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Unveiling the solar resource potential for photovoltaic applications in Mauritius

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ABSTRACT

Mauritius is considered to have high solar resource potential but it has not yet been fully quantified and exploited due to the lack of valid solar energy data. This paper unveils the solar potential of Mauritius. Ground-based measurements were performed at intervals of 30 s in order to obtain accurate global horizontal irradiance data which can depict all changes in solar power. The latter is used to evaluate average monthly global horizontal irradiance, maximum irradiance, monthly average insolation and monthly sky clearness index. A solar geometry model was used to define the average monthly, seasonal and yearly maximum elevations and extraterrestrial radiation. Measurement data were compared to Meteonorm and NASA SSE 3-hourly averaged solar data. Comparison shows that average irradiance values are in good agreement, whereas insolation and sky clearness values obtained from external sources are inferior to high quality measurement data. The results, presented in this paper, complement solar data of Meteonorm and NASA SSE and secondly, provides PV and solar engineers as well as scientists with highly valuable information on the solar resource of Mauritius that can be used during planning and design of PV systems as well as for conducting further research in Mauritius and surrounding regions.

1. Introduction

The energy per capita requirements of Mauritian citizens have consistently increased during the last decade. 2689 GWh of electricity was generated in 2010 as compared with 2577 GWh in 2009 and 1500 GWh in 2000, showing a 79% increase in energy generation since year 2000. The peak power demand in 2010 reached 404.1 MW in Mauritius as compared with 388.6 MW in 2009 and 288 MW in year 2000. This shows an increase in demand by 36% during the last decade [1]. In year 2012 the maximum electricity load reached 430.1 MW and the electrical energy generation reached 2796 GWh. 79% of the latter was generated from non-renewable energy sources and the remaining 21% from renewable energy – mainly bagasse and hydro. 2561.7 GWh of electrical energy was consumed in 2012 compared to 1844.1 GWh in 2003 [2]. The government of Mauritius has initiated the 'Maurice Ile Durable' project in order to improve energy efficiency and has targeted to achieve about 35% self-sufficiency by 2025. To date, Mauritius produces approximately 22% of its electricity from renewable resources namely hydro and sugar cane bagasse, and as such is among one of the world leaders in renewable energy use. Nonetheless, with increase in peak demand from 288 MW in year 2000 by 36% in 2010, there is an urgent need for democratization of the energy sector and diversification towards photovoltaics. Numerous projects are being developed to promote the integration of photovoltaic (PV) systems. In addition, the government of Mauritius is boosting the integration of Independent Power Producers (IPPs) and Small Scale Distributed Generators (SSDGs).

Mauritius is located in the tropic of Capricorn and has favourable weather conditions to efficiently harvest solar energy. The annual average daily solar radiation for Mauritius is estimated to be approximately 6 kWh/m^2 [3], but PV engineers and contractors do not have reliable and valid local solar data to perform holistic system sizing and evaluation. The local meteorological station has recently started to measure radiation data in a few locations in Mauritius, but reliable high resolution measured solar data for PV system modelling and assessment is not available. Solar data usually consists of sky clearness index, global horizontal irradiance, maximum solar irradiance and monthly average insolation

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computed from ground stations measurements and satellite images. Complementary meteorological data also include cloud cover, temperature, humidity, wind direction and speed as well as sunshine hours. Some common existing sources of solar irradiance datasets include Meteonorm, Satellight, TMY, NASA-SEE and WRDC among others [4]. These solar data are generated from satellite images and are for horizontal planes and all provide averaged insolation values. These data are better indicators for averaged long-term performance rather than performance for a given month or year. Accurate information on site specific solar radiation is essential to the development of photovoltaic projects, as the design details and economic feasibility of the PV system is a direct function of the local solar resource [5], even if obtaining such ground-based measurements requires high expenditure in setting up and maintaining monitoring stations [6]. Duffie and Beckman (2006) [7] recommend that to predict the performance of a solar process in the future, past measurements of solar radiation at the location in question or from a nearby location should be used and that it is not ideal to base predictions or calculations of solar radiation purely on radiative transfer models. Based on irradiance data obtained from the SolarGIS website [8] Africa will play an increasing role in the global energy balance as it receives one of the highest received level of insolation, in excess of 2000 kWh/m^2 per year over 80% of its landscape. More importantly, Europe and Africa jointly span the world spectrum of complete solar irradiance range. In an attempt to unveil the real solar resource potential in the southern African countries numerous research work were carried out during the previous years [6,9–13].

The objective of this study was to unveil the solar potential of Mauritius. Ground-based measurements have been performed at intervals of 30 s in order to obtain global horizontal solar irradiance data of very high accuracy. The latter is hence used to evaluate the average monthly global horizontal irradiance, maximum solar irradiance and monthly average insolation and monthly sky clearness index. A solar geometry model, described by mathematical equations based on fundamentals of solar engineering principles, was first validated using data from Mauritius Meteorological Services and then used to define the average monthly, seasonal and yearly maximum elevations and the extraterrestrial radiation. The measured solar data were then compared to Meteonorm hourly averaged data as well as NASA SSE 3-hourly averaged solar data, which were obtained from satellite-image based models. Hence, the measurement data validated and complemented the NASA SSE and Meteonorm data.

2. Location and equipment details

Mauritius is a tropical island which lies between Latitudes 19°58.8′ and 20°31.7′ South and Longitudes 57°18.0′ and 57°46.5′ East [14]. It enjoys a mild tropical maritime climate throughout the year. The country has two seasons: a warm humid summer extending from October to March and a relatively cool dry winter from April to September. The months of October and April are commonly known as the transition months [15]. The measurement site is located at 20°17′ South and 57°33′ East in the island of Mauritius which is considered as the middle-east part of Mauritius and is at an altitude of approximately 200 m above sea level. Solar irradiance data was measured using a c-Si Soldata pyranometer connected to a Hobo data logger. The Soldata reference cell measured global irradiance at 30 s interval on a horizontal surface. The device has a calibration factor of 144.5 mV $kW^{-1}m^{-2}$ and an accuracy of 3%. The equipment was calibrated by PV calibration laboratory of Fraunhofer-Intitut fur Solare Energiesysteme. But the calibration factors were verified against 1 kW/m^2 irradiance (at nearly 60 degrees of solar elevation) twice during a year. The HOBO data logger which is connected to the pyranometer has a 12-bit resolution and is connected to a computer with a USB cable for data acquisition and analysis. Measurement started in March 2012 and data are downloaded on a weekly basis.

3. Solar geometry fundamentals for Mauritius

During this research work a solar geometry model, based on fundamental solar engineering principles, has been applied to define the sun path motion in Mauritius throughout the year as well as daily extraterrestrial solar radiation. The model defines the sun path motion and the extra terrestrial radiation by equations (1)–(6) [16–18]. Sunrise, sunset hour and sunshine hour data were obtained from the Mauritius Meteorological Station. The latter was used to validate the model used for defining the solar geometry and secondly, together with measured solar data, to assess the real solar potential of Mauritius. Cooper (1969) and Goswami et al. (1999) [16,17] have described the position of the sun at any time by the angles:

(i) The solar altitude (solar elevation), $\alpha(n,t)$. While the maximum elevation angle is used in very simple PV system design, more accurate PV system simulation requires the knowledge of how the elevation angle varies throughout the day. The solar altitude or elevation, $\alpha(n,t)$, can be described with the fundamental quantities by:

$$\alpha(n,t) = \mathrm{asin}\{(\sin(L)^*\sin(\delta_s(n))) + (\cos(L)^*\cos(\delta_s(n))^*\cos(h_s(t))\} \quad (1)$$

where n − day number with 1st January as day 1, t − time, L − the latitude angle, which is positive north of the equator and negative south of the equator. The solar declination, $\delta_s(n)$, can be calculated by the equation:

$$\delta_s(n) = 23.45°^*\sin\{(284 + n)360/365\} \quad (2)$$

$h_s(t)$ − the hour angle, determines the number of degrees that the sun moves across the sky as from solar noon and is defined by

$$h_s(t) = 15°(t-12) \quad (3)$$

(ii) the Solar azimuth angle, $\alpha_s(n,t)$, which, can be calculated using the equation:

$$\gamma(n,t) = \mathrm{acos}\{[(\sin(L)^*\sin(\alpha(n,t)) - \sin(\delta_s(n))]/[\cos(L)^*\cos(\alpha(n,t))]\} \quad (4)$$

(iii) The solar zenith angle between the site to sun line and the vertical at the site.

The projection of the Sun's path on the horizontal plane for the site in Mauritius was computed using equations (1) and (4) and is shown in Fig. 1. Azimuth 0° represents South and ±180° represent North.

As shown in Fig. 1, the Sun is directed from the North from 21 January to 19 November and is from the South during two months, from 20 November to 20 January, which are the summer months with maximum solar radiation. The Sun has a maximum elevation on day 20 and day 325 respectively and the lowest elevation of 46.3 on 21 June, the day of winter solstice. For optimum PV system design, engineers require the knowledge of optimum tilt angles of panels for a given location. For this purpose, based on the solar geometry model, average yearly, monthly and seasonal elevations and tilt angle for solar panels were hence calculated. The results of