Solar energy estimation and generation in Ibadan Nigeria

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Abstract. Energy challenge in Nigeria is really disturbing due to many factors that borders on the inability of the national grid to meet-up with the huge energy demands in the most populated country in Africa. About 85% industries and domestic users patronize fossil fuel generators. This development had increased the air pollution load over the country. In this research, fourteen years dataset from the Nigeria Metrological Agency (NIMET) was used to simulate the energy accruable from solar energy in Nigeria. The study is poised to enhance higher patronage of solar technology in the research site.

Keywords: solar, energy, solar radiation, meteorology, solar energy

1. Introduction
In 1929, the first electricity supply company in Nigeria was established but electricity generation began in Nigeria around 1896. It was later in 1972 that all isolated electricity-generating corporations in Nigeria were amalgamated with the Niger Dams under the unified operations i.e. National Electric Power Authority (NEPA). The monopoly of NEPA was broken Electric Power Sector Reform Act (EPSRA) in 2005. In 2010, Power Holding Corporation of Nigeria (PHCN) emerged and was made up of eleven distribution companies, six-generation companies and one transmission company [1]. An annual report from PHCN shows that Nigeria Electricity consumption per capita within 2010 and 2014 is 149kWh [2].

The energy crisis in Nigeria has been a major issue for both the Nigerian government and the citizens for the past four decades [2]. This energy issue has caused businesses to run into loss while homes depend solely on the off-grid supply (i.e. using diesel/gas/petrol-powered electric generators), thereby accumulating huge costs and contributing to greenhouse gas pollution amongst other dangerous environmental problems [3]. The Nigerian government has a plan of increasing electricity production to 40,000MW by the year 2020 [2].

Analysts have projected that Nigeria could generate 600,000MW by deploying Solar PV panels from just 1% of Nigeria's land mass [4]. Despite the affordability of solar device set-up, there is the technical challenge that may hinder the reality of this projection [5]. The challenges includes: shadows- which may be natural or man made; dust, dirt, frost and snow on modules- which depends on location and also on rainfall and module inclination; reflectance of module surface; PV conversion efficiency (which depends on temperature and irradiance); and sunlight spectrum. The known types of PV systems are: grid-connected PV systems and off-grid PV systems. In the study area, the off-grid PV system is widely used. In regards to a consumer solar installation, there are two main photovoltaic
technologies used in solar panels across the variety of manufacturers. Specifically, mono-crystalline silicon and poly-crystalline silicon. In this study, the adaptation both types of PV panels in different scenarios were simulated to assist solar device companies and government to invest in solar generation in the study area.

2. Experimental Design, Materials and Methods
The dataset that was used for this research was obtained from the Nigerian Metrological Agency (NIMET). Fourteen years dataset (1981-1994) was used for the research. The sunshine hour and solar irradiation dataset was extracted from the bulk dataset.

The efficiency of the solar cell is mainly dependent on the temperature of solar cell they acquire during sunshine. Hellman [6] gave the approximated cell temperature without considering the cooling via airflow under the PV panel as:

\[ T_c = T_\alpha + (T_{NOCT} - 20) \frac{G}{1000 \text{W/m}^2} \]  

(1)

where \( T_\alpha \) is the ambient temperature, \( T_{NOCT} \) is the normal operating cell temperature (47 \(^\circ\)C), and \( G \) the global irradiance. The efficiency of the solar module can then be estimated by different methods and one of them is:

\[ \eta = \eta_{STC} (1 - \beta_p (T_c - T_{STC}^\circ) + \gamma \log G) \]  

(2)

where \( \eta_{STC} \) is the efficiency in STC, \( \gamma = 0 \) [7]. Hence, the power in this regard is given as:

\[ P = \frac{G}{1200} P_{max} (1 - \beta_p (T_c - T_{STC}^\circ)) \]  

(3)

\( \beta_p \) is the power temperature coefficient (typically around 0.45–0.48 \%/\degree C), \( T_{STC}^\circ \) is the temperature at standard test conditions (25 \(^\circ\)C), \( P_{max} \) is the nominal power of the module in STC. Hence the open circuit voltage \( (V_{OC}) \) at this point is given as [8]:

\[ V_{OC} = V_{OC}^\circ (1 - \beta_P (T_c - T_{STC}^\circ)) + V_t n_p n_s I_n \left( \frac{G}{G_0} \right) \]  

(4)

\( G \) is irradiance, \( G_0 = \) monthly average daily extraterrestrial radiation for a PV panel composed of \( n_p \) cells in parallel and \( n_s \) in series.

The monthly average daily extraterrestrial radiation is calculated as:

\[ G_0 = \frac{24}{n} I_{SC} \left[ 1 + 0.33 \cos \left( \frac{360 \theta}{365} \right) \right] \times \left[ \cos L \cos \delta \sin \omega_e + \frac{2 \pi \omega_e}{360} \sin L \sin \delta \right] \]  

(5)

\( \omega_e = \) sunset hour angle, \( I_{SC} = \) solar constant, \( L = \) latitude of location, \( \delta = \) declination angle, \( \omega_n = \) day of the year starting from January

\[ \omega_e = \cos^{-1}(-\tan L \tan \delta) \]  

(6)
Unlike, the conditions in equation (3), power in the PV panel can be calculated as:

$$ P = \frac{\delta}{1 + \frac{\delta}{2.45 \sin \left( \frac{\pi (284 - 15.2)}{365} \right)} } $$

(7)

where $P_{\text{max}}$ is the peak power, in kWp. From literatures, monocrystalline solar cells has peak power (Wp) of $140 \text{W} \pm 5\%$ and voltage at maximum power (Vmp) of $17.5\text{V}$[9] and for poly crystalline solar cells, the peak power (Wp) is $250 \text{W} \pm 5\%$ and voltage at maximum power (Vmp) of $30.5\text{V}$[10]. The ratio between actual power and the theoretical power is called Performance Ratio (PR). This terminology may also be referred to as module PR (PRm) or system PR (PRs).

### 3. Results and Discussion

The solar irradiance over the research was analysed between 1981 and 2004. It was observed that 1984 had the highest solar irradiance (Figure 1). The solar irradiance between 1988 and 1996 was almost uniform i.e. showing that the research area does not have significant solar irradiance perturbations.

![Figure 1: solar irradiance in Ibadan](image)

Figure 1: solar irradiance in Ibadan

This is particularly interesting because it means that the results can be projected (in form of forecast) with minimal errors. The ambient and solar cell temperatures are presented in Figure 2. This result suggests that the solar cell (due to its inherent properties) retains temperature. The thermal gradients between the ambient and solar cell temperatures are good reasons to make the PV panel work at lower efficiency. The solar module efficiency is presented in Figure 3. The highest and lowest efficiency was observed in 1984 and 1998 respectively. The solar module efficiency for PV panels (for the years considered in the dataset) showed that the outcome from the PV system is not proportional to the solar irradiance. This shows that solar cell anomalies can be adduced to the material type. Hence, the optimization of the PV panel is essential for perfect conversion of solar irradiance to electricity.
The meteorological dataset was used to calculate the power outcome in normal (equation 8) and optimized (equation 3) state as shown in Figure 4. It is observed that optimized state is more stable to accommodate solar irradiation perturbation. Same scenario occurred in the polycrystalline PV panel displayed in Figure 5. This scenario is essential in prolonging the lifespan of the PV system.
Figure 4: Power in mono-crystalline PV panel

Figure 5: Power in poly-crystalline PV panel

However, the outputs presented in Figures 4 and 5 do not reveal a perfect scenario of optimal working solar cells.

4. Conclusion
The study shows the theoretical analysis of PV systems in Ibadan Nigeria using meteorological dataset. The direct perturbations noticed in the dataset were seen to reflect in the outcome of the PV system i.e. solar cell temperature, solar module efficiency, and power output. The thermal gradients between the ambient and solar cell temperatures are good reasons to make the PV panel work at lower efficiency. Also, it was reported that the solar cell anomalies observed in PV systems could be adduced to the material type of the solar cells. More so, it was observed that solar irradiance fluctuation have significant effect on the power output of the PV system. Hence, it is recommended
that PV systems brought to the research site should incorporate spectra filtering layer to stabilize the solar irradiance fluctuations.

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