DESIGN OF A SOLAR FARM USING HORMER FOR BORNO STATE UNIVERSITY

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ABSTRACT

The Borno State University relies heavily on backup generators, powered by diesel or petrol, to meet its energy needs due to frequent power outages, resulting in significant financial burdens. These generators are in constant use for extended hours each working day. Recognizing the urgent need for a reliable power source, there is a compelling case for exploring renewable energy solutions. The aim of this study is to design a solar farm for the Borno State University using HOMER. Through an in-depth analysis of energy consumption patterns within the university, significant variations across facilities, with administrative and information technology departments being major consumers, were identified. To tackle these challenges, the study proposes the design of a solar farm for Borno State University using the Hybrid Optimization Model for Electric Renewable (HOMER). Leveraging solar irradiance data and load assessments, the study determines an optimal system configuration featuring Canadian Solar Max power CS6U-340M panels, Tesla Powerpack 2 batteries, and an 1852 kW converter. This configuration is projected to meet the university's energy demands, offering a sustainable, clean, and cost-effective alternative to conventional energy sources. The proposed solar farm would not only address the immediate energy needs of the university but also aligns with the global trend towards sustainable and renewable energy solutions. It is recommended that further comprehensive feasibility studies, including detailed site-specific environmental assessments, precise cost-benefit analyses, and technical validation by renewable energy experts, be conducted to ensure the proposed solar photovoltaic system is optimally designed, financially viable, and environmentally sustainable for long-term implementation.

Keywords: Solar energy, Renewable energy, HOMER, Maiduguri, Irradiance

1 INTRODUCTION

In recent years, the global demand for energy has markedly risen, driven by swift population expansion and industrial development. This situation presents a grave risk to economies, energy security, and the pursuit of sustainable development [1]. Electricity is one of the major factors for economic prosperity of a country [2]. Presently, Nigeria is grappling with a widespread shortage of electrical energy. Inadequate power generation has led to frequent outages and the need to ration energy supply, placing a strain on people's livelihoods [3]. The root of this problem lies not in the absence of energy resources but can be attributed to factors like inadequate resource planning and management, ineffective energy policies, economic challenges, and limitations in funding and implementing energy initiatives. Unstable electricity distribution and frequent blackouts are a prevalent concern within the urban area of Maiduguri, located in Borno State, Nigeria [4]. To illustrate, the city experienced a total separation from the national electricity network for an extended period subsequent to an attack by insurgents on the Damaturu-Maiduguri Transmission Line in January 2021 [5]. In order to fulfil their energy requirements, there is a growing focus on using backup generators for self-generation. However, relying on these backup

generators consistently comes with significant financial burdens for the local population. The educational sector of the nation, crucial for advancing cutting-edge research in science and technology to enhance technological progress and global competitiveness, has not been exempt from challenges. Government-owned higher education institutions now rely on fossil-fuelled generators to fulfil their energy needs [6, 7]. This shift is due to the absence of a designated energy allocation, which was guaranteed prior to the disaggregation and privatization of the former Power Holding Company of Nigeria in 2013 [8]. Consequently, electricity provision to these institutions has decreased significantly, adversely affecting research accomplishments and administrative efficiency. A majority of government-run higher education institutions are reliant on fossil-fuelled generators, while those unable to afford this option must contend with insufficient electricity supply from the main grid. To address this issue, a study was carried out at the University of Lagos, Nigeria, with the aim of quantifying the financial burden that diesel generators impose on the university [9]. The investigation focused on several grid schemes, including 132/33/11 kV substations, and power generated from captive Cummings diesel generators. The findings indicated that the University expended so much on power generation, with 71.21% of the amount allocated to diesel generator use and the remainder attributed to grid supply. Such high costs are problematic, especially considering the financial requirements for establishing and maintaining a fully equipped university that meets academic and institutional standards across all domains. In addition to financial concerns, there are also environmental consequences linked to the emission of greenhouse gases (GHGs) from conventional diesel generators [10, 11]. This aspect imposes a substantial environmental burden, particularly when considering the total hours of generator operation and carbon dioxide and other GHGs emissions. The increasing demand for electricity and persistent grid failures necessitate the exploration of alternative power sources. Renewable energy sources (RES) are expected to play a key role in guaranteeing a clean and sustainable development [12]. Furthermore, a university community, despite its dynamic nature and diverse way of life, serves as a representative modern community that can serve as a prototype for emerging urban areas. As a result, the aim of this study is to design a solar farm for the Borno State University using HOMER.

2 METHODOLOGY

2.1 Study Area

The University is located on a parcel of 107.558 hectares of land along Kano Road in Maiduguri, capital city of Borno State. The site is between the geographical coordinates of 11.8480° and 13.0040° (Figure 1). The location, natural site factors as well as existing development within and around the site offer opportunities and also impose constraints on the site development potentials. The site for the University is located in a suburban setting, about 15 kilometres west of Maiduguri town centre. The entire area of the University site is a largely flat terrain. It is on an average elevation of 337m above the sea level. The site rises slightly effectively towards the northwest where the knoll, the highest point on the site is visible.

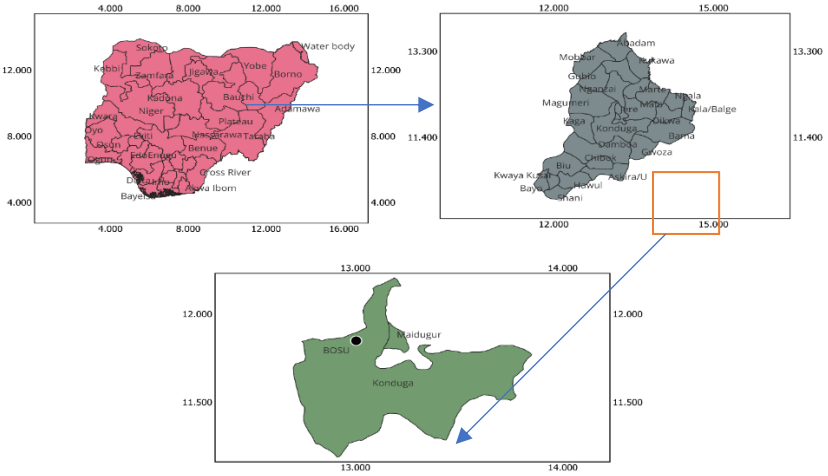

Figure 1. Map of Maiduguri showing the study area

2.2 Methods

2.2.1 Projected Energy Consumption

Firstly, energy audit was carried out to obtain the energy consumption of the university and the is used to project the future energy consumption of Borno State University.

2.2.2 Design Analysis

The analysis is conducted using the Hybrid Optimization Model for Electric Renewable (HOMER) tool, created by the National Renewable Energy Laboratory (NREL). This software is employed for designing and assessing the technical and financial aspects of off-grid and on-grid power systems, catering to remote, stand-alone, and distributed generation applications. The software serves as a comprehensive weather database primarily utilized for modelling diverse energy systems and processes. The required inputs for the HOMER software include electric load data, solar radiation, and temperature [13].

Load Assessment: The load assessment is determined based on the energy audit conducted. The average yearly, daily and hourly energy consumption is determined from the audit conducted and used for the design accordingly.

Solar Radiation: The solar radiation data for the project is obtained from the centre at Nigerian Meteorological Agency (NiMet). The solar energy potential at the location is as shown in Figure 2.

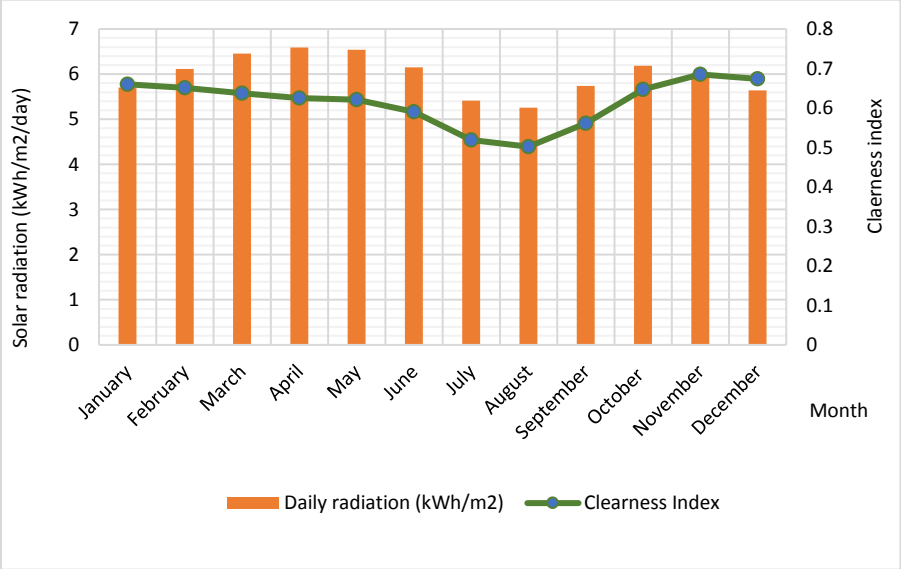

Figure 2. Solar energy potential at BOSU

Solar PV System: The model selected from HOMER library is Canadian Solar max power CS6U-340M 340W monocrystalline flat plate module manufactured by Canadian Solar with 17.49% efficiency and 0.34kw rated capacity. The power output of the PV System is given in Equation 1 [13].

$$PV_{PV} = F_{PV} \cdot Y_{PV} \cdot \left[\frac{I_T}{I_S}\right] \quad (1)$$

In this context, F_{PV} represents the derating factor, Y_{PV} denotes the rated capacity of the PV array in kilowatts (kW), IT signifies the global solar radiation (inclusive of both beam and diffuse) incident on the PV array's surface in kilowatts per square meter (kW/m²), and I_S is set at 1 kW/m², serving as the standard radiation level used for rating the capacity of the PV. The effectiveness of a solar PV system takes into account all the losses in a solar PV panel resulting from temperature fluctuations, shading on the panel, dirt, and inverter losses. The photovoltaic derating factor (F_{PV}) is a multiplier applied by the HOMER tool to the power output of the PV array, addressing the reduced output under real-world operating conditions.

2.2.3 Battery Storage Sizing and Modelling

The battery bank is composed of one or more individual batteries. In HOMER, a single battery is represented as a device with the capacity to store a specific amount of DC electricity and possesses a fixed round-trip energy efficiency. There are limitations on how quickly it can be charged or discharged, the extent to which it can be discharged without causing damage, and the amount of energy that can pass through it before requiring replacement. HOMER assumes that the battery's characteristics remain consistent throughout its lifespan and are not influenced by external factors such as temperature. Critical physical attributes of the battery in HOMER include its nominal voltage, capacity curve, lifetime curve, minimum state of charge, and round-trip efficiency. Given the inherent intermittency of solar power generation, energy storage serves as a backup to meet energy demand, particularly during nights and cloudy days. In the battery selection process, various factors must be considered. Initially, a survey of suitable batteries with low cost, availability in the country, proper size, suitable mobility, and compatibility with the system application is conducted. Subsequently, HOMER calculates the lifespan of the battery bank in years, as outlined in Equation 2 [13].

$$R_{batt} = \min\left(\frac{N_{batt} * Q_{lifetime}}{Q_{thrpt}}, R_{batt}, f\right) \quad (2)$$

In the equation, N_{batt} represents the number of batteries in the battery bank, *Qlifetime* is the lifetime throughput of a single battery, Q_{thrpt} denotes the annual throughput (the total energy cycled through the battery bank in one year), and R_{batt}, f signifies the float life of the battery (the maximum life irrespective of throughput). The model of the battery which is selected from HOMER library is Idealized battery model (Tesla Powerpack 2). It has a nominal voltage (V) of 380, nominal capacity (KWh) of 210, nominal capacity (Ah) of 553, efficiency (%) of 88%, maximum charge current (A) of 131 and maximum discharge current of 131.

2.2.4 Converter

This model is also selected from the HOMER library. It is a system converter of 0.34kw and 90% efficiency. The converter is expected to deliver maximum AC load in the University. Hence, inverter power rating, P_{inv} is selected using Equation 3, where P_{ACload}total power from AC load demand and 1.25 is set as oversized factor [14].

$$P_{inv} = P_{ACload} \cdot 1.25 \quad (3)$$

3 RESULTS AND DISCUSSION

3.1 Projection of Energy Consumption

Figure 3 outlines the yearly projected energy consumption for various facilities within the school. The projection considers 8 hours as duration of energy consumption daily. Notably, the Senate Building is anticipated to be the highest energy consumer, with a substantial projected consumption of 728,157.48 kWh. This suggests a significant demand for energy resources in the administrative and governance hub of the institution. The ICT department is another notable area with a substantial projected consumption of 389,411.20 kWh. Given the critical role of information and communication technology in modern educational institutions, this high energy usage is expected. The Faculty of Education, Agriculture, Social and Management Science, Medical College and the Hostel are also projected to have considerable energy needs, with consumption estimates of 239,810.84 and 214,865.28 kWh, respectively. These areas involve various activities such as classrooms, laboratories, and residential accommodations, contributing to their higher energy demands. The Miscellaneous category, with a projected consumption of 325,468.16 kWh, suggests that there are several decentralized energy-consuming entities or activities within the school that do not fall into specific facility categories.

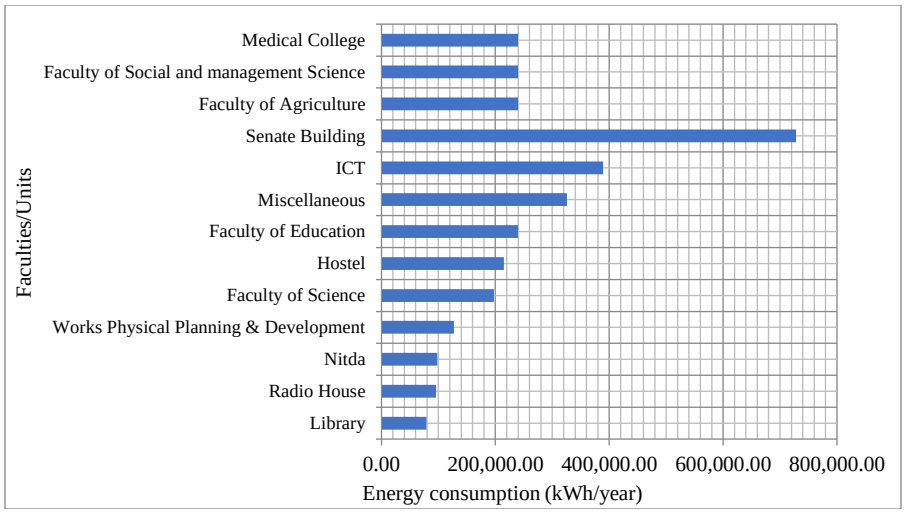

Figure 3. Projected energy consumption

3.2 System Sizing and Optimization

The process of determining the optimal system size was conducted using HOMER Pro. The solar irradiance data utilized for this analysis is visually represented in Figure 2, and the outcomes generated by HOMER are presented in Figure 4. The results show a comprehensive exploration of various configurations, considering diverse combinations of PV panels and battery banks. The ultimate system selection was based on evaluation of factors such as excess electricity generation and overall system efficiency. In the outcomes, various combinations involving different quantities of PV panels and battery banks were computed using HOMER. Eventually, the selected system was determined based on the surplus electricity generation and the overall efficiency of the system. As per the optimized results, a configuration comprising 6094 Canadian Solar Maxpower CS6U-340M panels with 340W each, 432 TeslaPP2 batteries (arranged in 36 strings of 48V, with 12 strings in parallel), and an 1852 kW converter will be sufficient to fulfil the load of 3.214 GWh/year.

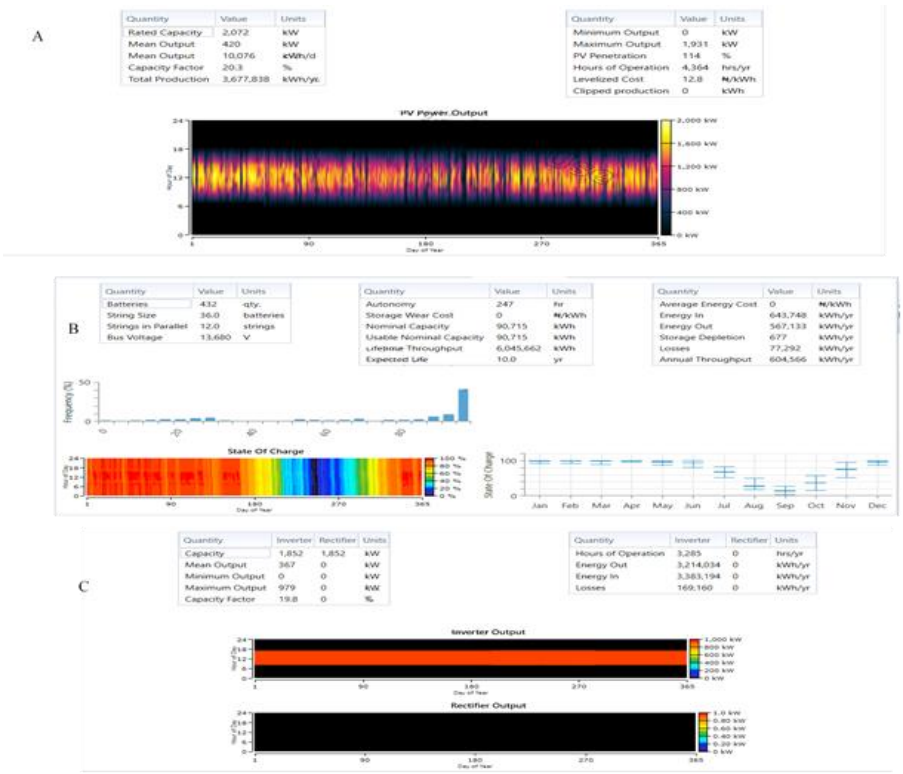

Figure 4. Outcome generated from HOMER. (a) solar panel (b) battery (c) inverter

Figure 4 (b) illustrates the storage state of charge, percentage of discharge, and the depth of discharge, which never exceeds 25%. Canadian Solar Maxpower monocrystalline was chosen for the photovoltaic (PV) system due to its efficiency of 17.49% monocrystalline nature. The power inverter, with a capacity of 1,852 kW, was sized based on the AC load's peak demand, capped at 3.214 GWh/year. The sizing of the PV panels took into account factors such as load demand, required power backup, and irradiance. The battery bank, in a floating state when PV output meets demand, is discharged only during night-time or insufficient PV output. Furthermore, considering the institution's average daily energy consumption of 8,807.37 KWh, the proposed battery bank size, determined through HOMER size optimization, ensures sufficient backup for adverse weather conditions. In the actual system sizing, a safety factor of 1.3 times was incorporated to protect against overloading and surges. The efficiency of the PV system is confirmed to be 17.49%, aligning with the specifications of the Canadian Solar Maxpower. The system block diagram is presented in Figure 5, where Figure 5(a) illustrates the solar panel connected to the DC bus, equipped with a maximum power point tracker (MPPT). The battery bank block, which includes a charge controller and under/overvoltage protection, is also connected to the same DC bus. The third block in this figure is the converter, responsible for converting DC to AC, ensuring power quality (harmonics reduction), and linking the DC and AC buses. The proposed system, as outlined in Figure 5(b), is an extension of the blocks presented in Figure 5(a). The output from the PV system is directed to the DC/DC converter block with a controller. The maximum power point tracker (MPPT) algorithm is integrated into the same block to regulate the converter's duty cycle, maintaining the output DC voltage at 48 V, which is then supplied to the battery bank. During normal operating conditions, when the PV output is sufficient to meet the load demand, the battery bank remains in a floating state.

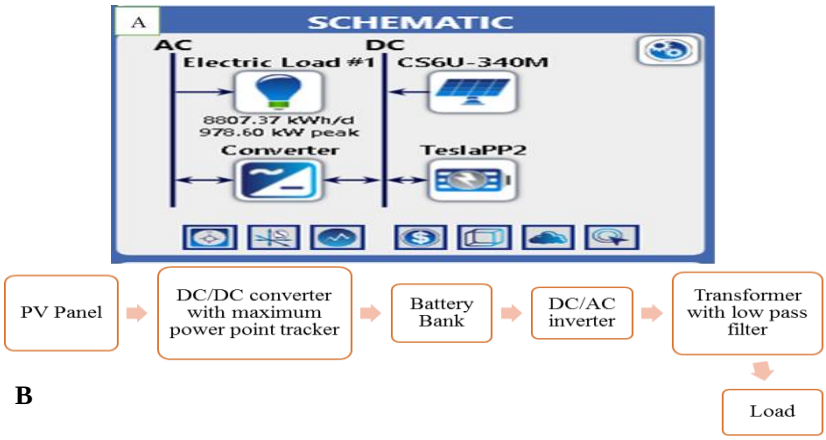

Figure 5. (a) System structure with integrated subblocks. (b) Flow chart of the system structure with subblocks

4 CONCLUSIONS

This study successfully demonstrates the feasibility of implementing a solar farm at Borno State University to address the energy challenges. The proposed solar system, comprising 6,094 Canadian Solar Max power CS6U-340M panels, 432 Tesla Powerpack 2 batteries, and a 1,852 kW converter, is designed to meet the university's annual energy consumption of 3.214 GWh. This renewable energy approach not only offers a sustainable alternative to fossil-fuel generators but also addresses multiple critical issues, including reducing financial burden, mitigating environmental impact through lower greenhouse gas emissions, providing a reliable power solution for critical university infrastructure, and serving as a potential model for other urban and educational institutions in Nigeria.

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