ASSESSMENT OF SOLAR OUTPUT INTERMITTENCY THROUGH DOMESTIC ROOFTOP SITE DATA FOR 2017-2021

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ABSTRACT

Rooftop solar photovoltaic (PV) systems are commonly used in homes to supply excess electricity to the grid. Although, the variation of the average energy supplied during a given month shows a regular behaviour to a certain extent, not only is the generated power intermittent but sometimes varies drastically from day to day, even within a given week. These hourly and daily variations, although well known in the solar industry are not readily available to the public, are quite often not taken into account in studies on solar generation. These can also lead to the supply authority having to plan without detailed knowledge of the likelihood of such loss of energy. This paper analyses the known concepts considering the power output of a 4 kWp solar rooftop system, in a site in Mount Lavinia Sri Lanka. It allows the public to envisage rooftop solar, to understand the fluctuations of solar energy and the chance of daily and seasonal output energy variations.

KEYWORDS: *Solar PV, Power Fluctuations, Rooftop solar, Intermittency, Daily variations, Monthly variations, Database*

1. INTRODUCTION

With Sri Lankan Government incentives, many rooftop solar PV installations have come up throughout the country, not only in large industrial installations but also in domestic installations. Most owners of these installations do not have any guide to the probable solar energy that can be collected and are at the mercy of the solar system vendors. While these producers would like to maximize the amount of energy harvested over the year, they would like to have minimum operation or maintenance costs for the installation. As most of Sri Lanka is located at a latitude of around 7°N (with Colombo 06.927°N) the rooftop installation should preferably be facing South with the tilt angle of the PV panels being approximately 7° to optimize energy yield. However, the slope of a domestic roof is generally much higher, at around 30°, and the solar panels would probably be laid parallel to the slope. Although steeper angles would give a slight decrease in solar energy harvested, they would facilitate self-cleaning of panels, which is an advantage to domestic users.

The daily energy harvested would vary due to cloud cover, monthly variations [1], [2] due to the position of the Earth relative to the Sun, or monthly weather variations [3], [4]. The decrement in output energy other than due to the position of the Sun, is the clearness of the sky, temperature, wind speed, precipitation, and the number of wet days [5].

This paper aims to provide a multitude of solar fluctuation information, especially for the general public who wish to become rooftop solar electricity producers by producing electricity daily, and are probably paid monthly.

2. MAXIMUM AVAILABLE SOLAR ENERGY

It is now generally accepted that the total solar irradiance at the top of the Earth's atmosphere, or extra-terrestrial radiation is around 1361 W/m^2 [6]. However, due to the transparency of the atmosphere, defined by a clearness index [7], the maximum direct beam irradiance reaching the Earth's surface is around 1050 W/m^2 [8], and the maximum global irradiance on the horizontal Earth's surface is around 1120 W/m^2 including the effects of diffused sunlight, which would occur in a cloudless sky when the Sun is at its zenith. The direction in which the Sun falls on the Earth depends on the location and how near it is to the equator. Further, the path the radiation takes to reach ground level changes as the day progresses with maximum radiation at noon. Thus, near the equator, the Sun's beams reach the Earth's surface from 6 a.m. to 6 p.m. and only diffused light can reach it at other times. When looking at it in a different way, some part of the Earth receives sunlight 24 hours a day while the Earth's surface is approximately spherical with a surface area of 4πR^2, as shown in Figure 1.

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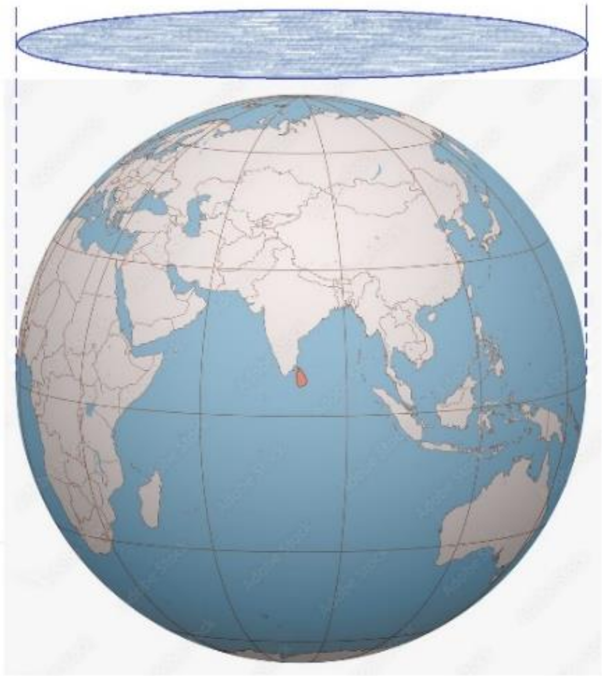

Figure 1: Surface area and projected area

The projected area (corresponding to that falling on the horizontal surface) is πR^2, giving a maximum of one-fourth of the energy falling on the horizontal area on which the sunlight falls. Thus, the maximum energy that could even theoretically be harvested from a given site would be 8.17 kWh/m^2/day (=1.361 × 24/4) including any harvested diffused radiation. Solar panels have at present a typical maximum efficiency of 18.6% at standard test conditions (including a nominal cell temperature of 25° C). Thus, the maximum realisable solar power generation is 0.253 kWp or 1.52 kWh/m^2/day.

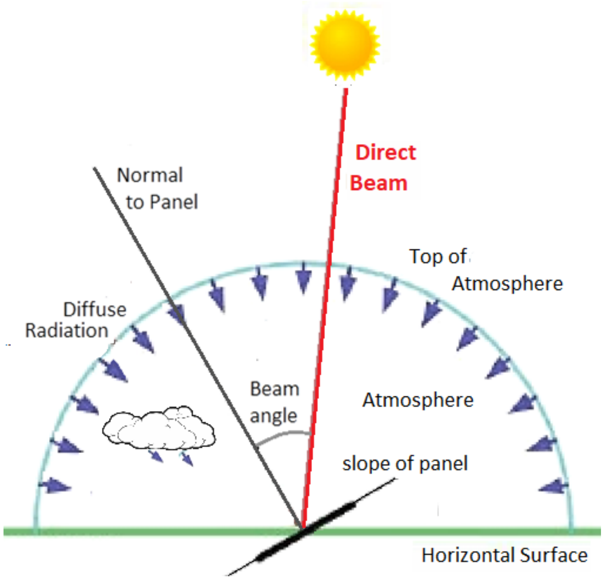

Figure 2: Composition of Irradiance

Figure 2 shows the direct beam component normal to the panel, and the diffuse radiation of the Sun. While maximum electricity is produced during noon time, the cell temperature of the panel would also be highest at this time; typically, it can rise to 30°C above ambient temperature.

Monocrystalline solar cells have a temperature coefficient of -0.4%/°C [9]. Thus, for a 30°C rise in cell temperature, there would be a drop of 12% in power output, reducing the effective panel efficiency to 16.4%. Since most of the solar power produced is when the solar panel is hot, around 1.34 kWh/m^2/day will be produced with what is normally considered a clear sky. A typical monocrystalline solar panel would be of size 1 m × 1.65 m so that 2.21 kWh can be expected per panel per day.

For a 12-panel installation, this would mean a maximum of around 26.5 kWh/day. The daily solar electricity production depends both on seasonal variations as well as cloud cover in addition to the variation of sunlight from sunrise to sunset.

3. MONTHLY VARIATION OF SOLAR INSOLATION

Due to the tilt of the Earth on its axis of rotation and the elliptical rotation of the Earth around the sun, there is a declination angle that varies seasonally as shown in Figure 3.

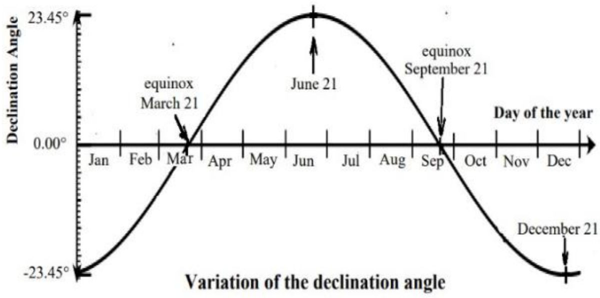

Figure 3: Monthly variation of the declination angle

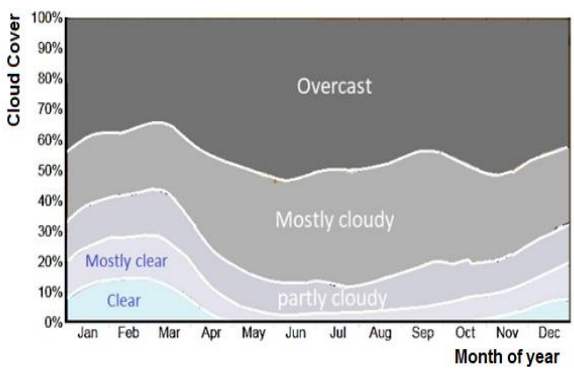

Figure 4: Cloud cover categories

Figure 4 shows a typical categorization of the percentage of time the sky is covered by clouds on a monthly basis in Dehiwala-Mount Lavinia in Sri Lanka

[3]. These are categorized in 20% steps as clear, mostly clear, partly cloudy, mostly cloudy, and overcast conditions which greatly affect the solar output.

A study [10], considering the period 2017-2021 for Mount Lavinia, has shown that for any month, 90% of the maximum solar energy yield can be guaranteed only on 17% of the days. However, 70% of the possible energy can be supplied on 60% of the days. It has also shown the rare possibility, on less than 2% of the days of less than 10% of the possible energy yield.

4. SELECTED SITE IN MOUNT LAVINIA

The data of a domestic site in Mount Lavinia Sri Lanka has been considered for detailed analysis. This site has 12 monocrystalline panels of size 1.65 m × 1.0 m installed with a total capacity of 4.16 kWp. Based on the current study, this site can be considered to generate a maximum of 3.3 kW (based on a nominal 80%) at around noon on a clear day with corresponding maximum energy of 26.4 kWh/day.

5. SOLAR OUTPUT MEASUREMENTS

Solar output measurements have been recorded online at the Mount Lavinia site from August 2017 to July 2021. Near ideal conditions have been recorded on 1st February 2018 and are shown in Figure 5 with a peak power of 3.332 kW and energy of 26.27 kWh/day. These correspond very well with the theoretically anticipated values.

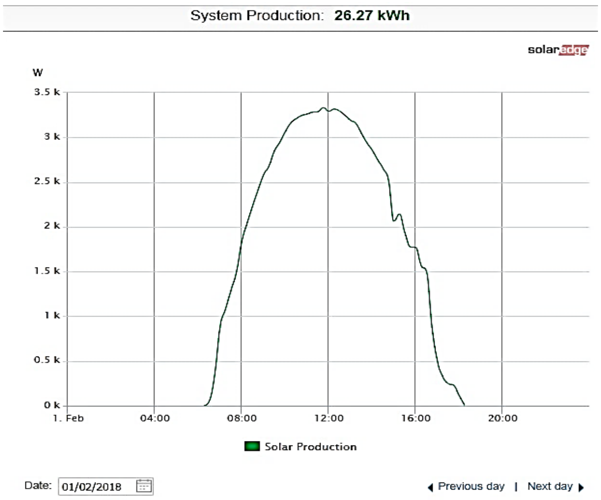

Figure 5: Peak solar energy day (1st February 2018)

It has been observed that the sky is relatively clear with nearly cloudless skies in January and February.

However, ideal days do not last the whole week-long. The best week for solar production during the 4-year period occurred from 3rd to 9th January 2019 as seen in Figure 6. However, the peak solar energy was observed on a different day on 1st February 2018.

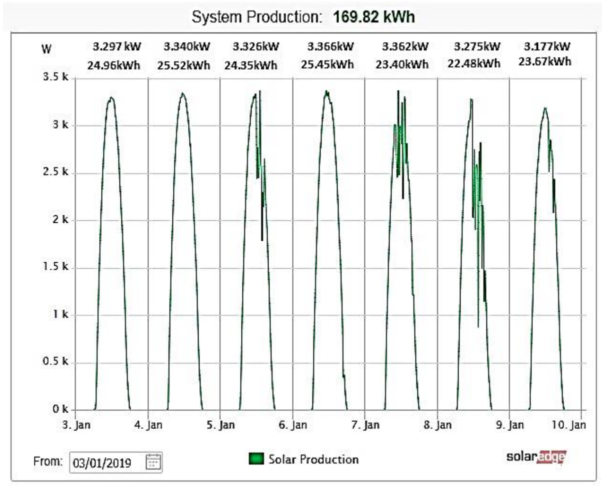

Figure 6: Solar output in a good week in January

It is seen that during this week, the peak power is virtually the same, but the daily energy produced varies slightly from 22.5 kWh to 25.5 kWh with a mean of 24.3 kWh.

On the other extreme, May and June are very unproductive months, with the lowest recorded during the 4 year period being on 3rd June 2021, just 0.324 kW peak power, but with the peak energy being just 0.807 kWh as shown in Figure 7.

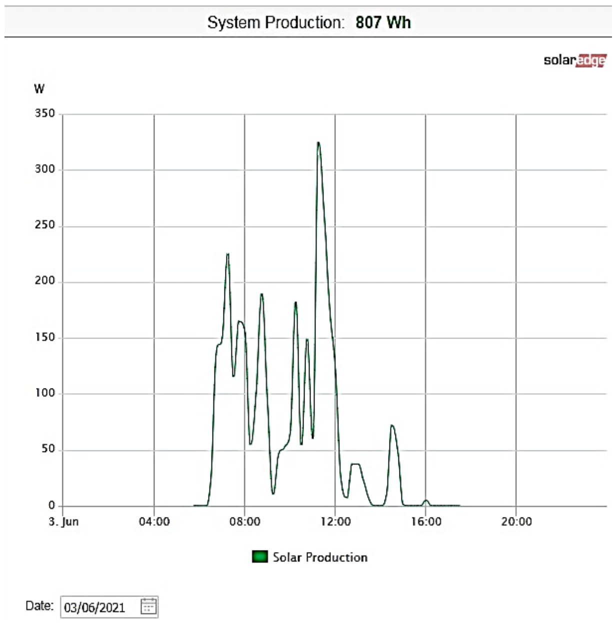

Figure 7: Minimum energy day in June 2021

Further, during this period the power and energy varied substantially from day to day as shown in Figure 8.

The overall solar output energy from month to month is shown to be somewhat consistent as in Figure 9. This is also consistent with the variations from month to month due to changes in declination angle and cloud cover as expected theoretically.

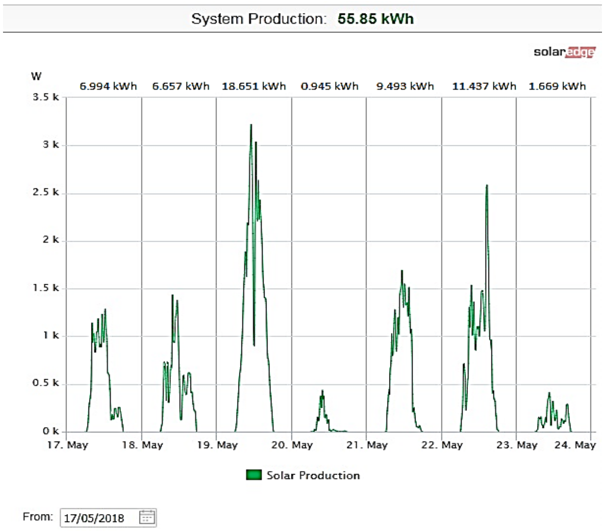

Figure 8: Solar output on a highly fluctuating week

6. SOLAR OUTPUT FLUCTUATIONS ANALYSIS

To understand the solar output behaviour, the intermittent output on 25th September 2017 has been compared with that of the maximum energy day and a maximum power day in September as shown in Figure 10.

It is seen from the figure that while the peak power for a clear day was 3.332 kW with energy of 26.27 kWh/day, the pattern did not completely match the pattern for September. Thus, a peak day in September was found where the peak power corresponds to 3.055 kW. It might be surprising that the peak power on a cloudy day like 12th September 2018 with 13.42 kWh/day, was much higher at 4.436 kW, compared to what could have been expected as 3.055 kW for even a clear day.

While it seems strange, the detailed analysis gives the reason for this apparent discrepancy. Studying the curves of 12th September 2018 with a clear day in September shows that there are many points which are above the clear day curve. Further examination of each of these points shows that each higher point occurs just after a very low point just before that instant.

For example, for the 4.436 kWp, moments before the power stood at 1.188 kW, and moments later falls to around 0.3 kW, seems very strange, but it is just due to the movement of relative clouds above the panel.

While a solar panel normally operates at around 30°C higher than the ambient temperature at mid-day, the temperature would fall to near ambient during cloud cover. Thus, soon after a cold session for the panel, when the sun suddenly appears, the solar panel efficiency is high giving a value very close to the nominal value of 4.16 kWp.

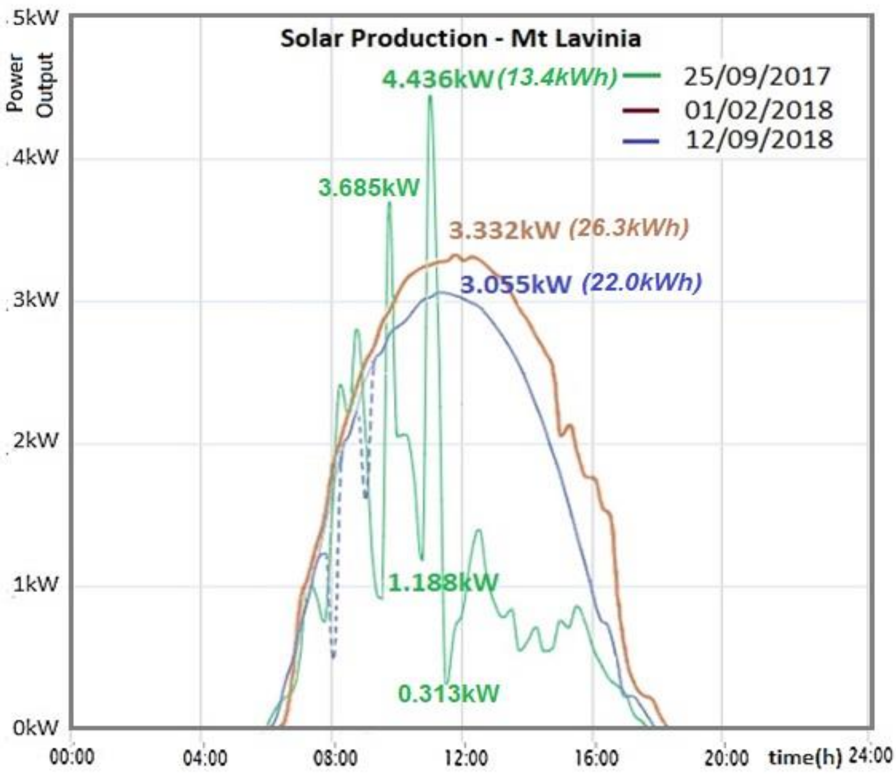

Figure 9: Average monthly solar output over the 4-year period

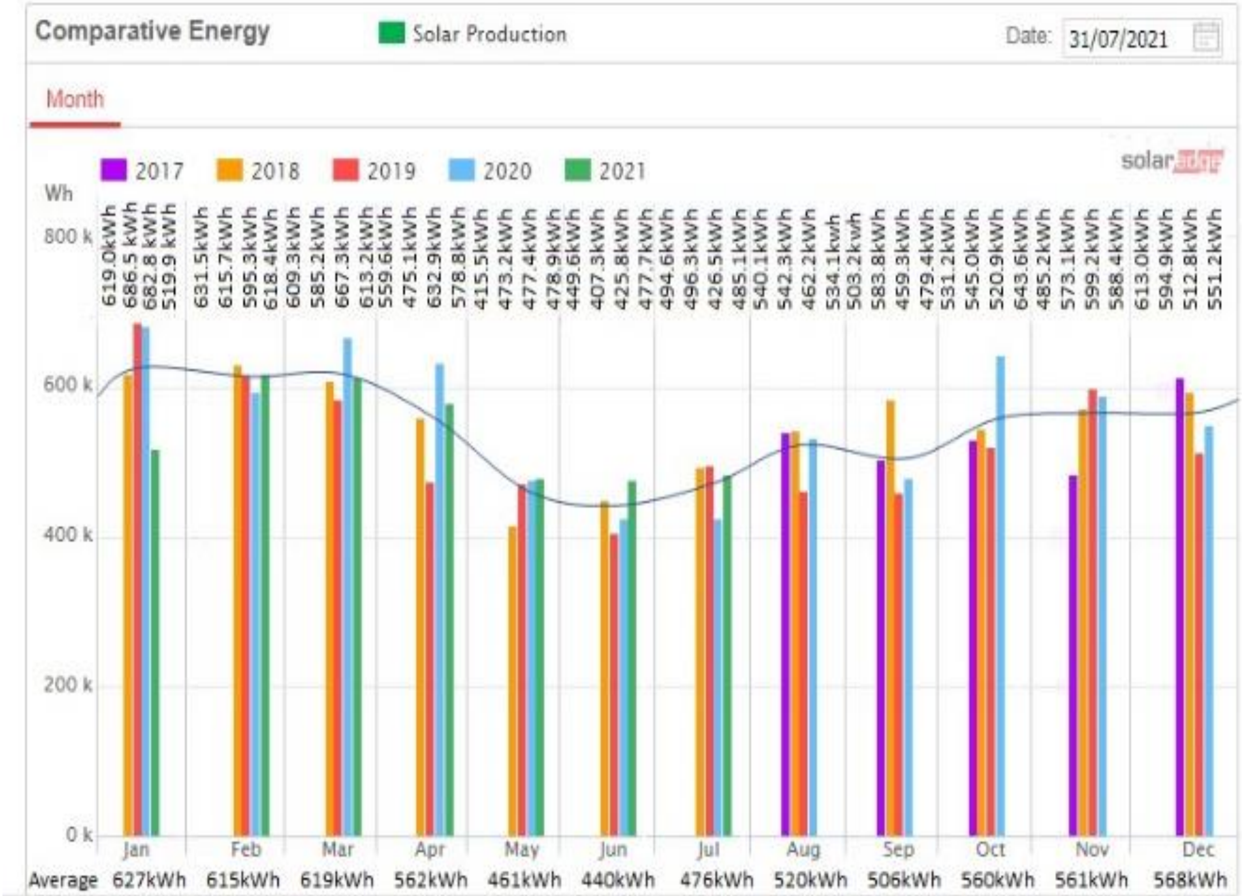

Figure 10: Analysis of solar output during fluctuations

7. CONCLUSION

The paper has presented an analysis of solar output for rooftop solar PV systems in the presence of both daily and seasonal fluctuations. Statistics represent how the generated power sometimes varies drastically from day to day, even within a given week. The review of analysis has been presented with respect to a 4.6 kWp monocrystalline solar rooftop system, on a site in Mount Lavinia Sri Lanka. Solar output patterns are analysed, and reasons for even higher power outputs during high fluctuations are explained to enable domestic solar roof-top owners to effectively utilise the power.

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