A technical assessment on photovoltaic power generation under varying weather profile – Northumbria university pilot

Rahul R Urs, Zunaib Ali, Mousa Marzband
Dep. of Math,
Physics, and Electrical Engineering
Northumbria University
Newcastle, UK

Komal Saleem
Queen Mary University
London, UK

B. Mohammadi-Ivatloo, A. Anvari-Moghaddam
Department of Energy Technology
Aalborg University
Aalborg, Denmark

***Abstract*—The output from Photovoltaic (PV) system's is mostly dependent on the weather of the area in which it is installed and it is greatly influenced by the amount of sunlight, irradiance intensity and the time of day (sunny or daylight hours). Consequently, climate in the United Kingdom (UK) does not allow the production of consistent power throughout the year. This paper discusses and analyses the realistic weather data in the UK to provide the accurate climate factor for solar energy production. The present study aims to help decision-makers take reasonable steps to provide solar energy production solutions while considering the weather benefits and as well as abnormalities. This paper tends to provide a comparative analysis of actual and theoretical performance conducted over a one-year monitoring cycle. The paper starts with an overview of performance co-efficient followed by the details of energy produced during various weather periods to investigate the reliability of depending solely on solar. A 75% decline in winter output relative to the summer and an energy generation of only 1.8% on the darkest day of the year compared to the brightest day are reported.**

***Index Terms*—Technical assessment, Photovoltaic Power, Weather profile, PVsyst , Performance ratio**

I. Introduction

The rising levels of carbon emissions and increased utilization of conventional energy sources give rise to the issue of global warming. Thus, the need for meeting the increasing energy demand as well as mitigating for climate change (such as global warming) necessitate the use of green and clean source of energy such as solar photovoltaic (PV), wind, tidal, geothermal (all of them are abundant in nature). As citizens are increasingly aware of their rising carbon footprint and since, PV systems work best under direct sunlight, global warming can be of real benefit towards extracting energy from solar power plants. Nevertheless, not all countries or regions benefit from this form of climate change in the development of solar energy.

The PV system converts light energy into electrical energy under certain standard conditions. Thus, the generation of solar energy depends on various parameters having a strong impact on its performance. Some of the parameters include type of solar cell, solar irradiation, cell temperature and weather conditions like sunny days and sunshine hour in the prospective installation region. The sunshine hours mainly depend on the length of the day and cloudiness. In the northeast of England, length of the day is shorter during December and long in the period of June. Thus, making December a dullest month and June to be the brightest. The sunshine hour in UK varies from 1.7 hours to 9 hours per day. Among which as expected, the sunshine hours would be more in June and minimum in December. It is also worth mentioning that the length of daylight mainly depends on the latitude and altitude of the region. This project evaluates the performance of 109.5 kW PV system installed in University of Northumbria, Newcastle. The plant considered in this project is benefited with around 1445 sunshine hours annually. Consequently, along with the performance evaluation, the output from actual PV system installed is compared with the output from modeled PV system using PVsyst software. The solar map provided by Solargis provides an estimation of solar irradiation, which is of about 2.5–3.1 kWh/m2/day and 949 kWh/m2/year in the UK [1]. Importantly, the contribution of solar power to the total generation (that was 1.272TWh in 2012) has now increased to 10.70 TWh in 2019 [2], increasing in this way the energy mix of solar from 0.4% to 4.08% of total generation in the UK [2]. Furthermore, UK is expecting the installed capacity of solar to be 15.7 GW by 2023 and has integrated 13.356 GW by the end of December 2019 [3]. Also, the carbon emission being 245gCO_2/kWh in 2019, UK has set a goal to achieve 100gCO_2/kWh by the end of 2030 [2]. There are studies in [4]– [10] evaluating the performance feasibility and reliability of PV installed in their specific country/region. Likewise, the impact of weather on PV power generation has been explained in [11]– [14].

Consequently, our paper aims in presenting the outcome of evaluation considering the performance of Northumbria University Newcastle (UNN) pilot. In addition, the objective is to show discrepancies between expected power (from the practical PV system) and calculated power (using PVsyst software) over a specific climate span of a year. Furthermore, the generation of power during four different periods is also discussed. The rest of the paper is organized as: Section 2

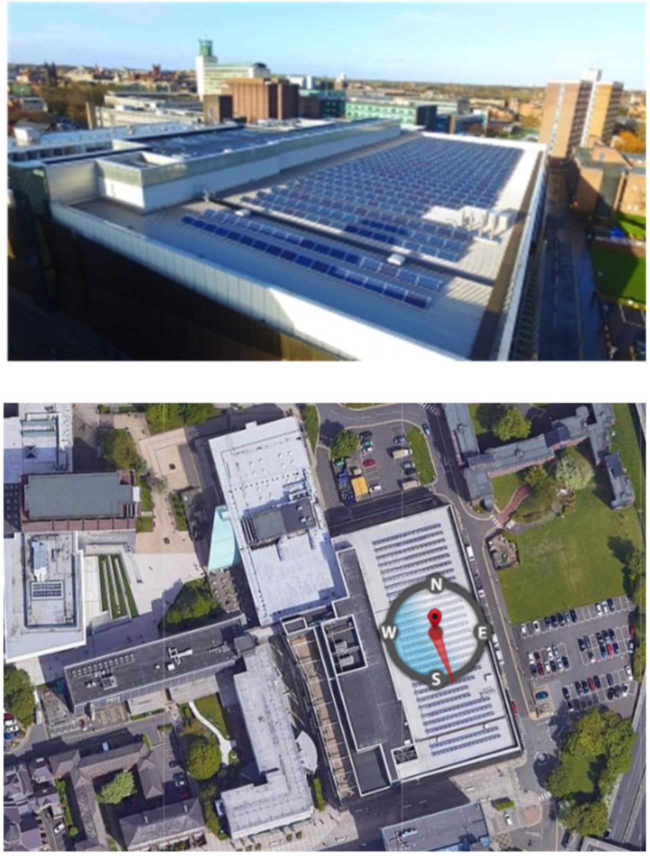

Fig. 1. The photo of Sport Central rooftop PVs (actual photo and google view) – obtained from [17].

presents the methodology, describing the details of practical UNN photovoltaic system, the modelling in PVsyst software and the performance indices. The results and discussion are provided in Section 3 and paper concludes in Section 4.

II. Methodology

A. Photovoltaic system description

The PV system is installed at the top of sports central, University of Northumbria Newcastle upon Tyne (as shown in Fig.1). The location of the plant is benefited with Global Horizontal Irradiance (GHI) of 2.54 kWh/m2/day. The ambient temperature of this location is 9.6 C. The latitude and longitude being 54° 58' 40.9692'' N and 1° 36' 24.1416" W, respectively. The area consumed by the plant is 662m2.This plant is owned by Northumbria University and installed by Advanced Renewable (AR) Power. The PV module used in the system is Seraphim-SRP-6PB-250 having a power of 250 Wp (437 modules in total with overall nominal power of 109.5 kWp) and inverter being SMA -Tripower 25000TL with a nominal power of 25 kWac (there is pack of 4 inverter unit with a cumulative power of 100 kWac). The operating voltage of inverter is 390-800 V. The results from the actual system are obtained using SCADA system.

B. Modelling of the PV system in PVsyst

The rooftop system described in the previous subsection is modelled using PVsyst. The tilt angle and azimuth angle of the plant being 30 and 160 (same are used in this simulation). In order to obtain optimum and realistic results, the actual values and specifications of plant components are used in the simulation. The number of modules and strings can also be changed accordingly for an appropriate design and output. The meteorological data is used from the PVsyst database, given the geographical coordinates of site. Once all the necessary inputs are provided, it is important to check the system for error given the selected major components.

C. Modelling of the PV system in PVsyst

For the evaluating the performance of PV system during whole year, four different periods are defined based on the varying weather profile [16], as summarized in Tab. 1.

TABLE I
SIMULATION RESULTS

Sl No	Period	Length of Period
1	Period 1	Feb 20th – April 29th
2	Period 2	April 30th – August 14th
3	Period 3	August 14th – October 22nd
4	Period 4	October 23rd – February 19th

The following steps (also shown in Fig.2) are used for the performance evaluation of PV system over a period of one year:

Step 1. Initialize the predefined parameters such as the temperature, solar irradiance and weather conditions of the PV plant in the PVsyst software.

Step 2. Once the initialization of the parameter is completed, choose appropriate panels and select the type and number of on-grid inverters required.

Step 3. Check if the inverter is perfectly sized and if no warning displayed, choose the number of strings required and the number of panels in a string. However, if the warning symbol is shown due to the selection of inappropriate inverter, go to step 2 and repeat the inverter selection process.

Step 4. Simulate and save the results

Step 5. Compare the result obtained from PVsyst software with the SCADA result pre-defined weather periods.

III. Results and discussion

The monthly average solar irradiance and ambient temperature from PVsyst are presented in Fig. 3. The global horizontal irradiance per day varied from 2.5kWh/m2 to 3.1 kWh/m2. The annual average of the solar irradiance being 914 KWh/m2, observed to be high in the month of May (142.6 KWh/m2) and lower in the month of December (13.1KWh/m2). As obvious from Fig. 3, the plant results performed better during Period 2 and minimum during Period 4.

Fig. 4 displays the monthly energy output from both PVsyst model (Pg,t) and SCADA (Pg,a) of the PV plant. The outcome of the simulation revealed that the plant could generate 13.36 MWh in the month of May and 2.72 MWh in the month of

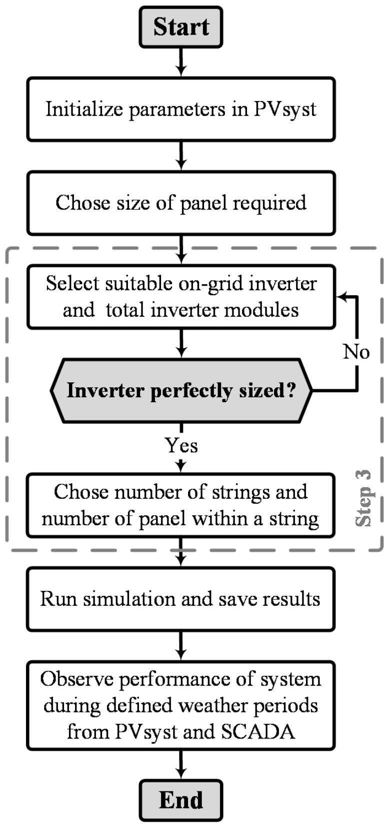

Fig. 2. The flow diagram used for performance evaluation.

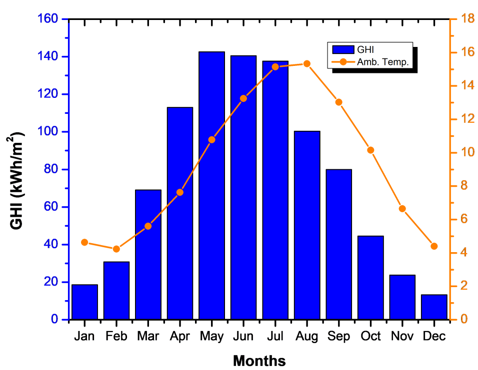

Fig. 3. Monthly average solar irradiance and ambient temperature.

December. Whereas the actual production is found to be 13.31 MWh in the month of May and 1.71 MWh in the month of December. The theoretical power from PVsyst is approximately equal to the real results (with a minute difference). In addition, concerning the annual PV production, the PVSyst estimate indicates that although the total production was 101.74 MWh, the PV plant is able generate 100.16 MWh. This is because of the unpredictable environment profile in any region of interest.

Furthermore, results in Fig. 5 show a minute difference between the theoretical (Pr,t) and actual (Pr,a) values of performance ratio. The measured output from plant to the calculated output defines the ratio and it is directly affected by various factors such as temperature, irradiance, and weather profile. The actual value derived from SCADA shows that

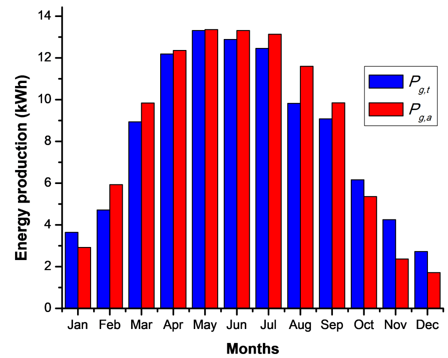

Fig. 4. Monthly energy output from PVsyst and SCADA.

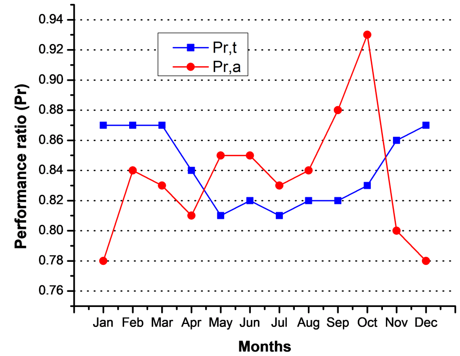

Fig. 5. Monthly theoretical and actual values of performance ratio.

during October, the system works at its peak and in December, the output drops drastically. However, the annual average is found to be nearly the same, where the measured value is 0.835 and the simulated value is 0.841.

Alongside, the normalized device and array losses during each month are shown in Fig. 6. The normalized system production (Yf) is the subtraction between the energy of the reference incident (Yr) and the summation of losses in the system (Ls) and the array (Lc). From PVsyst results, these losses are shown to be highest in the month of May and June (this is due to increased operation of system) and low in the month of December and January due to less performance of the rooftop PV plant.

Interesting results presented in Fig. 7 show that before receiving AC output, there are some power losses due to module quality, module mismatch, wires/cables specification and inverter efficiency. The "module quality loss" is the difference

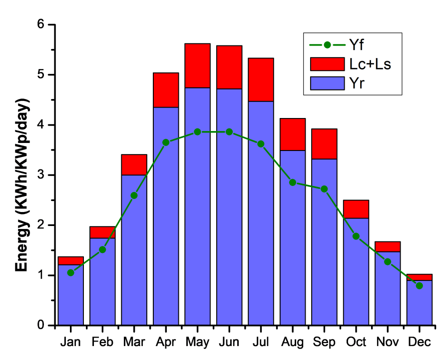

Fig. 6. Monthly normalized performance Coefficients

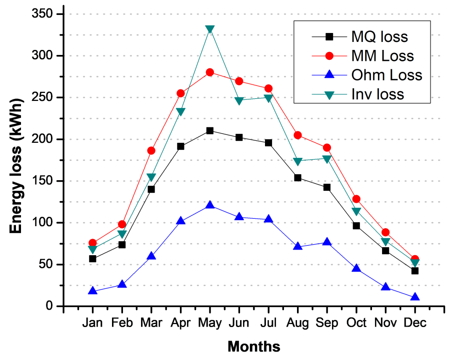

Fig. 7. Detailed System losses of the designated system

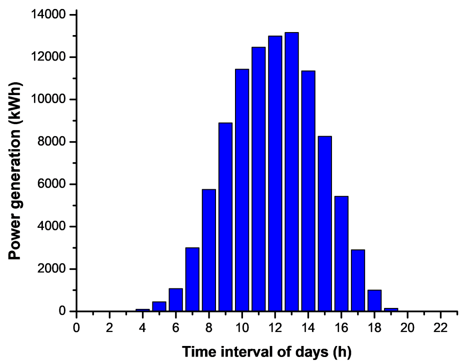

Fig. 8. Power generation during different time interval of a day (obtained from simulation data).

in the performance of the actual modules with respect to the manufacturer's specification. The mismatch losses are induced by interconnecting solar cells or modules that do not have similar properties or that experience different conditions from each other. Further, the wiring circuit's ohmic resistance causes losses between the power available from the modules and the power in the subarray terminals. Finally, the inverter loss is due to the efficiency of the selected inverter [16].

The power generated from the plant modeled in PVsyst during discrete time interval of the day is shown in Fig. 8. From the statistics, it can be inferred that the plant production is at its peak between 10 a.m. and 2 p.m. However, considering annual generation, even during the unexpected hour, which is at 4 am and 7 pm, there is a small amount of power generated during specific months.

As obvious, the climate would not be the same in all the months of any year. Consequently, four different periods are considered, based on the lightening condition of days (that is brighter and darker days), as presented in Table 1 [10]. The span in Period 2 consists of more hours of sunshine, providing in this way brighter days. On the other hand, Period 4 usually span the entire length winter season with less daylight hours and with more dark days. Furthermore, period 1 (February 20th to April 29th) and period 3 (August 14th to October 22nd) do not belong to any single specific category and exist precisely between brighter and darker period. The production of power during all these periods is shown in Fig. 9 (obtained from the actual system via SCADA). The brighter days (Period 2) as expected contributed about 45.61 MWh to the total

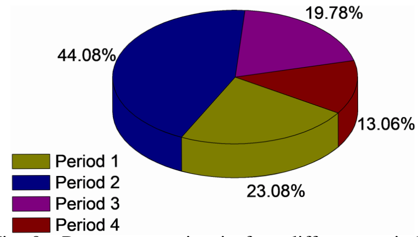

Fig. 9. Power generation in four different periods.

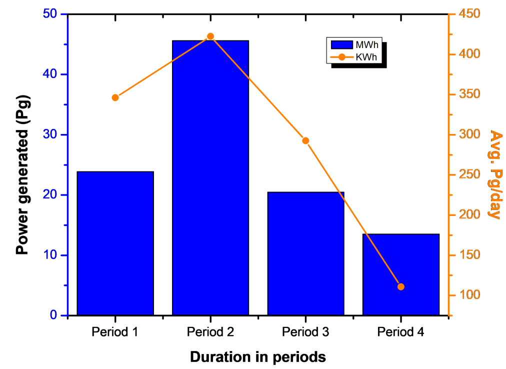

Fig. 10. Avg. power Generated per day during each period

annual power generation, whereas the darker period (Period 4) contributed only 13.51 MWh. Thus, a reduction in power generation of around 75% in period 4 is observed as compared to period 2.

In Fig. 10, the average output per day can be seen in all four periods (obtained from SCADA system). On June 20th, the sunrise was at 4:27 a.m. and the sunset at 9:49 p.m. During this period, plant produced a maximum power of 651.50 kWh. On the other hand, on December 21, the sunrise was at 8:29 a.m. and the sunset at 3:39 p.m. contributing a generation of 11.97 kWh. This shows that due to the nature of climate and weather, the plant which generated 651.5 kWh on a brightest day is able to generate only 1.8% of it in on the darkest day of the year.

IV. Conclusion

In this paper, one of the solutions for reducing the carbon emission from an educational institution is discussed. A one-year (2019) performance analysis of 109.5 kW PV power plant installed at Northumbria University Newcastle is presented. The performance data is obtained from PVsyst for a span of one year and is correlated with the SCADA results from the actual power plant. It is observed that the solar irradiation in the location varied stochastically (2.5kWh/m2/day to 3.1 kWh/m2/day) over the year, however, presents a good annual global horizontal irradiance (914 KWh/m2). It is shown that rooftop PV system performs maximum during Period 2 and minimum during Period 4. Although, the performance ratios depicted a minute difference in the comparison results, but it is worth mentioning that the mean performance ratio turns out to be the same for both cases. As expected, system losses are more during maximum power production months and lower during the period of winter. It is also observed that with respect to irradiance, PV device provides maximum power for a total of four hours every day. Furthermore, the power production during period 4 was reduced by 75% as compared to period 2. A further analysis showed that 1.8% percent of the power produced on the brightest day of the year was produced by rooftop PV system on the darkest day. Thus to conclude, we cannot rely solely on solar during specific periods of year because of varying weather profile, and thus require an extra back to continue supplying the demanded power in case PV production is less than the required level. Nevertheless, the energy obtained from PV helps in supporting the local consumption, benefits such as supporting grid during peak hours and above all, serve as a road for sustainable and green environment.

V. Acknowledgments

This research was supported by the British council under grant contract No: IND/CONT/GA/18-19/22.

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