Modified Angstrom Solar Radiation Model for Abeokuta Nigeria

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Abstract. Sustainable power supply still remains the challenge in developing countries. Unfortunately the growing energy need is directly proportional to the population growth. Hence, there is the need to step-up on the alternative energy use. The adoption of solar technology in the research site is encouraging-partly because of the low cost of purchasing solar devices. However, there is the issue of short lifespan of the photovoltaic (PV) panel that operates in the area. This research used the modified Angstrom solar radiation model to determine that the main cause of short PV lifespan is solar spectrum signature over the research area. It is recommended that solar companies should start incorporating spectra filtering layer to protect the PV panel.

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

1. Introduction

The scorching sun in sub-Saharan Africa has been regarded by many for decades as having little or no economic value and a possible hindrance to development. This perception has fundamentally changed though due to the emergence of technologies in solar energy utilization [1]. One of the main drivers of development is electricity. In Nigeria, less than 40% of the country is connected to the National Grid yet, less than 60% of the energy needs of this group is generated and distributed [2]. Erratic and insufficient power supply has been a major problem bedevilling Nigeria resulting in the use of fossil fuel generators both in residences and industries with the attendant emissions that increase the rate of air pollution accompanied with possible adverse health effects on the populace [3,4]. The discovery of the use of the sun’s energy in the production of photovoltaic effect was made in 1831 [5]. According to Nasir [6], the utilization of solar energy is dependent on its availability and appropriate technology. The amount of energy radiated by the sun in a year is greater than that used by man since the beginning of time. Okafor and Joe-Uzuegbu [7] reported that the 6.25 hours average daily sunshine and 5.25kW/m per day average daily solar radiation in Nigeria translates to about $4.851 \times 10^{12}$ kWh of energy per day or $1.804 \times 10^{15}$ kWh per annum. Standalone photovoltaic (PV) system is a collection of interconnected electrical components used in the generation of electricity from sunlight. One of its components, the solar panel is responsible for trapping the solar energy [8]. Most citizens welcomed the advent of standalone solar PV installations into the country though; the cost of purchase and installation is still quite high for the average citizen to afford. It offers advantages such as environmental friendliness, quiet operations, high reduction in cabling for external lighting, does not require transformer, high or low tension wiring making its installation on individual establishment and premises easier [2, 9]. The challenges facing the utilization of solar energy system in Nigeria include...
high initial investment cost, variability and intermittency of radiation, operation and maintenance cost, ineffective quality of products, insecurity of solar plant infrastructure etc. [10]. The research site Abeokuta, the capital of Ogun State, Nigeria (Figure 1), also known as the Gateway State can serve as a model for other states in the south-western region of the country. In this research, the focus is to use the modified Angstrom solar radiation model to determine the causes of short PV panel lifespan.

Figure 1: Map of Abeokuta

2. Methodology
The dataset that was used for this research was obtained from the Nigerian Meteorological 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 dataset where used to obtain the required parameter for the solar radiation model. The average monthly global radiation model as derived by Angstrom[11] and modified by Page[12] and Prescott [13]. Is given as:

\[
\frac{H}{H_0} = a - b \left( \frac{S}{S_0} \right) \]

(1)

\(H\) =monthly average global radiation, \(H_0\) = monthly average daily extraterrestrial radiation, \(S\) = monthly average daily bright sunshine hour, \(S_0\) = maximum possible monthly average daily hour, \(a=b=\) constants.

The monthly average daily extraterrestrial radiation is calculated as:

\[
H_0 = \frac{24}{\pi} l_{sc} \left[ 1 + 0.33 \omega_s \left( \frac{3600n}{365} \right) \right] \times \left[ \cos \theta \cos \delta \sin \omega_k \times \left( 2 \frac{\omega_k}{360} - \sin L \sin \delta \right) \right]
\]

(2)

\(\omega_s\) = sunset hour angle, \(l_{sc}\) = solar constant, \(L\) = latitude of location, \(\delta\) = declination angle, \(D\) = day of the year starting from January
The regression model was used to obtain the value of ‘a’ and ‘b’

\[
\omega_v = \cos^{-1}(-\tan \Lambda \tan \delta) \quad (3)
\]

\[
\delta = 23.45 \sin \left[ \frac{564(244-14\delta)}{365} \right] \quad (4)
\]

\[
S_\nu = \frac{2}{15} \cos^{-1}(-\tan \Lambda \tan \delta) \quad (5)
\]

The regression model was used to obtain the value of ‘a’ and ‘b’

### 3. Results and Discussion

The monthly variation was used to calculate the constants (‘a’ and ‘b’) for Lagos. For January, the modified Angstrom model (MAM) is given as:

\[
\frac{H}{H_p} = 0.211 - 0.068 \left( \frac{S_\nu}{S_\nu^0} \right) \quad (6)
\]

The linear regression for this result is 27.64%. Though the result is low, however, it should be noted that the relationship depends on the measured data provided by NIMET. The results for February is displayed as:

\[
\frac{H}{H_p} = 18.03 - 0.071 \left( \frac{S_\nu}{S_\nu^0} \right) \quad (6)
\]

The linear regression for this result is 42.76%. The results for March is displayed as:

\[
\frac{H}{H_p} = 18.04 + 0.039 \left( \frac{S_\nu}{S_\nu^0} \right) \quad (7)
\]

The linear regression for March result is 6.1%. The results for April is displayed as:

\[
\frac{H}{H_p} = 7.00 + 0.109 \left( \frac{S_\nu}{S_\nu^0} \right) \quad (8)
\]

The linear regression for April result is 18.55%. The results for May is displayed as:

\[
\frac{H}{H_p} = 6.048 + 0.104 \left( \frac{S_\nu}{S_\nu^0} \right) \quad (9)
\]

The linear regression for May result is 28.5%. The results for June is displayed as:

\[
\frac{H}{H_p} = 6.94 - 0.022 \left( \frac{S_\nu}{S_\nu^0} \right) \quad (10)
\]

The linear regression for June result is 1.65%. The results for July is displayed as:

\[
\frac{H}{H_p} = 4.88 + 0.063 \left( \frac{S_\nu}{S_\nu^0} \right) \quad (11)
\]
The linear regression for July result is 11.25%. The results for August is displayed as:

\[
\frac{H}{H_p} = 7.72 + 0.024 \left( \frac{S}{S_{no}} \right)
\]  

(12)

The linear regression for August result is 1.02%. The results for September is displayed as:

\[
\frac{H}{H_p} = 7.064 + 0.204 \left( \frac{S}{S_{no}} \right)
\]  

(13)

The linear regression for September result is 37.57%. The results for October is displayed as:

\[
\frac{H}{H_p} = 7.32 + 0.077 \left( \frac{S}{S_{no}} \right)
\]  

(14)

The linear regression for October result is 18.77%. The results for November is displayed as:

\[
\frac{H}{H_p} = 7.53 + 0.009 \left( \frac{S}{S_{no}} \right)
\]  

(15)

The linear regression for November result is 0.12%. The results for December is displayed as:

\[
\frac{H}{H_p} = 6.57 + 0.062 \left( \frac{S}{S_{no}} \right)
\]  

(16)

The linear regression for December result is 7.93%. The average of the twelve months is given as:

\[
\frac{H}{H_p} = 0.78 + 0.069 \left( \frac{S}{S_{no}} \right)
\]  

(17)

It is observed that February had the highest linear regression. Also, constants ‘a’ and ‘b’ has high variability on a monthly basis. This means that the solar spectrum over this region is the main cause of low lifespan of PV panel. This result is far from the known models discussed in literature [14-16].
4. Conclusion
The modified Angstrom solar radiation model has been proven to be very reliable. Hence, the results in this research are reliable to give scientist and energy professional clue into the solar energy sustainability over the research site. The results show that the solar activity of Nigeria is dynamic with high monthly variability (via the values of ‘a’ and ‘b’). This means that the solar spectrum over this region is the main cause of low lifespan of PV panel. It is recommended that solar device companies should seek ways of incorporating spectrum filter layer over the surfaces of PV systems.

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