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Analysis of Solar Radiation Availability for Deployment in Solar Photovoltaic Technology over a Tropical City

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Abstract
The sunshine hours and solar radiation data for Ibadan (7° 30′ N, 3° 54′ E.), South West Nigeria in the last twenty years was analyzed, with a view to determining the abundance of solar energy available for deployment for solar photovoltaic technology applications. The solar radiation and actual sunshine hour data were obtained from International Institute of Tropical Agriculture (IITA), Ibadan. The data were analyzed using the statistical package of 'origing' software. The maximum of $16.1 MJm^{-2}day^{-1}$ and minimum of $10.71 MJm^{-2}day^{-1}$ occurred in months of May and August respectively while the actual sunshine hour variation follows the same general trend but with the maximum of 6.99hrs in February and a minimum of 2.37hrs in August. At the current solar to electric conversion efficiency of 10%, the minimum solar radiation of $10.71 MJm^{-2}day^{-1}$ can supply a $1.0m^2$ solar panel a minimum of 44.6KWhr of Energy. Thus an abundance of solar energy has been established at Ibadan which in recent times has been witnessing incessant power outages from the national grid and thereby contributing to efforts in improving power supply. This implies that solar energy technology can thrive not only at Ibadan but in the whole of South West of Nigeria.
Keywords: Solar-radiation, Sunshine-hours, photovoltaic, cloud-cover, energy.

Introduction

The sun supplies nearly all the energy used on the surface of the earth. The sun's energy is available in various forms depending on the mode of use, storage and conversion. For instance it can be used directly for heating and drying purposes, the chlorophyll of green leaves taps the sun's energy, stores it in roots and stems as food while the photovoltaic cells trap solar energy and convert it to electrical energy.

There are three basic technologies through which solar energy are deployed namely solar thermal electricity, solar heaters and photovoltaic cells. Solar thermal electricity uses solar energy to generate steam to drive turbines for electric energy generation in a manner similar to gas fired turbines while solar heaters utilizes solar radiation to heat air or water in a tunnel which is in turn used for heating or drying purposes. On the other hand photovoltaic solar cells (PVC), mounted in arrays on a panel, convert solar radiation to electricity which can be used directly or made to charge a heavy duty battery for later use when solar radiation is no longer available. Photovoltaic solar power can help meet peak load and distributed power needs and could scale rapidly if PV efficiency and storage technology developments accelerate [Khosla and Khoslaventures 2010]. Similarly, solar heating can displace fossil fuel use in residential and industrial uses as process heat.

Solar energy is just having its debut as a form of electrical energy generation in this part of the country. We are interested in solar energy because of its various advantages over other forms of electric power sources. According to [Khosla and Khoslaventures 2010]**,** solar energy can provide a significant part of global low-carbon electricity needs at costs directly competitive with fossil alternatives, and can meet "utility grade" power quality, cost and reliability requirements. In addition to significant emissions reduction and environmental benefits, solar offers sharply reduced supply and commodity risk. In the view of the experts on the National Action Plan on Climate Change, (2008), solar energy's most significant advantage over traditional energy sources is environmental. Concentrated solar plants (CSP) produce no CO_2 or other emissions during operation; by contrast, the average 500 MW coal plant produces 3.7 million tons of CO_2 annually, along with major releases of other greenhouse gases (GHG). Philibert (2006) affirms that solar energy offers nearly unlimited potential to generate clean, carbon-free power. In theory, about one percent of the world's desert areas, if devoted to solar power generation and linked to demand centres by high-voltage DC (HVDC) cables, could be sufficient to meet total global electricity demand as forecast for 2030. Moreover solar energy is renewable and almost inexhaustible. Unlike fossil fuels that are only found in selected regions of the world, solar energy is available just about everywhere on earth (Salima and Chavuka, 2012).

[Khosla and Khoslaventures 2010] reiterates that for the solar energy to meet its potential and provide a significant proportion of the world's electric power, it must meet three key thresholds – for cost, availability and reliability. They explained further that the cost of energy must be directly competitive with new fossil fuel or nuclear powered generation. Power generated on the other hand must be "dispatchable" in the sense that power must be available when utility customers need it, not when it is convenient to produce it. Energy storage will therefore be required for intermittent resources such as the sun for utility needs, except when matched to local peak load conditions. For solar thermal, storage is relatively easy and can actually reduce the cost of providing power overall. Where there is an intermittent source and storage presents a problem, an hybridization of multiple sources like solar and wind, can be deployed.

Several authors, Sambo (1986), Fagbenle (1990), Buhari and Sambo (2001), Akpabio and Etuk (2003), Liu and Jordan (1961), Falayi and Rabiu (2005), Falayi, Rabiu and Teliat (2011) and Augustine and Nnabuchi, (2009) have reiterated the fact that an accurate knowledge of solar radiation distribution at a particular geographical location is desirable for the development of many solar energy devices and for estimates of their performance potential.

Hence this paper focuses its attention on ascertaining the abundance of solar energy over the location under study with a view to assessing potential of deploying solar photovoltaic technology. This is imperative because if a hydroelectric power plant is to be constructed there is the need to site it in area where constant supply of water is assured all the year round either by direct constant in flow of water into a reservoir or a sort of recycling mechanism is adopted for getting water to turn the turbine all year round. Also in the case of thermal station a constant supply of gas or coal must be guaranteed. However in the case of solar energy the availability and variability of sunshine or solar radiation, the main source of solar energy must also be ascertained.

Materials and Methodology

Ibadan is a fast growing city located North-East of Lagos the commercial capital of Nigeria. It is the capital city of Oyo State, one of the thirty six states in Nigeria. The city lies within latitude 7° 30′ N and longitude 3° 54′ E, hence it enjoys two climatic seasons in a year - the rainy season from April to October and the dry season from November to March. Though of recent due to factors not unconnected with climate change the city is now having rain from February. The data used for the study were obtained from The International Institute of Tropical Agriculture (IITA). The International Institute of Tropical Agriculture is located in the North eastern outskirt of the city.

The station measures solar radiation and other meteorological parameters directly and consistently in the last twenty years. These mean daily data for each month of the twenty year period for both solar radiation and actual sun shine hours were analyzed for their trends using the six-month moving average while the maximum possible sunshine hour was computed using the Angstrom's equation. The plots were performed by means of the 'Origing' software.

Results and Discussion

The mean value of daily average solar radiation and sun shine hours for each month of the year are shown in Table 1.

Table 1: Mean Daily Maximum Possible Sunshine Hour, Actual Sun Shine Hour and Solar Radiation for each Month of the Year.

Month	Maximum Possible Sun Shine Hour	Actual Sun Shine Hour	Solar Radiation ($MJm^{-2}day^{-1}$)
January	11.62	6.70	13.3
February	11.76	6.99	15.2
March	11.96	6.26	16.6
April	12.17	6.66	16.3
May	12.34	6.73	16.1
June	12.43	5.74	14.8
July	12.39	3.57	11.9
August	12.23	2.73	10.7
September	12.03	3.90	12.8
October	11.82	5.85	14.2
November	11.65	7.08	15.1
December	11.57	7.15	13.7

The values revealed that the magnitude of the mean solar radiation varies depending on the prevailing synoptic conditions. However the least value of mean solar radiation observed is 10.7 $MJm^{-2}day^{-1}$ in the month of August while the highest is 16.6 $MJm^{-2}day^{-1}$, occurring in the month of March. This translates to between 445.83KWhr to 691.67KWhr per square meter of solar energy. At the current solar-electricity conversion efficiency of about 10% this implies an availability of 44.6KWhr to 69.2KWhr for every square meter of exposed space at the location under study.

Table 1 also shows that the monthly average is approximately 13.3$MJm^{-2}day^{-1}$ for January, 15.2$MJm^{-2}day^{-1}$ for February and this value increases gradually to the highest value of 16.6$MJm^{-2}day^{-1}$ in March. This increase is due to rain wash which has cleared the sky of the harmattan dust signaling the end of dry season and the beginning of the raining season. Thus there is an increase in the amount of solar radiation reaching the surface. However heavy cloud cover that sets in from April caused a reduction in the amount of solar radiation reaching the surface from 16.6MJm^{-2}day^{-1} in March to all time low of 10.7MJm^{-2}day^{-1} in August. It then picks up again from September (12.8 6MJm^{-2}day^{-1}) to November (15.16MJm^{-2}day^{-1}) and decreases again in December. Thus the major impediment to the receipt of solar radiation at the surface of the location under investigation in December and January is the large scale dust-bearing North Easterly wind, locally called the harmattan that predominates during the dry season while in the wet season of April to August it is the heavy cloud cover that causes the same effect. The deviation of the mean monthly solar radiation from the annual mean is shown in Fig.1.

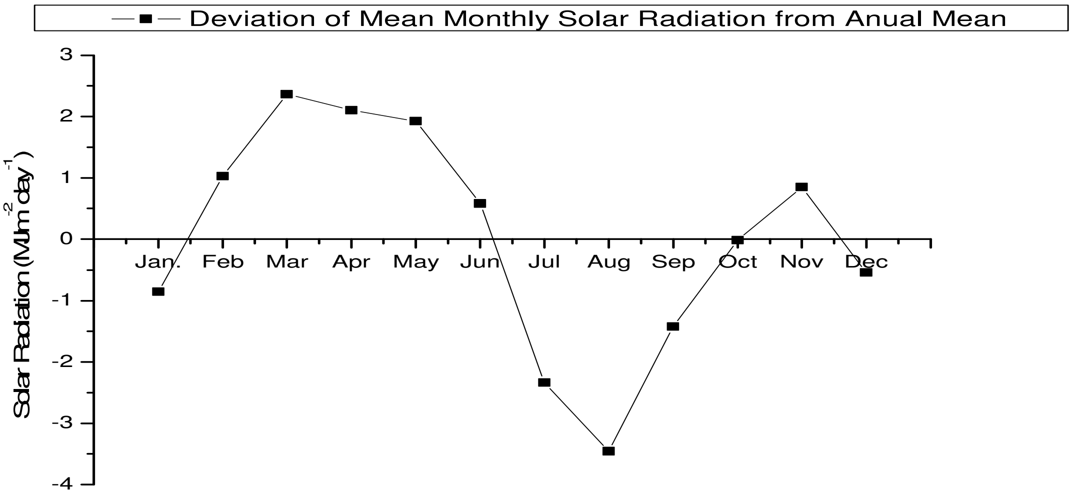

Fig 1: The deviation of Monthly Mean Solar Radiation from Annual Mean

It revealed that six clear months have values above the annual mean while five have values below the annual mean. In order to augment the required power when the solar radiation is relatively low, the authors proposed a hybridization of solar with wind energy (Subject of a paper by the authors under review).

The percentage of the ratio of the actual sunshine hours to the maximum possible sunshine hours in ascending order is depicted in Table 2 with seven months having 50% and above.

Table 2: Percentage of Actual to the Maximum Possible Sun Shine Hour

Month	Aug	Jul	Sep	Jun	Oct	Mar	May	Apr	Jan	Feb	Nov	Dec
(n/N)%	22.32	28.81	32.42	46.18	49.49	52.34	54.54	54.72	57.66	59.44	60.77	61.8

The variation of the daily mean sun shine hours and solar radiation for each month of the year is shown in Fig. 2 while the same variation for the twenty years under study is shown in Fig. 3.

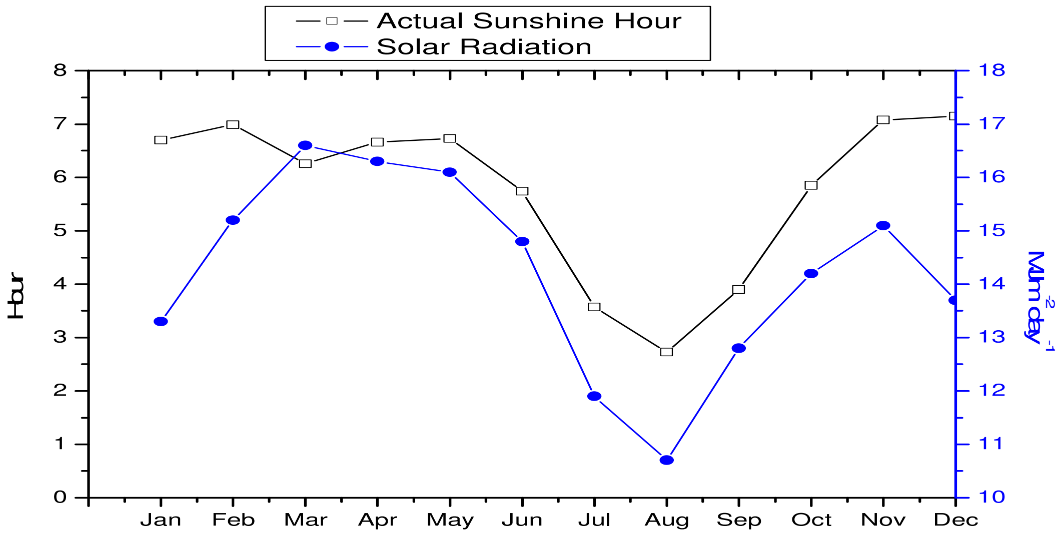

Fig 2: Variation of Mean Daily Mean Sun Shine Hour and Solar Radiation for each Month of the Year.

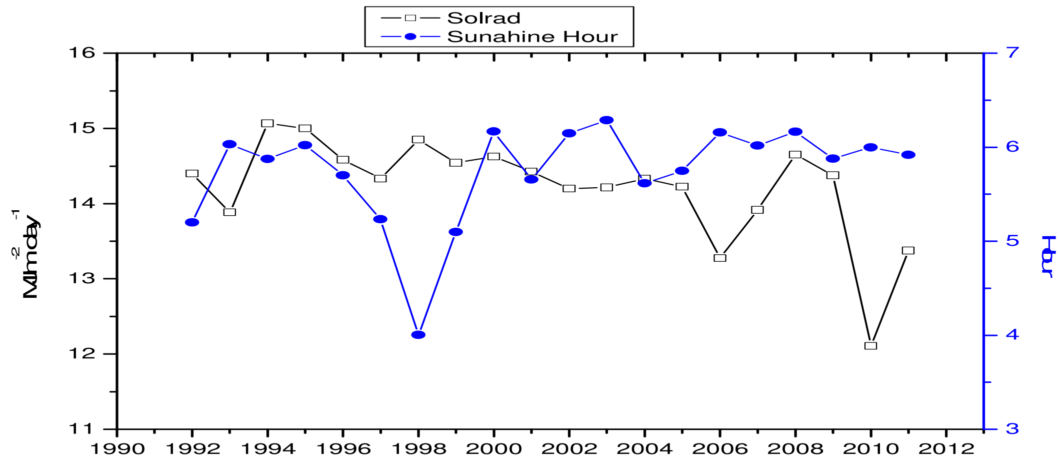

Fig 3: Variation of Mean Monthly Sun Shine Hour and Solar Radiation for each Year of under Study.

Clearly, solar radiation and sun shine hours decrease from May to reach the lowest value in August as a result of the cloud cover during this period of raining season. This trend is corroborated by Madgu and Yakubu (2011) who reported maximum and minimum occurrence of solar radiation in May and August respectively in Yola though they got their values from model estimation. On the contrary Salima and Chavula (2012) reported that maximum and minimum solar radiation in Malawi occurred in October and January respectively.

The actual sunshine hour follows the same general trend but with the maximum in February and the minimum in August. This could be due to the fact that February represents a transition period between the dry and the wet season when the first rain would have cleared off the harmattan dust from the atmosphere and no much cloud to prevent solar radiation from reaching the surface.

Summary and Conclusion

The amount of solar radiation and actual sun shine hours reaching the surface at the location under study was analyzed. The result shows that the maximum solar radiation of $16.1MJm^{-2}day^{-1}$ occurred in May while the minimum of $10.7MJm^{-2}day^{-1}$ occurred in August. This translates to between 445.83KWhr to 691.67KWhr per square meter of exposed space. Thus implying an abundance of 'raw material' required for the deployment of photovoltaic cells in the area. The minimum actual sun shine hour of 2.73 occurred in August while the maximum of 6.99 occurred in February. Hence the abundance of solar radiation at the location has been established. Thus the use of photovoltaic cells can be encouraged for at least eight months of the year and if the efficiency of the photovoltaic cells can be improved, it may be deployed throughout the year. Also a form of hybridization can be employed wherein wind power is deployed to compliment solar power during periods of low solar radiation to form a robust and reliable renewable power system especially for the rural populace in remote off-grid locations.

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