Analysis of Hybrid Energy Systems for Telecommunications Equipment: A Case Study in Buea Cameroon

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Abstract. The considerable expansion of telecommunications infrastructure in non-electrified areas has led to massive consumption of non-renewable energy sources by diesel generators. The promotion of renewable energy technologies as an alternative to these diesel generators is until now confronted with the problems of Capital Expenditures and system reliability. The hybridization of fossil fuels with renewable energies would make it possible to find a better quality/cost/environment ratio for the supply of off-grid telecommunication base stations (BSs).This paper presents the analyses of eight different hybrid energy systems dedicated for telecommunications equipment with a BS antenna as case study. The techno-economic analysis of hybrid energy system comprises solar, wind and the existing power supply. All the necessary modelling, simulations, and techno-economic evaluations are carried out using the assessment software package HOMER (Hybrid Optimization Model for Electric Renewable). The result shows that adding solar PV to the existing system is the optimal option. For the site studied powered by grid and diesel generator, the hybrid PV-diesel-grid with storage battery system is the best optimal system configuration for the chosen antenna with an initial capital cost of 34,619$, a Net Present Cost (NPC) of 55,588$ and a Cost of Energy (COE) of 0.39$/kWh.

1. Introduction

Telecom network operators are installing a higher number of base stations (BSs) to meet the demand of ever-increasing data rate and the number of mobile subscribers across the world. The exponential growth of mobile networks and the corresponding demand of huge amount of energy has become a great challenge to the researchers and network operators due to the limited reservation, higher capital cost, and the negative impact of fossil fuel. As much of the consumption of energy is mainly supplied by fossil fuel, the telecommunication sector has become one of the key emitters of carbon contents. The rapidly increasing energy demand by the ICT industry not only places heavy pressure on the public utility grid but also exerts a negative impact on the economy apart from greenhouse gas (GHG) emissions [1]. Considering the above circumstances and due to the growing awareness of pollution rate and economical perspectives, hybrid renewable energy system (HRES) technology plays a significant role in promoting green mobile communication. The HRES technology primarily aims to find out the sustainable energy sources, to minimize the capital cost, and to reduce the carbon contents by maintaining the guaranteed quality of services (QoS) [1].

A hybrid energy system consists of two or more energy sources used together to provide increased system efficiency as well as greater balance in energy supply. They integrate two or more energy generation, storage and consumption technologies in a single system, improving the overall benefits compared to a system that depends on a single source.

Figure 1: typical off-grid hybrid PV-wind-diesel powered mobile base station [2].

They generate electricity from two or more sources, usually renewable, sharing a single connection point.

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Hybrid installation may or may not always include storage systems. There are many types of hybrid energy systems, they include; Photovoltaic/wind, Photovoltaic/wind/diesel, Photovoltaic/hydraulic, Hydraulic/wind, Biomass, Photovoltaic/wind/biomass, etc. In addition, a hybrid generation plant can be created from scratch or more commonly, an existing plant can be hybridized by adding a new module from another source to the existing generation technology. Novelty of the present paper is the upgrading of an existing energy system to supply telecoms base station.

2. Related works

Over the past years, significant developments have been made in integrating electrical grids and renewable energy into a smart grid to manage the power supply of BS sites. The telecom operators and academia to develop an eco-friendly have completed a number of research works and sustainable green cellular network for the next-generation mobile communications utilizing the locally available renewable energy sources [1].

For instance, Olatomiwa et al. [2] in 2015 did techno-economic analysis of PV-diesel-battery and PV-wind–diesel–battery power systems for mobile BTS. Their study, presents the results of technical and economic feasibility of employing HRES to power a remote location mobile telecom BTS in Nigeria. Their study aimed to determine the viability of hybrid PV–diesel–battery and PV–wind–diesel–battery power systems as well as selecting the most cost-effective and environmental friendly configuration for the site. Hybrid optimization model for electric renewable (HOMER), one of the most widely used optimization tool for renewable energy systems was employed to carry out the techno-economic analysis. Their selection of the suitable configuration was based on net present cost (NPC), cost of energy (COE), and renewable energy fraction obtained from HOMER simulation software. The methodology they used was organized as follows:

- Assessment and analysis; presents the brief description of HOMER software.
- Site location was selected.
- Load profile collected.
- Solar and wind resources of the study area obtained.

Their simulation results from HOMER showed that the most economically feasible configuration for the site load of Doka-Sharia rural area of Kaduna State in Nigeria blessed with considerable annual average global solar radiation (5.8 kWh/m2 per day) and average wind speed (3.2 m/sec) was PV/diesel/battery hybrid system.

During the years 2000-2006 the Operational Program "Competitiveness" was conducted under the European Union’s 3rd Community Support Program [3]. Many HPS systems were installed in Greece for three telecommunication operation companies, in order to replace their autonomous diesel generators in remote areas. Those power systems were designed and installed by a Greek company named GERMANOS S.A. The HPS installed for the three mobile operators were consisted of photovoltaic panels, an auxiliary diesel generator, two battery banks, one three-phase two-way inverter and a system controller. The methodology they used was to simulate the old and new power supply system of the BTS using HOMER. After the implementation of the HPS investments and the start of its operation, the total annual O&M costs greatly reduced. Also, the annual consumption of diesel fuel was reduced over 96%, the diesel generators efficiency was increased from 5.69% to 30% and the emissions or the air pollution were reduced by more than 90%.

Alsharif and Kim [4] addressed the feasibility of a solar power system based on the characteristics of South Korean solar radiation exposure to supply the required energy to a remote cellular base station. They used HOMER to determine the optimum size of the system components, to perform an energy production analysis, and to analyse the cost details of the project. The methodology they used was as follows:

- they studied the feasibility of the solar power system to feed remote cellular base stations under various cases of daily solar radiation in South Korea;
- determined the optimum criteria and the economic and technical feasibility of the solar power system using HOMER software;
- and did economic comparison of the proposed solar power system with diesel generators. The simulation results showed that the proposed solar power system can achieve total operational expenditure savings of up to 48.6% by using sustainable and clean energy. This result means a significant long-term benefit can be achieved for cellular network operators.

All the above mentioned papers used HOMER software to perform techno-economic analysis of different hybrid systems dedicated for telecommunication base stations. Some did optimization analysis by comparing the existing diesel generators to a new proposed hybrid energy system consisting of solar, wind, biomass energy systems, others proposed new hybrid energy systems. Their simulation results showed the most cost effective, reliable and low pollution hybrid energy to be used for the site, depending on the NPC, COE and level of CO_2 emission.

3. Methodology

The prime objective is to carried out the optimization of RES utilization to minimize net present cost (NPC) and fossil fuel consumption while ensuring long-term energy sustainability over a period of 20 years. However, the optimization of technical and economic feasibility for various sorts of BS are analyzed using a hybrid optimization model for electric renewables (HOMER) software. The telecommunication antenna at university of Buea, Cameroon as shown in Figure 2 was taken as case study.

3.1. Site location

The mobile telecommunication antenna considered for this study is located at university of Buea, Southwest region of Cameroon with latitude (4° 8’ North) and longitude (9° 17’ East). The weather here can be characterized as humid, and there are two major seasons namely rainy and dry seasons. Each season remains about 6 months.

Figure 2: Telecom antenna located at the University of Buea, Southwest region Cameroon.

3.2. Site load profile

This antenna consists of base stations for MTN (67A), ORANGE (33.1A), NEXTTEL (27.2A) and CAMTEL (13.9A). The load present at this location include base station (main load with in-build DC air conditioner), and lightening bulbs. The power supply unit is made of grid, diesel generator and storage battery bank. They work together to supply the Base station at the antenna site. The voltage supplied to all the base stations is 12V each but the current differs.
Detailed hourly data for a single day of the load profile of antenna (focus only on base station) was collected to be used as input for simulation with HOMER. The load profile at the site in Table 1 consisted of collecting load current and power during 24 hours in a day.
The load profile data collected were current values in Ampere (A) after every hour of the day. The load power was obtained from these current values by multiplying them with the base station (load) voltage, which is 12V.
Daily load profile of base station at antenna (May 27, 2021), Base station voltage = 12V

$$\boldsymbol{Power_{BS} = I_{load} \times V_{BS}} \qquad (1)$$

Where $\boldsymbol{Power_{BS}}$ is the power of the base station, $\boldsymbol{I_{load}}$ is the load current and $\boldsymbol{V_{BS}}$ is the base station voltage.

Power of Base station is equal the load current times base station voltage.

Table 1: Daily load profile of antenna near U-block of University of Buea

Time (Hour)	Load current (A)	Load power (kW)
00-01	62.25	0.747
01-02	67.92	0.815
02-03	68.83	0.826
03-04	68.00	0.816
04-05	81.75	0.981
05-06	82.00	0.984
06-07	107.5	1.290
07-08	128.0	1.536
08-09	137.6	1.651
09-10	133.7	1.605
10-11	129.3	1.551
11-12	133.2	1.599
12-13	131.3	1.575
13-14	140.2	1.682
14-15	137.8	1.654
15-16	148.6	1.783
16-17	131.5	1.578
17-18	133.3	1.600
18-19	113.1	1.357
19-20	113.9	1.367
20-21	112.6	1.352
21-22	95.00	1.140
22-23	94.75	1.137
23-24	77.83	0.934

Inputting this data in HOMER, we obtained a scaled annual average energy consumption per day of 34kWh/day and a peak load of 3.5kW. The daily profile is obtained as shown in Figure 3. This shows how the load varies during each hour of the day.
The existing power supply at the antenna site consist of diesel generator, storage battery bank and the grid. To explore more possibilities of hybrid power supply which can be more economical (low NPC), reliable and less polluting, we will introduce a solar PV and wind turbine system to the existing power supply.

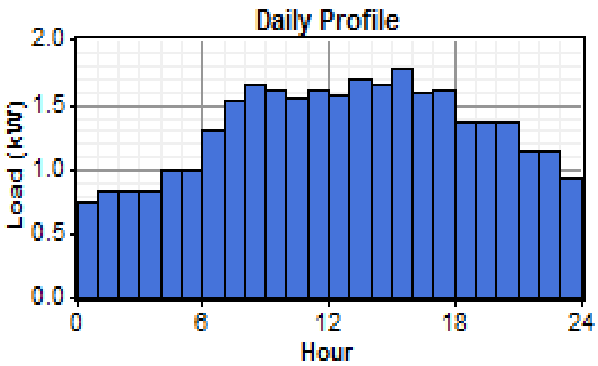

Figure 3: Daily load profile of the site [5].

3.3. Solar and wind energy resources

Cameroon is endowed with abundant renewable energy resources due to its coordinate position. It lies within a high sunshine belt and thus has enormous solar energy potential. Figure 4 shows the monthly variation in solar radiation with the clearness index. These data serve as input to the HOMER for the analysis. Solar radiation is seen to be well distributed in the site with average monthly solar radiation of 4.37 kWh/m^2/d.

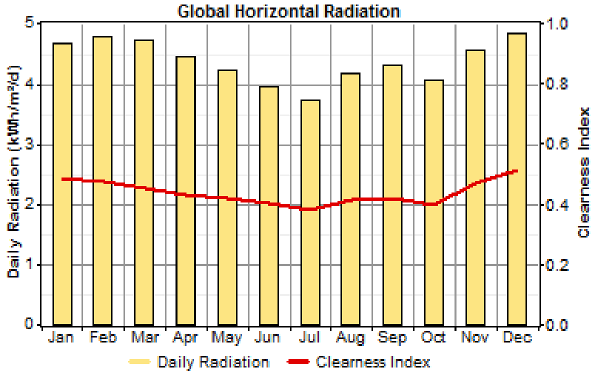

Figure 4: Average monthly solar irradiation index of the University of Buea [5].

Wind energy is available with an annual average speed of about 4.42 m/s. Figure 5 represents the monthly average wind velocity of the city of Buea. The low solar power output during the rainy season is offset by the high power wind generation, which leads to minimizing the fluctuation of hybrid RE production.

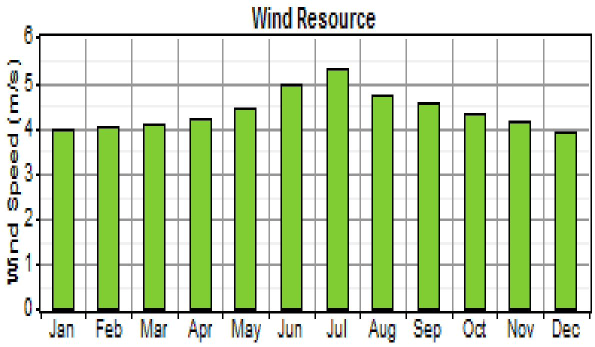

Figure 5: Average monthly speed for Buea in South West Cameroon [GlobalWindAtlas].

3.4. Solar and wind energy resources

In this section, detail system design and simulation of 8 different hybrid energy systems is done using HOMER. These hybrid energy systems are:

- Diesel generator, battery backup and the main grid (ENEO); existing system
- PV and the main grid.
- PV-diesel generator only.
- PV-diesel hybrid system connected to the unreliable grid (existing system + PV)
- Diesel Generator-Wind turbine and grid (existing system + wind)
- PV-wind-diesel generator
- PV-wind and the unreliable grid
- PV-Wind-Diesel generator-battery connected to grid (existing system + PV-Wind)

The following steps are included in the system design: PV module selection; Wind turbine selection; Details on the existing 12V Lead acid Battery; Details on the existing 20 kVA diesel generator.

3.4.1. PV module selection

12V DC supplies the base station and the maximum power of all the base stations is 1.8kW.This study considered a polycrystalline solar PV panel of 12V, 1kW. Table 2 shows the Solar PV specification. Two of this solar system is needed to make up the 2kW.

Table 2: Solar PV specification

Solar PV specification	
Solar panel type	Polycrystalline
Maximum power	$1kW_P$
Operating voltage	12V
Cost/kw	647,000 XFA (1,200USD)
Efficiency	14%
Warranty	10-25 years

The kWh usage of the battery (Bat kWh) is obtained by multiplying the Amp hour (Ah) rating of the battery (Bat Ah) by the system voltage (Bat voltage) and the number of batteries present (n) in parallel.

$$Bat\ kWh = Bat\ Ah * n * Bat\ Voltage \quad (2)$$

Battery $kWh = 180Ah \times 8 \times 12V = 17.28kWh$

The power of the battery ($W_{battery}$) is given by

$$W_{battery} = \frac{\text{Battery } kWh}{\text{time}(hours)} \quad (3)$$

The power delivered by the battery for 8 hours, the time of autonomy is;

$$W_{battery} = \frac{17.28kWh}{8\ hours} = 2.16kW$$

For a 12V, $2kW$ solar panel, the 8 batteries (all in parallel) of 12V, 180Ah are sufficient for storage.

Table 3: Existing battery bank specifications

Battery characteristics	
Battery type	PC12/180FT
Part number	NGPC120180HSOMA
No of batteries in a strings	1
No of parallel strings	8
Battery nominal voltage	12V
Battery rating	180Ah
Life cycle	20years
Cost of each battery	517,000 XFA (960USD)

3.4.2. Wind turbine selection

A Whisper 500 wind generator model is proposed to power cellular BSs due to low capital cost and longer life span and its rated power is suitable for our load [6]. It has the following characteristics

Table 4: Whisper 500 wind turbine specifications

Whisper 500 wind turbine specifications	
Rotor diameter	4.5m
Start-up wind speed	3.4m/s
Rated power	$3kW$
Body	Welded steel-powder coat protection
Blades (two)	Carbon reinforced fiberglass
Cost	4.7 million XFA (8780 USD)
Warranty	3 years limited warranty

3.4.3. *Existing 20kVA diesel generator*

Detailed characteristics of the 20kVA diesel generator was inputted in HOMER simulation. A 20kW converter is used to convert the AC produced by the generator and the grid to DC for the load.

Table 5: Diesel generator specification

Existing diesel generator	**Characteristics**
Diesel generator type	PERKINS 404A-22G1
No of cylinders	4
Fuel type	Diesel
Rating	20 kVA
Diesel tank capacity	50liters
Specific fuel consumption	4liters/h
Capacity Kw	16Kw
Cost	2.85million FCFA (5300USD)

3.5. Simulations

The simulation study will be performed on different cases to verify the effectiveness of adding a solar PV and/or wind turbine generator to the existing mini-grid supply system. The actual electricity cost for the grid is Rate1 with 0.17USD/kWh.

- ***PV and the grid system***

The proposed system shown in Figure 6 consists of the grid, the PV generator, the converter and the storage battery. Diesel generator is not included in the system. This simulation is to compare the technical and economic impact of integrating PV generator to the grid of the system performance.

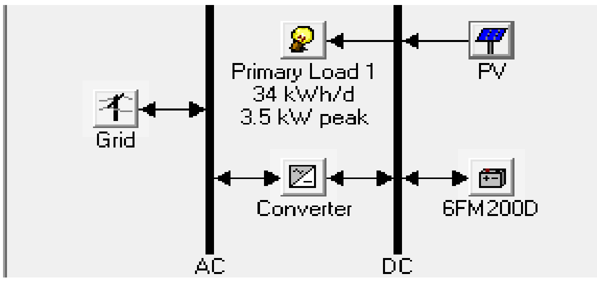

Figure 6: simulation of PV and grid system [5].

The remaining 7 systems were configured in a similar manner and simulated in HOMER to obtain the various NPC and COE.

4. Results

This section is an analysis result on 8 system models. This analysis will cover the technical and economic system performance for 20years lifetime. The simulation performed with HOMER is aimed towards finding the optimized system based on the cost and size for the existing components. Analysis will be focused on the system NPC (Net Present Cost) and COE (Cost of Energy). The optimum HRES for the site is based on lowest net present cost (NPC) and cost of energy (LCOE) using HOMER software model for a project life of 20years. The average daily load was found to be approximately 34.2 kWh with peak load of 3.5 kW.

4.1. Hybrid energy systems Net Present Cost (NPC) and Cost of Energy (COE)

NPC of components is the present value of all cost of installing and operating the component over the project lifetime minus the present value of all the revenues that it earns over the project lifetime.

The table 6 shows the different hybrid energy systems NPC and COE

Table 6: Hybrid energy systems Net Present Cost (NPC) and Cost of Energy (COE)

System	NPC ($)	COE ($/kWh)
Diesel-grid (existing)	**57,693**	**0.401**
PV-grid	**46,471**	**0.323**
PV-diesel	178,161	1.237
PV-diesel-grid (existing + PV)	**55,588**	**0.386**
Diesel-wind-grid (existing + wind)	70,329	0.488
PV-wind-grid	64,481	0.448
PV-wind-diesel	144,792	1.011
PV-wind-diesel-grid (existing + PV-wind)	69,904	0.488

As seen from Table 6 above, the hybrid system with the least NPC and COE is the PV-grid hybrid system with a NPC of 46,471$ and COE of 0.32$/kWh followed by the hybrid PV-diesel-grid system with NPC of 55,588$ and COE of 0.39$/kWh.

Since the existing system already includes the diesel generator and the grid is not always reliable, the both hybrid system (PV-diesel-grid and PV- grid) are the best supply systems for this antenna according to cost and reliability. Figure 7 shows the flow chart for the proposed hybrid energy system.

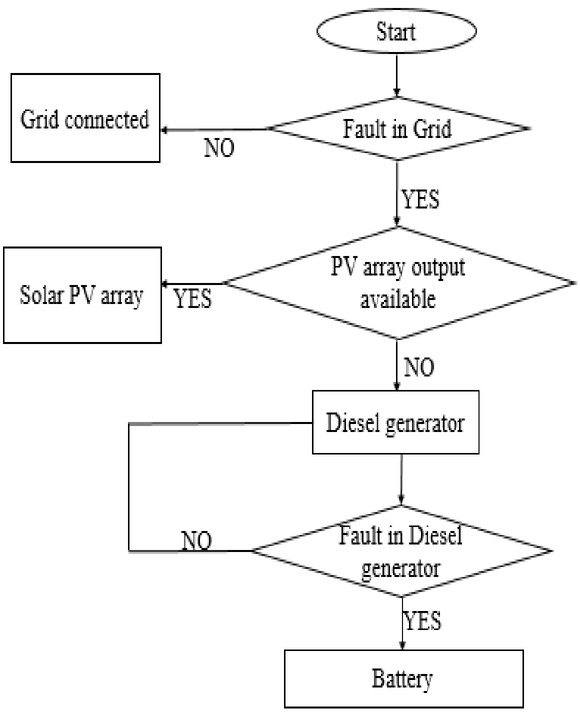

Figure 7: Flow chart of proposed hybrid energy system

This flow chart is similar to that of the existing supply system; the only difference is that the solar PV array is the second choice for power supply since it is cheaper and less polluting than the diesel generator.

5. Conclusion

Techno-economic analysis of hybrid power system for a telecommunication mobile base station (BTS) using HOMER, hybrid system optimization tools is presented in this study. The study indicates that the antenna at the University of Buea, Southwest region of Cameroon blessed with considerable annual average global solar radiation (4.37 kWh/m^2/day) and average wind speed (4.42 m/s) is a potential site for installation of PV/diesel/battery hybrid system. Eight different hybrid energy systems have been studied using HOMER simulation software to clarify the economic aspects of such systems and to obtain the most reliable and cost effective hybrid system. As results, the best hybrid energy system for the chosen antenna site is the hybrid PV-diesel-grid with storage battery system with an initial capital cost of 34,619$, a Net Present Cost (NPC) of 55,588$ and a Cost of Energy (COE) of 0.39$/kWh. Which is the existing energy supply system with the integration of a 2kW solar PV array.

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