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Increasing household solar energy penetration through load partitioning based on quality of life: The case study of Nigeria

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ABSTRACT

The inadequate power supply in Nigeria has resulted into the use of diesel/petrol generator by almost every household. The implicating death and health risk recorded has made sustainable alternative sources imperative. Solar energy has been identified as a viable option; however, the greatest challenge is its affordability due to high installation cost. This paper proposes the installation of solar energy system using energy partitioning approach based on scalable level of importance to quality of life. First, household energy utilization is partitioned into different energy sectors, and then the importance of each sector as it affects the basic quality of life of the intending users are determined using structured questionnaire. Using a typical medium income house as a case study, different analyses are performed based on the level of quality of life that can be afforded by the different users. The result reveals that the life cycle cost over a period of 20 yr, of solar energy system for level 1 (Lighting only) which has the highest impact on the quality of life of Nigerian is $10,600. The cost of energy is 0.3341$/kW h, the cost of diesel fuel saved 1380$/annum, the break-even point is 7.7 yr and the estimated carbon credit is 1095.7 kg/yr.

1. Introduction

The absence of reliable power and energy supply is an established challenge on the quality of life. This is because most activities are dependent on affordable and adequate energy for effective operation (Oyedepo, Fagbenle, Adefila, & Adavbiele, 2014). The basic human needs are food, health services, education, housing, clean water and sanitation. Energy plays an important role in ensuring these services. The more accessible it is, the better the quality of life enjoyed. To keep up with some of these activities, most household rely on backup generators with high environmental and economic cost (Adaju, Gada, Sojinrin, & Okoh, 2011). Renewable energy remains an effective option for the future energy supply.

In Nigeria, there is a high gap between the electricity generation and demand resulting into energy poverty. Also, the electricity power supply is inadequate thus promoting self-production via the use of diesel/petrol generator by almost every household in the country (Ajayi & Ajayi, 2013). It has been estimated that about 60 million Nigerians own power generator in the country (Frank, 2009) with an estimated spending of ₦3.5 trillion for fuelling and maintenance annually (Mbisiogu, 2013). Nigeria is the highest importer of power generator in the world (Nwachukwu, 2011) with the sales of generator to hit ₦151billion by year 2020 (Mgbeokwere, 2013). This has led to increasing death and health risk in recent time, for example, a family consisting of 7 members died as a result of generator fume at Bagio area of Ijede Lagos in April 2014 (Usman, 2014). Similarly, 4 family members were fair dead in September 2014 due to carbon monoxide coming from the exhaust of nearby diesel generator (Ikeji, 2014) in Ikorodu, Lagos. It was also reported that generator fume killed 80 yr old woman and her four grandchildren (Bisiriyu, 2014) at Abule-Egba. This has led to an increased agitation for Renewable Energy Sources (RES) into the generation mix of the country for electricity generation.

To keep up with this, various renewable energy resources (solar, wind, hydro and biomass) have been assessed by the indigenous researchers with the view of establishing their potential and viability for electricity generation in the country. One of the outcome of the research revealed that the annual average solar radiation varies from about 12.6 MJ/m^2/day (3.5 kW h/m^2/day) in the coastal latitudes to about 25.2 MJ/m^2/day (7.0 kW h/m^2/day) in the far north (Oyedepo, 2014). A total of 17,459,215.2 MJ/day (17.439 TJ/day) is estimated as the solar energy potential in Nigeria with average solar intensity of 6898.5 MJ/m^2/yr or 1934.5 kW h/m^2/yr (Oyedepo, 2014). In Nigeria, the wind speed at anemometer height of 10 m ranges between 1.0 and 5.1 m/s (Ohunakin, Ojolo, Ogunsina, &

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Dinrifo, 2012). Generally, the local wind regimes in Nigeria can be classified into >4.0 m/s; 3.1–4.0 m/s; 2.1–3.0 m/s; and 1.0–2.0 m/s (Oyedepo, 2014). According to NREL classifications, Nigeria falls into the moderate wind regime. It is observed that the wind speeds in the country are not evenly distributed with high wind power potential in the north and weak wind speed in the South except for the coastal regions. Hydro power is another huge exploitable renewable energy resource in the country. The current exploitable hydro power potential is estimated to be about 11,250 MW with an annual electricity generation potential in excess of 36,000 GW h. Biomass has also been reported to have considerable exploitable potential in Nigeria. It was estimated that about 80 million cubic meters (43.4–109 kg) of fuelwood is consumed annually for cooking and other domestic purposes (Sambo, 2005). Forage grasses and shrubs produce 200 million tons of dry biomass, which gives up to 2.28–106 MJ of energy. It has also been revealed that animals and poultry produced 227,500 t of waste with energy content of 2.2–109 MJ when converted to biogas (Oyedepo, 2014).

Of these various renewable energy sources, solar energy has been identified as a viable alternative option because of its huge potential and good spatial distribution across the country compared to other renewable energy resources (Sambo, 2009). Moreover, photovoltaic (PV) modules which convert solar energy into electricity are more suitable for residential buildings on small scale because of its modular structure, zero operating noise, ease of maintenance as well as the environmental friendliness. However, the challenge with the utilization of solar PV system is its affordability to average individual house owners, due to high initial cost of purchasing and installation bearing in mind that there is no obvious or popular national policy that encourages increased penetration of RES.

Studies by different authors have established the potentials of solar energy utilization for various activities in the country (Nwofe, 2014). Some of these areas of applications have been identified by Coker (Coker, 2004) and these include; village electrification, residential and commercial building, water pumping and purification, agricultural utilization, heating sources and industrial utilization. The possibility of utilizing solar energy for electricity generation in residential buildings has also been explored by Oji et al. (2012). In their work, the average solar power requirement for 2 and 3 bedroom based on the local solar regime was calculated. The feasibility of using solar energy in agriculture has been identified by Yohanna and Umogbai (2010). He demonstrated its usage for heating and lighting of animal pens, pumping of water and irrigation, food and vaccine preservation. Abdulkareem (2005) investigated the cost of solar energy systems and compared the economic value of solar technologies with the conventional technologies for power generation. He considered the Nigerian socio-economic environment to emphasize the need to supplement with and eventually replace existing power generation systems with available, abundant and inexhaustible solar energy system.

However it has not been popularly investigated for use as source for individual residential energy application. This paper therefore analyzes the energy poverty in Nigeria, and as a case study investigates the possibility of utilizing standalone solar system on a scalable level constrained by the quality of life (QoL). This will encourage increasing penetration of solar power integration in the country. The economic analysis and the environmental benefits were also analyzed to create a background for policy in renewable energy in Nigeria.

2. Energy poverty in Nigeria

The quality of life enjoyed by the citizenry of any nation can be measured by the level of availability of electricity a citizen has access to. Energy poverty is referring to lack of access to adequate, affordable, reliable, high quality, safe, and environmentally benign energy services. i.e. a situation where the well-being of large numbers of people especially in the developing countries are negatively affected by very low consumption of energy (Gonzalez-Eguino, 2015). The index of energy poverty can be determined to ascertain to what extent people lack access to energy (Chidebell-Emordi, 2015). Average Energy per capital $\left(E_{\text{capital}}\right)$ and average power per capital $\left(P_{\text{capital}}\right)$ are two of the indices by which energy poverty can be measured and they can be calculated as (1) and (2), respectively once the nation's total electric energy consumption and the population is known from available statistics.

$$E_{\text{capital}} \quad (\text{kW h}) = \frac{E_{c(\text{total})} \times 1000}{\text{PL}} \tag{1}$$

$$P_{\text{capital}} \quad (\text{W}) = \frac{\text{EPC} \quad (\text{W})}{\text{PL}} \tag{2}$$

where $E_{c(\text{total})}$ is the total electric energy consumption of the nation and can be obtained from public utility, PL is the population of the nation and can also be easily obtained from public domain, EPC is the total electric power consumption and can be determined using the following the equation:

$$\text{EPC} \quad (\text{W}) = \frac{E_{c(\text{total})} \quad (\text{MW h/yr}) \times 10^6}{365 \times 24} \tag{3}$$

The data of population and electric energy consumptions of Nigeria and some randomly selected countries are obtained from Jimoh (2012) to calculate E_{capital} (kW h) and P_{capital} (W) using Eqs. (1)–(3). This is to compare the level of energy poverty in Nigeria with some other nations. The result is presented in Table 1. The table reveals that energy poverty is higher in Nigeria with average energy per capital and average power per capital of about 107 kW h and 12 W compared to South Africa (4347 kW h and 496 W), Malaysia (3310 kW h, 377 W) and other countries depicted in Table 1.

It is evident from the table that, for Nigeria to achieve her vision 20:2020 (i.e. to be within the 20 largest economies in the world by 2020), then, drastic measures and policy has to be put in place to improve energy poverty in the country. This is especially necessary at the micro level (household), where transformation implies direct uplift in individual standard of living, economic empowerment, improving education, good health and security.

The electrical installation and generating capacity as well as the capacity utilization in Nigeria are very low as depicted in Table 2. It is worth noting that for the present population of Nigeria, the installed capacity cannot effectively improve the per capital power of the nation, yet the capacity utilization is still around 46%.

A study on the energy consumption pattern of Nigeria classified the Electricity consumption into three sectors: industrial, residential and commercial (Oyedepo, 2014). The energy consumption pattern based on these sectors is shown in Table 3. It is observed from the table that the bulk of electricity consumption in the country is from the residential sector with over 50% of the total consumption. As such, a good energy policy in respect of the residential sector at the micro level will have significant impact on improving the energy poverty status of the country.

3. Nigerian energy policy framework

Prior to 2003, Nigeria had no comprehensive energy policy. Although, there are separate policy documents for different energy sub-sectors such as electricity, oil, gas and solid minerals (Sesan, 2008). There was no consideration whatsoever for the inclusion of renewable energy sources in the national energy mix. However, in 2003, an overall National Energy Policy (NEP) for the nation (Sambo, 2009) was proposed by the collaborative effort of ECN-UNDP. The