Evaluating the Influence of Intermittent Weather Condition on the Effectiveness of Solar Photovoltaic System: The Case of Ntyuka Transmission Station

John Francisco Maginga*, Isack J. Mwakitalima and OwdeanSuwi
Department of Electrical and Power Engineering
Mbeya University of Science and Technology, P.O Box 131, Mbeya, Tanzania
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ABSTRACT

Conventional fossil-based power generation has increased global electrical output but introduced environmental stress, cost volatility, and resource depletion. Solar photovoltaic (PV) systems offer a feasible low-emission option; however, their efficacy is intrinsically affected by nonlinear factors associated with solar irradiance and module temperature, rendering weather variability a significant operational limitation. This study assesses the impact of intermittent weather conditions on the performance of the standalone 6 kW PV system at Ntyuka Transmission Station in Tanzania. Measured site parameters—including hourly global horizontal irradiance, module surface temperature, system component specifications, and recorded AC output power—were incorporated into a MATLAB/Simulink model representing the PV array and inverter configuration. Model validation was performed by comparing simulated system behaviour against measured operational data under varying environmental scenarios. Results indicate that fluctuations in irradiance from 1200 W/m² to 700 W/m² lead to significant voltage and power reductions, contributing to an average energy loss of 18–22%. The study confirms that intermittency reduces system efficiency, output stability, and supply reliability. The findings highlight the need for improved system control strategies, optimised sizing, and supportive policy measures to enhance the technical viability of off-grid PV systems in Tanzania.

*Corresponding author's e-mail address: magingajohn2@gmail.com (Maginga, J.F)

1.0 Introduction

Solar power generation refers to the process of converting sunlight into electricity using photovoltaic cells or into heat using solar thermal systems. A solar photovoltaic array absorbs radiation from the sun and converts it into electricity. (Kale *et al.,* 2025)

The 122 W of solar energy that reaches the earth's surface is nearly 10,000 times more than the 13 TW equivalent of the average power consumed by humans in this Tanzania receives 4–7 kWh/m²/day of global horizontal irradiation (GHI) across most of the country. However, solar energy is pollution-free, and the heat absorbed by solar cells contributes to the reduction of the amount of heat in the atmosphere; therefore, solar power is the solution to the crisis of global warming. This indicates that solar energy will soon become the world's primary energy source (Soomar *et al.,* 2022).

Intermittence is among the serious problems for the solar PV systems, as it decreases the maximum power that can be generated. Several factors contribute to this issue, the most common intermittent ones including shade from adjacent solar panels, neighbouring trees and buildings, typical cloudy weather and soiling (Albadi, 2019). While designing a solar PV system, these factors must be considered to optimise system performance so that maximum output can be obtained. Two technologies of harnessing solar photovoltaic power are employed: off-grid or standalone systems and grid-connected solar PV. In off-grid or standalone technology, the system is independent and not connected to any electrical grid. These are mostly used in locations where there is little access to grid infrastructure. Ntyuka transmission station is among the off-grid solar plant stations in Tanzania; it is located at Image Hill, 20 km from Dodoma Municipality. A standalone PV of 6 kW is installed to supply several residences, a hospital, a school, and commercial and social buildings like a mosque and a church. The area is surrounded by high rocks and baobab trees. It has a single rainy season yearly, and the surrounding activities include small retail farms of wheat and groundnuts and milling machines that lead to solar PV surface soiling and partial shedding from rocks and baobab trees, which contribute significantly in blocking the direct sun rays, hence reducing the output power generation at Ntyuka.

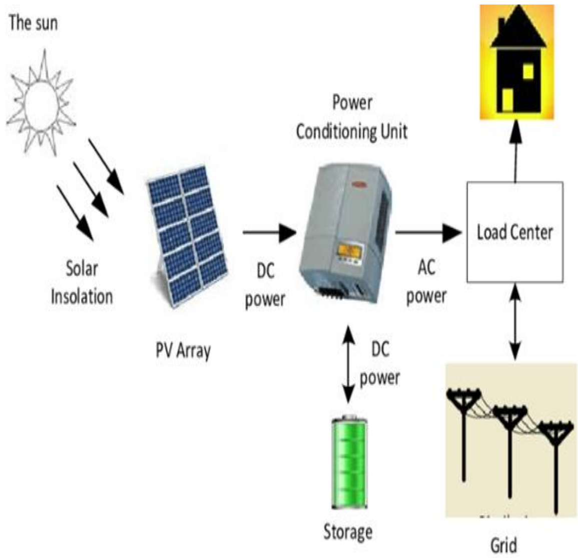
2.0 Material and Methods

2.1 Review of PV System Components

Photovoltaic systems generally consist of six individual components: the solar PV array, a charger controller, a battery bank, an inverter and a load.

Figure 1

Solar PV Systems Components



2.1.1 Solar PV Array

The solar PV array, or photovoltaic module, is the primary source of energy in a solar power system. It converts sunlight into electrical energy through the photovoltaic effect. This is achieved using semiconductor materials, commonly silicon-based, that absorb photons from sunlight and release electrons. These electrons then flow through an external circuit, generating an electric current (Sathyanarayana *et al.,* 2015). The panel consists of multiple solar cells connected in series and parallel. A solar PV cell has two key electrical parameters: short-circuit current (Isc), which is the maximum current a PV cell can produce when the output terminals are shorted (voltage is zero), and open-circuit voltage (Voc), which is the maximum voltage a PV cell can produce when no current is drawn from the cell (current is zero). Solar panel operation depends on two important parameters: irradiance, which is the amount of sunlight falling on the panel, usually measured in

W/m², and temperature, which is the operating temperature of the solar cells.

2.1.2 Solar Charger Controller

Solar charge controllers are used in off-grid systems to maintain batteries at their highest state of charge without overcharging them to avoid gassing and battery damage (Soomar *et al.,* 2022). This helps to prolong battery life. Charge controllers also deliver proper current and voltage that meet the rated capacity of electrical loads.

2.1.3 Boost Converter

A boost converter is a type of DC-DC converter that is used to step up (increase) the voltage from a lower value to a higher value while maintaining the power (minus losses) in the circuit (Rourkela, n.d.). This is achieved through the use of inductors, capacitors, diodes, and switches (typically MOSFETs) to convert energy efficiently from one voltage level to another.

It takes a lower input voltage and increases it to a higher output voltage. It can be designed for various applications depending on the desired output voltage and power requirements.

2.1.4 Boost Converter Control

The output voltage of a boost converter depends on the duty cycle, which determines how long the switch is on versus off during each cycle. The duty cycle is controlled by a pulse width modulation (PWM) controller, which adjusts the timing of the switch to maintain a desired output voltage.

The control method can be: Open-loop control: The duty cycle is fixed and does not adjust based on output voltage. Closed-loop control: The output voltage is monitored, and the duty cycle is adjusted in real time to keep the output voltage constant despite variations in input voltage or load.

2.1.5 Mathematical Model of a Boost Converter

The boost converter's operation can be described by a few key equations. Assuming ideal components (no losses), the output voltage Vout and output current Iout are related to the input voltage Vin and input current Iin by the following relationships (Sachin Agadi, 2021).

Output Voltage:

$$Vout = \frac{V\text{in}}{1-D} \quad \textbf{(1)}$$

Current output

$$Iout = \frac{Iin}{1-D} \quad (2)$$

Where D is Duty Cycle for conversion ratio.

2.2 Inverter

An inverter is an electrical device used to convert direct current (DC) into alternating current (AC). Inverters are essential in a wide range of applications, especially in renewable energy systems (such as solar power), uninterruptible power supplies (UPS), and electric vehicles (EVs). They play a vital role in converting DC power, which is commonly available from batteries, solar panels, and DC sources, into AC power that is used by most household and industrial electrical appliances. The inverter operates based on control strategies such as pulse width modulation (PWM) to ensure that the output AC waveform matches the required frequency (50 or 60 Hz) and voltage levels for grid synchronisation or use in standalone applications.

2.3 Grid or Load

In a solar power generation system, energy storage systems such as batteries may be used to store excess energy generated during the day for use during periods of low solar irradiance (e.g., night or cloudy days). The system can also send power directly to a load, like a household or industrial appliance (Ejnar *et al.,* 2001).

2.4 PV System Configurations

Solar photovoltaic (PV) systems use semiconductor materials that exhibit the photovoltaic effect, which directly converts sunlight into electrical energy. Both off-grid and grid-connected applications, including residential power systems, solar farms, electric cars and battery charging stations, frequently use these systems (Kale *et al.*, 2025). This section provides a detailed overview of the basic principles of solar panels, the effects of temperature and irradiance, PV system configurations, and the performance metrics used to evaluate solar energy systems. PV systems can be configured in various ways depending on the application and desired output. The main configurations involve the arrangement of solar panels in series or parallel to meet the voltage and current requirements of the system (Kumari *et al.,* 2022).

2.4.1 Series Connection

When solar panels are connected in series, the output voltage is the sum of the voltages of the individual panels, while the current remains the same (Sathyanarayana *et al.,* 2015). This configuration is used when higher voltage is required for charging batteries or feeding power into the grid. However, if one panel in the series chain is shaded or malfunctions, the performance of the entire string is affected.

2.4.2 Parallel Connection

In a parallel configuration, the output current is the sum of the currents of the individual panels, while the voltage remains the same (Bennani *et al*., 2020). This configuration is often used to increase the current output when the required voltage is already sufficient. One of the benefits of a parallel arrangement is that if one panel is shaded or faulty, it does not affect the performance of the other panels in the array. The choice of series or parallel arrangement depends on the specific application and the electrical characteristics of the load or battery being used (Ejnar *et al*., *2001*). A combination of series and parallel connections can be used to balance voltage and current requirements while providing redundancy.

2.5 Photovoltaic Effect and the Conversion of Sunlight to Electricity

When sunlight strikes a PV cell, it is absorbed by the semiconductor material (typically silicon). The energy from the sunlight excites electrons in the material, causing them to break free from their atoms. This creates electron-hole pairs, where the electron is negatively charged and the hole is positively charged (Han & Li, 2024). The electric field within the PV cell drives the electrons toward the external circuit, while the holes are directed to the opposite side of the cell. The movement of these free electrons through the external circuit generates an electric current (Understanding Solar Photovoltaic System Performance, 2021). The amount of electrical energy generated depends on the intensity of the incident sunlight and the physical properties of the PV cell, such as its efficiency in converting sunlight into electricity.

2.6 Performance Metrics for Solar Panels

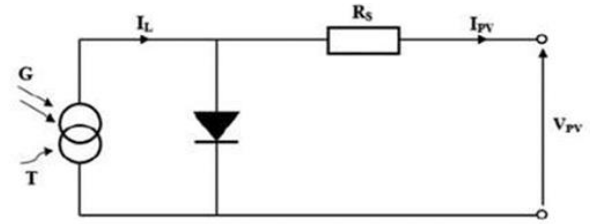
To evaluate the performance of PV panels, several key metrics are used, including conversion efficiency and power output.

2.6.1 Efficiency

Solar panel efficiency refers to the percentage of sunlight that can be converted into usable electrical energy. It is defined as the ratio of the electrical output to the incident solar power on the panel's surface (Raju *et al.,* 2024).

Figure 2

Irradiance and Temperature on PV Cell

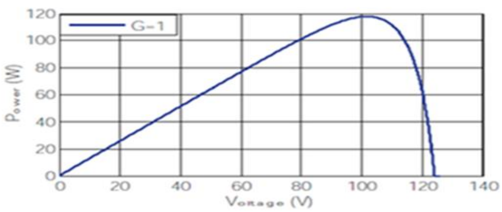


2.6.2 Output Power

The performance of a PV cell is commonly represented by its current-voltage (I-V) curve. The I-V curve shows the relationship between the output current and voltage of the solar cell under varying sunlight conditions. This curve is essential for understanding the behaviour of solar cells and optimising their performance.

Figure 3

VI Curve of PV Solar Cell



2.7 Variability of Solar Irradiance

Solar irradiance varies throughout the day due to the Earth's rotation and across seasons due to its axial tilt (Sreedhar & Jagadeesh, 2016). The amount of solar energy received by a PV panel changes depending on the time of day, geographical location, and season.

2.7.1 Daily Variation

Irradiance is typically highest around midday when the sun is directly overhead, and it decreases in the morning and evening as the sun's angle changes.

2.7.2 Seasonal Variation

During summer, days are longer, and the sun is higher in the sky, resulting in higher irradiance. In contrast, winter days are shorter, and the sun's angle is lower, resulting in lower irradiance. Weather conditions: Cloud cover, atmospheric scattering, and pollution can all significantly reduce the amount of solar irradiance reaching the Earth's surface (Kumari *et al.,* 2022). This variability in solar irradiance can have a major impact on the performance of PV systems.

2.8 Impact of Irradiance and Temperature Variations

The temperature has an effect on both the electrical and thermal properties of PV panels. When the ambient temperature increases, the open-circuit voltage (Voc) of the PV cell decreases, which leads to a reduction in the overall power output (Lysko, 2006). However, the short-circuit current (Isc) increases slightly with temperature, although this effect is less significant than the voltage decrease (Shahatha *et al.,* 2013). Therefore, a temperature rise generally reduces the voltage output, leading to a lower power output from the panel. The temperature dependence of a PV panel's efficiency can be quantified using the temperature coefficient of power. This coefficient indicates the percentage decrease in power output for every degree Celsius increase in temperature. As a result, PV panels are usually less efficient in hot climates or during peak sun hours, necessitating thermal management strategies (e.g., passive cooling, ventilation) to optimise performance (Sathyanarayana *et al., 2015*).

2.9 Dependence on Weather

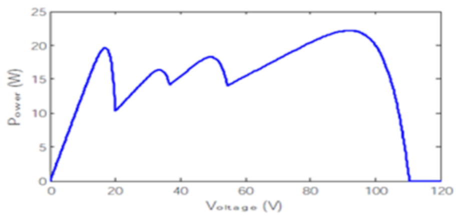
2.9.1 Effect of Temperature and Irradiance on Solar Panel Output

The output performance of PV panels is highly dependent on solar irradiance and ambient temperature (Qasim & Atyia, 2023). These environmental factors significantly affect the power output, efficiency, and overall performance of a solar system. Irradiance refers to the amount of solar power (in watts per square meter) that reaches the surface of the PV panel. It varies throughout the day and across seasons due to the Earth's rotation, geographical location, and weather conditions. Higher irradiance generally leads to higher current and power output from a PV cell. The irradiance is typically highest around midday when the sun is at its peak intensity (Sreedhar & Jagadeesh, *2016*). Temperature also plays a crucial role in the efficiency of solar panels. As the temperature increases, the efficiency of PV cells typically decreases. This fact is because higher temperatures increase the rate at which electrons recombine in the semiconductor material, reducing the overall efficiency of the conversion process (Sathyanarayana *et al., 2015*). The temperature coefficient of the solar cell is a measure of this temperature-dependent performance. Typically, silicon-based solar cells experience a reduction in voltage with increasing temperature, which leads to a decrease in output power.

2.10 Partially Shaded Condition

Partial shading conditions (PSC) in large PV systems are mostly caused by buildings, moving clouds, and other nearby objects such as trees (Sathyanarayana *et al., 2015*). As they cast shadows on PV modules, it causes a non-uniform solar insolation, resulting in the PV characteristic curve becoming complex with multiple peaks, as depicted in Fig. 4.

Figure 4
Curve under Partial Shaded Condition



The non-uniform irradiation causes the hotspot problem and the effect of a potential differential between the PV strings, whereby some PV modules in an array that are in series receive less illumination and dissipate some of the power generated by the rest of the modules (Hamoodi *et al.,* 2023). The PSC decreases the power output of the PV array, and the quantum of power lost depends on the system configuration and the shading pattern on the PV modules.

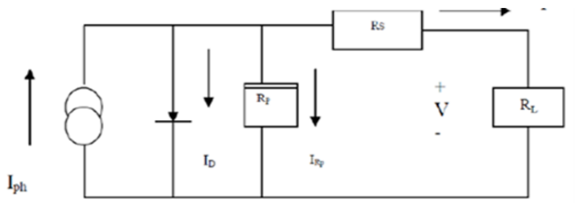
2.11 Photovoltaic Power Output and Irradiance Correlation

Solar cells consist of a p-n junction fabricated in a thin layer of semiconductors, whose electrical characteristics differ very little from a diode. Thus, the simplest equivalent circuit of a solar cell is a current source in parallel with a diode (Qasim & Atyia, *2023*). The output of the current source is directly proportional to the light falling on the cell. The modelling of the PV is done using the data collected and by applying the theories discussed. Note that the irradiance and temperature are the inputs of the system model. Key Components of a Solar PV System: A solar PV system consists of several components, each of which can be modelled using the MATLAB tool.

2.11.1 Modelling PV Cell Characteristics

The PV cell is made up of semiconductor materials which convert solar irradiance into electrical energy. Based on the electronics theory of the semiconductor p-n junction, it can be described by a current source (Cirak, *2023*). The circuit model of the PV cell is shown in Fig. 5.

Figure 5
PV Cell Circuit Model



Iph is the PV generated current which is relative to the solar radiation and temperature. The stronger the irradiance is, the greater the Iph will be. The output is described as

$Iph = Io - Ioexp(\frac{V+IR}{V}) - 1) - \frac{v+IR}{Rp}))$**(3)**

where,
Iph is the Insolation current or photon current
I is the Cell current
I_o is the Reverse saturation current
V is the Cell voltage
R_p is the Parallel resistance
The PV mathematical model used to simplify the PV array is represented by the equation

$I = npIo(\exp(\frac{q}{KTA} X \frac{v}{ns}) - 1)$ **(4)**

Where, I is the PV array output current
V is the PV array output voltage
n_s is the number of cells connected in series
n_p is the number of cells connected in parallel
A is the p-n junction ideality factor
I_o is the cell reverse saturation current.
R_s is the Series resistance
R_p is the Parallel resistance
V_T is the Thermal voltage(kT/q)
K is the Boltzmann constant
T is the cell temperature in Kelvin
q is the Charge of an electron
The factor „A" determines the cell deviation from the ideal p-n junction characteristics; it ranges from 1 to 5. The cell reverse saturation current Io varies with temperature according to the following equation:

$Io = Irr(\frac{T}{Tr})\exp(\frac{qEG}{KA}\left(\frac{1}{Tr} - \frac{1}{T}\right))$ **(5)**

Where,
Tr is the cell reference temperature, I_{rr} is the cell reverse saturation temperature at Tr
EG is the band gap of the semiconductor used in the cell
The temperature dependence of the energy gap of the semiconductor is given by:
The photo current I_{ph}depends on the solar radiation and cell temperature as follows

$Iph = (Iscr + Kt(T - Tr))(\frac{S}{100})$**(6)**

Where,
$I_{scr}$is cell short-circuiting current at reference temperature and radiation
Ki is the short circuit current temperature coefficient
S is the solar radiation in mW/cm2

$P = VI = npIph((\frac{q}{KTA} X \frac{q}{ns}) - 1)$ **(7)**

From the mathematical model, equation 7 and 8 suggests that there is correlation or interdependence of power output of the PV module with solar radiation and temperature.

2.12 Case Study Area

Ntyuka transmission station is located at Image Hill, 20 km from Dodoma Municipal, surrounded by high rocks and baobab trees. The region's climate is semi-arid with periodic blowing winds, with a single rainy season typically occurring between November/December and April/May. The average weather condition is partly sunny with a maximum temperature of 30°C and a minimum of 19°C. The sunrise is always at 6:16 AM, and the sunset at 6:59 PM. The site's neighbouring activities are small retail farms of wheat and groundnuts and milling machines that lead to solar PV surface soiling and partial shedding from rocks and baobab trees.

Figure 6
Ntyuka Transmission Station

2.13 Data Collection

Important data was gathered from the field at meteorological stations, and some was obtained from the NASA website, such as irradiation levels, sunshine hours, the temperature of the surroundings, average cloud cover hours, and the load profile. Also, technical details such as electrical parameters of the installed PV system at a particular station, for example, the power rating of the PV system, the number of panels, the types of panel strings and the maximum output voltage. The collected data should be processed or analysed in a manner that can fit the use of the model.

Table 1
Technical Data of the Study area (Ntyuka Transmission Station)

S/N	Item	Amount
1	Site Irradiation	700w/m^2-1200w/m^2
2	Ambient temperature	30^{0}C
3	Panel max power	335W
4	Open circuit voltage	46.1V
5	Shot circuit current	9.44A
6	Maximum voltage	37.5V
7	Maximum current	8.94A
8	Series string	4
9	Parallel string	12
10	Inverter output power	15kW
11	Inverter output voltage	380V-400V
12	Peak generation	15kW
13	Peak demand	6kW

2.14 Data Analysis and Solar PV System Modelling

2.14.1 PV Panel String Analysis

PV panel model requires the total resistance of both parallel and series string; the parallel string has 12 modules while the series string has 2 modules making a total of 16 modules

$Rst = \frac{V}{Ist}$(8)

= 0.871

R_{st}=0.871 ohms

Where V_{st} is the total voltage of both string

$I_{st}$is the current of both string and

R_{st} stands for Resistance of the string

2.14.2 Inverter Modelling

In order to model the inverter in MATLAB SIMULINK, inverter characteristics and parameters must be identified. Important inverter parameters are parameters of the universal bridge, such as the maximum capacitor switch, inductor frequency and inductor resistance.

$$Cfmax = (\frac{0.5 \times P}{2}) \times \pi f V^2 \quad (9)$$

=(0.5*15000/2)(π*50*380^2)

Cfmax =1.1022e^{-5} Farads

$$Lf = \frac{0.1v^2}{2\pi f P} \quad (10)$$

=(0.1x380^2)/(2πx50x15000)

Lf = 0.0045Hz

R_{lf}=100Lf (11)

= 100x0.0045

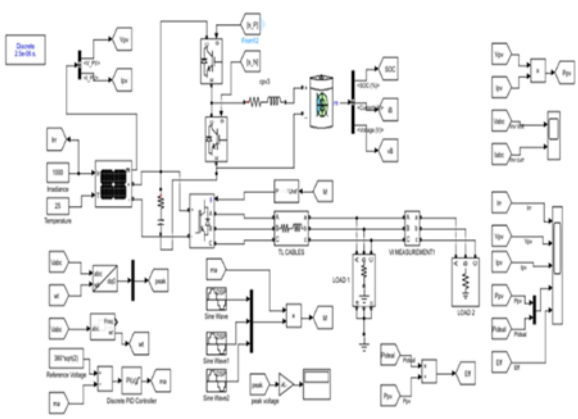
R_{lf} = 0.4596 ohm

NOTE:

C_{fmax} is the maximum capacitor switch

L_f is the Inductor frequency and R_{lf} is the inductor resistance

Figure 7
Complete PV System Model



The system modelling is done using the MATLAB tool to evaluate the influence of intermittent weather on the photovoltaic system's operation under varying solar irradiance. Different parts of the model, including the photovoltaic panel, the converter, the storage, the inverter, the cabling, and the load parts, were designed. The model also includes scope for results visualisation. Some parameters of the analysed data were fed into a model, and the performance was validated through simulation using MATLAB SIMULINK simulation. The results of the model simulation are presented in Figures 8 and 9.

3.0 Results

The minimum irradiance of 700 W/m² and maximum of 1200 W/m² were selected for simulation from a NASA source as the irradiance level in the Dodoma area. The minimum irradiance level is taken as the irradiation corresponding to the amount of insulation during intermittence, while the maximum irradiance corresponds to the insulation at full irradiation.

Figure 8
Inverter Output Voltage at Varying Solar Irradiance

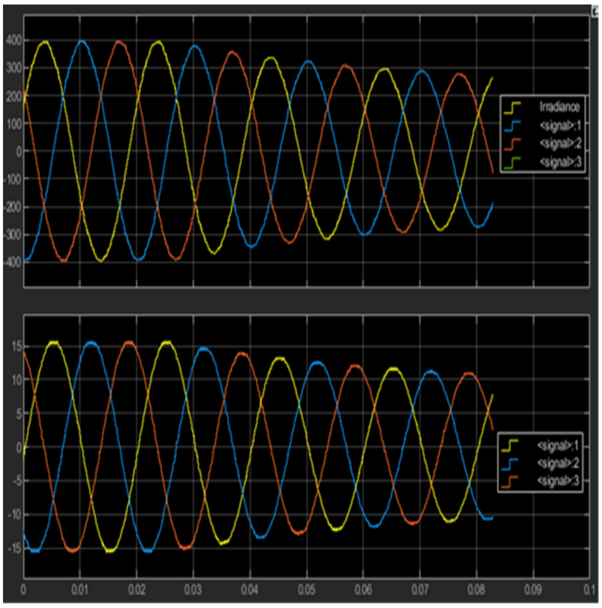
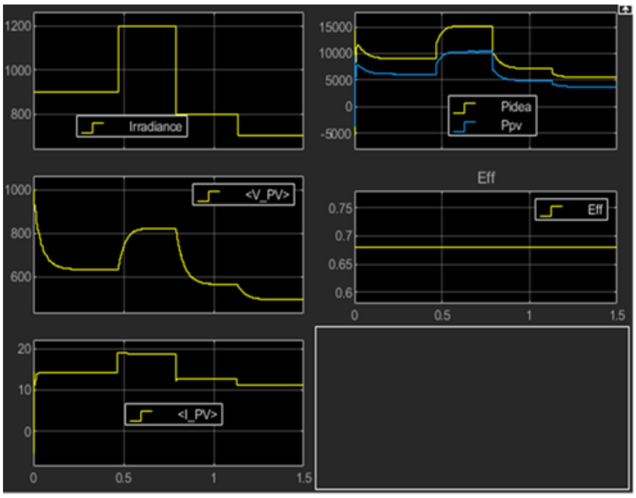


Figure 9
Ideal and PV Generated Power at Varying Irradiance



4.0 Discussion

The results of the simulation show that the inverter output voltage varies from 400V to 300V as irradiance varies from 1200 W/m² to 700 W/m², respectively, as indicated in Figure 8. This indicates a serious voltage drop at lower irradiation, as the AC voltage demand for three-phase loads at the Ntyuka transmission network is 380 V and above.

The power output also varies with varying insolation, as indicated by Figure 9. As the insolation level increases, the PV generation status also increases and decreases as insulation decreases. The simulation was done by varying solar irradiance at 700 W/m², 800 W/m², 900 W/m² and 1200 W/m². It was observed that, at a lower irradiance level of 700 W/m², the photovoltaic panel generates 4.474 kW while generating 10 kW at a maximum irradiance of 1200 W/m². It is also observed that the ideal power corresponding to 700 W/m² was 6.6 kW, and 15 kW corresponds to 1200 W/m² irradiance. This indicates a lower efficiency of 0.68 as per Figure 9. However, the simulation results show a minor impact of temperature variation and are almost negligibly small since the site area temperature has less temperature variation of 50°C, i.e., from the standard temperature of 250°C to 300°C at the site area.

In summary, the PV generation of 4.5 kW during intermittence with the load demanding 6 kW of power indicates that the PV generation does not meet the load power demand during lower irradiation levels. Finally, field data comparison shows the model is reliable (±5% deviation, ±6% uncertainty), while dust reduces efficiency by 2–4%; implementing MPPT optimisation, hybridisation, and regular cleaning can improve PV stability and performance under intermittent conditions.

5.0 Conclusion

The presented research paper concentrated on the modelling and simulation of a photovoltaic (PV) power generation system at Ntyuka transmission station to evaluate the consequences of intermittent conditions on the solar photovoltaic system. The simulation reveals the significant impacts of intermittence on the power output and inverter output voltage, as it leads to the solar irradiation fluctuations. This leads to fluctuating of PV system performance shown by multiple peaks and notches and lowering the PV system efficiency as indicated in F(Sachin Agadi, 2021)igure 8 and 9. The underperformance of the PV system leads to lower power generation during intermittence, especially when solar irradiance becomes minimum, causing a total shutdown of the system at the Ntyuka transmission network, although the use of strategies such as MPPT optimisation, system hybridisation, and regular cleaning can greatly enhance the reliability and efficiency of PV systems under intermittent weather conditions.

6.0 Recommendations

The impact of intermittence on the energy generation capability and operational efficiency of PV solar systems was investigated. Through site visits and NASA weather data records, the system's components' technical specifications, irradiation status, and power demand and generation status data were collected and analysed. The simulation reveals the significant impacts of intermittence on the power output and inverter output voltage, as it leads to the solar irradiation fluctuations causing overall poor system performance and lower PV system efficiency. More efforts should be made to harmonise the system performance.

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