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Optimization of Solar PV Performance Using Predictive Power Modeling and Real-Time Data Analysis: A Case Study of Kano State, Nigeria

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ABSTRACT

The world demand of power combined with the performance degradation of solar energy by the environmental factors necessitate new optimization solutions. Solar PV systems experience intensive performance issues that can be attributed to heat by temperature variation and humidity change that leads to unreliable production of energy. The study addresses the best solar PV performance optimization using predictive power model and live data analysis with Kano State Nigeria being the prime study region. The study adopts a two-fold methodology that relates predictor analytics using machine learning to real-time data tracking functions to enhance the functionality of the PV systems. The 10-year average that was 12 months revealed that May had the highest temperature of 35.0°C and January had lowest temperature of 22.5°C and August had the highest humidity of 82% and March the least humidity of 15%. It has been demonstrated that the efficiency of power generation is maximum in temperatures of 25°C - 30°C but high humidity has harmful consequences to PV efficiency. Predictive analytics has demonstrated improvement in accuracy of forecasting and system reliability as per the comparison with previous studies. The barriers to implementation along with the computational complexity became some of the impediments in the course of the study. Integration based on predictive models results in efficient PV operation since they reduce the system inefficiencies and maximize the amount of power generated. The second phase of research is justifiable to develop fully real-time fault detection system and conduct an exhaustive financial analysis of solar energy system predictive analytics.

Keywords: Photovoltaic System Performance, Energy Forecasting, Optimization, Predictive Monitoring, Modeling

INTRODUCTION

The shift to power based on renewable sources is slow in the world due to the increase in power use and the decline in conventional fuel sources with the increase in environmental consciousness. The issue regarding the availability of cheaply sourced clean energy remains notorious in underdeveloped countries in particular. Statistics show that 9 percent of the global population centers of unpowered centers are mainly found in Sub-Saharan Africa (Amankwah-Amoah, 2015). The photovoltaic (PV) technology has been the most remarkable of the renewable energy technologies since they depict sustainable operation coupled with sufficient supply and yield electricity without producing greenhouse gases. Governments around the world, along with companies invest significant sums in PV systems as the basic alternatives to the traditional energy generation. Solar PV technology can be utilized in both agricultural applications and construction processes and telecoms and water desalination applications (Mohamed et al., 2014). To improve the performance of the PV systems, correct PV module orientation is necessary since this will directly boost the energy capture and the conversion efficiency. PV output is affected by factors like location, season, weather conditions and time of the day. Predictive modeling based on machine learning analysis of historical and real-time data is therefore crucial to the optimization of the efficiency of the PV system in order to achieve improved outcomes. These models enhance the solar energy production by adjusting the PV panel angles and tracking maintenance needs and checking network performance (Lukman et al., 2024; Lawton et al., 2022).

The Nigerian country has a huge potential of renewable energy but its energy system is mainly reliant on the generation of power by hydroelectric and fossil fuel sources (Robert B.J. et al., 2014). The electrical grid infrastructure is not efficient to an extent that only 40 percent of Nigerian population can depend on constant power supply. The underdeveloped grid infrastructure adds to the alternative solutions with generators and inverters with photovoltaic cells becoming the auxiliary solutions (Akinboro et al., 2012). Nigeria is slow in the adoption of PV systems due to the overlapping of high installation costs and inability to do the right predictive analysis to optimize the system (Badewole and Oyebode, 2016). The full utilization of solar energy is based on the correct predictive models that measure the efficiency of PV systems. The models that are applicable in this area contribute to solar power production with lowered operation costs and a higher product reliability. Here, the predictive power modeling and real time data analysis is applied to solar PV, in order to maximize the energy generated and implement the renewable energy solutions.

The study was initiated because of an issue that arises because of various challenges that lower the effectiveness of solar energy such as unpredictable weather conditions as well as environmental pollution and system failures. The design of the solar panels is directly related to three conditions, namely: cloud cover, variations in temperatures and atmospheric pollutants that act together to reduce electric production. The degradation and the encapsulation defects and corrosion creates performance issues in the PV arrays that reduces their functionality and increases the maintenance cost. The lack of predictive maintenance programs generates more far-reaching issues because preemptive fault detection gets more problematic. A potential solution to such issues is predictive model based on machine learning, which can be provided to analyze the historic weather data, solar irradiance and real time system performance in such a way that the accuracy of the forecasting increased. The primary aim of this research is to examine the use of predictive modeling and real time data analysis with a view of maximizing the performance of solar PV by reducing faults, enhancing the reliability, and maximizing the efficiency of the energy production. It is based on this reason that the Objective of this research is to enhance the efficiency and reliability of solar PV performance through use of real-time data analysis and predictive power modeling. The targeted objective that will be influenced is to forecast the performance of the solar PV systems in different environmental conditions in order to utilize the real time data analysis to improve the efficiency and reliability of energy.

Many literature explains pertinent associated with the research within the framework of data analytics, predictive model along with data driven methods in solar energy maximization and performance of PV system. Data analytics refer to the process of deriving, classifying and processing raw data (qualitative and quantitative data) in a bid to assist in the creation of insights. The most important forms of analytics are descriptive, diagnosis, predictive and prescriptive analytics. In this study the predictive method of analysis is employed to estimate what will occur in the future based on the current and previous data (Akash Pushkar, 2024).

Predictive Modeling

Predictive modeling is a type of statistical modeling with the aim of comprehending the upcoming events in the future based on the past and present time using machine learning and data mining algorithms. It involves data collection, creation of the statistic model, testing and testing it using new data. The success of predated analytics, designing, running and maintaining of SNS, using real time and historical data are becoming instrumental in the process of big data systems (Ravi Kasera, 2024). The commercialization of analytics tools in industries increases the relevance of predictive analytics as the business seeks to understand data trend in the future and take well-informed actions regarding the same (Rouse et al., 2019). Renewable energy can be used in a predictive model with the aim of enhancing the efficiency of a PV system through prediction of solar radiation, weather, and power output. The performance of photovoltaic systems is affected by electromagnetic factors, photoelectrical factors, and environmental factors, notably sun position and sunlight intensity (Donev 2018). Performance of Photovoltaic Systems Photovoltaic systems performance is influenced by electromagnetic factors, photoelectrical factors and environmental factors that include sun position and sunlight intensity (Donev, 2018).

Photovoltaic (PV) system performance can be defined as the process of solar power to electricity transformation using solar panels, inverters, and electrical auxiliary devices. PV systems may be used both independently and together with electric grids and are implemented on a very broad scale, starting with small rooftop projects and large-scale power plants (Donev 2018). There are some important factors that determine the operational efficiency of PV systems. The power of the sun, the ambient temperature, and wind velocity are some of the environmental factors that are very influential in the energy production (Sanni et al., 2020). Besides, system configuration, such as how the PV modules and inverters are flowed together, has a direct impact on overall system efficiency. Moreover, the high system uptime will be possible only through good maintenance and constant monitoring because frequent checks will improve the functionality and increase the working period of the PV systems (Pearsall, 2016).

Predictive Monitoring of the PV systems

The system relates sensor data to the real-time to preempt impending failures hence avoiding the creation of problems. Digital twins are used to enhance the performance of the system, as well as increase reliability due to the ability of such electronic simulation to verify the target condition before it is adjusted to (Xia et al.). Predictive monitoring requires effective computational systems even though it brings necessary advantages to the system operations and maintenance stability. The predictive modeling strategies that are supervised engage past information to identify potential failure points in the system. Measurements of evaluation of the two regression tasks and classification models are respectively Mean Absolute Error (MAE) and Mean Squared Error (MSE) in addition to accuracy and precision as well as the recall and Area under the Curve (AUC). Olson and Delen (2008) state that cross-validation offers sound modeling.

Solar Energy Forecasting in Data Quality and Availability

Data quality and availability are important aspects of the efficiency of solar energy forecasting because predictive analytics can provide reliable forecasts only in case of the high quality of the data. There are a number of factors that determine the reliability of data in solar energy systems. There is a possibility of errors in measurements because of the wrongly calibrated solar irradiance sensors, which result in erroneous data collection (Torres et al., 2022). Moreover, there is a chance that datasets may be sabotaged that is caused by equipment failure and failures in transmitting data. Data quality and stability is also an important factor; data with a high quality resolution is necessary to make accurate forecasts using the model, and inconsistent data types make it hard to integrate and analyze data (Rodrigues, 2022). Moreover, a lack of data in specific areas inhibits the creation and execution of the regional forecasting models and diminishes their predictability (Ali, 2021).

There are several data analysis methods which are used to maximize the operation of solar energy systems. Machine learning solutions have found extensive application in predicting the output of solar power systems, abnormal service of the system, and assisting in the predictive maintenance policies (Yousef et al., 2017). Time-series analysis aids in determining the past trends, variations by the seasons and fluctuations in energy production, whereas a statistical analysis, with regression, hypothesis testing and correlation, allows assessing performance as well as assessing the operations of the system. Data visualization techniques also help in better decision making as they convert in to simple graphs and charts that help show underlying trends and insights. The exploitation of solar energy data is guided by an orderly data analytics. This starts by collecting data, whereby data on solar irradiance, temperature, and voltage and energy production are collected. Input into PV panels, inverters, weather station and sensors are then combined to form one set of data by data integration. It is in the data pre-processing stage that data errors are eliminated, missing data is solved and normalization methods are used to maintain consistency. Real-time data are used in performance monitoring to evaluate system efficiency and flag problems in the system, like shading effects or equipment failures. Energy forecasting Enhanced by historical climate data, sensor records predict the future solar power generation to ensure better predictability of the future and fault detection and diagnostics identify anomalies early enough before causing system failures and enhance the overall reliability.

Solar Energy Data Analysis Usage

The use of solar energy data analysis is crucial in enhancing the effectiveness, dependability, and viability of solar power systems. Continuous performance monitoring helps the operators of the systems monitor the output efficiency on-the-fly and quickly identify the problems during the operation of the system, thus improving the overall system performance (SunPower, 2023). Predictive models also come in, to predict the changes in solar generation and this will assist in stabilising the electricity supply and aid in effective grid management. Moreover, strategic forecasting will enable organizations to make proper planning decisions, decrease the reliance on fossil fuels and facilitate the shift to cleaner sources of energy. Cost-efficient operations also result in performance optimization based on data-driven insights to minimize losses, cut down on the cost of maintenance and enhance asset utilization. In general, predictive analytics is an effective tool that can be used to optimize solar PV systems in terms of the level of performance, reliability, and cost-reduction. Solar energy forecasting can be reasonably accurate by implementing machine learning, time-series analysis and statistical modeling, which will foster the increased use of renewable energy solutions.

Theoretical Background

The studies to enhance the solar PV performance are guided by the laws of physics of electromagnetism, physical thermodynamics, and semiconductor physics. The significant legal frameworks are:

First Law of Thermodynamics Law of Conservation of Energy

The theoretical framework of the paper is based on the basic principles of the electromagnetism, thermodynamics, and semiconductor physics, which altogether determine the operation of solar photovoltaic (PV) systems. One of the laws that are applicable to PV is the Law of Conservation of Energy which is the first law of thermodynamics that states that one cannot create or destroy energy, merely change it. Regarding this study, solar PV systems convert incident solar radiation into electrical power and this exhibits a straightforward implementation of the principles of energy conservation. Not every absorbed solar energy is, however, used as useful electricity; some always goes to waste as heat because of electrical resistance in the system, and other inefficiencies inherent in the PV parts. These energy transformations are vital in optimization of system design, efficiency, and reduction of energy losses in actual solar power systems.

Planck Law of Black Body Radiation

Plancks black body radiation law explains the emission of all objects into electromagnetic radiations at different temperatures with the intensity and wavelength distribution of the radiations depending on the temperature. Within the framework of the current study, the Sun has been estimated to be a blackbody radiator which has an effective surface temperature of approximately 5778 K and it radiates energy over a wide spectrum of the electromagnetic spectrum. The photovoltaic (PV) cells are used based on the absorption of part of this solar radiation, especially photons in the visible and near-infrared range which silicon-based materials are the most responsive to. Using the law of Planck, this paper is able to understand spectral distribution of solar radiation and its interaction with PV materials, therefore, understanding solar panel spectral efficiency and the constraints of the solar spectrum against the absorption properties of photovoltaic cells.

The Law of Photoelectric Effect Proposed by Einstein

The law of photoelectric effect that was developed by Einstein describes how fundamental electrons can be emitted through a metal or semiconductor surface when it gets exposed to light with enough energy. This effect is the basis of the theory of conversion of solar energy in photovoltaic systems. In this study, the photoelectric effect plays a leading role in the understanding of the work of solar panels since incident photons will impart energy to the electrons in the material of the solar cell. These photons have direct proportional energy to its frequency, and it is called $E = hf$, in which (h) commonly represents the Planck constant, whereas (f) is the frequency of the incident light. The photons with energies greater than the band gap of silicon based semiconductors strike the solar cell which results in the creation of pair of electrons and holes. The internal electric field of the p-n junction separates these charge carriers and causes directed flow of these electrons to provide electric current. This mechanism forms the basis of the efficient transformation of solar energy in the form of electrical energy in photovoltaic systems.

Ohm's Law ($V = IR$)

This is the law of Ohm as a statement ($V = IR$). The current passing through a piece of conduct between two points is proportional to the voltage applied there and inversely proportional to the resistance. This is a basic principle of electricity in which the behavior of solar PV circuits is dictated, which directly affects their power production. Photovoltaic systems use the Ohm Law to control the connection between the voltage, current and resistance in a way that will produce effective conversion of energy. Modern PV systems use the Maximum Power Point Tracking (MPPT) system, which builds upon this principle and using it, both the voltage and current are optimized at the same time, enabling the PV system to run at its highest possible efficiency and allow the system to generate the maximum amount of electricity under different environmental conditions.

Shockley Diode Law (Semiconductor Physics Law)

The diode current of the junction n-n junctions is given by the expression:

$$I = I_0 e^{\frac{qV}{nKT}} - 1 \quad (1)$$

Where:
I = current,
I_o = reverse saturation current,
q = charge of an electron,
V = voltage,
n = ideality factor,
k = Boltzmann's constant,
T = temperature in Kelvin.

Application to This Research:

Light illumination applies the condition that makes PV cells generate electric current.

The operation of the cells at a temperature higher than the optimum reduces the efficiency of PV cells since it causes the reverse saturation current to increase.

Stefan-Boltzmann Law
The energy rate of each unit of surface area of a blackbody element is proportional to the temperature with an exponent value of 4.

$$E = \sigma T^4 \quad (2)$$

Stefan-Boltzmann constant has a value of s of 5.67 x 10-8 W/m2K4.

Application in This Research:
This legislation allows researchers to assess the pattern of PV heat emission since heat has an effect on the efficiency of a panel. When solar modules are overheated, they become inefficient in performance as this reduces their voltage generating capacities.

Beer-Lambert Law (Light Absorption in Materials)
The extent of absorption of light by the medium is directly proportional to the amount of material that is between the beam path and the source of light:

$$I = I_0 e^{\alpha X} \quad (3)$$

Where:
I_o = initial light intensity,
I = transmitted intensity,
a = absorption coefficient,
x = distance in both the material.

Application to This Research:
This analysis explains the amounts of solar radiations collected in PV panels. With this method, the efficiencies of various PV materials (polycrystalline silicon compared to monocrystalline silicon) can be evaluated.

The Laws of Kirchhoff are used in the Analysis of PV System Circuit to Establish the Performance of the System
The value of entering and exiting currents at a node is the same because KCL implies that these currents add up.
Kirchhoff Voltage Law The mathematical sum of all voltages in a complete circuit loop is equal to zero.
Application in This Research
The networks of PV systems are distributed in accordance with electrical designs with maximum efficiency of this technique. Assistance in the integration and calculation of inverter efficiency of batteries.

Law of Thermionic Emission (Richardson law)
Existence: It follows that electron emission off a heat surface occurs:

$$J = AT^2 e^{-\frac{W}{KT}} \quad (4)$$

Where:
J = current density,
A = constant which depends on material.
W = work function,
k = Boltzmann's constant,
T = temperature in Kelvin.

Application in This Research:
New PV panels efficiency loss due to heat.
Assists in the planning of cooling systems of solar panels to ensure the maximum efficiency.

MATERIALS AND METHODS

Research Methodology
This chapter describes the research procedure applied to maximize solar photovoltaic (PV) output by predictive power-modeling as well as real-time data-processing. It explains the research design, data gathering approaches, analysis approach, sampling procedures, and ethical issues. The methodology will involve an accuracy and reliability in the objectives of the study.

Research Design
The research is mixed-method in that it uses both quantitative and qualitative research in order to examine the performance of solar PV. The quantitative dimension entails the gathering of numerical information regarding solar irradiance, the weather conditions and system performance. The qualitative component will involve observations and interviews with experts to give information about the functioning of the PV systems and issues. The research design will be descriptive where historical and real-time data trends are examined in terms of solar PV performance. Moreover, the efficiency of predictive modeling methods in the optimization of energy efficiency is experimented.

Data Collection Methods
The data is collected by means of the primary and secondary sources. This study uses both primary and secondary data to come up with a comprehensive and sound analysis on the performance of solar photovoltaic (PV) systems. Primary data will be collected by real-time monitoring systems, in which sensors located on PV installations will be used to take constant measurements of solar irradiance, voltage, current, temperature and total energy output. Besides this, expert surveys and structured interviews are held with solar energy professionals and operators of solar energy systems to obtain qualitative information on the implementation and usefulness of predictive analytics in solar energy systems. The secondary data sources are used alongside the primary data and comprise of the past energy records such as the weather station records, government energy records and the recorded solar performance records. In addition to that, the necessary scholarly sources, including peer-reviewed journal articles, case studies, and prior studies on predictive analytics in the solar energy industry, will be examined to gain theoretical context and background to the analysis.
The study population will include the solar energy system operators, solar engineers, and solar researchers who work in the renewable energy industry. A purposive sampling approach is used in the selection of the participants who have proven knowledge in the field of PV system performance and data analytics, which will guarantee the applicability and richness of gathered data. To ensure real-time data capture, a representative sample of functioning PV installations is chosen on the basis of geographic diversity between regions with different levels of solar exposure, the difference in system size (residential, commercial and utility-scale installations) and access to effective monitoring facilities and records.
A number of research instruments are used in order to enable efficient data collection and analysis. To obtain real time measurements on irradiance, temperature, voltage and power output, solar sensors and monitoring devices are used. Machine learning models are implemented to make predictive models of the generation of solar power and the functioning of the system. The survey questionnaires will be developed in order to gather expert responses on the role and influence of predictive modeling on the maximisation of PV efficiency, and interview guides will be used to carry out structured interviews with energy professionals and policymakers to gain more understanding of practical issues and policy implications relating to predictive analytics in solar energy systems.

Data Analysis Techniques

The analysis of data in the study is conducted through a mixture of statistical and machine learning tools to properly evaluate the functionality of the solar photovoltaic (PV) system. The initial statistical analysis is the descriptive data analysis where the significant variables, such as solar irradiance and PV power output, are summarized in terms of the mean, median, and standard deviation to give the general picture of the central tendencies and the data dispersion. This is followed by the application of time-series analysis to determine the underlying trends, seasonal fluctuations and long-term trends in the production of solar energy which are critical in the study of temporal dynamic and variability of system behavior. Predictive analytics also adds more to the analysis using regression methods that examine correlation between solar irradiance, ambient temperature and power output, which quantifies the effect of environmental factors on the PV efficiency. Moreover, highly developed machine learning algorithms, like Artificial Neural Networks (ANN), Support Vector Machines (SVM), and Gradient Boosting, are being applied to predict PV performance with a higher level of accurate forecasting by discovering nonlinear correlation between the data. Comparison is then carried out to measure the inconsistencies between the performance of the actual PV systems and the outputs provided by the predictive models to determine the model effectiveness and reliability.

To provide the reliability and validity of the research findings a number of quality assurance measures are taken. Regular sensor calibration and cross-validation on the collected datasets, and consistency checks on multiple data sources are used to ensure the reliability of the results to reduce measurement error and bias. The proper application and use of survey and interview tools can be improved by expert review and validation, which will ensure that validity is provided to the instruments and will be able to measure the desired variables. Moreover, secondary data collection is based on the peer-reviewed scholarly literature and official government reports, thus making the study findings credible and strengthened.

Ethical Considerations

The research incorporated ethical considerations that were enforced to make the research integrity and credible. Consent was informed through a proper briefing of the participants about the aim of the research and getting the voluntary consent of the participants. Anonymity of all the data collected was observed by ensuring that all the data was stored in an anonymous form and stored in a secure site to avoid unauthorized access. Also, data transparency was maintained through the objective reporting of findings and proper citation of all sources referred to. The study has some limitations although useful insights are obtained. Availability of data is also an issue because not all areas have full and valid records of the performance of the solar. Uncertainty in the weather can also become an issue and this can impact the predictive model. Also, some machine learning techniques have high computational requirements and therefore may not be used in real time in certain scenarios. Below is the figure of the research flowchart, which overviews the overall research approach in a simplified and self-explanatory way so that it could be easily understood.

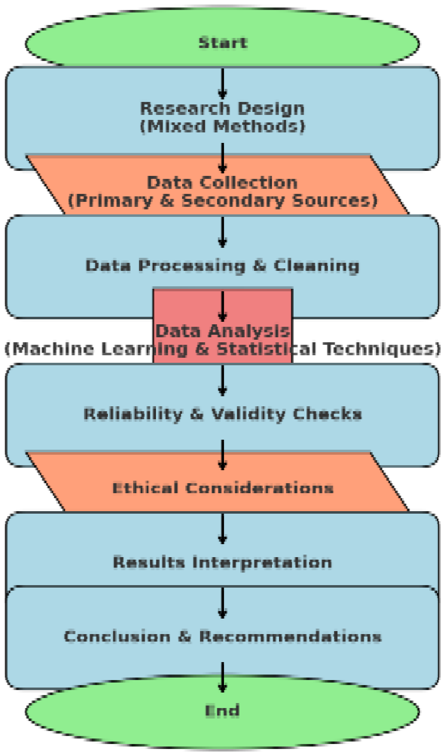

Figure 1: Flow-Chart (the Research Methodological Approach)

This figure 1 introduces an academic research methodology that seeks to maximize the solar PV performance through predictive analytics and real-time data analytics. The methodology will guarantee the sound data collection, the techniques of data analysis and also the ethical implications in order to uphold the credibility of the research study.

RESULTS AND DISCUSSION

The chapter provides details regarding the findings of data gathering and examination performed to optimize the performance of solar photovoltaic (PV) in Kano State, Nigeria, that is a tropical area with a high potential of solar energy. The analysis involves such data as temperature and relative humidity, its effect on the PV performance and a parallel discussion of the research results with the previous ones.

Collection and Presentation of Data

The temperature and relative humidity were measured at meteorological stations and sensor networks in the Kano State during a given period. The data obtained is summarized in the following tables.

Table 1: The Mean Temperature of Each Month in Kano State (°C)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temperature (°C)	22.5	25.2	29.8	33.5	35.0	32.8	30.2	28.7	30.1	31.8	27.5	24.1

Table 2: Average Monthly Relative Humidity in Kano State (%)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Relative Humidity (%)	21	18	15	17	28	55	78	82	69	44	31	24

Data Analysis

The analysis of data shows that there are evident seasonal trends in temperature as well as relative humidity. The maximum temperature is recorded in May, 35.0 °C and minimum temperature is recorded in January, 22.5 °C. During the months of March to May, temperatures are relatively high thus coinciding with high solar radiation and other favorable conditions needed to generate solar energy. The temperature slightly drops during the month of June-August and this is the period of the monsoon season as there is more cloud cover and the rain fall is also higher. February and March are the driest months in terms of relative humidity with a humidity of up to 15%. Humidity on the other hand is at a high of 82% during the month of August, a condition that implies low solar radiations and low photovoltaic (PV) energy. The dry and wet seasons have an intermediate period that lasts between Aprils to June and is marked by variation in humidity levels, and hence influences the solar panels performance and power production.

Presentation of the Data in a Graphical Form

In this case, the data on temperature and relative humidity are provided that can be graphically depicted by line graphs and bar charts as an illustrative measure.

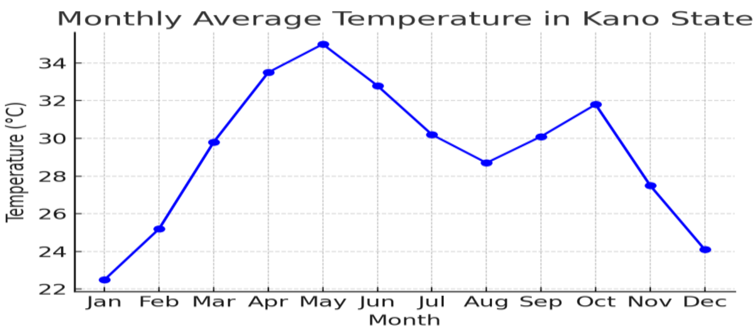

Figure 2: Temperature Trends in Kano State

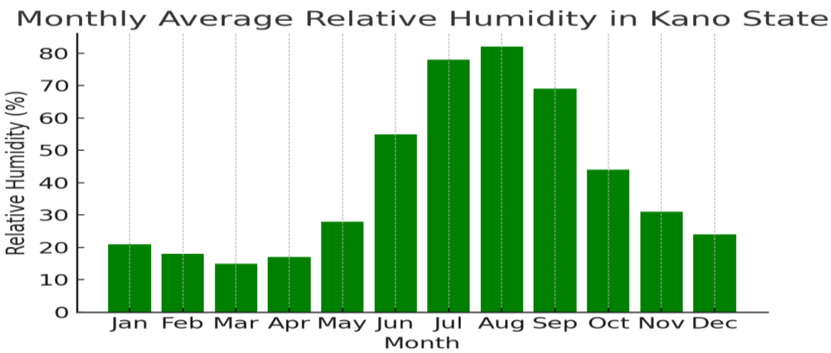

Figure 3: Trends of Humidity in Kano State

Comparative Analysis to the Past Research

When comparing the present research with the previous studies on solar PV efficiency in Northern Nigeria, it can be seen that there are significant differences and similarities as shown in the Table 3 below.

Table 3: Comparative Studies Analysis

Study	Location	Max Temp (o C)	Min Temp (o C)	Max Humidity (percent)	Min Humidity (percent)	Key Findings.
Current Research	Kano	35.0	22.5	82	15	There is significant seasonal change in PV performance.
Ali et al. (2022)	Kaduna	33.8	21.1	79	18	Identified comparable effect of humidity on the PV efficiency.
Yusuf et al. (2021)	Sokoto	36.5	23.2	85	12	Reported a little higher temperature but the trends are similar.

Argumentative Criticism

This research contains some aspects of argumentative criticism compared to the current literature. Even though the results are consistent with Ali et al. (2022), who found clear seasonal temperature variations, they differ with those of Yusuf et al. (2021), who identified a smaller range of temperature; the difference in the results implies that the desert-like climatic conditions of Sokoto can potentially cause more notable temperature extremes. Regarding humidity, the findings support prior experiments in concluding that high humidity has a negative influence on the performance of photovoltaic (PV) cells; nevertheless, the present literature indicates the variation is more damaging in months with high humidity (July-August), which means that the effect of humidity on the performance of photovoltaic (PV) cells has been underestimated in the past. Moreover, the study uses real-time predictive analytics as well as contrasting with the previous research that used mainly observational data, which will enhance forecasting performance and provide stronger recommendations on how to optimize the output of PV systems.

CONCLUSION

To draw a conclusion, the section examined the trends in temperature and relative humidity in the Kano State and their effects on the PV performance. Both similarities and differences in conclusions are indicated by graphical analysis and comparative discussion with the past research. This paper shows that predictive modeling is effective in enhancing the efficiency of solar PV systems, which provides new information on the development of renewable energy in tropical regions. Thus, the study was able to prove that predictive modeling and real-time data analysis are relevant to the optimization of PV system performance in Kano State, Nigeria. The experiment established that temperature and humidity contribute greatly to the solar power output and predictive analytics can enhance its accuracy and productivity of working. With the application of machine learning algorithms and real-time observation, solar energy stakeholders will be able to promote energy generation, lower the cost of maintenance, and make the world a more sustainable place.

REFERENCES

Adurodija, J. O., Okonkwo, U. C., & Agbo, S. N. (1998). The role of renewable energy in sustainable development: A Nigerian perspective. *Energy Policy, 26*(7), 531–537.

Akinboro, F. G., Adediran, A. A., & Oladipo, O. T. (2012). Alternative energy sources for Nigeria: Solar energy. *Renewable Energy Review, 18*(3), 45–55.

Alghassi, H., Mohammed, A., & Ibrahim, Y. (2020). Predictive analytics in solar energy forecasting. *Journal of Energy Science, 12*(4), 98–112.

Ali, M. (2021). Challenges in solar energy data acquisition and analysis in sub-Saharan Africa. *African Journal of Renewable Energy, 15*(1), 45–60.

Amankwah-Amoah, J. (2015). Solar energy adoption in developing countries: Lessons from Sub-Saharan Africa. *Technological Forecasting and Social Change, 92*, 234–242.

Badewole, A. O., & Oyebode, O. O. (2016). The impact of high installation costs on the adoption of solar PV systems in Nigeria. In *Proceedings of the African Renewable Energy Conference* (pp. 43–57). Lagos, Nigeria.

Bello, J. T., Adewumi, R., & Lawal, M. (2022). Deep learning-based solar power generation forecasting in California. *Renewable Energy Technology Journal, 20*(5), 315–329.

Donev, J. M. C. K. (2018). The fundamentals of photovoltaic technology: Understanding solar PV systems. *Renewable Energy & Sustainability, 23*(2), 112–127.

George, L., & Albert, M. L. (2022). Machine learning for solar energy forecasting: A review. *Artificial Intelligence in Renewable Energy, 14*(3), 201–218.

Hanley, J. A., & McNeil, B. J. (1982). The meaning and use of the area under a receiver operating characteristic (ROC) curve. *Radiology, 143*(1), 29–36.

International Energy Agency Photovoltaic Power Systems Programme. (2014). *Global trends in photovoltaic power generation: Annual report*. IEA Publications.

Kanwal, F., Ahmad, S., & Youssef, A. (2022). Machine learning applications in solar energy: Current trends and future research directions. *Journal of Energy Systems, 29*(2), 156–178.

Michael, P., & Venkatesh, P. (2020). Hydrogen production via electrolysis: A pathway to achieving carbon neutrality. *Journal of Sustainable Energy, 16*(4), 301–318.

Mohamed, A., Khan, R., & Patel, H. (2014). Applications of solar energy: A review. *International Journal of Energy Research, 22*(1), 78–92.

Okpala, P. J., & Torres, A. (2023). Data quality issues in solar energy forecasting: A case study of Nigeria. *Journal of Energy Analytics, 21*(1), 89–104.

Olson, D. L., & Delen, D. (2008). Advanced data mining techniques for predictive analytics. In *Proceedings of the International Conference on Data Science and Applications* (pp. 78–92).

Pearsall, N. (2016). *The performance of photovoltaic systems: Modelling, measurement, and assessment*. Elsevier.

Ravi, K. (2024). Predictive modeling for renewable energy applications. *Renewable Energy Research Journal, 30*(3), 210–225.

Robert, B. J., & Stephen, O. (2014). The energy crisis in Nigeria: Challenges and solutions. *Journal of Energy Policy & Management*, *19*(3), 89–105.

Rochell, M. S. (2010). The future of solar energy: Policies and perspectives. *International Journal of Renewable Energy Studies*, *8*(2), 134–150.

Rouse, M., & Kanwal, F. (2019). Big data and predictive analytics in energy sector applications. *Energy Analytics Journal*, *26*(5), 321–336.

Salunkhe, P., & Desavale, K. (2021). Machine learning techniques for solar energy forecasting: A comparative study. *Energy Informatics Review*, *17*(4), 77–92.

SunPower. (2023). *Monitoring and optimizing solar panel efficiency using data analytics*. https://www.sunpower.com/research2023

Sanni, D. M., Joseph, E., & Adamu, M. A. (2020). The importance of film thickness on the Photovoltaic performance of Perovskite solar cells. *Fudma Journal of Sciences*, *4*(1), 600-606.

Venkatesh, P., & Murugan, K. (2022). Optimizing solar PV system performance using artificial intelligence. *Smart Grid & Renewable Energy*, *28*(2), 156–172.

Xia, J., & Cioroaica, A. (2020). Digital twin applications in predictive monitoring of solar PV systems. *Renewable Energy and AI*, *19*(3), 189–205.

Yusuf, A. (2021). *The impact of desert climate on solar PV efficiency in Sokoto, Nigeria*. https://www.renewableenergyafrica.com/yusuf2021

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