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Optimisation analysis of a stand-alone hybrid energy system for the senate building, university of Ilorin, Nigeria

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ABSTRACT

This study investigates the feasibility of providing electric power from a PV-Wind-Diesel-Battery hybrid system as an alternative energy supply to the Senate Building of the University of Ilorin, Nigeria. The case study presents an average daily energy demand of 1520 kWh, 712.5 kWh and 212.8 kWh during a typical dry season, rainy season and weekend days respectively. The daily average energy demand data is logged using Fluke 432-II Power Quality and Energy Analyzer. The solar irradiance and wind speed data of the site over one year period were sourced from the National Aeronautics and Space Administration (NASA) website. A two-objective optimisation cost function is formulated and solved considering three different scenarios of the case study. Analysis of various system configurations is carried to meet the power demand at the possible minimum cost of energy (COE). The results obtained are compared with that of Hybrid Optimisation Model for Electric Renewable (HOMER) software. Both approaches reveal that PV-Diesel-Battery system configuration yields the optimal results for the case study. Sensitivity analysis is carried out to examine the conditions under which it is technically and economically feasible to include wind turbine in the system design as proposed. However, comparative cost analysis carried out shows that the hybrid energy system with a cost of $0.283/kWh (#84.90/kWh) is not economically viable yet compared with $0.087/kWh (#26.00) currently charged by most electric utilities in Nigeria.

1. Introduction

A study carried out by the United Nations Environment Programme (UNEP) shows that between 1.7 and 2.0 billion people around the world do not have access to grid-based electricity, the majority of who live in the underdeveloped rural areas [1,2]. To provide power supply to such remote areas, two or more renewable energy sources could be employed. This is called hybrid energy system (HES). Hybrid energy systems are becoming popular as stand-alone power systems for providing electricity in remote areas due to advances in renewable energy technologies, rise in prices of fossil fuels, and need to conserve our environment.

In other words, the term ‘hybrid energy system’ describes a system in which different energy sources (solar, hydro, diesel generator, wind, biomass, etc) and energy storage systems are interconnected to supply the energy demand at a particular time [3–5]. As a matter of fact, the concept of hybrid energy system is not new in the power industry; however, it has only gained popularity in recent years. Hybrid power system has proved to be advantageous in reducing the depletion rate of fossil fuels, as well as supplying energy to remote areas with little or no pollution to the environment [6–9].

A number of research works have been carried out on hybrid energy systems. For example, in [10] a comparative techno-economic analysis of hybrid PV/Diesel and hybrid Wind/Diesel energy generation for a commercial farm land in Nigeria was performed. The result shows that Wind/Diesel hybrid is cheaper than PV/Diesel configuration.

In [11], a hybrid of photovoltaic system and wind power system with battery storage was presented using HOMER software for the optimisation analysis. LabView software which allows a real-time acquisition of electrical parameters and a data acquisition card used for voltage and current sensors of the global system was employed. The result revealed that the proposed hybrid system and its management control strategy are suitable for real life implementation as in electrification or water pumping for standalone applications.

The performance of a Wind-Solar hybrid power generation system was evaluated in [12]. The cost benefit analysis indicated that the hybrid system had a pay-back period of about 33 years. The autonomous distributive system of hybrid power generation was advantageous. In

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[13], the economic analysis of Solar-Wind-Diesel generator hybrid system in remote areas of Southern Ghana using levelized cost of energy (LCOE) and net present cost (NPC) of the system was investigated. Based on the sensitivity analysis results, the configuration can be applied to other locations in the region with global solar irradiance and wind speed similar to the chosen case study.

Based on the available literature, use of hybrid energy system as a form of alternative energy supply to tertiary institutions in Nigeria is very limited, despite the huge amount of money being spent on diesel fuel. However, in a related work by Ajao et al. [14], the load profile data based on hourly energy consumption of an apartment in University of Ilorin, Nigeria, was used in HOMER software for cost benefit analysis of hybrid-solar power generation relative to the utility cost of energy in Nigeria. However, the shortcoming of the work is that the load data collection approach is unprofessional, as it is devoid of thorough data acquisition and analysis.

Another related work on Nigerian tertiary institution to reduce carbon dioxide emissions released through retrofitting of lighting bulbs in various student hostels at the University of Lagos, Nigeria was carried out by Abolarin et al. [15]. The data used for the research analysis was based on existing electricity consumption data obtained from questionnaires, personal interview of students and management of the hall's facilities. However, the untechnical method of data collection in this study cannot guarantee accurate results.

Similarly, Asrari et al. [16] carried out economic evaluation of a hybrid renewable energy system for rural electrification in Iran. The hourly load profile data of the case study was a challenge. So the authors synthesized the hourly load profile of the case study using HOMER software by entering a value for a typical day. A 3% value was used for both day-to-day randomness and time step-to–time step randomness. This data collection method is unprofessional and could affect the reliability of the results.

On the premise of some of the above enumerated inadequacies, this study was carried out with the aim of filling the identified gaps. In this work, the authors used Fluke 432-II power quality and energy analyzer to log the hourly load consumption data of the case study building. A two-objective optimisation cost function was formulated and solved considering three different scenarios of the case study. Specifically, the contributions of this study include the following:

- Determination of the optimal renewable energy mix in the three scenarios considered in the work.
- Formulation of a two-objective optimisation cost function taking into account maximisation of profit and minimisation of CO_2 emissions.
- Assessment of the optimal system configuration to determine the technical and economic condition to realise the proposed system configuration for the case study.

2. Background

2.1. Description of the case study site

University of Ilorin is located in the ancient city of Ilorin, Kwara State, Nigeria. It is about 500 km from Abuja, the Federal Capital city of Nigeria. The University is one of the seven institutions of learning established by the Federal Government in August 1975 [17]. The institution is located on latitude 8º 26′ N and longitude 4º 29′ E. The Senate Building is a 6-storey building with 98 offices.

2.2. Daily load profile of the senate building

The daily load consumption pattern of the case study building was investigated for three different scenarios; a working day in the dry season, a rainy season working day and a weekend day during the dry season. All the three cases were carried out when the University was in session. The data of the daily load demand was logged using the three-phase Fluke 432-II Power Quality and Energy Analyzer shown in Fig. 1. The data logger is also capable of measuring the power quality, conduct load studies and capture hard-to-find voltage events.

Fig. 1. The three-phase data logger connected in the case study feeder pillar.

In this work, the instrument was employed to measure the case study daily load energy consumption over 24 h for 5 consecutive days in the working days and the two days of the weekend. The daily load profile of the case study building is as presented in Fig. 2, having computed the average values for each case. It is observed from the figure that the peak power demand for a working day in the dry season is approximately 226 kW at around 16 h, while its rainy season equivalent is roughly 81 kW. On the other hand, the peak weekend day was obtained as approximately 22 kW at around 20 h of the day. The logged data was imported into the laptop for further analysis using the SD card of the instrument.

2.3. Source of solar irradiance and wind speed data

The solar irradiance profile of the case study over one year is presented in Fig. 3 while Fig. 4 shows the annual average wind speed data collected for the same site. The two weather data were obtained from the Surface Meteorology and Solar Energy database hosted on the National Aeronautics and Space Administration (NASA) website [18]. The data was generated on entering 8.26° latitude and 4.29° longitude of the case study site. From Fig. 3, the monthly average irradiance value is minimum in August, with the value of 3.90 kWh/m^2/day and maximum in March having a value of 6.05 kWh/m^2/day.

The wind speed data for one year was obtained when a height of 10 m above the ground level was entered into the field of the software interface on the NASA website, from which a monthly average wind speed of 2.22 m/s was calculated. Given the wind speed data plotted in Fig. 4, it can be concluded that the case study site has low wind speed regime, which means it is not really viable for wind energy production.

2.4. The proposed hybrid energy system

Presented in Fig. 5 is the schematic layout of the proposed hybrid energy system. It is to be designed to consist of two renewable energy sources – wind energy conversion system and solar photovoltaic system, with diesel generator and battery energy storage system as back-up, in the event that the two renewable energy sources are inadequate to meet the total load demand.