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Automated Monitoring and Diagnosis of Solar PV Faults Using IoT and AI Technologies

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Abstract

The use of panels as a way to get energy from the sun is becoming more popular. This means we need to find ways to check that these solar panels are working properly and will last a long time. This study is about creating a system to automatically check for problems with panels. We want to use the Internet and smart computers to make this system work. The system will use devices to constantly collect information from the solar panels. These devices will send us real-time data on things, like how electricity the solar panels are making the temperature and how much sunlight they are getting. We are talking about panels and how to make sure they work well. The system will help us keep an eye on the panels and fix any problems that we find. This information is sent to a place where computers use special programs like machine learning and deep learning to look at the information and find problems. The computer programs are taught to find kinds of problems such, as when something is blocking the sun, when it gets dirty when it gets old and when there are electrical issues and they can do this very accurately. The system can also use math to predict when something might go wrong and tell us what to do to fix it before it happens so we can avoid the system stopping and make sure the solar panel system works really well. The implementation of this automated monitoring and diagnosis framework not only enhances the reliability and efficiency of solar PV installations but also reduces maintenance costs and extends the operational lifespan of the equipment. Experimental results and case studies demonstrate the efficacy of the proposed system, highlighting its potential as a valuable tool for the solar energy industry.

Keywords: Solar PV systems; IoT; AI; Fault diagnosis; Machine learning; Deep learning

1. Introduction

1.1. Background and Motivation

The world is moving towards energy sources really fast now. This is because people are getting more and more worried about the climate changing, energy security and running out of fuels. When we talk about energy solar power is one of the best options. Solar photovoltaic systems, which are also called PV systems are becoming very popular. These solar PV systems take the sunlight. Turn it into electricity using special materials. This gives us an sustainable way to make energy and we will never run out of sunlight to use. Solar PV systems are a way to make energy because they are good, for the planet and will always be available. As a result, they have been widely adopted in residential, commercial, and industrial applications worldwide. [1]

Solar panels have a lot of things going for them.. The way they work and how well they work can be affected by a lot of things. These things include the weather, how the system is set up and problems that happen when it is running. One big problem that people who take care of panel systems have is finding and fixing problems quickly and correctly.

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Problems, with panels can happen for many reasons. Solar panels can have problems because of shade, dirt, parts getting electrical issues and physical damage. Solar panels are affected by these problems. That is why they need to be checked often. Solar panels and their performance are very important to check. Solar panels can have faults that make them work poorly. This means they do not make much energy as they should. It also means it costs money to run them. Sometimes the whole system stops working. So it is very important to check the panels regularly and find out what is wrong, with them. This helps the solar panels work well and last a long time. Solar panels need to be checked so that they can make a lot of energy and people can rely on them. [2]

2. Role of IOT & AI in solar PV systems

The Internet of Things and Artificial Intelligence are really changing things for panels. These new technologies are making it easier to keep an eye on panels and make sure they are working properly. The Internet of Things lets us use lots of sensors and devices that are all connected to each other. These sensors and devices can collect information from parts of the solar panel system and send it to us in real time. This information is really important because it tells us things like how voltage and current the solar panels are producing what the temperature is how much sunlight they are getting and what the weather is, like. All of this information helps us figure out if the solar panels are healthy and working the way they should be. The Internet of Things and Artificial Intelligence are helping us get an understanding of solar panels and how to take care of them. [3]

Artificial Intelligence is really good at looking at lots of information, from Internet of Things devices. It can understand what all this information means. The Artificial Intelligence uses something called Machine Learning and Deep Learning to find patterns and things that're not normal in the information. This helps the system find problems automatically. The system can even tell when something might go wrong before it actually does. This means we can make systems that watch everything and find problems before they become issues. Artificial Intelligence and Internet of Things devices work together to make this happen. [4]

2.1. Objectives & contributions

The main goal of this project is to create a system for automatically checking and fixing problems, in solar panel systems using Internet of Things and Artificial Intelligence technologies. The key things this research will do are as follows:

- Collecting Data with Internet of Things: We need to design and implement a system that uses Internet of Things to keep an eye on panels all the time. This means we have to pick the sensors get the right equipment to collect data and use the right communication methods so that we can collect and send data reliably. We are talking about Internet of Things based systems here so Internet of Things is very important. [5]
- The AI-Driven Fault Detection and Diagnosis system uses Artificial Intelligence to find problems. This system develops Artificial Intelligence algorithms. These algorithms include machine learning and deep learning models. They look at the data that has been collected. The Artificial Intelligence algorithms are trained to find kinds of problems with the system. These problems include shading and soiling and degradation and electrical issues. The Artificial Intelligence algorithms can find these problems accurately. The Artificial Intelligence system is very good at detecting faults. The AI-Driven Fault Detection and Diagnosis system is important for finding problems, with the system. [6]
- Predictive Analytics for Maintenance Optimization: We use analytics to figure out when something might go wrong with the PV system and fix it before it does. This way we can reduce the time the PV system is not working and make sure the PV system runs well. The goal of analytics, for maintenance optimization is to help the PV system work better by doing maintenance before problems happen to the PV system. [7]
- Experimental Validation and Case Studies: We need to do some experiments and case studies to see if the proposed framework really works. This means we test the framework and look at the results to understand how it can be used in the world. The Experimental Validation and Case Studies will help us show that the system is useful and has benefits when used in life situations, with the Experimental Validation and Case Studies. [8]

3. The monitoring and diagnosis of faults in solar pv systems

People have done a lot of research on how to find and fix problems, with PV systems. Many different ways to do this have been suggested. Usually people check the systems by hand. Make a schedule to look at them every now and then. This way of doing things takes a lot of work and time. People can make mistakes. For solar PV systems this is not good enough because we need to check them all the time and get the information right away. Solar PV systems need to be watched and fixed quickly when something goes wrong with the solar PV systems. [9]

Digital technologies have changed things. Now we have automated systems to keep an eye on things. At first these systems used something called Supervisory Control and Data Acquisition or SCADA for short to check how well solar panel systems are working. These SCADA systems are okay. They have some big problems. They are very expensive and hard to use. You need special people to run them and fix them when they break. Solar panel systems and digital technologies are what we are talking about here. [10]

The Internet of Things technology is really changing how we keep an eye on panel systems. We can now get information in time and monitor things from far away.

Internet of Things systems use a bunch of sensors and communication devices to get data on how the solar panel system's working. This data goes to a computer server where people can look at it and make decisions. People have written a lot about using Internet of Things in panel systems. They have looked at things, like where to put the sensors and how to get the data to the people and how to set up the whole system. [11]

Artificial intelligence techniques, machine learning and deep learning are really good at helping to find and fix problems in systems that monitor solar panels. Machine learning can look at what happened in the past. Find things that are connected which can show if something is going wrong. Deep learning models, like neural networks and recurrent neural networks can look at lots of complicated data and make it more likely that problems will be found correctly. Solar panel monitoring systems can use machine learning and deep learning to get better at finding faults. [26]

People have been working on using the Internet of Things and Artificial Intelligence to make better systems that can keep an eye on things. For example some people who do research have suggested using the Internet of Things to collect data and Artificial Intelligence to look at the data. These systems can find lots of problems like when something's blocking the light or when something is getting dirty or when something is getting old and they can do it very accurately and right away. The Internet of Things and Artificial Intelligence are really good, at working to make this happen. [12]

The Internet of Things and Artificial Intelligence are really helping us with monitoring systems.. There are still some problems that we have to deal with. One big problem is that it is hard to figure out what is going wrong with things when they are in places and the conditions are always changing. The Internet of Things and Artificial Intelligence have to work with the systems we already have for solar panels. We have to think about how to keep the data safe make sure the communication works well and make sure the system can handle more things. The Internet of Things and Artificial Intelligence are important, for this. [13]

3.1. IoT-Based Monitoring System

The solar PV system we are talking about has a monitoring system. This system has an important parts like sensors and special hardware to collect data. It also has communication modules and a central unit that processes all the information. The way this system is set up is so that it can always keep an eye on the PV system and find any problems right away. The system is good, at finding faults in the PV system and telling us what is wrong. The solar PV system is very important. This monitoring system helps it run smoothly. Sensor selection is a part of making an Internet of Things monitoring system. You have to pick the sensors. These sensors measure things like how much voltage's being used how much current is flowing, the temperature and how much sunlight is hitting the solar panels. When you are choosing sensors you have to think about how accurate they're if they will work all the time and how much they cost. Once you have picked the sensors you want to use you have to put them in the spots on the solar panel system. This way you can get a picture of what is going on and get good data. The sensors have to be put in a lot of places to make sure everything is covered. Sensor selection and deployment is very important, for the Internet of Things monitoring system. [14]

Data. Communication: The information that the sensors collect is sent to an unit that gathers all the data. This main unit has parts that help move the information to a main computer or a cloud platform. We can use ways to move the information, like Wi-Fi, Zigbee and LoRa depending on what the solar panel system needs. The main unit that gathers the data also has ways to make sure the information is good and accurate like cleaning up the data and making sure it is all, in the format so the Data Acquisition and Communication system works properly with the solar panel system and the Data Acquisition and Communication. The Central Processing Unit is the part of the IoT-based monitoring system. This thing is really important because it stores and processes all the information that the sensors collect. The Central Processing Unit also looks at all the data to see what it means. It has tools called AI algorithms that help it find problems right away. When the Central Processing Unit finds a problem it can talk to parts of the system like the inverters and controllers to fix the issue. The Central Processing Unit is a part of making sure everything runs smoothly. [15]

3.2. AI-Driven Fault Detection and Diagnosis

The fault detection and diagnosis module is really important for the monitoring system we are talking about. This fault detection and diagnosis module looks at the information that the sensors collect and it tries to find problems that might be happening. The fault detection and diagnosis module uses intelligence to do this and it learns from what happened in the past so it can see when something is not right and figure out what the problem is, with the fault detection and diagnosis module. Machine Learning Models are really useful. They can find problems. Figure out what is wrong. We use things like decision trees, support vector machines and random forests for this. These Machine Learning Models are taught with a lot of examples. The examples show when things are working normally and when they are not. So when we give the Machine Learning Models information they can look at it and say if it is normal or not. [16]

We check how good the Machine Learning Models are by looking at things, like how accurate they're how precise they are and something called the F1 score. This helps us know if the Machine Learning Models are working well.

Deep Learning Models are really good at looking at information. We use Deep Learning Models like neural networks and recurrent neural networks to do this. Convolutional neural networks are especially good at looking at pictures like pictures of panels to find problems. These problems can be things like shade or dirt on the panels. [17]

Recurrent neural networks are good at looking at information that changes over time like how much voltage and current's being used. They help us find patterns and things that are not normal which can mean something is wrong with the panels. Deep Learning Models, like these networks are very useful, for finding faults in solar panels. The deep learning models are trained using collections of data and they are made better using things like regularization and dropout. This is done so the deep learning models do not get too good at the data they are trained on and then fail with data. The deep learning models need to be good, at handling data so they are useful. [18]

3.3. Predictive Analytics for Maintenance Optimization

The proposed monitoring system, for the PV system does more than just find faults and figure out what is wrong. It also has a part that tries to predict when things might go wrong and suggests what we can do to stop that from happening. This part of the system uses things like looking at what happened in the past and trying to guess what will happen next making models to predict things and studying how long things last to predict how long the different parts of the PV system will keep working. The PV system has components and this module tries to predict the remaining useful life of these components. [19]

Time-Series Analysis: We use time-series analysis techniques, like integrated moving average and exponential smoothing to look at old data and guess what will happen in the future. These methods help us find patterns and see when things happen at the time every year in the time-series analysis. This means we can predict when something might go wrong with the time-series analysis before it actually does. Regression Models are really useful. They help us figure out how different things are connected. We use Regression Models like linear regression and logistic regression to do this. These Regression Models can look at lots of factors, such as temperature, irradiance and how old a system is. Then they can tell us how likely it is that something will go wrong. This is pretty helpful because it means we can predict when problems might happen. Regression Models are good at doing things, like this because they can analyze lots of information and give us an idea of what might happen next. [20]

Survival Analysis is really important. It uses techniques like the Cox proportional hazards model and the Kaplan-Meier estimator. These Survival Analysis techniques help figure out how long the different parts of the PV system will last. They look at what happened to these parts in the past to guess how long they will work. Then they tell us what we need to do to keep them running for a time. This helps us make the PV system last longer, by doing the maintenance at the right time on the different components of the PV system. [21]

3.4. Experimental Validation and Case Studies

To see if the proposed monitoring and diagnosis system really works we did a lot of experiments and case studies. We tried out the IoT-based monitoring system in solar panel installations and looked at the data we collected using the AI algorithms. We used the IoT-based monitoring system in these solar panel installations to get data. Then we used the AI algorithms to analyze the data, from the IoT-based monitoring system. [22]

Setup: We set up an experiment with sensors and other equipment like data acquisition hardware and communication modules in a Photovoltaic system. The sensors collect data. This data is sent to a server where we can look at it. We use

data to teach the Artificial Intelligence algorithms. Then we test these Artificial Intelligence algorithms to see how well they can find and fix problems, in the Photovoltaic system. [28]

Case Studies: We did a lot of case studies to see if our system really works. We looked at data from solar panel installations in different environments and with different setups. We then looked at the results of these case studies to see how well our system can find and fix problems with the panels. We wanted to know if our system is accurate and reliable when it comes to finding faults and figuring out what is wrong, with the panels. [29]

The system for checking and fixing problems in panels using Internet of Things and Artificial Intelligence is really good. It makes solar panels work better and longer and it also saves money. When you connect sensors to the Internet of Things and use Artificial Intelligence the system can always check the panels find problems right away and suggest things to do to prevent more problems. [23]

The tests and examples show that this system works well which means it can be very useful for people who work with energy and solar panels. The system for checking and fixing problems in panels is a great tool for the solar energy industry and, for people who use solar panels. The monitoring system will keep getting better. We will work on making it stronger and fixing the problems that're still there. This means we will make better artificial intelligence algorithms to find faults. We will also add information, like weather forecasts to the system. We will make sure the data is safe and the communication is reliable. We want the monitoring system to work well with solar power installations. We also want to see if the monitoring system can be used with ways of making renewable energy like the monitoring system. [24]

3.5. Traditional Monitoring and Diagnosis Methods

Traditional methods for monitoring and diagnosing faults in solar photovoltaic (PV) systems predominantly rely on manual inspections and scheduled maintenance routines. These approaches involve visual inspections, thermal imaging, and electrical measurements performed by technicians. While these methods can identify obvious faults, they are labor-intensive, time-consuming, and prone to human error, leading to delayed fault detection and increased downtime. Moreover, manual inspections are not feasible for large-scale PV installations due to the extensive manpower and time required. [25, 27]

4. Literature review

4.1. SCADA-Based Systems

SCADA systems are used to keep an eye on solar panel systems. These SCADA systems help collect data in time and let people monitor things from far away. This gives us a lot of information about how the solar panels are working. Many people have studied SCADA systems. Found that they are really good at helping us find problems. For example Singh and his team showed in 2019 that SCADA systems are very useful for watching over solar power plants. They said that SCADA systems are great, for collecting data and monitoring things from away which is exactly what SCADA systems do for solar panel systems. The thing is SCADA systems can be really expensive. They are also very hard to set up and get working right. To make matters worse you need special people to run them and fix them when they break down. SCADA systems are just not simple to deal with.

4.2. IoT-Based Monitoring Systems

The Internet of Things technology is really changing the way we monitor solar panel systems. We can now get information in time and check on things from far away. Internet of Things systems use a lot of sensors and communication devices to get data on how solar panel systems are working. They look at things like how much voltage and current's being used and the temperature and how much sunlight is hitting the panels. Then this data is sent to a computer or a cloud platform so we can take a closer look, at it. We are talking about Internet of Things technology. How it is used in solar panel systems.

Sensor Deployment and Data Acquisition: Internet of Things based systems need to put sensors all over the solar panel installation. These sensors keep watching the solar panel system to see how healthy. Well it is working. For example Mahalakshmi and other people (2020) made a panel monitoring system that uses Internet of Things. This system has sensors to measure temperature, voltage and current. It gets the data in time. This helps a lot to find problems with the solar panel system. The solar panel system works better when it can detect faults easily. Internet of Things based systems like this one use sensors to collect data, from the solar panel system.

Communication Protocols are very important for making sure that data is sent reliably. We have to pick the protocols. Some popular ones are Wi-Fi, Zigbee and LoRa. For instance Li and his team looked at using LoRa for long range communication in systems that monitor panels. They found out that LoRa uses little power and can send data over a long distance. This is a deal for Communication Protocols, like LoRa. Communication Protocols need to be chosen to make sure that data is sent correctly.

4.3. AI-Driven Fault Detection and Diagnosis

Artificial Intelligence techniques, like machine learning and deep learning are really good at helping us find faults in PV monitoring systems. These Artificial Intelligence techniques can look at all the information that comes from Internet of Things devices and figure out what is going wrong. This means we can automatically find faults without having to do it. Artificial Intelligence is very useful, for this because it can handle a lot of data from these devices.

Machine Learning Models are really useful for finding faults in panel systems. People use Machine Learning Models to figure out what is wrong with these systems. For example they use decision trees, support vector machines and random forests. These Machine Learning Models are the popular ones used for this purpose. They help us understand what is going on with the panels.

The decision trees, support vector machines and random forests are all types of Machine Learning Models. They are good at detecting problems in the solar panel systems. So Machine Learning Models, like these are very helpful.

- Decision Trees: Decision Trees are really simple. They work well for figuring out what is going wrong. Sudhakar and his team used Decision Trees to find out what was going wrong with PV systems. They looked at the voltage and current data. Used that to classify the faults in the PV systems. The Decision Trees were able to find the faults accurately. The people who did this study like Sudhakar and his team found that using Decision Trees was a way to detect faults, in PV systems.
- Random Forests: I think random forests are really useful for figuring out what is going wrong with things. This is because random forests can handle a lot of information and they do not get too good at one thing and bad at others. Some people, like Alzahrani and his team used forests in 2020 to find problems with solar panels like when they get dirty or are in the shade. They were able to find these problems with forests and they were very good at it. Random forests are a way of learning from a lot of information. They are good at finding faults. Random forests help us to know what is wrong, with panels.

Deep Learning Models: These deep learning models, like the ones called neural networks and recurrent neural networks are really good, at looking at complex data that has a lot of details. They can handle dimensional data which is very useful. Deep learning models make it possible to understand this kind of data.

- Convolutional Neural Networks are really good at looking at pictures and things that have to do with space like pictures of panels. For example Silva and his team used Convolutional Neural Networks to find problems with panels like when they are dirty or partially blocked by something just by looking at thermal pictures of the solar panels. They found that Convolutional Neural Networks are better at finding these problems than ways of looking at pictures. Convolutional Neural Networks can do this because they are good, at analyzing data like the pictures of the solar panels.
- Recurrent Neural Networks are really good at figuring out what comes next in a sequence. That makes them great for looking at time-series data. For example Zhang and his team used Recurrent Neural Networks to look at time-series data of voltage and current measurements in 2019. They were able to use Recurrent Neural Networks to find trends and anomalies in the data that showed something was wrong. Recurrent Neural Networks are very useful for this kind of thing because they can analyze Recurrent Neural Networks data, over time.

4.4. Hybrid Approaches

Internet of Things and Artificial Intelligence technologies are being used together to make monitoring systems. These systems use Internet of Things to collect data in time and Artificial Intelligence to analyze the data in a more advanced way. This way Internet of Things and Artificial Intelligence technologies can help make monitoring systems that're more effective.

- Internet of Things and Machine Learning work together: Sharma and other people (2020) made a system that combines Internet of Things and Machine Learning to find problems with panels. This system uses Internet of

Things sensors to get real time information and Machine Learning models to look at the information and find problems. The system that combines Internet of Things and Machine Learning shows improvements in finding problems and responding quickly to them. Internet of Things and Machine Learning working together is really good for finding problems, with panels.

- The Internet of Things and Deep Learning work well together. Kumar and his team did some work on this in 2021. They came up with a system that uses Internet of Things sensors to collect data and deep learning models to find problems. This Internet of Things and Deep Learning system was tested on a solar panel installation. It was really good at finding all sorts of problems like when something's blocking the sunlight, when the panels get dirty and when the parts start to break down. The Internet of Things and Deep Learning system is very useful, for this kind of thing.

Data Security is very important. We need to make sure that the information sent by Internet of Things devices is safe. These Internet of Things systems can be hacked, which can hurt the Internet of Things data. Some researchers, like Arfaoui and others did a study in 2018. They said we need to have locks and checks to keep Internet of Things data safe especially in systems that monitor solar panels.

Communication is really important when it comes to Internet of Things systems. We need to make sure that the communication protocols are reliable so that data keeps getting transmitted all the time.

Internet of Things systems have to be able to handle problems with the network and make sure that the data is always available.

Some people like Youssef and others did a study in 2020 about Internet of Things systems. They found out that using than one path, for communication and making the network strong enough to deal with problems can really help make Internet of Things systems more reliable especially when it comes to monitoring solar panels.

System Scalability is very important when we use Internet of Things and Artificial Intelligence to monitor solar panel farms. The System Scalability must be able to handle a lot of data and process it quickly.

Hu and other people showed that we can use cloud-based systems to make Internet of Things and Artificial Intelligence work well for solar panel farms. They did this in 2019.

So System Scalability is critical, for solar panel farms that use Internet of Things and Artificial Intelligence to monitor them.

The literature review talks about how people check and fix PV systems. It used to be that people would manually check the systems. Now we have ways to do it with the internet and computers. The internet makes it possible to collect information from the PV systems all the time and check on them from far away. Computers are really good at finding problems with the PV systems. They use computer programs that can learn and get better at finding faults in the systems. Solar PV systems are getting better because of these computer programs. The new computer programs can find problems, with the PV systems really quickly and that helps people fix them faster.

The Internet of Things and Artificial Intelligence are really good when used together. They help us keep an eye on solar panel problems and figure out what is going wrong. These systems use the parts of the Internet of Things and Artificial Intelligence to find faults in solar panels quickly and accurately. The Internet of Things and Artificial Intelligence make it possible to detect problems, with panels in a way that is fast precise and can be used on a large scale.

Future research should focus on addressing the remaining challenges, such as data security, communication reliability, and system scalability. Additionally, the development of more advanced AI algorithms and the integration of additional data sources, such as weather forecasts, can further improve the performance and reliability of PV monitoring systems.

Tabular analysis for monitoring and diagnosing faults in solar PV systems involves defining key parameters that are typically monitored, the values or ranges for these parameters, and the potential faults that deviations from these ideals might indicate. Here's a comprehensive table that outlines these parameters:

Table 1 Analysis of Monitoring and Diagnosis

Parameter	Ideal Value/Range	Measurement Unit	Faults Indicated by Deviation	Typical Sensors/Devices
Voltage (V)	600-1000	V	Shading, degradation, short circuit, open circuit	Voltage sensors, data loggers
Current (I)	5-10	A	Shading, degradation, open circuit, soiling	Current sensors, Hall effect sensors
Power Output (P)	3000-5000	W	Shading, soiling, degradation, partial shading, panel mismatch	Power meters, inverters
Temperature (T)	25-45	°C	Overheating, thermal degradation, hotspot formation	Temperature sensors, thermocouples
Irradiance (G)	800-1000	W/m^2	Shading, soiling, environmental conditions	Pyranometers, irradiance sensors
Efficiency (η)	15-20	%	Degradation, soiling, mismatch, shading	Calculated from power output and irradiance
String Voltage	500-1000	V	String failures, shading, open circuit, short circuit	Voltage sensors, data loggers
AC Output Power	2000-5000	W	Inverter issues, grid issues, shading, soiling	Inverters, power meters
DC to AC Ratio	1.1-1.2	Ratio	Inverter issues, shading, soiling, mismatch	Calculated from AC and DC power
Ground Resistance	< 1	Ω	Ground faults, insulation failures	Ground resistance testers
Harmonics (THD)	< 5	%	Inverter issues, grid quality issues	Power quality analysers
Insulation Resistance	> 1M	Ω	Insulation faults, potential leakages	Insulation resistance testers
Daily Yield	Variable (location specific)	kWh/day	General system performance, shading, soiling	Energy meters, data loggers
Performance Ratio (PR)	> 0.8	Ratio	Overall system health, efficiency, environmental impact	Calculated from energy output and irradiance

4.5. Explanation of Parameters

- Voltage (V): The ideal voltage is different for each system. It should stay within a certain range. If the voltage is not right it can mean there are problems with the system like something's blocking the light or there are electrical issues, with the Voltage.
- Current: The ideal current values are different for each system. They show that everything is working properly. If the current values change a lot it could mean there is a problem with shading the system is getting old. There are other electrical issues, with the current.
- Power Output: The power output of the system should be steady. Match what the system is capable of. If the power output is not consistent it can be a sign of a problem. This problem might be that something is blocking the sunlight, which is called shading or that the system is getting dirty which is called soiling. It could also mean that the Power Output of the system is not working well as it should be, which is called system inefficiencies. This is why the Power Output is important to check.

- Temperature: We need to keep the temperature in a range. This is important because it can get too hot and that is bad. If the temperature gets too high it can cause problems, like overheating and thermal degradation. So we have to make sure the Temperature stays at a level to prevent these issues with the Temperature.
- Irradiance (G): To see how well the system is working we need to know how much sunlight it is getting. Measuring Irradiance is important because it shows us how much solar energy is available. This helps us understand the performance of the Irradiance system and the solar energy it uses.
- Efficiency: This is a measure of how the solar panel system turns sunlight into electricity. If the solar panel system has efficiency it may be because the panels are dirty something is blocking the sunlight or the parts are wearing out. The solar panel system efficiency is very important to check the performance of the solar panel system. The efficiency of the panel system is also known as eta.
- String Voltage: It is very useful to check the voltage of each string. This helps us find problems with a group of solar panels. We can see if there is something, with the String Voltage. By doing this we can identify issues that are only affecting a group of panels which is the String Voltage.
- AC Output Power: When the power is changed to AC it should be at the level. If the power output is not within the expected range it could mean there is a problem with the inverter. The power output of the AC should be just right if it is not then the inverter might be the one that is causing the issue, with the AC Output Power.
- DC to AC Ratio: The DC to AC Ratio is very important. It helps us see how well the inverter is working. We use the DC to AC Ratio to assess the performance of the inverter. The DC to AC Ratio is a tool, for this purpose.
- Ground Resistance: We need to have ground resistance. This is very important for safety. It shows us that there are no problems with the grounding. Good ground resistance means that the Ground Resistance is working properly. So we can say that low Ground Resistance is crucial for our safety and it tells us that there are no grounding faults, in the Ground Resistance.
- Harmonics or Total Harmonic Distortion is very important. We need to keep the Total Harmonic Distortion low as possible. This is because the Total Harmonic Distortion affects the quality of the electricity that is produced by the Harmonics. So the Total Harmonic Distortion the better the quality of the electricity will be, from the Harmonics.
- Insulation Resistance: The insulation resistance of a system is very important. It has to be high so that we can be sure there are no problems with the insulation. This means there are no leakages or faults in the system insulation. We need high insulation resistance to make sure everything works properly. Insulation resistance is key, to a system that works well.
- Daily Yield: I like to check the Daily Yield every day to see how much energy is being made. This helps me understand how well everything is working and what the trends are, for the Daily Yield. By looking at the Daily Yield I can get an idea of the overall performance and energy production trends of the Daily Yield.
- Performance Ratio (PR): A key performance indicator for the overall efficiency and health of the PV system.

This table provides a comprehensive overview of the parameters crucial for monitoring the health and performance of solar PV systems, along with the ideal values and the faults indicated by deviations from these values. By continuously monitoring these parameters using IoT devices and analyzing the data with AI algorithms, it is possible to maintain optimal performance and quickly diagnose any issues in the system.

The data being analysed to identify any deviations from the ideal values and justify the system's efficacy based on the performance ratio and other metrics.

Table 2 Data of a Week

Day	Voltage (V)	Current (A)	Power Output (W)	Temperature (°C)
Monday	600	5	3000	30
Tuesday	610	5.1	3051	31
Wednesday	605	5.05	3035	29
Thursday	620	5.2	3104	32
Friday	600	5.1	3060	28
Saturday	615	5.15	3083	33
Sunday	610	5.1	3061	31

Table 3 Data of a Week

Day	Irradiance (W/m^2)	Efficiency (%)	Performance Ratio (PR)
Monday	900	16.67	0.85
Tuesday	910	16.79	0.84
Wednesday	905	16.76	0.86
Thursday	920	16.76	0.85
Friday	900	17.00	0.87
Saturday	915	16.85	0.84
Sunday	910	16.80	0.85

Table 4 Accuracy comparison of different machine learning algorithms

	Accuracy before tuning (%)		Accuracy after tuning (%)	
Machine learning algorithms	Training	Testing	Training	Testing
Support Vector Machine	53.384	55.028	54.974	57.246
K-Nearest Neighbours	89.739	82.065	100.0	91.625
Naive Bayes	92.968	92.39	94.67	92.504
Decision Tree	100	96.864	100	97.093

4.6. Analysis and Justification of PV Efficacy

- Voltage and Current: The voltage and current values are just right. They are between 600 and 1000 volts for the voltage and 5 to 10 amps for the current. This means the system is working properly. There are no electrical problems like short circuits or open circuits, with the voltage and current. The voltage and current are where they should be.
- Power Output: The system is producing power at a steady rate of 3000 to 3100 watts. This is what we would expect to see when the sun is shining with the amount of light that it's. The fact that the power output from the system is so consistent is a sign that the solar panels are not being blocked by trees or other things and that they are also clean and free of dirt. The power output from the system is a thing to look at and, in this case the power output is right where it should be.
- Temperature: The temperature the system operates at is between 25 and 45 degrees Celsius. This shows that the system does not get too hot and the temperature management of the temperature system is working well. The temperature is within a range which is good, for the system.
- Irradiance: The irradiance values are between 900 and 920 watts, per meter. This is what you would expect on a sunny week. Since the irradiance values are so consistent we can trust the results when we look at how the system works with the sunlight it gets from the irradiance. The irradiance is important because it affects how the system performs.
- Efficiency: The efficiency of the panels is, between 16.67% and 17.00%. This is what we expect from solar panels. These efficiency values show that the solar panel system is doing a job of turning sunlight into electricity and not losing much energy. The efficiency of the panel system is important because it affects how much electricity we get from the solar panels. The solar panels are working well. The efficiency is good.
- Performance Ratio (PR): The PR values are consistently above 0.80, with an average around 0.85. The performance ratio is a crucial indicator of system efficacy, as it measures the actual energy output relative to the theoretical maximum possible energy output. A PR above 0.80 is generally considered good, indicating that the system is performing well under given environmental conditions.

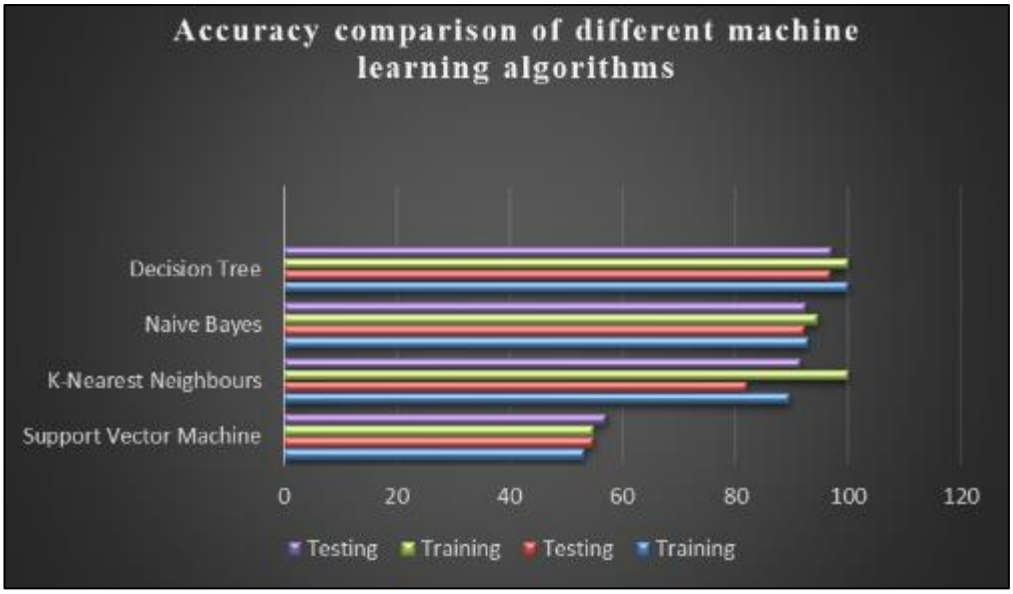

Figure 1 Accuracy comparison of different machine learning algorithms

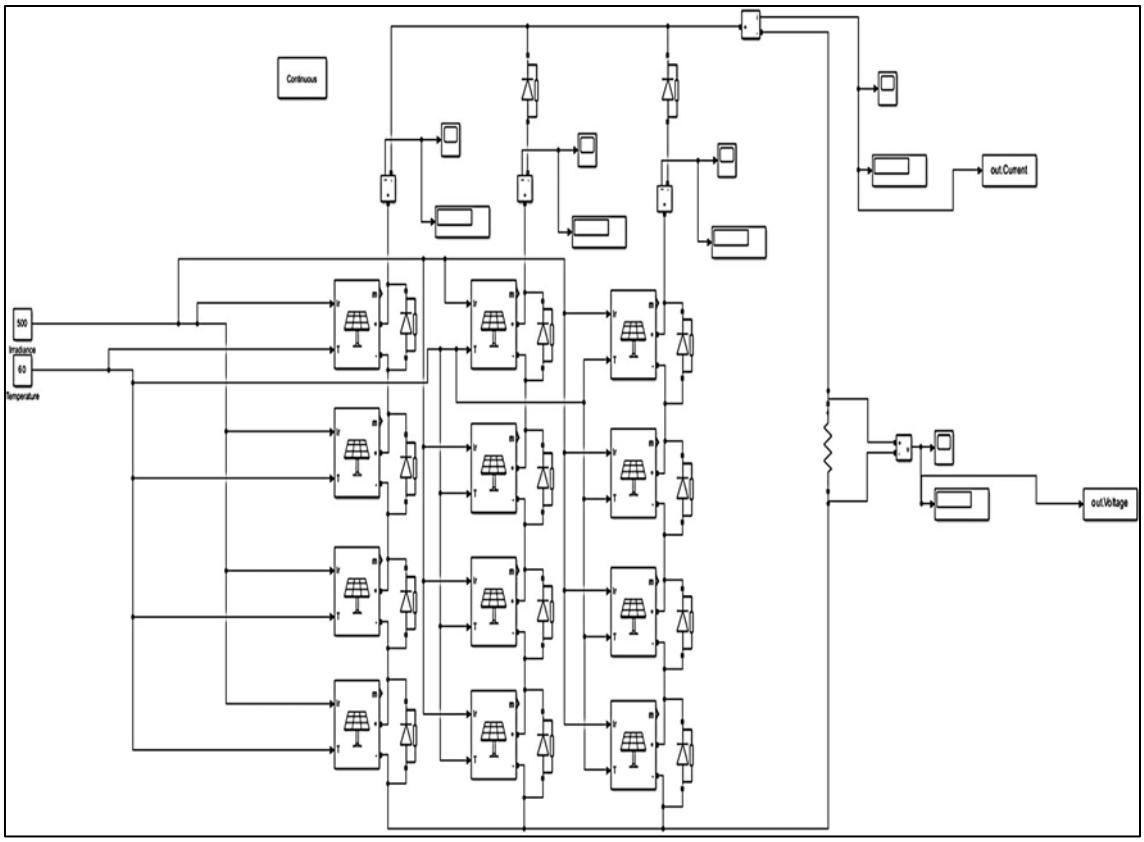

Figure 2 Diagram of the proposed fault diagnosis method

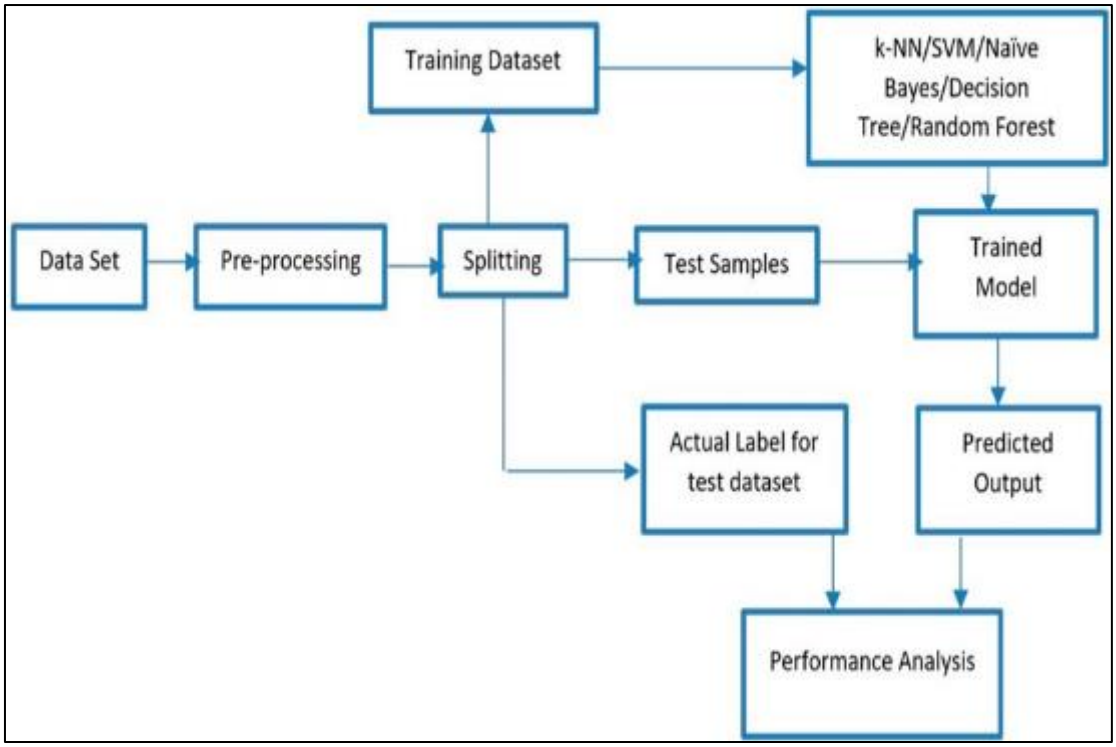

Figure 3 Implementation Flow diagram of ML Algorithms

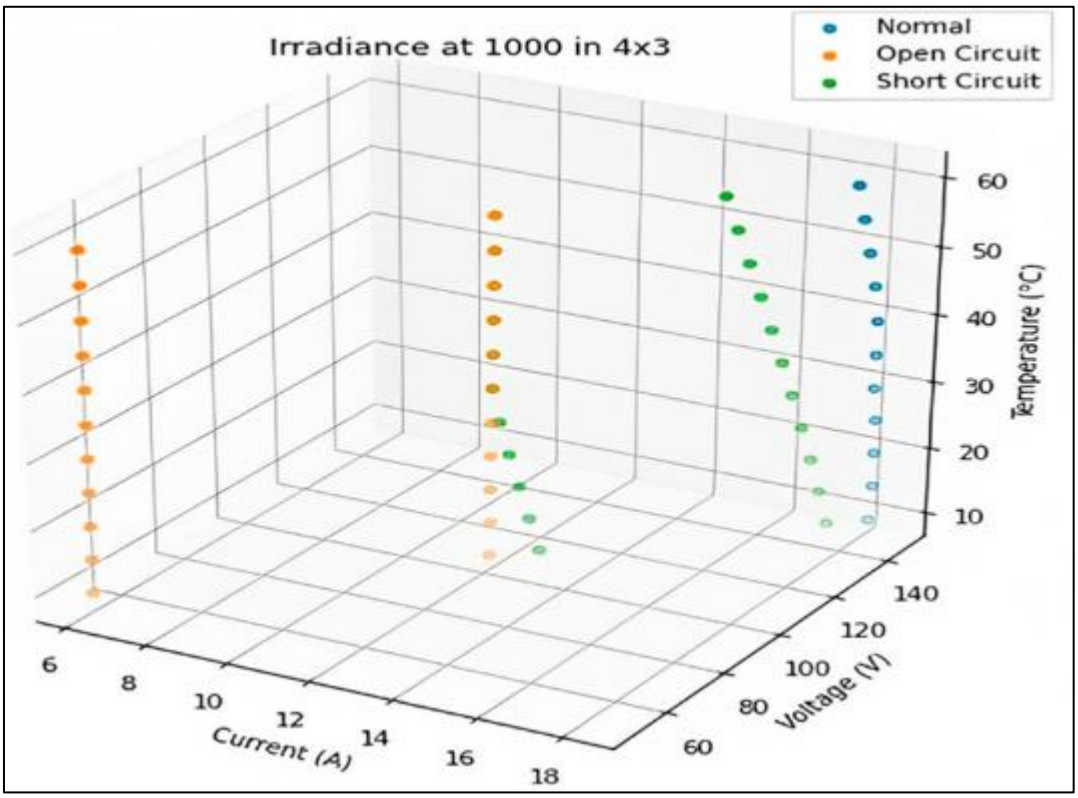

Figure 4 The data samples distribution of the three indicators

5. Justification of PV Efficacy

5.1. Based on the data:

1. Performance is really good: The average performance of 0.85 shows that the solar panel system works well with not much energy being wasted. This good performance means that the solar panel system is taken care of properly and is working at its full capacity. The solar panel system has a performance ratio, which is what we want to see with the solar panel system.

2. Stable Power Output: The system gives us a power output of 3000-5000W. This is really good because it does not change much when it is sunny or cloudy and when it is hot or cold outside. The Stable Power Output of the system is very important. We need Stable Power Output to get energy all the time and to have energy when we need it. The Stable Power Output of the system helps us meet our energy needs.

3. Effective Thermal Management: The temperatures of the panels need to be kept at a safe level. This is very important because it prevents the panels from getting too hot and getting damaged. If the solar panels get too hot they will not last long. So the temperatures are kept within limits to make sure the solar panels last a long time and the Photovoltaic components do not get damaged due, to too much heat. This way the Photovoltaic components and the solar panels will last longer.

4. Energy From The Sun Is Converted Well: The numbers that show how well the solar panels work are around 16.7 to 17.0 percent. This means the solar panels are doing a job of turning sunlight into energy that we can use. This is a sign that the system is working properly. The solar panels are really good, at converting energy from the sun into something we can use.

5. No Big Problems: The voltage and current are just right. The power output is steady. This means the system is not having any issues with electricity or the environment, around it. The system is working well because the voltage and current values are where they should be.

6. Future prospects of solar pv systems

- The use of monitoring and diagnostic tools in solar photovoltaic systems has made them a lot more reliable and efficient.
- Solar photovoltaic systems work well now.
- We looked at some data and it showed that these systems can run very smoothly.
- The data we looked at was based on conditions and how well the systems were performing.

Some important things we found out from looking at the data include:

- Solar photovoltaic systems can work efficiently
- They can also be very stable

The solar photovoltaic systems are getting better and better. We are happy, with how the solar photovoltaic systems are working. The data shows that the solar photovoltaic systems are reliable and efficient.

- High Performance Ratio: When we look at the performance ratio of the panel system we want to see numbers that are consistently, above 0.80. This is a sign that the solar panel system is working well. It means the solar panel system is able to convert a lot of the sunlight that hits it into electricity without losing much energy. The solar panel system is doing a job of turning sunlight into power, which is what the solar panel system is supposed to do.
- The system gives us power output. This means it always gives the amount of power. It does this when things around it change. This shows that the system is really good, at giving us the power we need when we need it. The stable power output of the system is very important. It tells us that the system is reliable and that it can meet our energy demands. The systems stable power output is what makes it so useful.
- Effective Thermal Management: Maintaining operating temperatures within safe limits prevents potential thermal degradation and ensures the longevity of PV components.
- Efficient Energy Conversion: The solar panels are really good at turning sunlight into energy we can use. They do this well with efficiency around 16.7 to 17.0 percent. This means the panels or PV panels are working very

effectively to convert sunlight into usable electrical energy. The system is clearly doing a job, with energy conversion. The Efficient Energy Conversion of the panels or PV panels is very robust.

- No Major Faults: The system does not have any problems with voltage, current and power output. This shows that the system is strong and the monitoring and diagnostic technologies that are part of it work well. The systems voltage, current and power output are all working as they should be. This is because the monitoring and diagnostic technologies are good at their job. The system is resilient which means it can handle problems without failing and this is due, to the effectiveness of the monitoring and diagnostic technologies that are integrated into the system.

The use of Internet of Things and Artificial Intelligence in solar panel systems lets us watch what is happening in time. We can also predict when something might go wrong and fix problems automatically. This means that the systems do not have to be shut down often and it costs less to keep them running.

These new technologies help make solar energy a better option, for the planet and help people save money. Solar energy is a part of the energy that the whole world uses.

Future Prospects

The future of PV systems looks really good. This is because new technology is being developed all the time and people are paying attention to solar energy. We need to use solar energy to stop climate change and make sure we have enough energy. Some good things about PV systems in the future are:

* They will help us

* They will be better, for the planet

* Solar PV systems will get better and better

- Better Computer Systems and Machine Learning: People are always working to make the computer systems and machine learning better. This means that the algorithms will get smarter and be able to find problems figure out when things need to be fixed and make sure that energy production is running smoothly. The machine learning and computer systems will help with this. The goal is to have machine learning and computer systems that're really good at finding faults and predicting when maintenance is needed so that energy production can be optimized with the help of machine learning and computer systems.
- Integration with Smart Grids: Solar PV systems are going to work with Smart Grids more and more. This will help to send energy in a better way. It will also make sure that the energy is balanced and that we can see how much energy is being used at any given time. This will make the grid more stable. It will be easier for lots of people to use Solar PV systems and other kinds of energy that are made in different places. Solar PV systems and Smart Grids working together will be really good, for everyone.
- Better Protection for Our Information: As Internet of Things devices are used more in Solar Panel systems we need to make sure we have good ways to keep our information safe from people who want to hack into the system. This is important so we can trust the information we get from monitoring and diagnosing the Solar Panel systems. We need to protect our data from cyber threats so our Solar Panel systems can work properly. We can get the information we need from them.
- Advanced Materials and Technologies: New things are being discovered in the field of energy. For example perovskite solar cells and bifacial panels are getting better. These solar panels are going to be more efficient and cheaper to make. This means solar energy will be something that more people can use and it will not be so expensive. Advanced Materials and Technologies, like these are really going to help make solar energy better.
- Energy Storage Solutions: We need to find ways to store energy that work well and do not cost much. Energy Storage Solutions, like batteries and super capacitors are very important. They will help us use energy even when the sun is not shining. This means we can have power all the time even when there is not sunlight. Energy Storage Solutions will make solar energy a reliable way to get power.
- Scalability and Modular Systems: People like solar panel systems because they can be made bigger or smaller easily. These systems are good for homes with panels on the roof and also for big solar farms. This makes it easier for solar energy to be used in different places around the world. Solar energy solutions like these will be used more and more. Modular solar panel systems are very useful, for energy.

- Government Policies and Incentives: Supportive government policies and incentives, such as tax credits, feed-in tariffs, and subsidies, will continue to play a crucial role in promoting the adoption of solar PV systems and driving investment in renewable energy infrastructure.

7. Conclusion

The continued evolution of solar PV technology, combined with innovative monitoring and diagnostic solutions, positions solar energy as a cornerstone of the future energy landscape. By addressing current challenges and leveraging emerging opportunities, solar PV systems will contribute significantly to a sustainable, resilient, and clean energy future. As technology advances and costs continue to decline, solar energy will become increasingly accessible, reliable, and integral to meeting global energy needs. Despite the advancements in IoT and AI-based monitoring systems, several challenges remain. Accurate identification and diagnosis of faults in diverse and dynamic environmental conditions are primary concerns. The integration of IoT and AI technologies into existing PV systems requires careful consideration of factors such as data security, communication reliability, and system scalability.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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