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RESEARCH ARTICLE

Renewable energy

Analysis of instantaneous, daily and monthly statistics 2017-2021 of rooftop solar energy

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Abstract: Solar photovoltaic systems are used in rooftops of buildings, especially to supply excess electricity to the grid. Analysis of the data from a site in Sri Lanka shows that, while the variation of the energy supplied during a given month is somewhat constant, large variations may occur from day to day, even within a given week. Further, dependent on the month, fluctuations from instant to instant could follow a typical sunny day sinusoid or on the other extreme fluctuate heavily. Since good statistics are not routinely available, many studies on solar electricity dispatch do not take these variations into account. Thus, supply authorities have to plan generation schedules without a knowledge of the likelihood of such variations. This paper analyses the power output of a 4.16 kWp domestic solar rooftop system, to allow the findings of fluctuations of solar energy output patterns to be used in system studies. The study shows that for a fixed rooftop installation, the maximum daily solar energy production can decrease to around 83% in months where the solar panel direction is adversely affected by the declination angle. It also shows that 80% of the maximum daily energy available in a given month can be assured 50% of the time in the worst-case scenario, while a day can produce just 3% of the maximum energy. It is also found that in the best month, near capacity production can be assured 90% of the time, where the sky is clear and the panel is ideally oriented.

Keywords: Fluctuation statistics, photovoltaic systems, rooftop solar, solar intermittency, solar power generation.

INTRODUCTION

With the world moving towards environmentally friendly sources of energy, harnessing rooftop solar electricity has become prudent (Atluri *et al*., 2018; *www.adb.org*, 2021). Thus, many rooftop solar photovoltaic (PV) installations are coming up in both industrial and domestic sites. However, there is little information available to the solar electricity producers on the probable solar electricity that can be extracted. They are thus at the mercy of the solar system vendors who paint a glorified picture. A site (latitude 6.83° N) in Mount Lavinia, Sri Lanka has been selected to study this global phenomenon. To optimise solar electricity generation, rooftop installations in the northern hemisphere should preferably be facing South with a tilt angle of the PV panels corresponding to the latitude for the site of around 7° N.

The instantaneous and daily electricity produced would vary due to cloud cover (Lucas, 2021), while monthly variations occur due to the position of the earth relative to the sun (*www.lankantrailblazer.wordpress.com*, 2019; Vidanapathirana *et al*., 2021) or to monthly weather variations. The decrease in the solar electricity output, other than due to the position of the sun, are the

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temperature, clearness of sky, rainfall, number of wet days, and wind speed (Wickramarathna *et al.*, 2011; *www.weatherspark.com*, 2016). This paper provides a multitude of fluctuation statistics for both the electricity supply authority and the solar electricity producer.

MATERIALS AND METHODS

In the present study, the radiation falling on the solar panel is first analysed starting from the global irradiation and the location of the site. Considering a site where the panels have a fixed orientation with respect to solar irradiation, the monthly variation of solar insolation is determined considering also the declination angle and the probable cloud cover. Daily solar output curves during a 4-year period from 2017 to 2021 have been considered for a domestic rooftop. Analysis is carried out on a monthly basis by considering the energy output in a number of bands. A particular site in Mount Lavinia Sri Lanka has been selected to illustrate the determination of assurance of solar energy production from the site. Variation of solar energy output with panel temperature is taken into account. The results of the analysis are presented in graphical form, and statistics obtained based on the probable energy output.

RESULTS AND DISCUSSION

Analysis of radiation falling on solar panel

The total extra-terrestrial radiation resulting in the solar irradiance at the top of the Earth's atmosphere is around 1361 W/m^2 (Tukiainen & *Gaisma.com*, 2021). However, based on the clearness of the sky (Tukiainen & *Gaisma.com*, 2021) or transparency of the atmosphere, the maximum direct beam irradiance reaching the earth's surface is around 1050 W/m^2 (Coddington, 2016). Thus, the maximum irradiance on the horizontal Earth's surface, which would occur in a cloudless sky when the Sun is at its zenith, is around 1120 W/m^2 including diffused radiation.

The direction of the sun's rays which fall on the Earth depends on the latitude of the site. Further, as the day progresses, the path of the radiation to ground level changes, with maximum at mid-day. Thus, near the equator, the Sun's beams can be considered to reach the Earth's surface from 6 am to 6 pm. However, diffused sunlight would still reach the earth's surface at night-time. It can be said that some part of the Earth's surface receives direct sunlight 24 hours of the day. The Earth, being a near sphere with radius R would have a surface area of $4\pi R^2$, and a horizontal projected area of πR^2. This means that a maximum of one-fourth of the direct sunlight falling would be captured perpendicular to the horizontal area on the Earth. Thus, the theoretical maximum energy that could be harvested from a given site would be one-fourth of 1.361×24 or 8.17 kWh/m^2/day, including any diffused radiation. At present, commercial solar panels can have a maximum efficiency of around 20% under standard test conditions, while 18.6% is more typical in currently installed sites (Lucas, 2021) and will be used in the present analysis. This yields a peak realizable solar electricity generation of 0.253 kWp or 1.52 kWh/m^2/day.

If the solar radiation (*www.newport.com*, 2021) falling on a solar panel is considered, there would be the direct beam, with a component normal to the panel, and diffused radiation from the top of the atmosphere and from clouds within the atmosphere, as seen from Figure 1. As the sun appears to move from East to West due to the rotation of the Earth, maximum electricity is produced near mid-day when the direct beam would be near normal to the solar panel. However, the temperature of the solar cells of the panel would also be highest at this time.

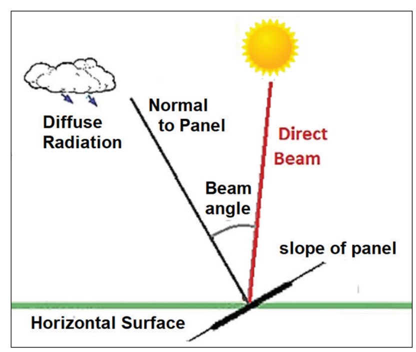

Figure 1: Composition of irradiance

It is known that on a hot sunny day, the cell temperature can rise to more than 30°C above ambient temperature. If efficient monocrystalline solar cells are considered, they have a solar panel efficiency of 18.6% and a negative temperature coefficient of 0.4%/°C (*www.solaredge.com*).

A rise in cell temperature of 30°C would cause a drop of 12% in power output, giving an effective solar panel efficiency of 16.4%. Since most electricity from the solar panel is produced near mid-day when the solar panel is hot, with a relatively clear sky, electrical energy output from the panel would be around 1.34 kWh/m^2/day. A typical monocrystalline solar panel of size 1 m×1.65 m can be expected to yield 1.34×1.65 or 2.21 kWh per panel per clear day.

Monthly variation of solar insolation

Figure 2 shows the seasonal variation of the declination angle between ± 23.45° due to the tilt of the Earth on its rotating axis and the elliptical path of the Earth around the sun.

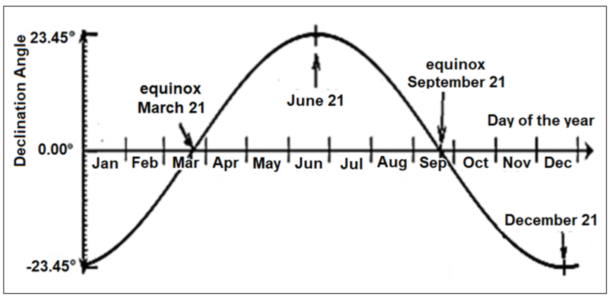

Figure 2: Monthly variation of the declination angle

The clearness of the sky, defined in terms of the percentage of time the sky is covered by clouds (Sanusi & Ojo, 2015) is usually categorized in 20% steps as clear, mostly clear, partly cloudy, mostly cloudy and overcast conditions and need to be considered to make a realistic prediction. Further, Lucas (2021) presents the probability of yielding a given solar energy on a monthly basis. Battery storage could be used to enhance the usability of solar panels and somewhat mitigate the effects of fluctuations (Nayanathara *et al*., 2019; Lucas *et al*., 2020).

Site in Mount Lavinia, Sri Lanka

Although the findings of the study are of general nature, analysis has been conducted with solar data of a domestic rooftop site in Mount Lavinia, Sri Lanka (Figure 3). The site has 12 monocrystalline solar panels installed, with each panel being of size 1.65×1.0 m. The vendor's stated capacity for the site is 4.16 kWp. Based on a typical 80% efficiency on rated capacity, when the solar panel is hot, this site can be considered to generate a maximum peak of around 0.8×4.16 or 3.328 kW near noon on a clear day, with an expected maximum yield of around 12×2.21 or 26.5 kWh/day. However, the actual daily solar electricity production will depend on both clearness of the sky as well as on seasonal variations, in addition to the variation of sunlight from sunrise to sunset.

Figure 3: Orientation of solar panels on roof

Solar output measurements are available online for the site on the SolarEdge monitoring portal provided by the manufacturer of the panels every 15 min although monitored continuously. Records are available from the inception for the solar system at the Mount Lavinia site, from mid July 2017. Thus, for analysis purposes, the four-year period from August 2017 to July 2021 has been considered.

The solar irradiance curve at the surface of the Earth is usually considered ideal, similar to part of a parabola as in Figure 4. Since the inverted parabola shown has a mean value equal to two-thirds, which can be easily obtained from integration, the energy in kWh works out to 8 times the peak value in kW, with the base duration from 6am to 6pm. Thus, quite often the solar curve is considered to be of duration 8 h at peak value giving the same energy. However, the ideal parabolic shape is rarely seen in practice.

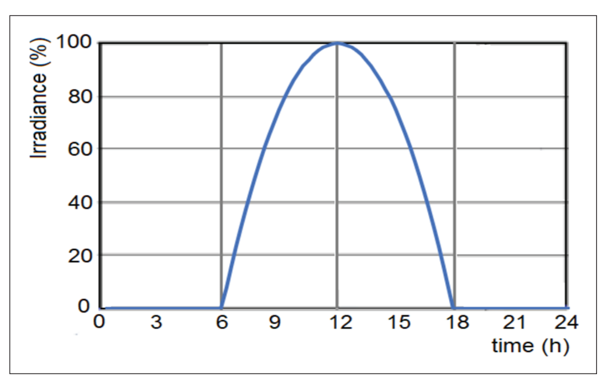

Figure 4: Daily solar irradiance

At the site considered, almost ideal conditions, although rare, were recorded on 1st February 2018 and shown in Figure 5 with a peak power of 3.332 kW and energy of 26.27 kWh. These values correspond very well with the theoretically anticipated values of 3.328 kW and 26.5 kWh/day. The shape also compares well with the expected parabolic shape also inscribed in Figure 5 for comparison.

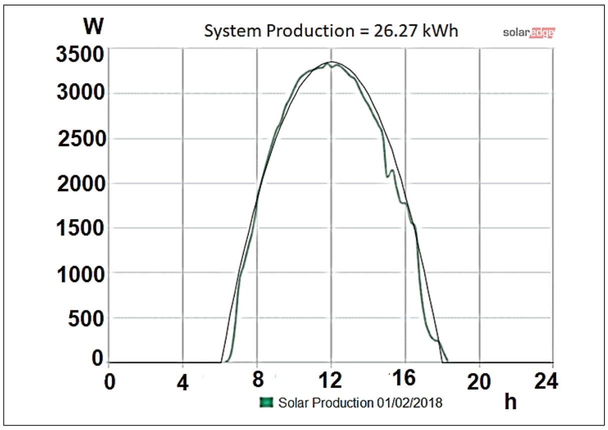

Figure 5: Peak solar energy day 1st February 2018

Clear blue skies have been commonly observed at the site during daytime in January and February, but near ideal days do not occur every day of week. At the site, the best week observed, during the four-year period evaluated for solar production, occurred from 3rd to 9th January 2019 of which the best four consecutive days are shown overlapped in Figure 6.

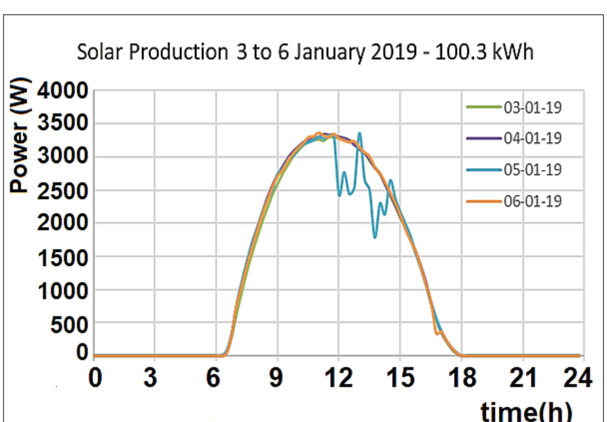

Figure 6: Solar output during a good period

It is seen that during this period, the peak power is virtually the same at around 3.3 kW each day, but the energy produced varied slightly from 24.4 to 25.5 kWh from day to day, with a mean of 25.1 kWh. While the total production for this period was 100 kWh, that for the week was 170 kWh.

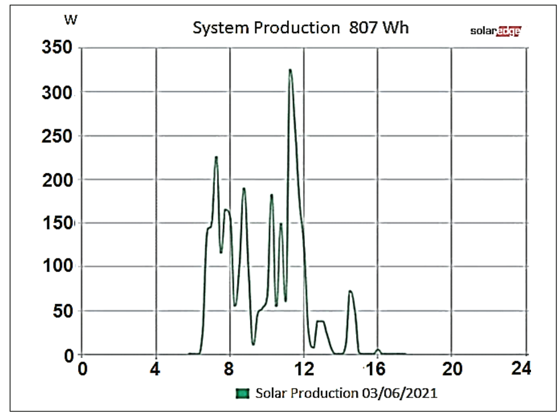

Figure 7: Minimum energy day

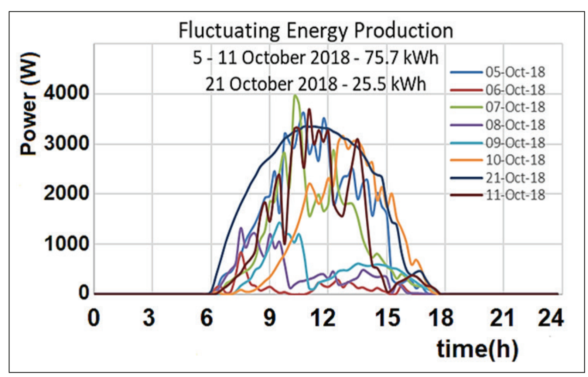

Figure 8: Solar output of a highly fluctuating week

The study has also found that certain months are relatively bad for the energy production, with the lowest recorded during the four-year period being on 3rd June 2021, just around one-tenth of maximum peak power, or 0.324 kW peak, and with the day's energy being just 0.807 kWh, or just 3% of the maximum energy produced, as shown in Figure 7. In particular, if the week of 5th to 11th October 2018 is considered, as shown in Figure 8, it can be seen that during this period the peak power varied drastically between 0.84 kW and 3.94 kW on adjacent days, 6th and 7th October. Correspondingly, the energy varied substantially from day to day during this week, between 1.5 kWh and 18.5 kWh. For comparison, the best production day in the month that year, 21st October has been plotted alongside for comparison. It is seen that while the peak power was 3.35 kW, the energy produced that day was 25.5 kWh. Comparison also shows that the energy of the particular week is just 3 times that of the best day for the month.

Planning to cater for highly fluctuating weeks like these is a tremendous task, and it is important to know how often such weeks occur. Thus, this aspect is also addressed in this paper.

The solar monitoring portal also stores monthly solar output energy, as shown in Figure 9 for the four-year period considered. It is seen that while the solar output is somewhat constant for the same month in different years, it also shows a significant seasonal variation from month to month due to changes in declination angle (on the 21st of each month), as given in table1, and seasonal weather, as expected.

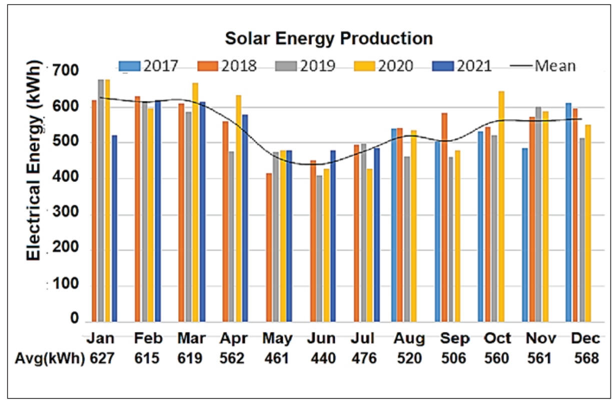

Figure 9: Monthly solar electricity production over a 4 year period

To obtain maximum solar electricity output, the solar panel needs to be rotated to face the sun throughout the year corresponding to the declination angle (Vidanapathirana *et al*., 2021).

Table 1: Monthly declination angle

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
-20.1°	-11.2	0°	11.6°	20.1°	23.4°	20.4°	11.8°	0°	-11.8°	-20.4°	-23.3°

Table 2: Correction factor for declination

Month	δ	ε	Cos ε	Max kWh	Observed max
Jan	-20.1°	0°	1	687	686.5
Feb	-11.2°	6°	0.994	683	631.5
Mar	0°	16°	0.961	660	667.3
Apr	11.6°	27°	0.891	612	555.9
May	20.1°	37°	0.799	549	455.3
Jun	23.4°	44°	0.719	494	427.6
Jul	20.4°	46°	0.695	477	472.5
Aug	11.8°	41°	0.755	519	519.7
Sep	0°	31°	0.857	589	506.4
Oct	-11.8°	21°	0.934	641	560.2
Nov	-20.4°	9°	0.988	678	561.5
Dec	-23.3°	2°	0.999	687	568

δ - Declination angle, ε - Correction angle

However, in a domestic solar installation, the panel is neither rotated to track the sun daily nor seasonally. The parabolic curve considered is based on the assumption that the panel is not rotated from sunrise to sunset, so that no correction needs to be made. However, depending on the direction the solar panel is installed to face, a correction for the maximum solar yield would need to be done. Based on the monthly solar output variation, it is likely that the particular solar system under investigation had been installed to give maximum output during January. Thus, the angles are corrected to be taken as reference, or give 0^o, on 1st January, and correction factors are based on that, as given in Table 2. Considering, from observations over 4 years, that the maximum solar energy output practically obtainable in a month to be 687 kWh, maxima for all the months have been calculated based on the correction factor cos ε and shown in Table 2.

The estimated monthly changes due to change in declination are compared with actual maxima in the corresponding month, over a 4-year period, and are shown in Figure 10. A very close match is seen.

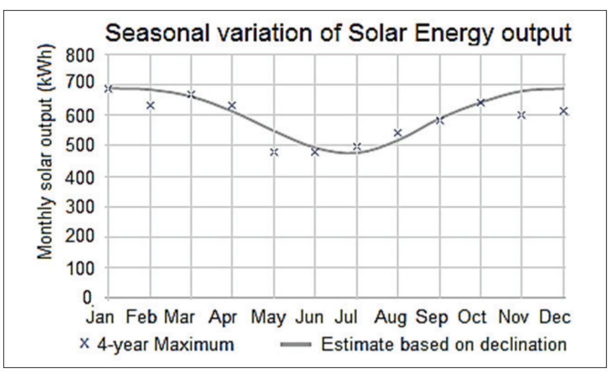

Figure 10: Comparison with seasonal variation

Figure 11 shows the variation of solar production for 22nd July 2018, a day with a very clear sky, as observed by the shape. However, the peak solar electric power produced, and the corresponding peak energy are 2.70 kW and 19.4 kWh respectively rather than the ideal 3.3 kW and 26 kWh.

Thus, the correction factor suggested in Table 2 has been selected as 19.4/26 or 0.75 and used to scale the maximum power output curve, which is drawn alongside in a dashed line. While the peak value of this scaled curve is lower at 2.50 kW the corresponding energy is 20.0 kWh which is slightly higher justifying the correction.

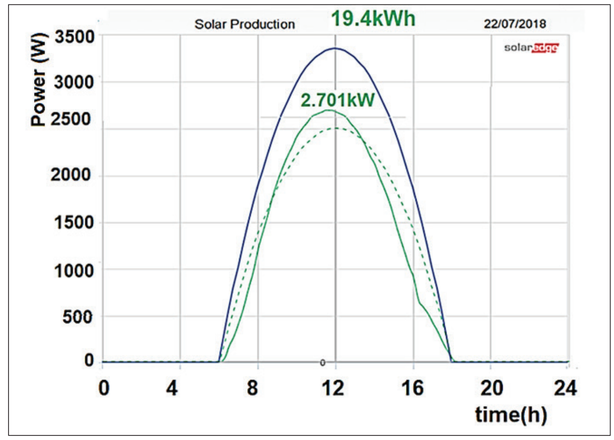

Figure 11: A near ideal day in July

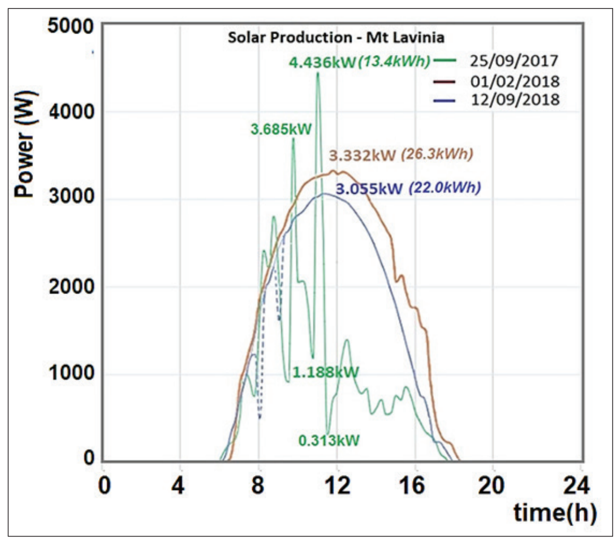

Figure 12: Analysis of solar output during fluctuations

Solar output fluctuations analysis

25th September 2017 has been found to be a day where the solar output power fluctuated a lot, going down to 0.313 kW while seemingly unexpectedly reaching even slightly higher than the stated capacity. to 4.436 kW moments later. Yordanov *et al*. (2012) have suggested that these bursts of energy are due to cloud reflections, but the author begs to differ as the conditions just prior to the dip have indicated a heavy dip, probably cooling the panel and increasing its efficiency The output of 25th September has been compared in Figure 12 with that of the overall maximum energy day (01/02/2018) and a maximum power day in September (12/09/2018) to take into account seasonal behaviour. On this particular peak day, 12th September, while the curve followed the expected parabolic shape, two minor dips are seen (shown dotted), but which did not change the basic shape during the time period investigated near noon.

It is seen from the figure that while, the peak power for a clear day achieved 3.332 kW with a daily energy of 26.27 kWh, the month of September never gave such high outputs for this site over the 4-year period considered. Thus, comparison only with the overall peak day was not considered prudent, and the best day ever in September (12/09/2018) was considered, where the peak power was nearly 10% lower at 3.055 kW.

It might be surprising to note that the peak power on a cloudy day like 25th September 2018, with 13.42 kWh/day, was in fact much higher at 4.436 kW, compared to what could have been expected, *i.e.*, 3.055 kW, for even a clear day. While it seems strange, detailed analysis gives the reason for this apparent discrepancy. Studying the curves of 25th September 2018 with those of 12th September shows that there are a number of points which are above the clear day curve. Examination of each of these points shows that each higher peak occurred just after a very low point just before that instant. For example, for the peak of 4.436 kW, the power stood at 1.188 kW moments before, and fell to around 0.313 kW moments later. This seems very strange at first sight, but it can be easily explained by considering the movement of clouds above the solar panel. Yordanov *et al*. (2012) have studied these bursts with probably 1 min data steps which showed many such bursts, but which did not show the energy fluctuations which became prominent with the integrated step of 15 min in Figure 12.

A solar panel of capacity 4.16 kWp under standard conditions would probably normally operate at around 30°C higher than the ambient temperature at mid-day. However, the temperature would fall to near ambient during cloud cover. Thus, soon after a cold session for the solar cell, when the sun suddenly appears, the solar panel efficiency is high due to the much lower temperature, giving a value very close to the nominal value of 4.16 kWp.

A sample of solar output patterns

Near ideal clear sky days, like Figure 5 or even Figure 11, are rare and do not occur even on one or two days of the month, even in clear sky months like January and February. In the months of May and June, it was not possible to even find a single clear sky day during the 4 years under investigation.

A collection of the days with the highest energy production for each month is compared and shown in Figure 13. The individual months are not identified in Figure 13, but could be identified, if necessary, by the observed peak values given in Table 2. The intention here is to show that if the solar panel is not rotated periodically, even the solar radiation falling on the panel cannot be fully captured, and thus the particular month is of no significance in this graph.

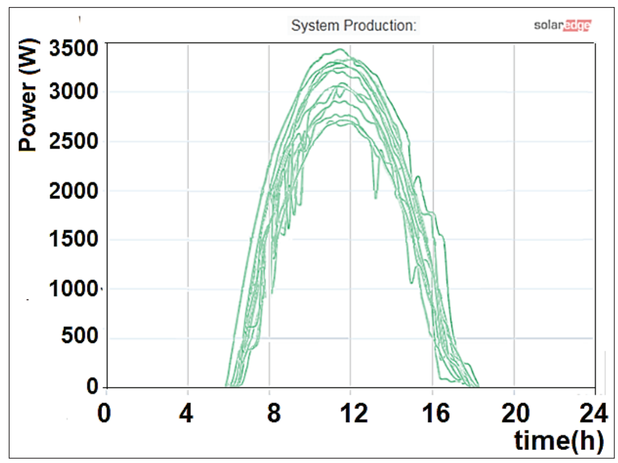

Figure 13: Near clear sky days in different months

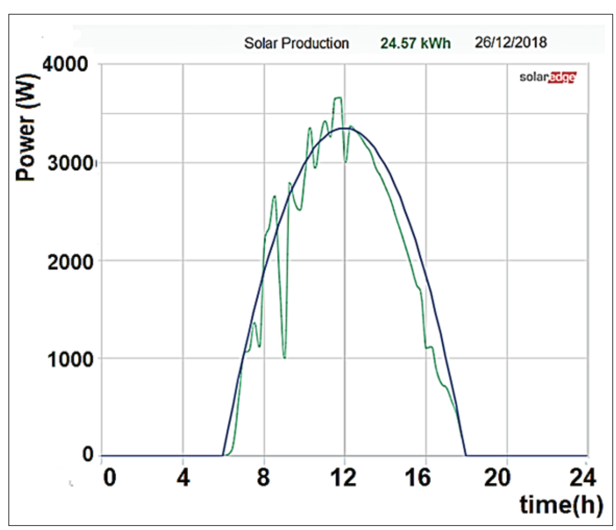

Figure 14: Minor fluctuations on good clear day

Since one of the solutions to mitigate the effects of fluctuations economically is the choice of optimum battery capacity, samples of partially cloudy, cloudy and overcast days are shown to give an insight on what sort of samples need to be put into the analysis basket for good validation or research studies. They are placed together with an ideal parabolic curve for comparison in each case.

Figure 14 shows minor fluctuations in solar power output caused by minor cloud movements on 26th December 2018. However, almost the maximum realisable energy is obtained (24.57 kWh).

On 9th February 2018, shown in Figure 15, partial clouds occurred in the morning (up to about 10 am), the normal peak was achieved slightly earlier, and the solar output dropped by 20% (21.38 kWh).

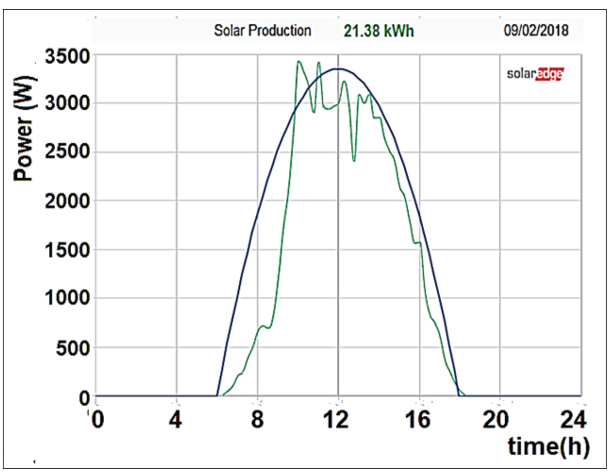

Figure 15: Solar output on a day with morning clouds

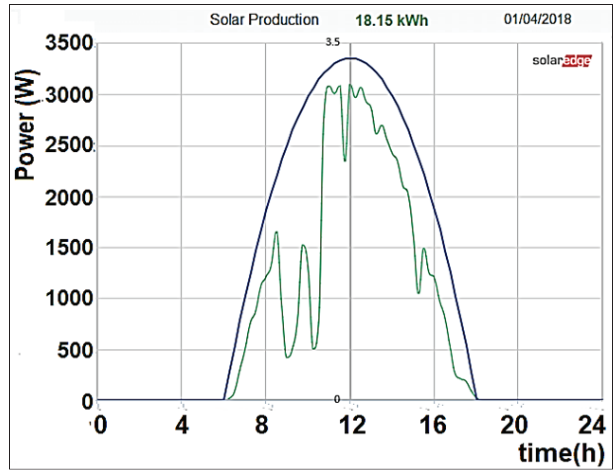

Figure 16: Solar output on a cloudy morning

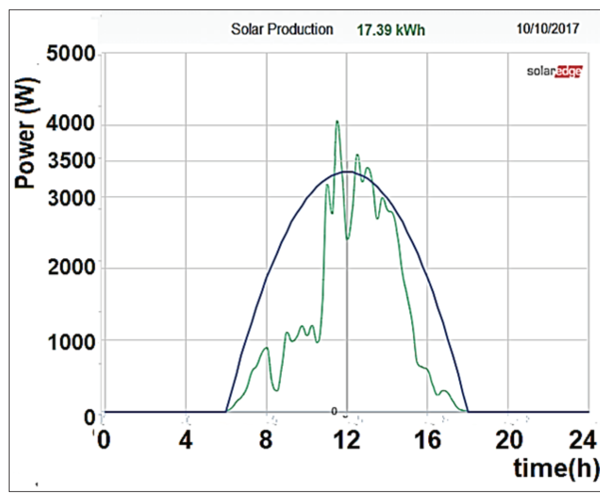

Figure 17: Solar output on an overcast morning

On 1st April 2018, a cloudy morning and the effect of declination angle have given rise to a 30% reduction of peak to around 3 kW and a reduction in the solar power output to 18.15 kWh as shown in Figure 16.

It is seen that it would have been a very cloudy morning with clearing of the sky thereafter.

Figure 17 shows the solar output on 10th October 2017, an overcast morning till about 11 am keeping the solar panels cool. A sudden clearing of the sky thereafter would have increased the efficacy of the panels giving a higher peak of 4 kW power output immediately thereafter. However, it is seen that while there is no reduction due to declination, there is still a near 35% reduction in the energy output (17.39 kWh).

17th March 2018 was a similar overcast morning, but with declination also affecting the solar power output and reducing it by nearly 45%. It can be seen from Figure 18 that in the evening the curve is nearly parabolic with the declination reduction factor.

The 25th September 2017 was a morning with a heavy movement of clouds and overcast conditions in the evening, as seen in Figure 19. It is seen that the alternate cooling and strong sunlight has caused the peak power to go to 4.4 kW, even above the value at test conditions of 4.17 kW. However, the resulting solar output energy has been reduced by nearly 50% due to the overcast conditions in the evening.

Figure 20 on 9th October 2017 shows an unusual day with overcast conditions during mid-day. It is seen that while the morning and evening are relatively free of clouds, mid-day has been completely overcast with power output falling to nearly zero just before mid-day, giving a reduction of the energy of just over 55% (11.45 kWh).

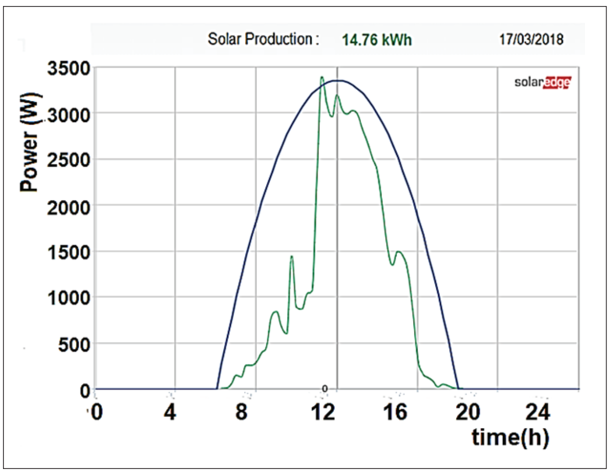

Figure 18: Solar output on an overcast morning in March

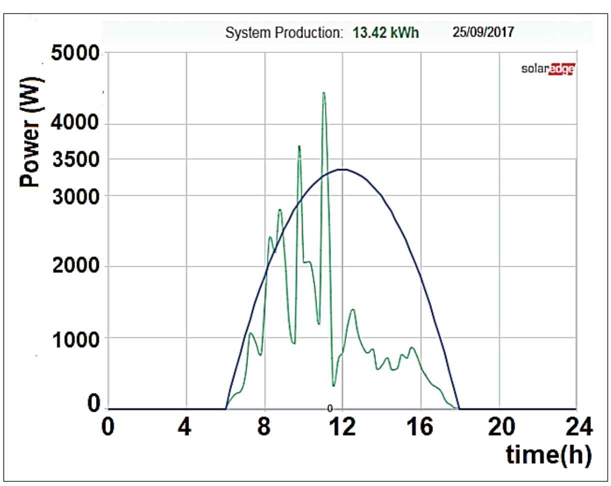

Figure 19: Solar output on a cloudy morning and overcast evening

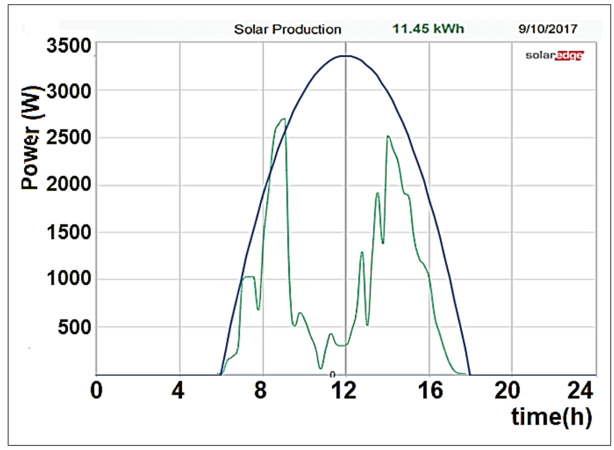

Figure 20: Solar output on an overcast mid-day

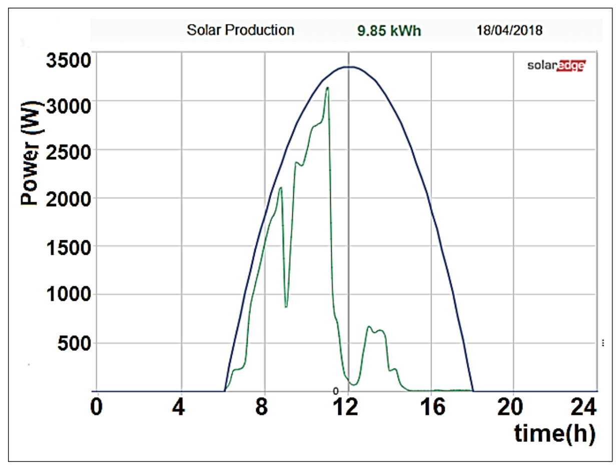

Figure 21: Solar output with a fully overcast evening

Figure 21 shows a partially cloudy morning on 18th April 2018, with the power curve following quite closely the theoretical curve, and a fully overcast sky in the evening. It is seen that the energy has reduced by over 60% to 9.85 kWh due mainly to the evening overcast conditions, with power not exceeding 0.5 kW from around 11 pm onwards.

Figure 22 corresponds to the solar output on a fully overcast day, 3rd September 2017, with a slight clearing of the sky later in the evening, allowing the power to rise to near normal at 2.1 kW in the late afternoon and thereafter. It is seen that the energy reduction corresponds to over 70% (7.8 kWh).

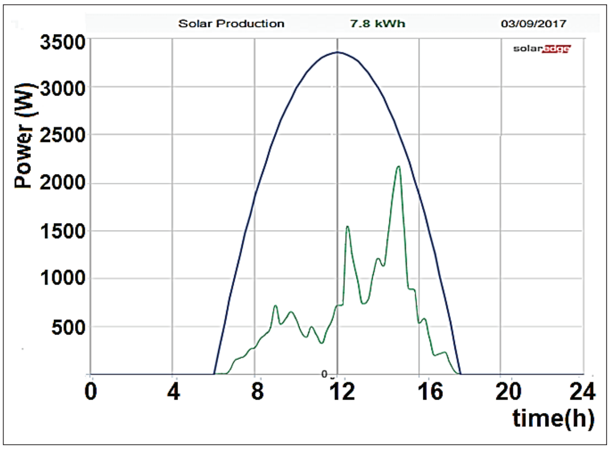

Figure 22: Solar output on an overcast day

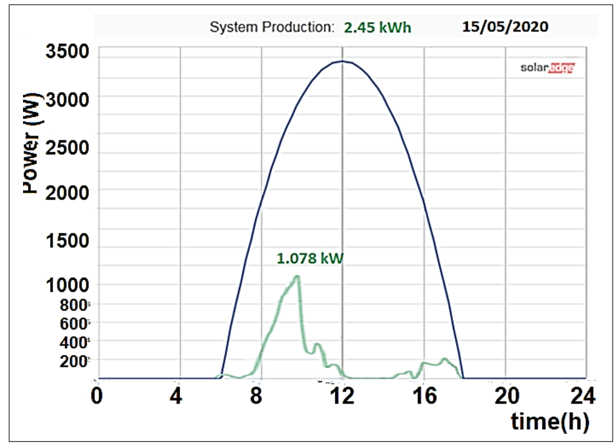

Figure 24: A very overcast day in May

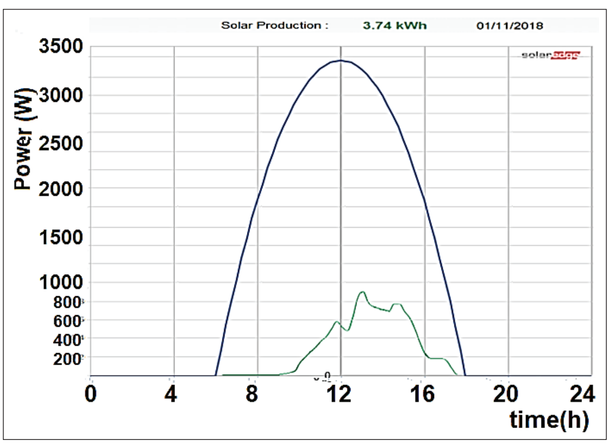

Figure 23: Very overcast day in November

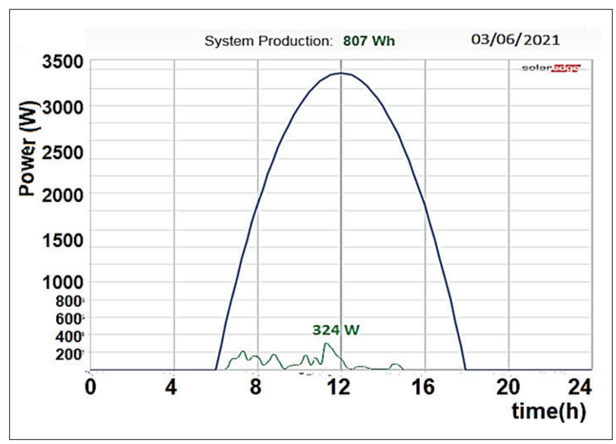

Figure 25: Lowest solar electricity producing day

Figure 23 shows a day with almost no sunlight throughout the day, with peak power around 0.8 kW or 25% of maximum achievable. The energy has also drastically reduced by 85% to 3.73 kWh.

Figure 24 shows a day with little sunlight in the morning and nothing after that (20 May 2020). The reduction in energy is 90% to 2.45 kWh with the peak power for the day just exceeding 1 kW. This day was however not the lowest energy producing day, which occurred on 3rd June 2021, as seen in Figure 25. This day had a peak solar output electric power of just 324 W (one-tenth normal peak) and an energy of 807 kWh, a huge reduction of 97%, with only 3.07% of maximum energy being generated on this day.

Categorization statistics of solar power

It is seen from the foregoing study that large fluctuations in both power and energy occur from season to season, day to day and hour to hour. Thus, statistics of the occurrence of varying levels of solar energy production would be very useful in planning and operating solar rooftop installations. Study of the energy production of the solar installation at the particular site considered, has shown, from both theoretical and practical considerations, that the maximum daily energy from the site is around 26.5 kWh. Thus, for statistical analysis, Categorization was done based on 2 kWh steps aligned at mid-value, for the 4-year period considered.

Figure 26 shows a summary of the probability of assurance of solar energy production at the site, plotted against assured energy. It is seen that in a good solar production month, like February for the site, over 20 kWh/day can be assured to be produced on around 25 days, while on a bad solar energy producing month like June, one would find it difficult to assure even 15 kWh/day on the same number of days,

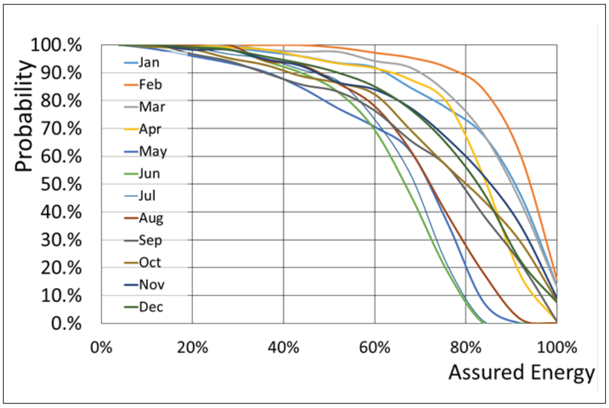

Figure 26: Probability of assurance of a solar energy production

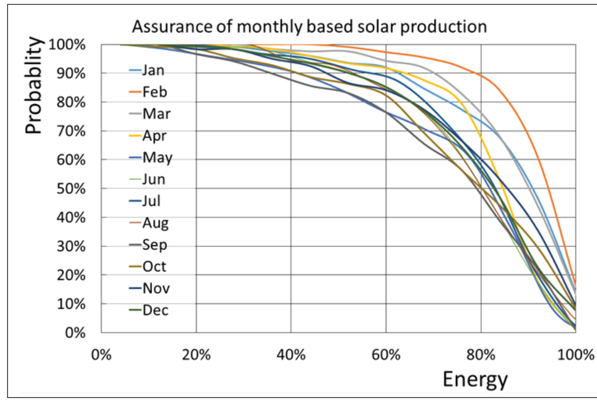

Figure 27: Assurance of a weighted monthly solar production

Table 3: Categorization of solar output days for the site

Category (kWh)	Average number of days in range												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1	0.0%	0.0%	0.0%	0.0%	1.6%	0.8%	0.0%	0.0%	0.0%	0.8%	0.0%	0.0%	**0.3%**
3	0.0%	0.0%	0.0%	0.0%	2.4%	0.0%	0.8%	0.0%	3.3%	0.8%	1.7%	0.8%	**0.8%**
5	0.8%	0.0%	0.0%	0.8%	2.4%	0.8%	2.4%	0.0%	2.5%	3.2%	0.0%	0.8%	**1.2%**
7	1.6%	0.0%	1.6%	0.8%	3.3%	4.3%	1.6%	5.6%	4.2%	2.4%	3.3%	2.5%	**2.6%**
9	1.6%	0.0%	0.8%	2.5%	5.7%	4.3%	4.0%	1.6%	4.2%	4.0%	2.5%	2.5%	**2.8%**
11	2.4%	0.9%	0.0%	2.5%	7.4%	6.8%	4.0%	6.6%	2.5%	2.4%	5.9%	3.3%	**3.7%**
13	1.6%	1.8%	3.3%	1.7%	6.6%	13.5%	14.%	8.2%	6.8%	4.0%	2.5%	5.0%	**5.7%**
15	7.4%	1.8%	2.5%	4.2%	9.0%	24.%	20.%	16.%	11%	13.%	6.8%	8.4%	**10.%**
17	7.4%	3.5%	9.1%	8.3%	25.%	27.%	32.%	23.%	9.3%	13.%	11%	12.%	**15.%**
19	9.8%	8.1%	15.%	27.%	29.%	19.%	20.%	21.%	18.%	12.%	13.%	18.%	**17.%**
21	21.%	23.%	24.%	35.%	7.4%	0.0%	0.8%	16.%	170%	15.%	18.%	24. %	**17.%**
23	32.%	45.%	31.%	17.%	0.0%	0.0%	0.0%	1.6%	21.%	21.%	26.%	15.%	**17.%**
25	14.%	16.%	13.%	0.8%	0.0%	0.0%	0.0%	0.0%	0.8%	8.2%	9.3%	7.5%	**5.8%**

It is seen from Figure 27 that for the particular solar installation, trying to assure a monthly energy of even 25 kWh can never be achieved. Table 3 shows that for any month, while 90% of the maximum solar energy production can be guaranteed on 62 days (17% of the days), 70% of the possible energy can be supplied on 219 (60% of the days). The days on which less than 10% of the possible energy can be supplied is less than 7 days

(2%). These results can be made use of to offer a partial capacity charge to rooftop solar producers for perhaps half the capacity, which can be guaranteed on 86.7% of the days or 317 days of the year. However, if we go month by month, a better guarantee can be made as seen from Figure 27. Columns 4 and 5 of Table 3 give the number of days in each category for two selected months, January 2019 and May 2019. For example, in January 2019, 15 kWh (60% of the maximum power) could be guaranteed 95% of the time with an average availability of 21.43 kWh. Similarly, on no day in May 2019 did the power exceed 19 kWh, and on 25 days (80% of the days) the power exceeded 55% of this capacity (10 kWh).

CONCLUSION

The paper has presented an analysis of solar output for solar photovoltaic systems, considering a 4.16 kWp monocrystalline rooftop solar system in Mount Lavinia, Sri Lanka. Fluctuation of actual power and energy have been observed over a four-year period from August 2017 to August 2021. It is seen that, not only is the generated power intermittent, with the peak for the day exceeding 4.5 kW on one occasion but going down to as low as 0.324 kW on a heavily overcast day, with variation of solar electric energy output per day from 0.807 kWh to 26.27 kWh. It was also observed that in a good month like January or February, daily output would be high, averaging 22 kWh/day, while on a month like May or June it could decrease to 13 kWh/day, sometimes varying drastically from day to day, even within a given week. A range of solar output patterns are analysed, and reasons for even higher power outputs during high fluctuations are explained. It is expected that the findings will be useful for those not having actual data, in analysing solar power systems. While this detailed analysis has been presented for a particular site, lessons to be learnt from this study are general. While the data presented is for a specific site in Mount Lavinia, cloud cover and other considerations would be perhaps very similar for a range of locations close to the site. Similar studies could be carried out for other sites to yield a map of solar energy assurances to permit partial capacity cost for solar installations.

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