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Optimal configuration assessments of hybrid renewable power supply for rural healthcare facilities

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ABSTRACT

This paper assessed optimal configurations of hybrid renewable system for rural health clinic (RHC) application in three grid-unconnected rural villages in Nigeria. The RHC consist of an emergency room, consulting room, nurse/injection room, male ward, female ward, a delivery room and a laboratory with average total daily energy consumption of 15.5 kWh and 2.75 kW peak demand. The assessment of configurations that optimally meet the daily load demand with zero loss of power supply probability (LPSP) was carried out using HOMER software, by considering three energy resources; photovoltaic (PV), wind and diesel with battery energy storage. The result obtained revealed hybrid PV/wind/diesel/battery system as the most cost-effective configuration for powering rural health clinic in both Maiduguri and Enugu sites, while that of Iseyin site was found to be hybrid PV/diesel/battery system. In all the sites, the selected optimal configuration is far better than the conventional diesel stand-alone system in terms of cost and emission reduction.

1. Introduction

Access to reliable electricity supply is an important factor in rural area healthcare development, absence of which could limit efficient delivery of healthcare services in rural communities, thus putting patient lives into danger (NREL, 1998). Recent advances in the vaccines and other cold-chain distribution across the world have posed new challenge for electricity in healthcare facility without or limited electricity access. Operators of rural health facilities in developing nations across the world are faced with many problems, such as poor medical infrastructure, even where available, unreliable power supply has hindered its functionality, thus, limiting the effective delivery of quality healthcare to the rural populace. For instance, unreliable power supply could render cold-chain activities inoperable and in most cases, healthcare facility without means of illumination (lighting) do keep the patients arriving late in the night for medical attention to wait until the next day before they receive medical attention.

In a recent study by world health organization (WHO), conducted for 11 countries in Sub-Saharan Africa (Nigeria inclusive) covering about 4000 clinics and hospitals (Adair-Rohani et al., 2013). It was observed that one-fourth healthcare facilities in the considered location lack access to electricity supply, and about three-quarter with unreliable power supply. Even in the facilities linked to the national grid, epileptic power supply (that characterizes insufficiency generation) has often been the case. Diesel generators have traditionally been used to power this off-grid clinics and hospital and in supplementing the unreliable grid supply in grid-connected facilities, with the attendant huge price of diesel fuel, unreliable delivery and high CO_2 pollutant emission contributing to air pollution exposures and climate change.

Over the years in Nigeria, government have expended huge financial resources in its power sector to ensure rural area electrification through various reforms. Reforms such as the development of the National Energy Policy which has the Renewable Energy Master Plan (REMP) as a key component, the establishment of the National Energy Master Plan in conjunction with United Nations Development Programme (UNDP), the implementation of independent power projects (IPPs) among others (Ohunakin et al., 2014). Nevertheless, even with all these reforms, provision of electricity to the rural communities is not expected to improve drastically as there are several constraints, which has hindered its connection to the national grid; among which are; inaccessible terrain, distance of rural communities to the grid center leading to high cost of incorporation into the national grid (Ohunakin et al., 2014; Sambo, 2009) etc. However, considering the fact that improving rural access to electricity through extension of the national grid does not look promising at present due to its associated cost, it is thus imperative for a system of autonomous, off-grid power generation be established. A solution that is based on renewable energy (RE)

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resources and technologies, due to the vast deposit, and environmental friendliness would be a viable option; more so that rural locations have lower electricity demand.

Nigeria is a country endowed with vast renewable energy resources ranging from hydropower, wind, solar and biomass (Ohunakin, 2010). An overview of literatures on rural electrification proves that combination of these renewable energy sources (RES) is one of the most effective solutions to provide electricity to these rural areas. The methodology has proved to provide quality and reliable electricity for different applications in the rural areas (Dihrab and Sopian, 2010; Olatomiwa et al., 2014; Hiendro et al., 2013; Olatomiwa et al., 2015a; Manas, 2015). The two most commonly explored renewable energy are wind and solar. The potential of these sources of energy has been analyzed in our previous study (Olatomiwa et al., 2016). However, this present study step it up by further analysis on determination of optimal configurations of the hybrid combination of the two energy sources in conjunction with backup diesel generator to meet the energy demand of three rural healthcare facilities in Nigeria. In addition to this, the paper aim to answer this research question; "will the selected optimal configuration still be the best if the input parameters changes?" To answer this, sensitivity analysis on the various inputs to the model was conducted.

These locations were strategically selected from different climatic zones in the country as seen in Table 1 with the aim that results of the analysis can be adopted to other rural villages having similar climatic condition as those considered in the study. Table 1 contains the parameters of studied locations. Analysis of potentials of solar energy resources at the selected site based on certain key solar resources parameters, such as monthly and annual global solar radiation (GSR), beam radiation, diffuse radiation, as well as clearness index has been carried out in our previous study (Olatomiwa et al., 2016). The optimal tilt angle for south-facing solar collector orientation was also determined in the said study. Examination of wind energy potentials, on the other hand based on monthly mean daily wind speed data has also been previously done. Therefore, the present study aims to determine the suitability of each of the renewable sources and the best optimal configurations suitable for rural healthcare applications in each of the selected locations with sensitivity analysis.

2. Description of study sites and data collection

The locations for renewable energy potential assessment in this study were selected from three geo-political zones in Nigeria characterized by different climatic condition. Iseyin in the West, Maiduguri in the North and Enugu in the East. The meteorological data (wind speed and solar radiation) used in the analysis were obtained from Nigerian Metrological Agency (NIMET, 2014). Wind speed data were recorded daily at 10 m height with a cup-generator anemometer at respective locations, while the daily solar radiations on a horizontal plane were measured with Gunn-Bellini radiometer (Olatomiwa et al., 2015). Wind data ranges between 28 and 39 years, and solar radiation data ranges between 18 and 31 years were use in the study (Table 1). These data were computed as an average of data for each month.

2.1. Solar radiation

The power output of the PV array depends on the direct and diffuse solar radiation over a particular area. The insolation reaching the earth's surface hinge on the cloudiness or clearness of the sky, which in turn depends on the season of the year (Duffie and Beckman, 2013; Shukla et al., 2015). Characteristics and potential of solar energy at selected sites are analyzed based on mean monthly global solar radiation as well as the monthly clearness index (Olatomiwa et al., 2016). Other parameters explored in the analysis include the monthly mean daily diffuse and beam radiation, this is essential for efficient design and performance evaluation of solar energy applications. In this study, the period of solar data available for the analysis defers from one location to another. For all the sites considered, the available daily data were averaged to obtain the monthly mean and annual mean value. Fig. 1 shows the percentage difference of annual global solar radiation in the three sites.

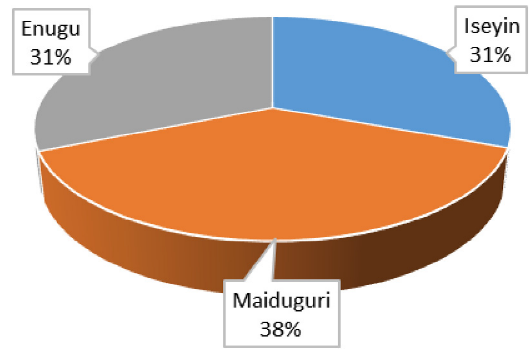

Fig. 1. Percentage of annual averaged solar radiation for all three site.

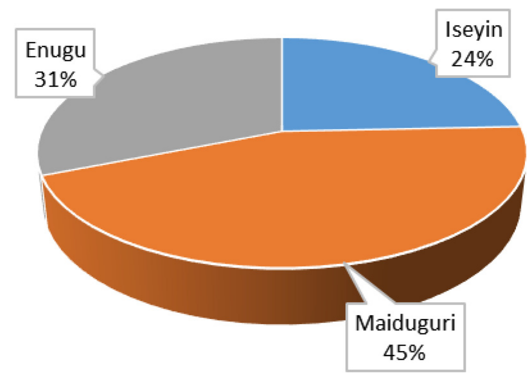

Fig. 2. Percentage of annual averaged wind speed for all three site.

2.2. Wind speed

Comprehensive study of available long-term solar insolation data and wind regime in a particular location is essential in designing and predicting energy output of the respective energy conversion devices; the in-depth knowledge will help in determining their suitability for any particular applications. Generation of electrical energy from wind energy occurs, when wind blows through a wind turbine. The kinetic energy of the wind at rated wind speed is converted into mechanical power by turning the turbine blade, thus producing electricity through the shaft connected to the alternator (Lang et al., 2011). Weibull distribution function (WDF) has been employed in describing the monthly wind speed variation and seasonal changes occurring in the selected sites as well as for estimation of wind power density (Olatomiwa et al., 2016). Fig. 2 shows the percentage difference of wind speeds in the three sites.

2.3. Rural health clinic load profile

The healthcare facility considered in this study is classified as a category 1 rural health clinic according to United States Agency for International Development (USAID, 2014). It consists of an emergency room, a doctor's consulting room, nurse/injection room, male ward, female ward, a delivery room, and a laboratory.