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INFLUENCE OF SITE AND SYSTEM PARAMETERS ON THE PERFORMANCE OF ROOF-TOP GRID-CONNECTED PV SYSTEMS INSTALLED IN HARLEQUINS, BELFAST, NORTHERN IRELAND.

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ABSTRACT: The problem of energy scarcity has hit a global scale because of the dependency of most of the energy generation on non-renewable sources (e.g., fossil fuels). As in supply and demand laws, the lower the amount of energy provided, the more expensive it becomes, causing a major problem for the industry in general, which is dependent on it. These non-renewable energy sources contribute to environmental degradation effects and depletion of the ozone layer from the atmosphere. To reduce this effect, the use of renewable energy sources which is environmentally friendly has been on the growing index across the globe.

Solar photovoltaic cells transform solar energy into electrical energy through the photovoltaic effect. Solar energy can minimise the carbon dioxide (CO_2) emissions associated with the generation of electricity from fossil fuels since the only CO_2 emissions associated with the generation of fossil fuels are those in their production. Solar PV electricity is more environmentally friendly since it is carbon-free at the point of generation compared to fossil fuel generation.

In this paper, we examine the various site and system parameters that influence the performance of the 49.92 kW_p roof-top grid-connected PV system installed at Harlequins, Belfast, Northern Ireland using a five-year dataset (from 2017-2021). The site parameters examined are ambient temperature, relative humidity, irradiation, wind speed and air pressure while the system parameters examined are inverter efficiency, system performance ratio, system efficiency, fill factor, DC array and AC final yields, DC array capture loss, AC system loss and normalised output power efficiency. The result of our analysis shows that an increase in ambient temperature, solar cell temperature, relative humidity and solar irradiation decreases the PV system performance output while an increase in wind speed reduces both ambient and solar cell temperatures but increases dust accumulation on the surface of the solar panel. An increase in air pressure increases the solar irradiation and AC power output generations.

KEYWORDS: Ambient temperature, Solar cell temperature, System performance, Normalised output power efficiency, Solar irradiation, Fill factor, Relative humidity, Wind speed, Air pressure, Efficiency.

1. INTRODUCTION

The problem of energy scarcity has hit a global scale because of the dependency of most of the energy generation on non-renewable sources (e.g., fossil fuels) [1]. As in supply and demand law, the lower the amount of energy provided, the more expensive it becomes, causing a major problem for the industry in general, which is dependent on it [1]. These non-renewable energy sources contribute to environmental degradation effects and depletion of the ozone layer from the atmosphere. To minimise this effect, the use of renewable energy sources which is environmentally friendly has been on the growing index across the globe.

Solar photovoltaic cells transform solar energy into electrical energy. Solar energy can minimise the carbon dioxide (CO_2) emissions associated with the generation of electricity from fossil fuels since the only CO_2 emissions associated with the generation of fossil fuels are those in their production [2]. Solar PV electricity is more environmentally friendly since it is carbon-free at the point of generation compared to fossil fuel generation [3]. The efficiency of the PV system increases with solar irradiance at a constant temperature because the greater number of photons generated by higher solar irradiance creates more electron-hole pairs leading to more current [4]. Performance ratio (PR) is a measure of the quality of a solar PV system independent of location or solar irradiance. It is often referred to as a quality factor. PR compares the actual and theoretical energy outputs of a PV system [5]. The nearer a PR approaches 100%, the more efficiently the respective PV system will be utilising the available solar energy resource. Because of unavoidable optical losses, PV array losses, DC to AC conversion losses, cabling losses, dust, shade, wind speed, ambient temperature, or module temperature [6], actual PR values are about 80% for well-operating PV systems [7]. Transient increases in PV cell ambient temperature led to reductions in efficiencies [3]. The effect of soiling composition is not limited to only the accumulation of dust particles but also combustion products, deposits of salts from non-distilled water, soot, ash, bird droppings, and growth of organic species [8]. Dust particles are defined as any particulate matter that is less than 500 µm in diameter which is approximately 10 times the diameter of human air [9]. The most common composition is organic minerals from geomorphic fallout such as sand, clay, or eroded limestone. Bird droppings have been seen as one of the significant problems that affect the performance of the PV modules because they are more opaque than dirt [8] and rainfall does not invariably wash them off the PV module surface [10], [11]. Solar PV power plants are mainly sited in semi-arid and desert regions because of the peak solar irradiance and least interruption by clouds. These regions are also known for frequent dust storms, which result in the formation of a dust layer on the surface of the solar PV collectors [12]. The build-up of these dust particles usually known as 'soiling' serves as a major hindrance to the PV modules in absorbing the solar irradiance and converting it to electrical energy [12]. Studies have proved that within an hour, a desert sandstorm can leave solar PV panels with a thick layer of residue, which is responsible for declining their efficiency by upwards of 70–80% [12]. Because of this effect, these panels therefore would need regular cleaning, even a daily cleaning routine, else they can be considered useless [12]. Since the energy output of PV power plants is largely decreased by the soiling effect, there is a need to devise a cleaning technology that will help minimise this effect [13]. Heavy rainfall is the most effective way to clean dust particles from the surface of a PV module. High relative humidity and low rainfall contribute to the adherence of the dust particles on the surface of the PV module trapping and converting fine dust particles to lumps of clay that become very difficult to remove with rainfall. This leads to permanent soiling. The accumulation of dust or dirt particles on the surface of the PV module is known as front surface soiling. The accumulated dirt may, at the same time, partially shade a PV cell in the module causing it to generate less current electricity than the other string in the PV cells. If there is inadequate electrical protection, the partial shading of the cell can lead to irreversible hot-spot damage with eventual module failure [14]. Front surface soiling can be noticed by visual inspection of the PV module [15]. The soiling effect causes optical losses both when soiling is homogeneously distributed, or not uniformly distributed [16].

2. SITE AND SYSTEM MONITORING ASSESSMENT

The system monitoring assessment focuses on the conversion processes while the site monitoring focuses on the effect of the environmental parameters on PV performance output. Figure 1 illustrates the energy conversion process in a grid-connected photovoltaic system. The in-plane irradiance, G_I (W/m^2) falls incidentally on the surface of the PV array which generates the PV array output power, P_{DC} (kW) and this output power, P_{DC} passes through the cable to the inverter to generate PV system output power, P_{AC} and thus transmit to the utility grid for public consumption. During the conversion process, site parameters such as in-plane irradiance, G_I, ambient temperature, T_{amb}, wind speed, S_W, relative humidity, R.H, air pressure, P_{Air} and system parameters such as solar cell temperature, T_{cell}, P_{DC}, P_{AC}, normalised output power efficiency, and fill factor are considered. The T_{amb} is the air temperature of the site where the PV array and the inverter are installed, the T_{cell} is the temperature generated by the PV array, the S_w is an atmospheric quantity that is determined by air moving from high to low pressure, R.H measures the amount of moisture that can be retained by the atmosphere of the environment of the installed PV systems at a given ambient temperature and air pressure without condensing and P_{Air} is the pressure within the atmosphere of the PV installed locations. An increase in T_{amb}, T_{cell} or S_w may cause losses in the system. Other system parameters to be considered during the energy conversion process are reference yield, y_r, array yield, y_A, system yield, y_f, array capture losses, Lc, system losses, Ls and system performance ratio, PR_{Syst}.

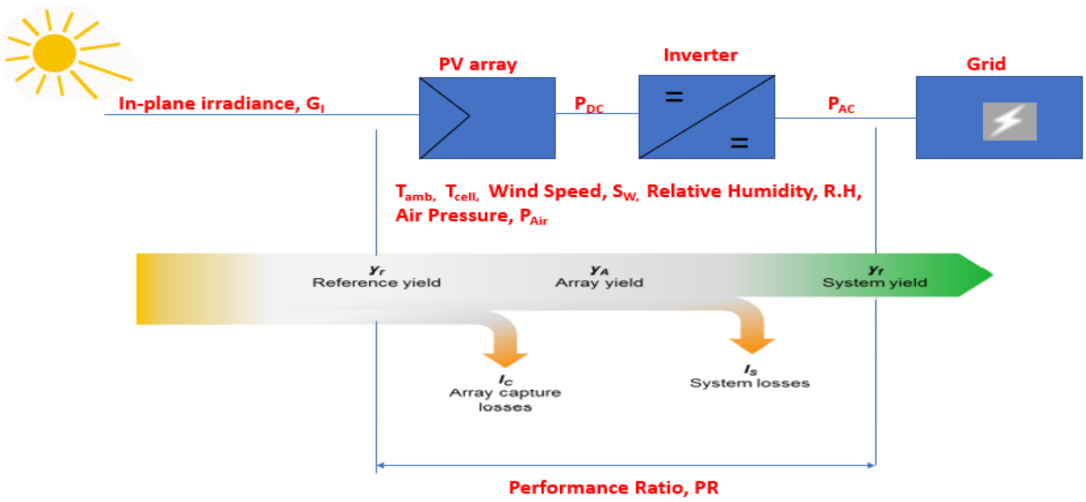


Figure 1. Energy Conversion Process in a Grid-Connected Photovoltaic System

3. ANALYSIS OF SYSTEM PARAMETERS

3.1 System and Array Performance Yields

System performance yields consist of the three parameters: DC array yield (y_A), AC final yield (y_f) and reference yield (y_r). During the conversion processes, the losses detected from the y_r to y_A is called the array capture losses (L_C) while the losses detected from y_A to y_f is called the system losses. All these parameters which determine the performance rates of the PV system is defined below:

i. Array Yield (Y_A). The array yield is the ratio of daily, monthly, or yearly direct current (DC) energy output from a PV array to the rated PV array power and is computed using equation (1) [17]:
where E_{DC} is the total DC energy output from the PV arrays (kWh) and $P_{PV,\text{ rated}}$ is the rated output power of the PV system (kWp).

$$Y_A = \frac{E_{DC}(kWh)}{P_{PV,rated}(kW_p)} \qquad \textit{Equation 1}$$

ii. Reference yield (Y_R) is the ratio of total daily in-plane solar irradiation (G) (kWh/m^2) over its reference solar irradiance (G_{STC}). This is computed using equation (2) [18]:

$$Y_R = \frac{G\,(\frac{kWh}{m^2})}{G_{STC}(\frac{kW}{m^2})} \qquad \textit{Equation 2}$$

iii. Final Yield (Y_F). The final yield is the total AC energy during a given period divided by the rated PV array power and is given by [19]:
where E_{AC} is the total AC energy output from the inverter generated by the PV power system for a specific period (kWh).

$$Y_F = \frac{E_{AC}(kWh)}{P_{PV,rated}(kW_p)} \qquad \textit{Equation 3}$$

Array and system PR values are calculated from [20]:

$$PR_A = \frac{Y_A}{Y_R} \times 100\% \qquad \textit{Equation 4}$$

$$PR_{Syst.} = \frac{Y_F}{Y_R} \times 100\% \qquad \textit{Equation 5}$$

Where:

PR_A is the array performance ratio (DC performance ratio).

Y_A is the array yield.

Y_R is the reference yield.

PR_{Syst} is the system performance ratio (AC performance ratio); and

Y_F is the final yield.

a. Array PR

The array PR (PR_A) is the ratio of the DC array yield (Y_A) to reference yield (Y_R) as expressed in equation (4). It is also known as the DC performance ratio (PR_{DC}) because it evaluates the performance of the DC-rated power of the PV array. DC array capture loss (L_C) is the common loss associated with PR_{DC}. The DC array capture losses are associated with PV conversion, ageing, module quality, mismatch, and wiring and it is expressed in equation (6).

$$L_C = Y_R - Y_A \qquad \textit{Equation 6}$$

b. System PR

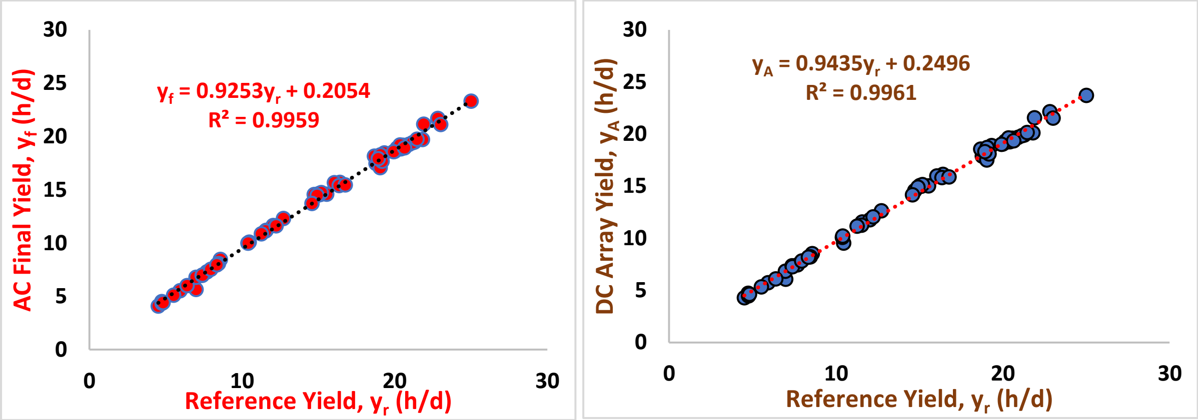
The system PR ($PR_{Syst.}$) is the ratio of the AC final yield (Y_F) to reference yield (Y_R) as seen in equation (5). This is also called the AC performance ratio (PR_{AC}) because it measures the output performance of the PV system. PR_{AC} is affected by an AC system loss (L_S). It is associated with system losses due to inverter conversion efficiency in grid-connected and given by equation (7).

$L_S = Y_A - Y_F$ *Equation 7*

3.2 Relationship between AC final yield (y_f), DC array yield (y_A) and Reference yield (y_r)

Figure 2 (a) shows the AC final yield, y_f versus reference yield, y_r. The system final yield, y_f versus reference yield, y_r forms the general set of performance parameters for a grid-connected PV system. This figure shows that system yield, y_f is proportional to the reference yield, y_r. The average system and array performance ratio of the Harlequins site is 92.53% which is found by the slope of the graph and the coefficient of determination, the R^2 value is approximated to 1 which shows that the data from the Harlequins site installation is in proper operation. This means that there is no form of shading observed on the site. Therefore, the relationship between system final yield, y_f and reference yield, y_r stands for the overall conversion efficiency of the Harlequins site installation.

Figures 2 (b) illustrates the DC array yield, y_A versus reference yield, y_r. This Figure shows that when the measurement of DC array yield, y_A is plotted over reference yield, y_r, its relationship can be approximated to 1 as seen by its coefficient of determination, the R^2 value. This is because the DC array yield, y_A is proportional to the reference yield, y_r. The average array performance ratio of the Harlequins site is 94.35% and is found by the slope of the graph which shows that the data from the Harlequins site installation is in proper operation since their R^2 value is approximate to 1. This means that there is no form of shading observed in the sites.

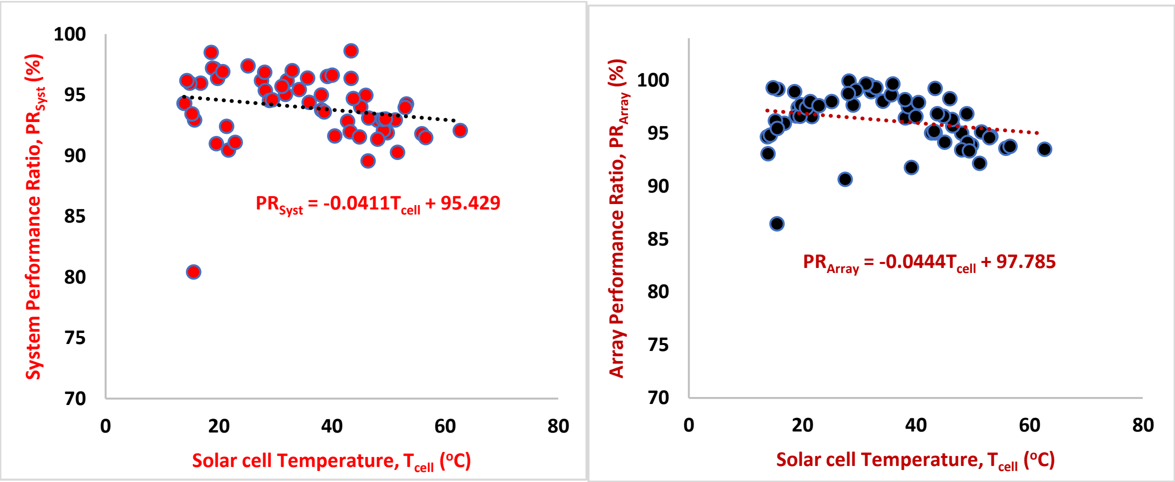


(a) (b)

Figure 2. (a) System final yield (y_f) versus reference yield (y_r) (b) Array yield (y_A) versus reference yield (yr) for hourly data from Harlequins site from 2017-2021

3.3 Effect of Cell/Module Temperature on PV System and Array Performance

Figure 3 (a) shows the plot of system performance ratio (PR_{Syst}) as a function of solar cell temperature. Harlequins site shows inverter performance with an intercept value of approximate 95.43% respectively. The slope of Figure 3 (a) shows the temperature coefficient of power whose value in the datasheet is given as -0.4%/°C or -0.004/°C. The temperature coefficient, α, influences the system performance. For instance, an increase in temperature coefficient, α, reduces the system performance and efficiency. Figures 3 (b) illustrates the plot of array performance ratio (PR_{Array}) as a function of solar cell temperature. Just like the system performance, Harlequins site shows a normal operation of the PV array at approximate 97.79% and the PV array began to reduce its array performance ratio as the solar cell temperature increases. The increase in temperature coefficient of power also influences the array performance and efficiency. The temperature coefficient of power is determined using the slope of Figure 3 (b). Therefore, the relationship between the array performance ratio and solar cell temperature shows the thermal behaviour of the PV array.



(a) (b)

Figure 3. (a) System Performance Ratio (PRSyst) versus Solar cell Temperature (Tcell) (b) Array Performance Ratio (PRArray) versus Solar cell Temperature (TCell) for hourly data from Harlequins site from 2017-2021

3.4 AC System Loss (L_S) and DC Array Capture Loss (L_C)

Figure 4 shows the monthly AC system losses (Ls) and DC array capture losses (Lc) in the Harlequins site. The Ls and Lc are the systems and capture losses due to P_{AC} and P_{DC} as shown in Figure 1. The system losses, Ls cause the physical dissipation of power in the inverter while capture losses cause the physical dissipation of power in the PV array. The Harlequins site shows the variation of Ls from a minimum of 0.02 h/d in November 2017, 0.06 h/d in September 2018, 0.1 h/d in December 2019, 0.12 h/d in February 2020 and 0.21 in December 2021 to a maximum of 0.58 h/d in October 2017, 0.43 h/d in August 2018, 0.43 h/d in June 2019, 0.43 h/d in July 2020 and 0.43 h/d in May and October 2021 while the Lc of Harlequins site varies from a minimum of 0.04 h/d in December 2017, 0.01 h/d in March 2018, 0.05 h/d in January 2019, 0.05 h/d in March 2020 and 0.05 h/d in March 2021 to a maximum of 1.28 h/d in June 2017, 1.71 h/d in July 2018, 1.57 h/d in September 2019, 1.51 h/d in May 2020 and 1.36 h/d in May 2021. The increase in Ls and Lc are due to a high solar cell temperature effect [21].

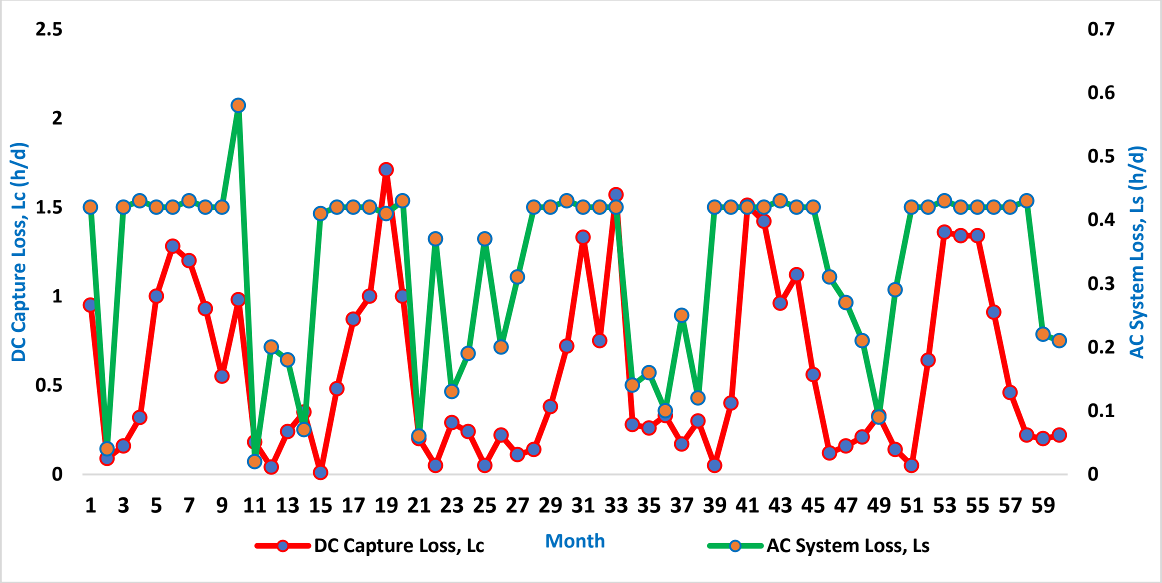


Figure 4. DC capture and AC system energy losses over the monitored periods (2017-2021)

3.5 INVERTER PERFORMANCE

3.5.1 Inverter input and output

Figure 5 indicates a collinear relationship between the DC output (inverter input power) from the PV modules and the AC output from the inverter as shown in Figure 1. In Figure 5, the slope is 1 which shows the normal operation of the inverter while the intercept is -880 W. This shows that the inverter started to generate the AC output at the DC output power (inverter input power) of 880 W which suggests an energy consumption of 880 W at their operating mode. This, therefore, agrees with the findings of Kamonpan et al [32].

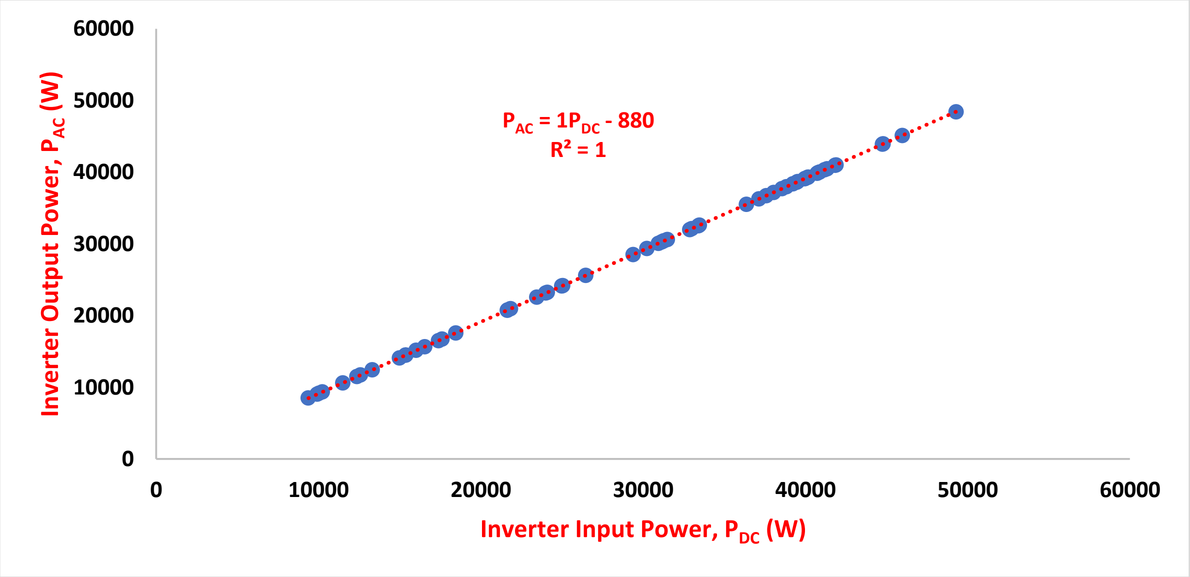


Figure 5. Relationship between input power and output power of the inverter

3.6 Inverter efficiency, inverter output power and inverter percentage conversion loss

3.6.1.1 Inverter efficiency and inverter output power

Figure 6 shows the variation of inverter efficiency with the inverter output power. There is an increase in the inverter efficiency when the inverter output power increase. For instance, the maximum inverter efficiency observed in the Harlequins site is 98.21% at an inverter output power of 48416 W.

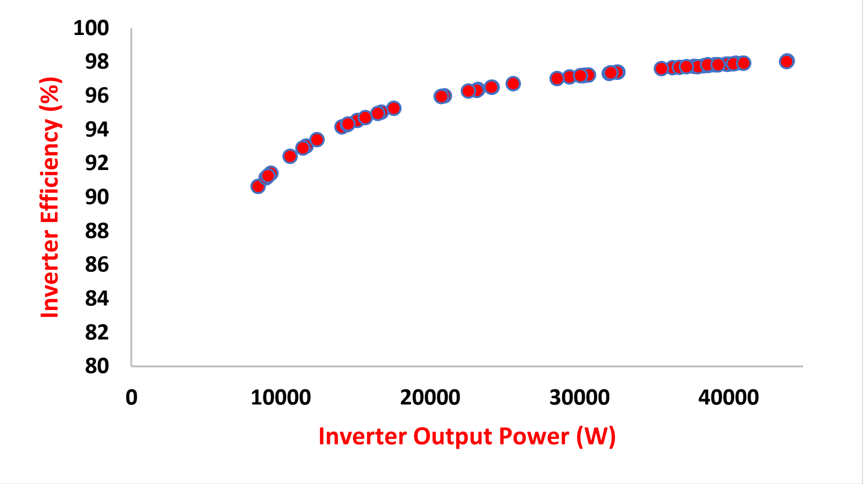


Figure 6. Inverter Efficiency versus Inverter Output Power

3.6.1.2 Inverter percentage conversion losses

No inverter can achieve 100% efficiency. This is because when the inverter converts the DC energy from the solar PV system to AC energy (as shown in Figure 1), some energy is lost, which could be due to the cable, PV module, inverter or increase in ambient temperature. This means that the output or AC energy (E_{AC}) is not the same as the input or DC energy (E_{DC}). This is known as inverter percentage conversion losses or inverter failures [33] and this causes large fluctuations in the PV systems performance ratios. Figure 7 shows that the inverter percentage conversion loss decreases exponentially to inverter output power.

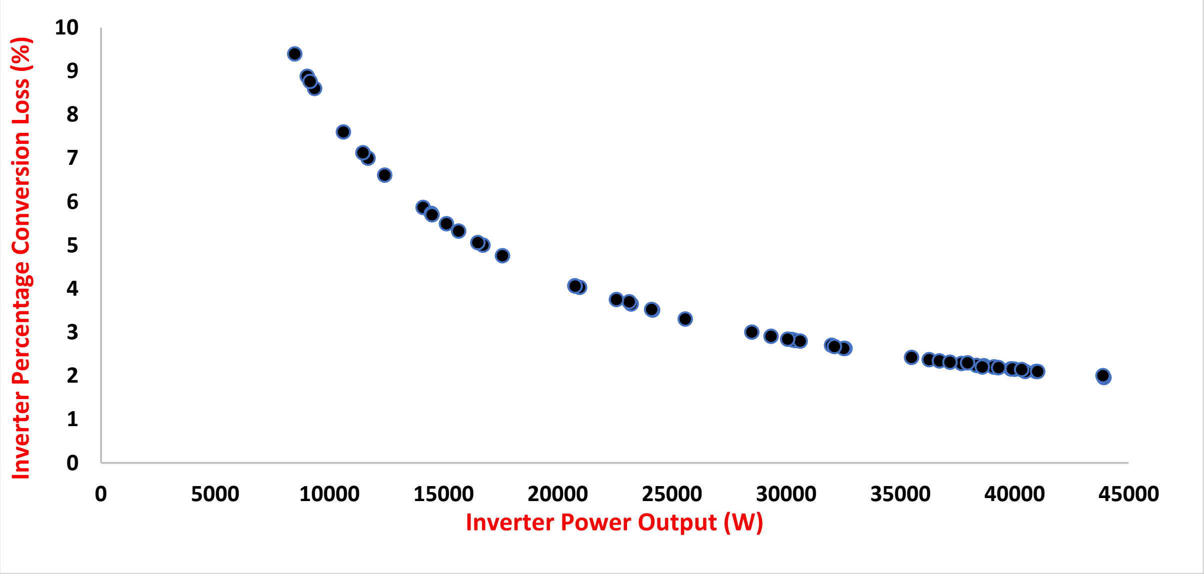


Figure 7. Inverter Percentage Conversion Loss versus Inverter Output Power

4. ANALYSIS OF SITE PARAMETERS WITH SYSTEM PARAMETERS

4.1 Inverter Efficiency, Ambient Temperature, and Inverter Output Power

Figure 8 indicates that the maximum efficiency of the inverter strongly depends on the ambient temperature. For instance, the Harlequins site shows the maximum inverter efficiency of 98.21% when the ambient temperature is 25.26°C (see Figure 8). It shows a drop of 0.36% when the ambient temperature increases from 25.26°C to 32.00°C. Therefore, the loss encountered during the conversion processes is due to the increase in ambient temperatures.

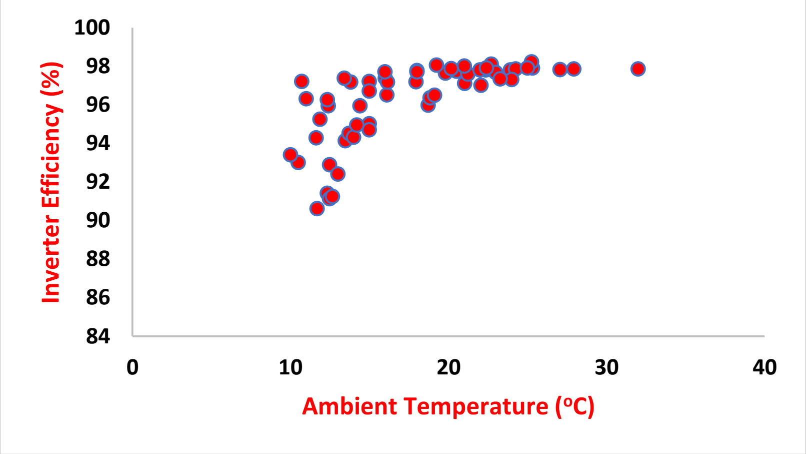
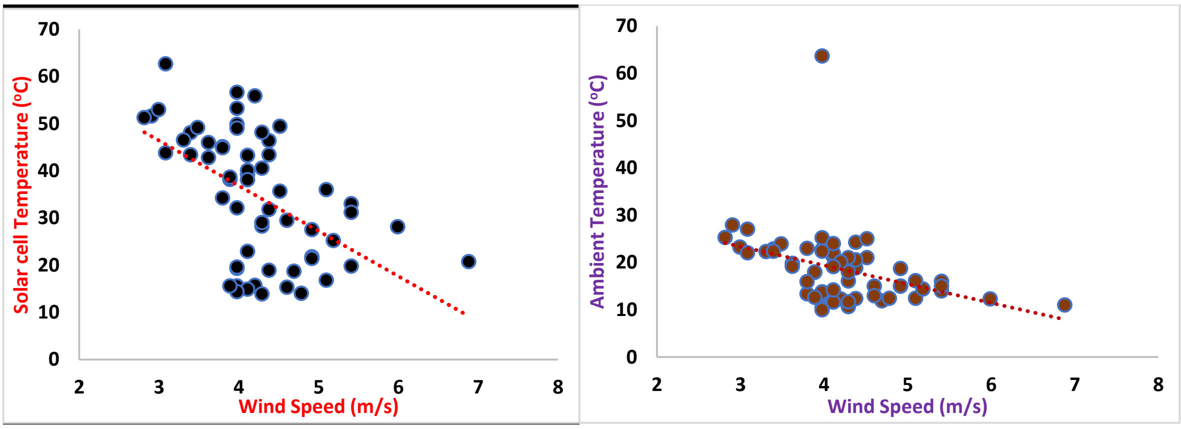


Figure 8. Relationship between inverter efficiency and ambient temperature

4.2 Effect of Solar cell and Ambient temperatures, Wind speed, Air pressure, Solar irradiation, and Relative humidity on the PV System Output Performance

4.2.1 Solar cell Temperature, Ambient Temperature and Wind Speed on PV System Performance

The influence of wind speed affects the performance of solar cells positively as it improves the efficiency of the solar cell [22]. This helps to reduce the influence of solar cells and ambient temperatures on the solar PV module by the generation of air on the surface of the solar PV module which boosts the performance of the solar panel. Therefore, as the wind speed increases, the solar cell and ambient temperatures decrease, that is, solar cell and ambient temperatures are inversely proportional to wind speed. This means that increase in wind speed promotes high solar PV system output performance [23] as shown in Figures 9 (a-b).

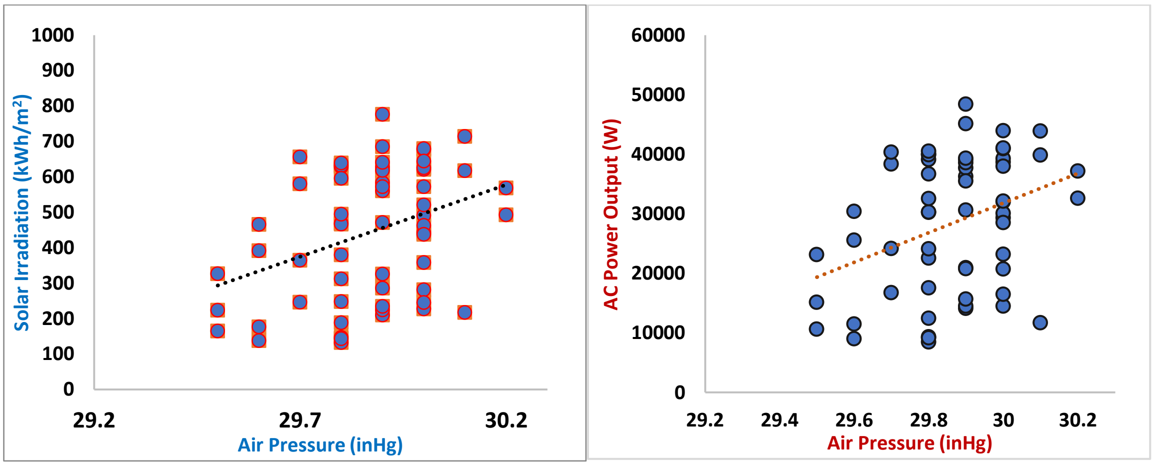


(a) (b)

Figure 9. Influence of wind speed, solar cell temperature and ambient temperature in Harlequins PV systems output performances from 2017-2021

4.3 Influence of Air Pressure and Solar Irradiation on the PV System Output Performance

Air pressure is the pressure exerted by the weight of air present in the atmosphere of the earth. Air pressure increases with a decrease in altitude from the earth surface and the weight of the air is the force acting downward and which increases towards the surface of the earth [24]. With an increase in light intensity, the performance of solar cells improves [24].



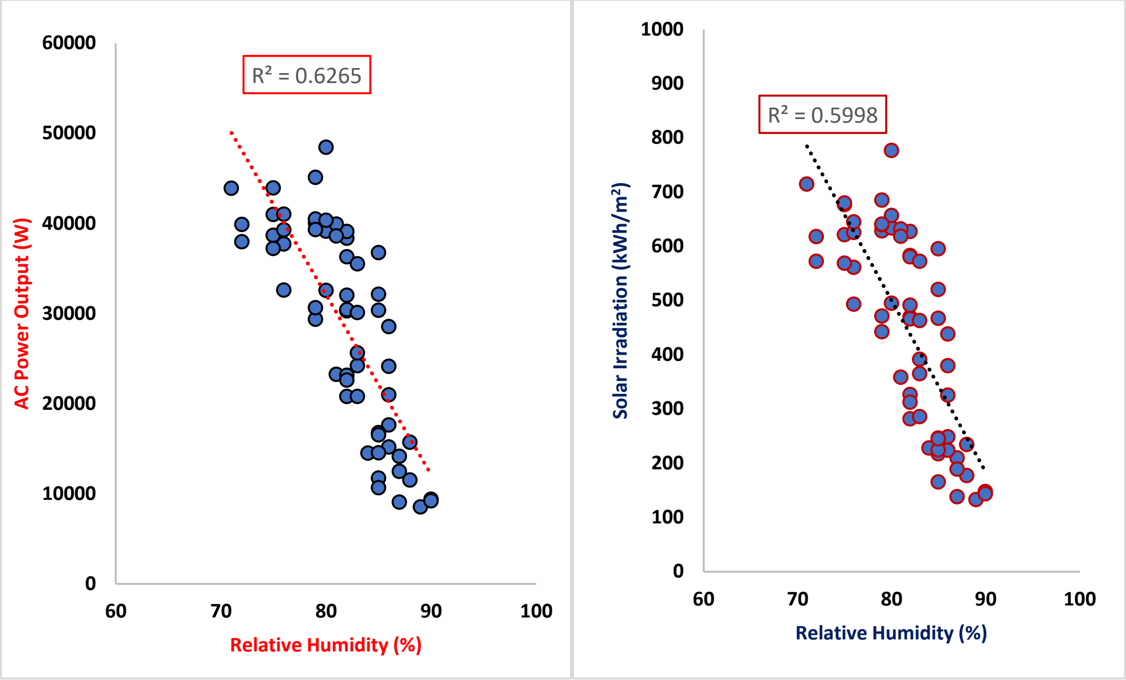
a. b.

Figure 10. Influence of air pressure and solar irradiation in Harlequins PV systems output performances from 2017-2021

Figure 10 (a) and Figure 6 (b) shows the relationship between solar irradiation, air pressure and AC power output in the Harlequins site. It can be seen from Figure 10 (a) that an increase in air pressure results in an increase in solar irradiation, that is, solar irradiation is directly proportional to air pressure and Figure 10 (b) shows that an increase in air pressure results in increases in AC power output of the PV system. This means that the force acting downward causes the falling of photons of solar irradiation to increase with an increase in air pressure [24] which suddenly increases the AC power output. Therefore, air pressure measurements are very important in PV performance study because it helps to adjust air mass estimates which may cause fluctuations in air pressure related to systematic changes to the solar spectrum on the ground.

4.4 Influence of Relative Humidity and Air Pressure on the PV System Output Performance

The humidity is the amount of water vapour measured in the air. The humidity affects the performance of solar cells in two ways: (1) due to the deposition of water droplets on the surface of the solar cells it reflects the sunlight and affects the total output of the solar cell and (2) due to the effect of humidity, the metallic parts of the solar panel start to rust and that decreases the life of solar panel [25]. Figures 11 (a-b) shows that the relationship between the relative humidity, solar irradiation and AC power output is inversely proportional, that is, when relative humidity increases the value of solar irradiation and AC power output decreases. Therefore, this shows a very strong negative correlation between relative humidity, AC power output and solar irradiation.



a. b.

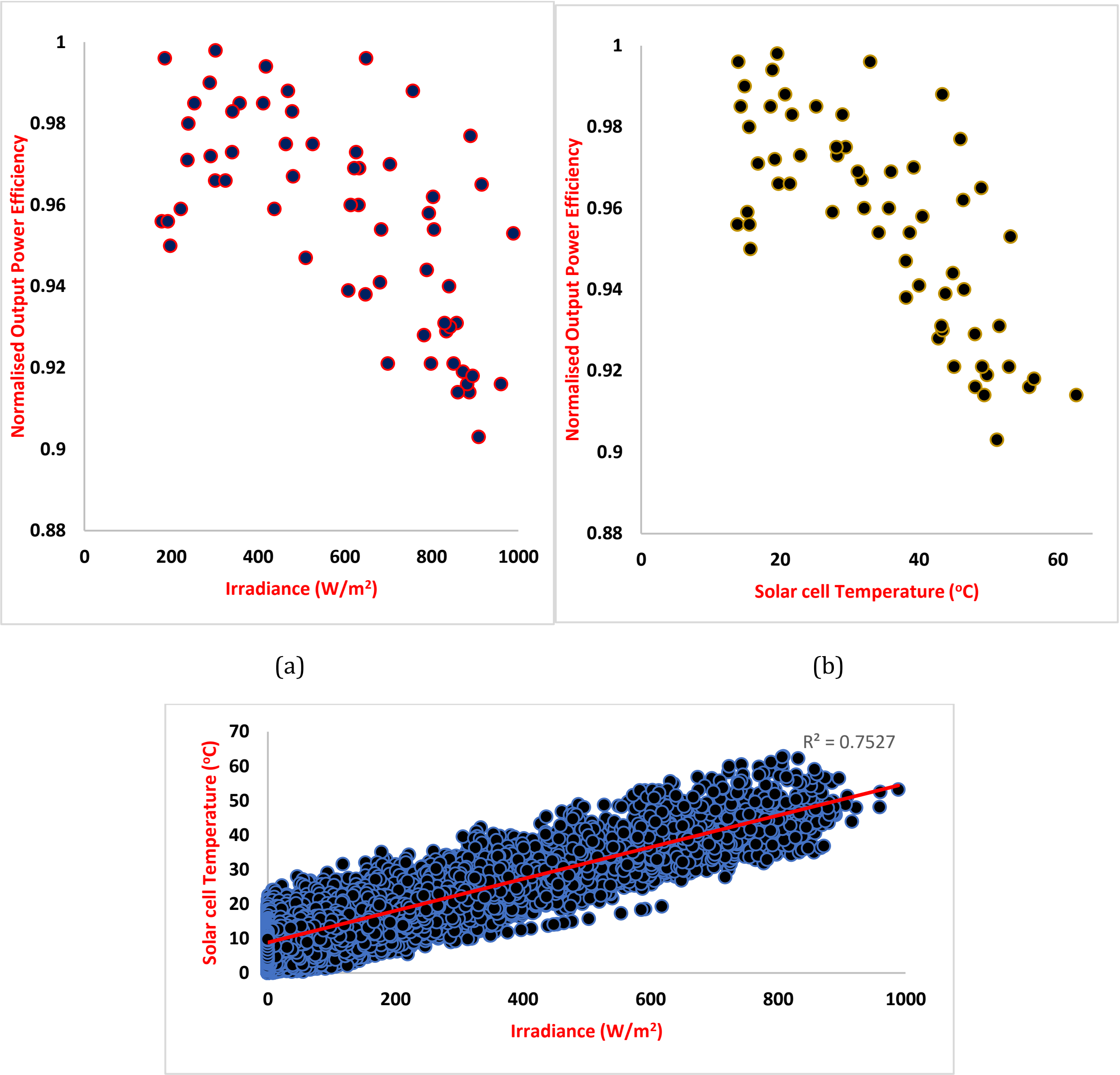
Figure 11. Influence of relative humidity and solar irradiation in Harlequins PV systems output performances from 2017-2021

5. EFFECT OF IRRADIANCE AND SOLAR CELL TEMPERATURE ON CONVERSION EFFICIENCY, FILL FACTOR AND MAXIMUM POWER OUTPUT

5.1 Effect of irradiance and solar cell temperature on Normalised output power efficiency

Figure 12 shows the effect of irradiance and solar cell temperature on PV module performance output in the hourly data collected from the Harlequins site. Figure 12 (a) shows that there is typically a higher value of normalised output power efficiency, η_{Norm} (computed using equation 8) [26] achieved when the irradiance is below 1000 W/m^2 and Figures 12 (b) shows that there is a decrease in normalised output power efficiency when the solar cell temperature increase. This is because as the irradiance increases the solar cell temperature increase which therefore decreases the normalised output power efficiencies as illustrated in Figure 12 (c).

$$\eta_{Norm} = \frac{P_{AC}}{P_{STC}} x \frac{G_{STC}}{G_{POA}} \qquad \textit{Equation 8}$$



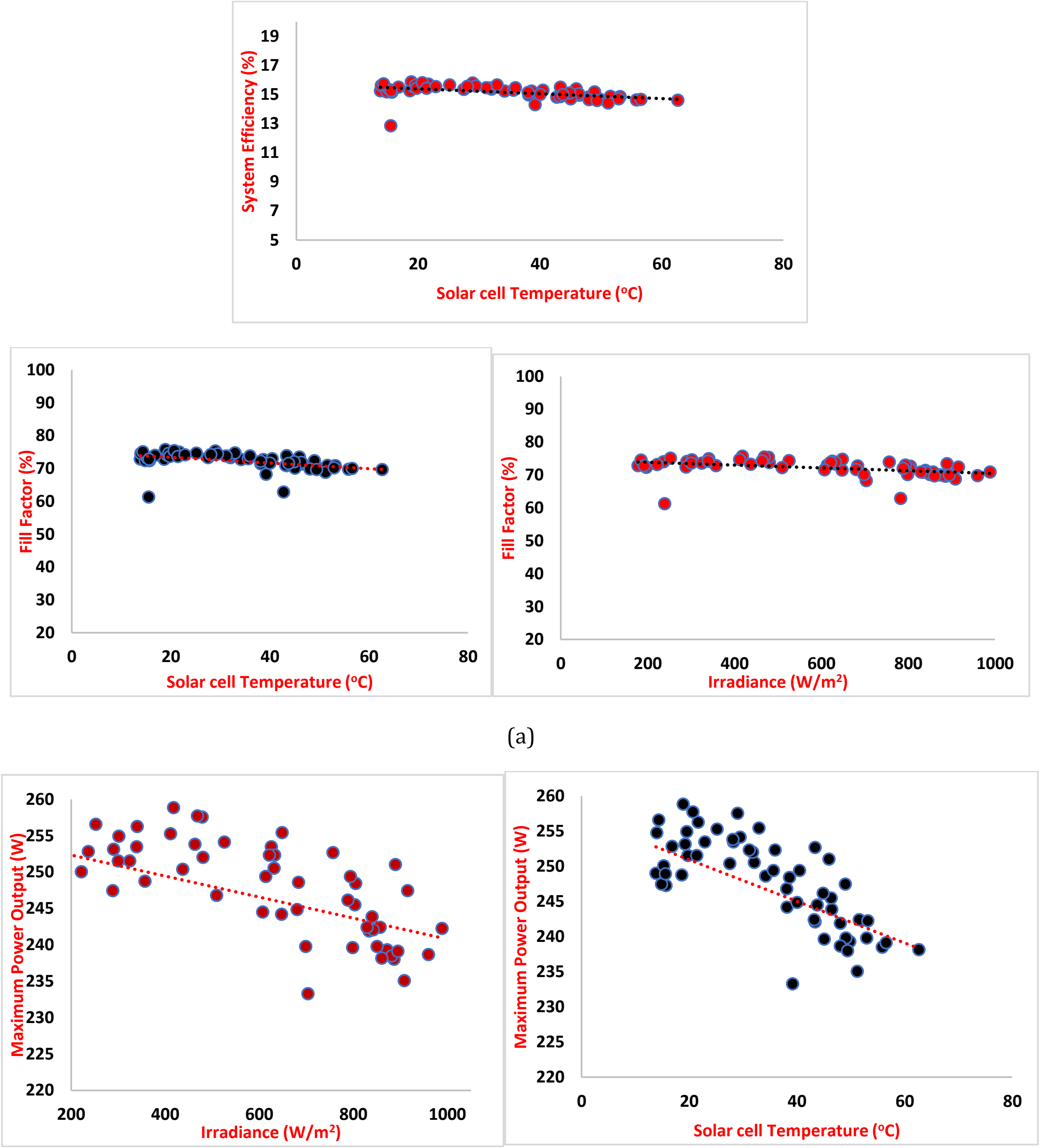
(a) (b)

(c)

Figure 12. Effect of irradiance and module temperature on normalised output efficiencies for the monitored period of five years (2017 – 2021) hourly data in Harlequins site

5.2 Effect of solar cell temperature and irradiance on system conversion efficiency, fill factor and maximum power output

Figure 13 (a) shows the effect of solar cell temperature and irradiance on the conversion efficiency and fill factor (FF) in the Harlequins site. From Figure 13 (a), the conversion efficiency of the solar cells decreases with an increase in solar cell temperature and a decrease in solar cell temperature results in more efficiency. This is caused by the reduction of FF as solar cell temperature and irradiance increase. FF increases at irradiance less than 500 W/m² and decreases at irradiance greater than 500 W/m² [27]. Efficiency increases logarithmically for irradiance less than 400 W/m² and it neither decreases nor increases for irradiance higher than 400 W/m² [27]. FF is an indicator in finding the quality of PV panels. The typical FF values range is between 60% and 70% [28]. For instance, the graphs of fill factors (FF) in Figure 13 (a) shows that the PV panels performed in good quality firstly in the range above 70% (at a low solar cell temperature) and later below 70% (at a high solar cell temperature) in five years. The least recorded FF value in the Harlequins site across the five years is 61.3%.



(a)

(b) (c)

Figure 13. (a-c) Effect of solar cell temperature, irradiance, conversion efficiency, fill factor and maximum power output on PV system performance output

From Figures 13 (b-c), it can be observed that the maximum power output from the module decreases as the solar cell temperature and irradiance increase and this lowers the conversion efficiency as seen in Figure 13 (a). This means that the irradiance during the peak sun period does not necessarily lead to the PV panel operating efficiently. Although the increase in irradiance increases the maximum power output, this effect was counterbalanced by the effect of the solar cell temperature which reduced the conversion efficiency. Hence, solar cell temperature can be considered a critical issue when forecasting energy generation. Therefore, to optimise and maximise solar PV panel conversion efficiency, fill factor (FF), open-circuit voltage (V_{OC}) and short-circuit current (I_{SC}) must be increased. Therefore, this behaviour of conversion efficiency with solar cell temperature agrees with the results of the experiment done by Fesharaki et al [29], Amelia et al [30], Tobnaghi et al [31].

6. CONCLUSION

The influence of site and system parameters on the performance of roof-top grid-connected PV systems installed in Harlequins, Belfast, Northern Ireland has been investigated. The study saw the influence of site and system parameters on the system performance output. For instance, site parameters such as ambient temperature, relative humidity, wind speed, air pressure and solar irradiation influence the PV system output performance. When the solar irradiation in the Harlequins site increases, the ambient temperature of the location increases. This reduces the efficiency of the PV output installed in the location. Wind speed in Harlequins site influences the PV output performance positively and negatively. For instance, an increase in wind speed reduces the ambient temperature thus promoting the PV output performance while such an increase can increase the rate of dust deposition on the surface of the PV panel. Therefore, the effect of wind speed on the PV system performance may be considered secondary because it is not often measured on the site of a PV installation [34]. When the air pressure in a site location increases, the solar irradiation in the site location tends to increase, thus increasing the PV output performance. This means that the force acting downward causes the falling of photons of solar irradiation to increase with an increase in air pressure [24] which suddenly increases the AC power output. Therefore, air pressure measurements are very important in PV performance study because it helps to adjust air mass estimates which may cause fluctuations in air pressure related to systematic changes to the solar spectrum on the ground. The presence of relative humidity in Harlequins site affects the PV output performance due to the deposition of water droplets on the surface of the solar cells which reflects the sunlight and affects the total output of the solar cell. Also, the effect of humidity causes the metallic parts of the solar panel to start rusting, thus reducing the life span of the solar panel [35]. Therefore, an increase in relative humidity decreases the solar irradiation and power output thereby influencing the PV output performance.

References

[1] C. Okorieimoh, "Energy Efficiency," Global Scientific , vol. 7, no. 4, pp. 763-775, 2019.

[2] B. Norton, "Renewable Electricity what is the true cost?," Power Engineering, vol. 13, pp. 6-12, 1999.

[3] C. Okorieimoh , B. Norton and M. Conlon, "Long-Term Durability of Solar Photovoltaic Modules," in Sustainable Ecological Engineering Design. Springer, Cham., Ipswich, England, 2020.

[4] D. Bagnall and M. Boreland, "Photovoltaic technologies," Energy Policy, vol. 36, pp. 4390-4396, 2008.

[5] D. Okello, F. Vorster and van Dyk E.E, "Analysis of measured and simulated performance data of a 3.2 kWp grid-connected PV system in Port Elizabeth, South Africa.," Energy Conversion and Management, vol. 100, pp. 10-15, 2015.

[6] C. Okorieimoh, B. Norton and M. Conlon, "Effect of transient performance changes on photovoltaic modules output.," 10th Annual GRS Symposium, Dublin (Poster), 2019.

[7] M. Nallapaneni, M. Rohit, P. Ruth and M. Mathew, "Performance analysis of 100 kWp grid-connected Si-poly photovoltaic system using PVsyst simulation tool.," Energy Procedia, vol. 117, pp. 180-189, 2017.

[8] A. Akram, "A New Method to Reduce Soiling Effect on Performance of a Solar PV Module.," International Journal of Advanced Research and Innovation, vol. 3, pp. 601-606, 2015.

[9] T. Sarver , A. Al-Quaraghuli and L. Kazmerski , "A comprehensive review of the impact of dust on the use of solar energy: History, investigations, results, literature, and mitigation approaches," Renewable and Sustainable Energy Reviews, vol. 22, pp. 698-733, 2013.

[10] S. Gibson, "Don't Hire a Cleaning Crew to Wash Your Solar Panels. Paying to have photovoltaic panels cleaned will cost more than the extra energy is worth," Green Building Advisor, 01 August 2013.

[11] R. Appels, B. Muthirayan, A. Beerten, R. Paesen, J. Driesen and J. Poortmans , "The effect of dust deposition on photovoltaic modules," in 38th IEEE Photovoltaic Specialists Conference (PVSC), Austin, TX, USA, 2012.

[12] R. Annie , E. Ryan and K. Malay , "Water Free Cleaning Solution: Environmental Durability of Electrodynamic Screen (EDS) Films in Water-Free Cleaning of Solar Collectors," in IEEE 46th Photovoltaic Specialists Conference (PVSC),

Chicago, IL, USA, 2019.

[13] M. Aidara , M. Ndiyae , A. Mbaye , M. Sylla and P. Ndiaye , "Study of the Performance of a system for dry cleaning dust deposited on the surface of solar photovoltaic panels," International Journal of Physical Sciences, vol. 13, pp. 16-23, 2018.

[14] J. Mazer, Solar Cells: An Introduction to Crystalline Photovoltaic Technology, Kluwer Academic Publishers, 1996.

[15] L. Edson and E. Eugene , "Assessing the Reliability and Degradation of Photovoltaic Module Performance Parameters," IEEE Transactions on Reliability, vol. 53, pp. 83-92, 2004.

[16] J. Lopez-Garcia , A. Pozza and T. Sample , "Long-term soiling silicon PV modules in a moderate subtropical climate," Solar Energy, vol. 130, pp. 174-183, 2016.

[17] L. Ayompe, A. Duffy, S. McCormack and M. Conlon, "Measured performance of a 1.72 kW rooftop grid connected photovoltaic system in Ireland," Energy Conversion and Management, vol. 52, pp. 816-825, 2011.

[18] E. Kymakis , S. Kalykakis and T. Papazoglou , "Performance analysis of a grid-connected photovoltaic park on the island of Crete," Energy conversion and management, vol. 50, pp. 433-438, 2009.

[19] C. Sidi, M. Ndiaye , M. Bah , A. Mbodji , A. Ndiaye and P. Ndiaye , "Performance analysis of the first large-scale (15 MWp) grid-connected photovoltaic plant in Mauritania," Energy Conversion and Management, vol. 119, pp. 411-421, 2016.

[20] I. 61724, "Photovoltaic system performance monitoring guidelines for measurement, data exchange and analysis.," 1998.

[21] A. Ghoname and N. Hidekazu , "Techno-Economic Performance Analysis of a 40.1 kWp Grid-Connected Photovoltaic (GCPV) System after Eight Years of Energy Generation: A Case Study for Tochigi, Japan.," Journal of Sustainability, vol. 13, p. 7680, 2021.

[22] M. Ranjan Das, "Effect of Different Environmental Factors on Performance Solar Panel," International Journal of Innovative Technology and Exploring Engineering (IJITEE), vol. 8, no. 11, pp. 15-17, 2019.

[23] D. Goossens and K. Van , "Aeolian dust deposition on photovoltaic solar cells: the effects of wind velocity and airborne dust concentration on cell performance," Solar Energy, vol. 66, no. 4, pp. 277-289, 1999.

[24] M. Ranjan Das, "Effect of Different Environmental Factors on Performance Solar Panel," International Journal of Innovative Technology and Exploring Engineering (IJITEE), vol. 8, no. 11, pp. 15-17, 2019.

[25] S. Mekhilef , R. Saidur and M. Kamalisarvestani , "Effect of dust, humidity and air velocity on efficiency of photovoltaic cells," Renewable and Sustainable Energy Reviews, vol. 16, no. 5, pp. 2920-2925, 2012.

[26] T. a. R. C. A. S. T. E. P. (STEP), "The Effect of Irradiance and Temperature on the Performance of Photovoltaic Modules," Sustainable Technologies, Toronto, Canada, 2017.

[27] M. Cheggar, A. Hamzaoui, A. Namoda, P. Petit, M. Aillerie and A. Herguth , "Effect of Illumination Intensity on Solar Cells Parameters," Energy Procedia, vol. 36, pp. 722-729, 2013.

[28] A. Amelia, Y. Irwan, W. Leow, M. Irwanto, I. Safwati and M. Zhafarina, "Investigation of the Effect of Temperature on Photovoltaic (PV) Panel Output Performance," International Journal on Advanced Science Engineering Information Technology, vol. 6, pp. 682-688, 2016.

[29] V. Fesharaki, M. Dehghani and J. Fesharaki, "The Effect of Temperature on Photovoltaic Cell Efficiency," in Proceedings of the 1st International Conference on Emerging Trends in Energy Conservation, Tehran, 2011.

[30] A. Amelia, Y. Irwan, W. Leow, M. Irwanto, I. Safwati and M. Zhafarina, "Investigation of the Effect of Temperature on Photovoltaic (PV) Panel Output Performance," International Journal on Advanced Science Engineering Information Technology, vol. 6, pp. 682-688, 2016.

[31] D. Tobnaghi , R. Madatov and D. Naderi , "The effect of temperature on electrical parameters of solar cells," International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, vol. 2, pp. 6404-07, 2013.

[32] C. Kamonpan, S. Vichit, U. Nuttakarn, K. Songkiate, S. Sasiwimon, C. Perawut, L. Amornrat, S. Jaran and S. Kobsak , "Effect of Ambient Temperature on Performance of Grid-Connected Inverter Installed in Thailand," International Journal of Photoenergy, vol. 2014, pp. 1-7, 2014.

[33] P. Hacke, S. Lokanath, P. Williams, A. Vasan, P. Sochor, G. Tamizhamni , H. Shinohara and S. Kurtz , "A status review of photovoltaic power conversion equipment reliability, safety, and quality assurance protocols," Renew. Sustain. Energy Rev., vol. 82, pp. 1097-1112, 2018.

[34] W. Achim, R. Mauricio , M. David and H. Nils , "Analytical Monitoring of Grid-Connected Photovoltaic Systems: Good Practices for Monitoring and Performance Analysis," International Energy Agency Technical Report, Brussels, 2014.

[35] S. Mekhilef , R. Saidur and M. Kamalisarvestani , "Effect of dust, humidity and air velocity on efficiency of photovoltaic cells," Renewable and Sustainable Energy Reviews, vol. 16, no. 5, pp. 2920-2925, 2012.