Sizes considered	0, 5.5 and 7.5 kW

V. SIMULATION RESULTS

A. Hybrid System Analysis

An hourly time series simulation was performed by HOMER for every possible system configuration on a yearly basis in order to evaluate the operational characteristics such as, annual electricity production, annual served, excess electricity and renewable fraction, etc. HOMER searched for optimum system configuration and component sizes that meet the load requirement at the lowest net present cost (NPC) and then presents the results of the simulation in terms of optimal systems and sensitivity analysis. The optimal results are categorized based on the sensitivity variables chosen. These results are discussed under the following subsections.

1) PV/diesel/battery Hybrid System

The cost of energy (COE) for a hybrid system consisting of 8 kW PV, 5.5 kW diesel generator with 64 batteries is $0.420/kWh. The total annual diesel consumption is 1,050L and total net present cost (NPC) reaches $71,739. The initial capital cost of a 8 kW PV system is around 60.24% of the total initial capital cost, whereas it is 3.8% and 26.3% for generator and batteries respectively. With regard to annual O&M cost for PV, it is negligible compared with the O&M cost of the diesel system.

2) PV/wind/diesel/battery Hybrid System

The hybrid system consisting of 8 kW PV panel, 1 kW of wind turbine, 5.5 KW diesel generator and 64 batteries, the COE from this hybrid system is $0.448/kWh. The total annual diesel consumption is reduced to 838L. NPC is increased to $76,473. The renewable fraction is 0.821 and the excess electricity is 3.14% (526 kWh).

3) PV/diesel Hybrid System

The hybrid system consisting of 8 kW PV panel and 5.5 KW diesel generator, the COE from this hybrid system is $0.664 kWh−1. The total annual diesel consumption is increased to 6,403l. NPC is increased to $113,334. The renewable fraction is 0.19 and the excess electricity is 43.2% (10,554 kWh).

4) Diesel/battery Hybrid System

The COE for a hybrid system consisting of 5.5 kW diesel generator with total number of 32 batteries is $0.665/kWh. For this scenario, the total annual diesel consumption is 5,902L and the total net present cost (NPC) reaches $113,586.

5) *Traditional Diesel Generator*

The traditional diesel generation system consisting of 5.5 KW diesel generator, the COE is $0.728/kWh. The total annual diesel consumption is increased to 7,804L. NPC is increased to $124,386. The excess electricity is 15.4% (2,441 kWh).

Table IV present the optimal configurations available based on the input data earlier introduced to HOMER and ordered it according to the lowest net present cost (NPC). The best optimal combination is PV-diesel-battery system at 5.8 kWh/m^2/d average global solar radiation, 3.2m/s annual average wind speed and 1.1$/L diesel price. It has a renewable fraction of 78% as shown in Table IV. It can be seen from this table that the site can adequately rely on the RE source (solar) to power the BTS equipment due to high presence of solar radiation at the site. Although the electric production of the wind turbine is limited due to the lower wind speed, but the diesel generator contributes to meet up the load demand during this period. The diesel generator operates for just 682hr/year (capacity factor 6.23%), produces 3000kWh/year and consumes 1050L of fuel per year. Limited hour of operation of diesel generator will reduce the operating cost and also lead to reduction in carbon emission into the environment. Increasing the size of the PV panel and the addition of more string of battery can also compensate the shortage of electrical production, thereby optimize the usage of excess electricity and increase the overall autonomy of the system.

TABLE IV. OPTIMIZATION RESULTS OF HYBRID SYSTEMS

PV (kW)	WT (kW)	Gen (kW)	Battery. (Unit)	Con. (kW)	TCC ($)	OC ($/yr.)	TNPC ($)	COE ($/kWh)	RF	Diesel (L/yr.)	Gen Hr. (hr./yr.)
8	-	5.5	64	4	33,198	3,015	71,736	0.420	0.78	1,050	682
8	1	5.5	64	4	39,958	2,856	76,473	0.448	0.82	838	543
8	-	5.5	-	4	22,062	7,140	113,334	0.664	0.19	5,533	6,403
-	-	5.5	32	2	7,230	8,320	113,586	0.665	0.00	5,902	4,134
-	-	5.5	-	-	1,262	9,632	124,386	0.728	0.00	7,804	8,759

TCC: Total Capital Cost, OC: Operating Cost, TNPC: Total Net Present cost, COE: Cost of Energy, RF: Renewable fraction

B. Sensitivity Analysis

Sensitivity analysis helps in exploring the effect the changes in the available resources and economic conditions of different system configuration. This analysis shows the range of the variables for which it makes sense to include the renewable energy in the system design. The sensitivity values entered for the solar radiation in kWh/m^2/d are 4.5, 5.0, 5.5, 5.8 and 6.0. For wind speed, the values are 3.0, 3.2, 3.3, 3.5and 4.0 m/s. Similarly, for the diesel price in l/$ are 1.1, 1.2, 1.3, 1.4 and 1.5.

HOMER simulates the entire system with respect to the search space. The feasible systems are ranked based on increasing net present cost (NPC), while the software eliminates all infeasible combinations. Fig. 3, 4 and 5 show the Optimal System Type (OST) sensitivity results for three different scenarios, namely variation of wind speed and solar radiation with constant diesel price, variation of wind speed and diesel price with constant solar radiation and finally, the variation of solar radiation and diesel price with constant wind speed. From Fig. 5, it is could be seen that at a wind speed less than 3.7m/s and lower diesel cost ($1.1/l), HOMER does not consider wind turbine to be feasible, it is more economical to exclude wind turbine from the system and consider PV-diesel-battery configuration to be the best optimal.

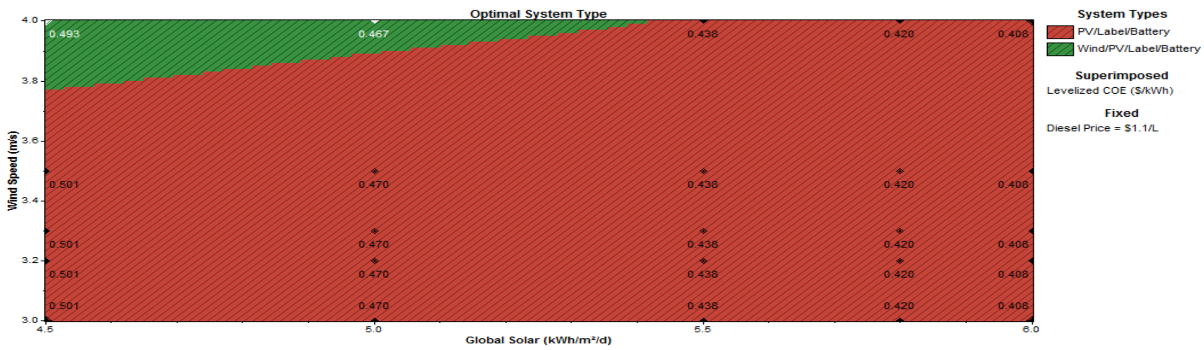

Fig.3. Optimal system type for variable wind speed and solar radiation with fixed diesel price

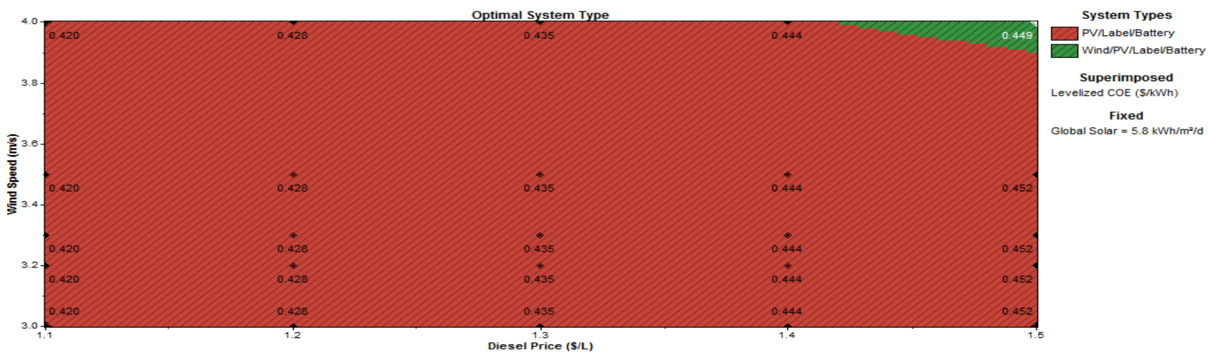

Fig 4.Optimal system type for variable wind speed and diesel price with fixed solar radiation

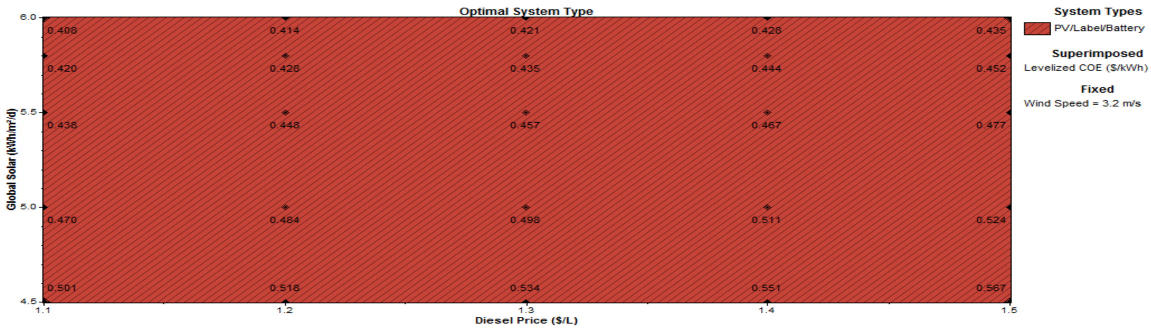

Fig.5. Optimal system type for variable solar radiation and diesel price with fixed wind speed

VI. Environmental Benefits

Renewable energy resources are clean and sustainable energy solution of a country. Table V shows the quantity of pollutants production in the hybrid systems compared to the conventional diesel based power generation system. The conventional diesel based power generation system produces a total of about 20,551 kg/year of CO_2 in the site. On the other hand, the hybrid PV/diesel/battery and PV/wind/diesel/battery systems produce a total of 2,765 and 2,207 kg/year of CO_2 respectively. This resulted in CO_2 emission reduction of 86.5% and 89.3% in the PV-diesel-battery and PV-wind-diesel-battery hybrid systems respectively. Other pollutants also reduce in the hybrid system compared to the conventional diesel system only.

TABLE V. COMPARISON OF EMISSIONS IN THE VARIOUS CONFIGURATION

Emissions (kg/year)	PV/diesel/battery	PV/wind/diesel/battery	Diesel only
Carbon dioxide (CO_2)	2,765	2,207	20,551
Carbon monoxide	6.83	5.45	50.7
Unburned hydrocarbons	0.756	0.603	5.62
Particulate matter (PM)	0.515	0.411	3.82
Sulphur dioxide (SO_2	5.55	4.43	41.3
Nitrogen oxides(NOx)	60.9	48.6	453
Total	2,840	2,266	21,105

VII. Conclusions

Techno-economic analysis of hybrid power systems for a remote telecom tower is presented in this paper. The study reveals that PV-diesel-battery system is a financially viable and sustainable solution for powering the proposed site. The most economically PV-diesel based hybrid feasible configuration is consisted of 8kW PV-array, 5.5 kW diesel generator and 64 units of batteries of which each has a nominal voltage of 6V and capacity of 255Ah having renewable fraction of about 78%. The diesel generation system is not financially viable due to the high cost of diesel, operating cost and also environmental negative impact due. Utilizing PV/wind/diesel/battery hybrid system for powering a BTS site in comparison with diesel system will decrease the operating hours and consequently the diesel consumption, thereby leading to reduction in greenhouse gas emission to the environment.

Acknowledgment

The authors would like to thank the Ministry of Higher Education, Malaysia and Bright Spark Unit of University of Malaya, Malaysia for providing the enabling environment and support to carry out this work. (Grant No. UM.C/HIR/MOHE/ENG/16001-00-D000024)

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