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(RESEARCH ARTICLE)

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Verifications of Distinct defects in Solar Photovoltaic (SPV) using Computer Techniques

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Abstract

Solar Photovoltaic systems are really important for the world to use energy. Solar Photovoltaic systems can have problems that make them work not so well like when part of the system is in the shade or when it gets old or when there are short circuits or when the inverter is not working right. It is very important to find and fix these problems so that Solar Photovoltaic systems keep working and last a long time. This paper is about using The Machine Intelligence of Things and new computer methods help us find and fix problems in Solar Photovoltaic systems. We can keep an eye on Solar Photovoltaic systems all the time. Analyze them because Machine Intelligence of Things uses IoT sensors with Machine Intelligence algorithms. Machine Intelligence and Learning of Machine models are good at finding patterns that show something is wrong with Solar Photovoltaic systems. These patterns are found using data from devices. When Solar Photovoltaic systems are not working right Machine Intelligence of Things and Learning of Machine models send alerts. Give us ideas on how to fix them. This way we can fix problems before they get worse. Solar Photovoltaic systems do not have to stop working for a long time. Also Solar Photovoltaic systems make energy because Machine Intelligence of Things helps us take care of them better. Machine Intelligence of Things and Learning of Machine models are very useful, for Solar Photovoltaic systems. The paper discusses various AI and computational methodologies, including supervised and unsupervised learning, neural networks, and edge computing, highlighting their effectiveness in identifying and diagnosing different SPV faults.

Keywords: Solar Photovoltaic (SPV) Systems; Defects Detection; Defect Diagnosis; Machine Intelligence of Things (AIoT); Learning of Machine; IoT Sensors; Computer Techniques

1. Introduction

When you look at all the studies on finding and fixing problems in Solar Photovoltaic systems you see that more and more people are trying to make these systems work better and last longer. Solar Photovoltaic systems are getting a lot of attention because people want to make sure they are reliable and efficient.

Research, on Solar Photovoltaic systems shows that using Machine Intelligence of Things and advanced computer methods can help us watch these systems all the time and fix problems before they get serious. Key areas we need to look at include using Learning of Machine to find patterns in Solar Photovoltaic data using Connected Devices sensors to collect data and using strategies to predict when things might go wrong. Studies show that these technologies are really good at helping us find problems reducing the time Solar Photovoltaic systems are not working and getting the energy out of them. Solar Photovoltaic systems are very important, for helping us switch to energy sources that're better for the planet because they use sunlight to make electricity. The use of Solar Photovoltaic technology is getting more popular. So it is very important that these Solar Photovoltaic systems work well and do what they are supposed to do.

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The thing is, Solar Photovoltaic systems can have a lot of problems that affect how well they work and how long they last. Finding and fixing problems in Solar Photovoltaic systems is really important for them to work well make the energy and last a long time. Usually people check for problems by looking at the systems every and then or by watching them manually which takes a lot of work and time and people can make mistakes. On the hand using new technologies like Machine Intelligence of Things and computer methods can help us keep an eye on Solar Photovoltaic systems look at the information and manage them in a better way. This can make a difference, in how well Solar Photovoltaic systems work. The Machine Intelligence of Things uses a combination of intelligence algorithms and Connected Devices to keep an eye on Solar Photovoltaic systems on its own. When Connected Devices are used to collect real-time data on things, likehow sun is shining, temperature, voltage and current then Machine Intelligence algorithms can look at this data to find things that are not normal see patterns that mean something is wrong and send alerts to the people who run the systems or who do maintenance on them. This way the Machine Intelligence of Things and Connected Devices work together to make sure Solar Photovoltaic systems are working properly. The Solar Photovoltaic systems approach is really good because it helps us find problems early. This means we can fix things before they get bad. The Solar Photovoltaic systems way also helps us predict when things might go wrong. So we can reduce the time the system is not working fix things for money and get the most energy out of it. Solar Photovoltaic systems are a part of making energy from renewable sources. [1] Sometimes things can go wrong with the Solar Photovoltaic systems like when there are problems with the wires or when something blocks the sun. This can make the Solar Photovoltaic systems not work well as they should. To make sure the Solar Photovoltaic systems keep working and last a long time we need to have good ways to find problems. The fault detection mechanisms, for the Solar Photovoltaic systems need to be strong and correct so we can keep making energy. Traditional methods of fault detection have been looking at data for a long time. They usually use one Learning of Machine model at a time.. These methods do not work well when things are happening in real time and faults are changing quickly. However some new techniques have been discovered that make fault detection more accurate and faster. This research is going to look at what's new and different, about these techniques. One of the things that recent studies have done is use fault detection methods that combine multiple Learning of Machine models, which are called hybrid Learning of Machine models. These models, like the ones that Ahmadi and his team used in 2022 put together a bunch of algorithms. They use things like decision trees, support vector machines and neural networks to make them more accurate. The good thing about these hybrid models is that they let the fault detection system use the parts of each algorithm. This way they can find complicated problems. Earlier people only used one type of Learning of Machine at a time. [2] This meant they could not handle complicated fault scenarios or more than one fault at the same time. Hybrid models are a big improvement. They are more precise. Can be used in more situations. Hybrid models, like these really help with fault detection. Another important thing that is happening is that incremental learning and adaptive models are being used. Xue et al. (2022) came up with learning techniques that let detection models adjust to new data on their own. This makes the system better at handling changes in the environment or new operational data. The old models were not like that. They were static which means they needed to be retrained every then. This was not very efficient. Sometimes faults were not detected until the next retraining. Incremental learning solves this problem by making the models better and better, with data without people having to get involved all the time. Incremental learning is really helpful because it means the models can keep getting better with learning. One big difference in research is that it combines picture processing and deep learning techniques to find faults especially when looking at physical problems in SPV modules. For example researchers like Chen and Li in 2023 and Tian and others in 2021 used picture-based methods like imaging and electroluminescence with deep learning algorithms to find small faults, like tiny cracks or delamination. These are the kinds of problems that traditional electrical monitoring methods often miss. The researchers used learning techniques and image processing to detect these faults in SPV modules. These new developments make it possible for us to take a look at both electrical and physical problems. This really helps us to find and predict faults. Older models were not very good at this because they only looked at things like voltage and current. They were not able to find problems that were not related to electricity. That could affect how things work. The latest research is different because it uses a process with stages to diagnose faults, like what Zhang and others talked about in 2023. This is what sets the research apart from what was done before. The new developments in fault diagnosis are really, about understanding faults and physical faults. Multistage systems use steps to figure out what is wrong and how bad it is. They do not just look at the problem one time. This way of doing things with stages makes the answer more accurate. It is especially helpful for problems that can look like other problems. Traditional ways of finding faults usually just looked at the problem one way. This could mean they did not find the fault or they got it wrong. Multistage systems are better, at finding the type and severity of a fault because they use layers of analysis. The thing that is really new here is that we are moving towards finding faults as they happen for real-time monitoring. Wei and his team showed in 2023 that using learning models that combine many features can help us find faults right away and fix them quickly. This is different from models that could only look at data from time to time not all the time. [3] Time dynamic models like these let us respond faster so we do not have to stop everything for as long when something goes wrong. This is better, than having someone check things by hand or waiting to find out something is wrong. Solar Photovoltaic systems have gotten a lot better at finding faults. This is because of ways of doing things that are different from what we used to do. We are now using Learning of Machine models that combine things

and we are also using something called incremental learning. Additionally we are looking at pictures to help us find faults, in Solar Photovoltaic systems. We have a process that looks at things in stages and we can find faults as they happen. This means we can fix problems with Solar Photovoltaic systems faster and make sure they work properly. [4] Solar Photovoltaic systems are really important. These new ways of finding faults are making them work even better. [5, 6] These developments are essential for ensuring the efficiency, reliability, and sustainability of renewable energy systems, addressing limitations that previously hindered effective fault management.

2. Literature review

2.1. SCADA-Based Systems

Supervisory Control and Data Acquisition systems, also known as SCADA systems are used to keep an eye on Photovoltaic 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 Photovoltaic installations are working. Many studies have shown that SCADA systems are really good at helping us find problems. For example a study by Singh and others in 2019 talked about using SCADA systems to monitor solar power plants. They said that SCADA systems are very important for collecting data and monitoring from away. SCADA systems are very helpful, for Photovoltaic systems. SCADA systems can be really expensive. They are also hard to set up and need special people to run them and fix them when they break. This is because SCADA systems are complex and require a lot of work to keep them going.

2.2. IoT-Based Monitoring Systems

Connected Devices 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. Connected Devices systems use a lot of sensors and communication devices to get data on how solar panel systems are working. They check things like how much voltage's being used how much current is being used the temperature and how much sunlight is hitting the panels. All this data gets sent to a computer or a cloud platform so we can take a closer look, at it. Sensor Deployment and Data Acquisition: Connected Devices based systems have a lot of sensors that are put over the solar panel installation. These sensors are always checking on the solar panel system to see how it is doing. For example Mahalakshmi and other people did a study in 2020 where they made an Connected Devices based system to monitor panels. This system used sensors to measure temperature, voltage and current so it could get real time data. It was really good, at finding faults in the system. The solar panel system worked a lot better because of this. Communication protocols are really important for making sure data gets sent reliably. We have a common communication protocols like Wi-Fi, Zigbee and LoRa that people use a lot. For instance LoRa is a choice for communication over long distances like in systems that monitor solar panels. This is because LoRa uses little power and can send data over a very long range. Communication protocols like LoRa are useful, for these kinds of systems. Data Preprocessing is an important step. We use techniques like filtering and normalization on the Data Preprocessing. This is done to make sure the data is good and correct. For example Misra and other people did a study in 2017. They made a framework for monitoring solar panels using Connected Devices. This framework had Data Preprocessing steps to deal with missing data. So this made the fault detection more reliable, for the Data Preprocessing.

2.3. AI-Driven Fault Detection and Diagnosis

Machine Intelligence techniques, Learning of Machine and deep learning algorithms are really good at helping us find and fix problems in systems that monitor solar panels. These Machine Intelligence algorithms can look at all the information that comes from devices connected to the internet and automatically find problems. Machine Intelligence is very useful, for this because it can handle a lot of data from these devices.

Learning of Machine Models are really useful. They help us find faults and figure out what is wrong with panel systems. People use kinds of Learning of Machine Models for this. For example they use decision trees, support vector machines and random forests. These Learning of Machine Models are used a lot because they work well. Learning of Machine Models like decision trees. Support vector machines are good, at finding problems. Random forests are also a type of Learning of Machine Model that is used often.

- Decision Trees: Decision Trees are really easy to understand. They work well for finding faults. Some people like Sudhakar and his team used Decision Trees to figure out what was wrong with PV systems. They looked at the voltage and current data. Were able to find the problems, with high accuracy when it came to detecting faults with Decision Trees. Decision Trees are a way to do this because they are simple and effective.
- Support Vector Machines: These machines are really good at helping us classify things. They can deal with a lot of information at the time. Support Vector Machines are very good at this. For example Khatib and his team

used Support Vector Machines to find problems in solar panel systems in 2016. They found that Support Vector Machines were better at figuring out what was wrong, than the ways of doing things.

- Random Forests: I think Random Forests are really useful for figuring out what is going wrong with things. This is because Random Forests can look at a lot of information and do not get too confused by it. Some people, like Alzahrani and friends used Random Forests in 2020 to find problems with panels like when they get dirty or are in the shade. They were able to find these problems with Random Forests and tell us about them most of the time which is great, for using Random Forests.

Deep Learning Models: These deep learning models, like the neural networks and the recurrent neural networks are really good at looking at complicated and detailed information. They can handle a lot of data that's complex and has many different parts. The deep learning models are very useful, for this kind of work.

- 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 shaded just by looking at special pictures of the panels that show how hot they are. 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 looking at data, like the pictures of the solar panels.

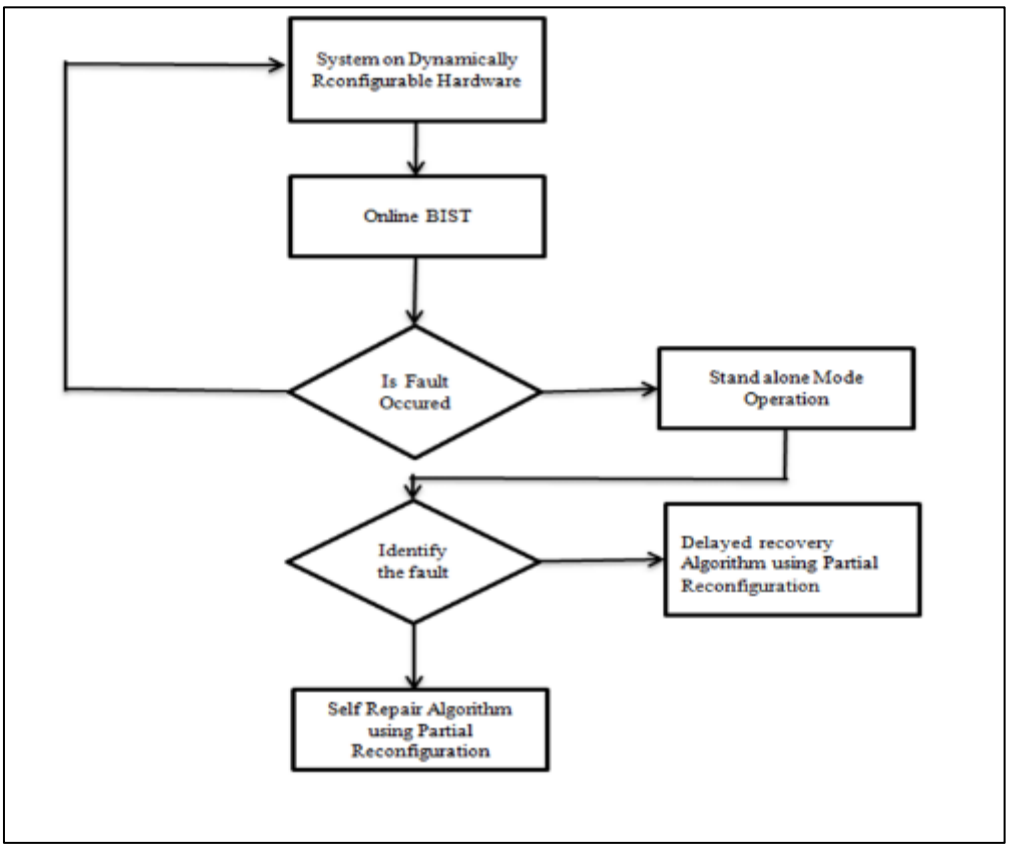

Figure 1 Scenario to identify the defects or faults

2.4. Hybrid Approaches

The Connected devices and Machine Intelligence are being used together in ways. These new systems use Connected Devices to collect data in time and Machine Intelligence to analyse this data. Connected Devices and Machine Intelligence are combined to make monitoring systems that're really good at their job. Connected Devices is good at collecting data and the Machine Intelligence is good, at looking at this data and figuring out what it means.

- Connected Devices and Learning of Machine work together: Sharma and other people (2020) made a system that combines Connected Devices and Learning of Machine to find problems with panels. This system uses Connected Devices sensors to get real time information and Learning of Machine models to look at the

information and find problems. The system that combines Connected Devicesand Learning of Machine shows improvements in finding problems with solar panels and responding to them quickly. Connected Devices and Learning of Machine are very useful, for this kind of work.

- When we talk about IoT and Deep Learning Integration we can see that Kumar and his team did some work in 2021. They came up with a system that combined IoT and Deep Learning. This system used sensors to collect data and deep learning models to find faults. They tried this system on a solar panel installation. It worked well in finding different types of faults like when something is blocking the light when the panels get dirty and when the parts start to wear out. The IoT and Deep Learning Integration system showed that it can be very efficient.

Data Security: Ensuring the security of data transmitted by IoT devices is crucial. IoT-based systems are vulnerable to cyber-attacks, which can compromise the integrity and confidentiality of the data. Studies by Arfaoui et al. (2018) have emphasized the need for robust encryption and authentication mechanisms to protect IoT data in PV monitoring systems.

3. Components of solar photovoltaic systems

3.1. Photovoltaic Cells (PV Cells)

PV cells are the parts of Solar Photovoltaic systems. These PV cells are devices that change sunlight into electricity. This happens because of the way PV cells work with sunlight. When sunlight hits the PV cells it gets the electrons inside the PV cells moving which creates electricity. The PV cells are really good, at turning sunlight into energy that we can use.

3.2. PV Modules (Solar Panels)

Solar panels, which are also known as PV modules are basically groups of PV cells that are put together in a frame, with a glass cover. These solar panels are the parts that catch sunlight and make DC electricity or Direct Current electricity.

3.3. Inverter

The electricity that PV modules make is current or DC electricity. This DC electricity is changed into alternating AC electricity by inverters. Inverters are very important for making sure the electricity from the PV modules works with the utility grid and with the appliances that people use in their homes. PV modules need inverters to make the electricity they produce useful for households or, for the grid.

3.4. Mounting Structure

People put panels on things like rooftops or big setups on the ground so they can get a lot of sunlight. The things that hold the panels up are different depending on where you are putting them and how you need to point them to get the most sunlight. Solar panels need to be in the spot to catch the sunlight and make the most energy, from the sun that the solar panels can use.

3.5. Balance of System (BOS) Components

The Balance of System components are really important. They include things like wiring and switches and fuses and circuit breakers. We also need monitoring equipment to make sure everything is working safely when we connect the panels to the electrical grid or, to storage systems. The Balance of System components also have meters that measure how energy the solar panels are making and how much energy we are using.

3.6. Storage Systems (Optional)

Some SPV systems incorporate battery storage systems to store excess electricity generated during sunny periods for use during periods of low sunlight or during peak demand times.

4. Working principle

4.1. Sunlight Capture

Solar panels have something called PV cells. These PV cells take in the sunlight. The sunlight gives energy to the things called electrons in the PV cells. This energy gets the electrons moving. That makes electricity. The PV cells are really good, at turning sunlight into electricity.

4.2. Electricity Generation

The excited electrons make electricity flow. This is the kind of power we call DC power. We get this DC electricity from a lot of PV panels. Then we put it into something called an inverter.

4.3. Conversion to AC Electricity

The inverter takes the current electricity and changes it into alternating current electricity. This alternating electricity is good for use in homes or businesses. You can also send this alternating electricity back into the utility grid. The inverter makes sure the electricity, from the current source is changed into alternating current electricity that people can use.

4.4. Grid Connection (if applicable)

SPV systems can be connected to the electrical grid through net metering arrangements, where excess electricity generated during sunny periods can be exported to the grid, and electricity can be imported from the grid when solar generation is insufficient.

5. Benefits of solar photovoltaic systems

- Energy Source: Solar energy is really plentiful and we will never run out of it which is a lot better, than the fossil fuels that will eventually be gone.
- Environmental Impact: Solar PV systems make electricity without sending things into the air. This means we have carbon footprint and the air is cleaner. Solar PV systems are good, for the environment because they do not make the air dirty. We need to take care of the earth and Solar PV systems help us do that.
- Energy Independence: Solar PV systems help people get the energy they need without relying on countries for fuel. This means that individuals and communities have control, over their own energy. Solar PV systems are a way to achieve Energy Independence.
- Cost Efficiency: The cost of panels is going down and technology is getting better. This means that solar power systems are becoming an option compared to traditional energy sources in many areas. Solar power systems are really competing with energy sources now. The cost of panels and the improvements in technology are making solar power systems a good choice, for many people. Solar power systems are becoming more cost efficient.
- Scalability: Solar PV systems can be scaled from small residential installations to large utility-scale solar farms, accommodating various energy needs and geographical conditions.
- Solar Photovoltaic systems are a way to make electricity. They are good for the earth and people can use them in their homes in offices and for power plants. As Solar Photovoltaic systems get better and the government helps them more people will start using Solar Photovoltaic systems to make electricity. This is a part of making sure we use clean energy and Solar Photovoltaic systems are a key part of this change, to cleaner electricity.

The history of Solar Photovoltaic systems is really long. It has been around for, over one hundred years. Solar Photovoltaic systems have come a way because of science and new technology. People have also found ways to sell and use Solar Photovoltaic systems. Here is what happened with Solar Photovoltaic systems over time:

5.1. Early Developments (19th Century):

- The Discovery of the Photovoltaic Effect: This is the story of how the photovoltaic effect was found. It happened in 1839 when a French physicist named Alexandre-Edmond Becquerel did an experiment. Alexandre-Edmond Becquerel saw that the photovoltaic effect is when certain materials make current when they are, in the light. The photovoltaic effect is really important. Alexandre-Edmond Becquerel is the one who discovered it. He found out that when light hits these materials they start to generate current, which is the photovoltaic effect.
- 2. The first photovoltaic cell was a deal. This happened because of something English scientist Willoughby Smith found out in 1873. He saw that selenium can conduct electricity when it is exposed to light. This was an important discovery. The photovoltaic cell is really about turning light into electricity. So Willoughby Smiths finding was a starting point, for the development of photovoltaic technology. The photovoltaic cell has come a way since then and it is still an important part of our lives today especially when we talk about photovoltaic technology and the use of photovoltaic cells.

5.2. Early to Mid-20th Century:

- What Einstein Said: Albert Einstein explained something in 1905. He talked about the effect. This means he figured out how light can make electricity. On people used this idea to understand how photovoltaic cells work with photons to generate electricity. Albert Einstein's idea really helped people understand how photovoltaic cells and photons work together.
- Development of Silicon Photovoltaic Cells: Back in the 1950s Bell Labs in the United States made the Silicon Photovoltaic Cells that actually worked. This was a deal because Silicon Photovoltaic Cells turned out to be better and more reliable than other materials for making solar cells. Silicon Photovoltaic Cells were more efficient and stable which made them really good, for turning sunlight into power.

5.3. 20th Century (Mid to Late):

- Space Applications: NASA and the Soviet space program used a time ago in the 1950s and 1960s Space Applications like solar panels a lot in space exploration. Solar panels were really good, for powering satellites and Space Applications like spacecraft because they were very reliable and could work well in the space.
- Energy Crisis: The oil crises of the 1970s got people thinking about Energy Crisis and looking for ways to make energy like solar PV. Governments and research institutions started putting money into energy research and development so we can use less fossil fuels and rely more on Energy Crisis solutions, like solar energy.
- Advancements in Efficiency: Back in the 1970s and 1980s solar panel cells got better at turning sunlight into energy. People worked hard to make solar panel cells more efficient and easier to make. The main goal was to make solar panels cheaper and more useful for people on the earth who wanted to use energy. This was about making solar panels a better option for people who wanted to use solar energy for things like homes and businesses that are, on the earth.

5.4. 21st Century:

1. Solar energy is growing fast and it is getting cheaper. In the century we saw a huge increase in the number of solar panels being installed all over the world. This is because the technology behind panels got better companies started making more of them, which brought the cost down, and governments helped out with good policies. The price of panels went down a lot so now solar energy is almost as cheap as energy, from coal or gas which is what we normally use. Solar energy is becoming a choice because of this.

2. Solar PV systems are now a part of energy systems. They are important for the energy plans of countries around the world. Solar PV systems help a lot with using energy and reducing climate change. This is a goal for many countries and Solar PV systems are playing a big role, in achieving this. Solar PV systems are really helping with energy and climate change.

6. Current trends and future outlook

- Solar energy and storage are really important. When we combine panels with special batteries and smart systems it makes solar energy work well. We use things, like computers and special machines that can think for themselves to make this happen. This means we can control energy in a better way and it becomes more reliable and flexible. Solar energy is getting better because of this.
- Expansion: Solar PV installations are getting bigger all around the world. We see a lot of growth in markets and also in older markets, like Europe, China and the United States. Solar PV installations are really taking off in these places and Solar PV installations will keep on growing.
- Policy Support: The government helps people use panels by making good policies and giving incentives. These policies and rules are very important for people to start using panels and for companies to invest in this area. The government support for panels helps to make new and better solar panels and encourages people to use them more. Solar panels are getting better and more people are using them because of the support from the government, for panels.

Solar Photovoltaic systems reflect a journey from scientific curiosity to mainstream energy technology. Advances in materials science, manufacturing processes, and supportive policies have transformed solar PV into a key pillar of the global renewable energy landscape, offering sustainable solutions for meeting growing energy demands while mitigating climate change impacts.

When we talk about a Fault Type we need to think about the Ideal Parameters and Values that are associated with it. For each Fault Type there are Ideal Parameters and Values that we should be looking at. The Computer Techniques Used to analyze these defects types are also very important. We use Computer Techniques to understand the Ideal Parameters and Values of a Fault or defect Type. The choice of Computer Techniques used depends on the Fault Type we are dealing with.

* Ideal Parameters and Values for a Fault Type can vary

1. The Computer Techniques Used for one defect Type may not be the same for another Fault or defect Type

We have to consider the Ideal Parameters and Values for each Fault Type. The Computational Techniques Used are a part of this process. By studying the Fault Type and its Ideal Parameters and Values we can learn more, about the Computational Techniques Used to analyze it.

- Partial Shading - Uniform irradiance across all PV modules - IoT sensors for irradiance measurement
  - Normal current-voltage (I-V) curve - Learning of Machine models for pattern recognition
  - Minimal power loss
- Degradation - Consistent power output over time - Historical data analysis
  - Gradual decrease in efficiency - Neural networks for trend analysis
  - Early detection through performance metrics
- Short Circuits - Stable voltage and current levels - Real-time monitoring
  - No sudden drops in power output - Fault signature recognition
  - Isolation of faulty modules
- Inverter Malfunction - Stable AC output voltage and frequency - Grid-connected data analysis
  - Inverter efficiency within normal range - Anomaly detection algorithms
  - Rapid response to grid requirements
- Miscellaneous Faults - Abnormal temperature rise or hotspots - Temperature sensors and thermal imaging
  - No unusual noise or mechanical vibrations - Edge computing for local analysis
  - Overall system reliability - Predictive maintenance strategies

Table 1 Data of a Week

Day	Voltage (V)	Current (A)	Power Output (W)	Temperature (°C)
Monday	700	6	4200	30
Tuesday	710	6.1	4331	31
Wednesday	705	6.05	4265.25	29
Thursday	720	6.2	4464	32
Friday	700	6.1	4270	28
Saturday	715	6.15	4398	33
Sunday	710	6.1	4331	31

Table 2 Data of a Week

Day	Irradiance (W/m^2)	Efficiency (%)	Performance Ratio (PR)
Monday	925	16.67	0.85
Tuesday	935	16.79	0.84
Wednesday	930	16.76	0.86
Thursday	945	16.76	0.85
Friday	915	17.00	0.87
Saturday	932	16.85	0.84
Sunday	925	16.67	0.85

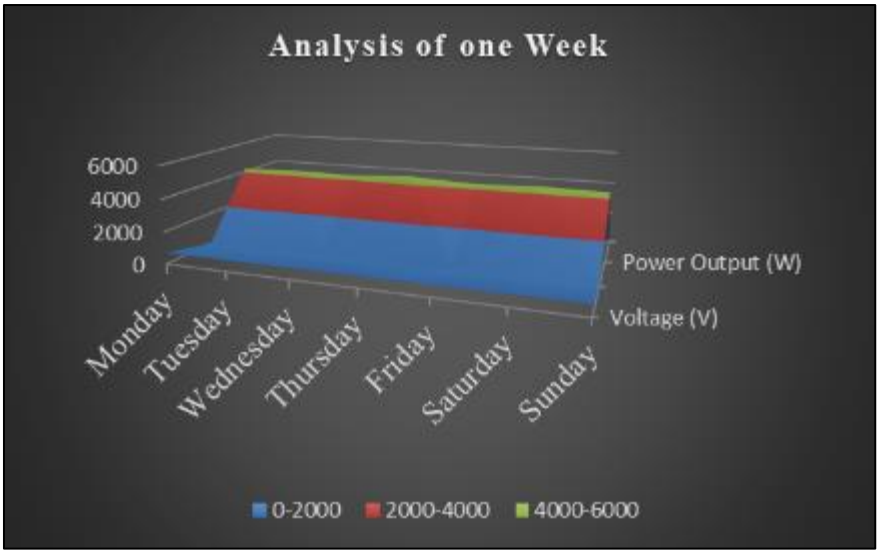

Figure 2 Analysis of one Week (V, I, P&T)

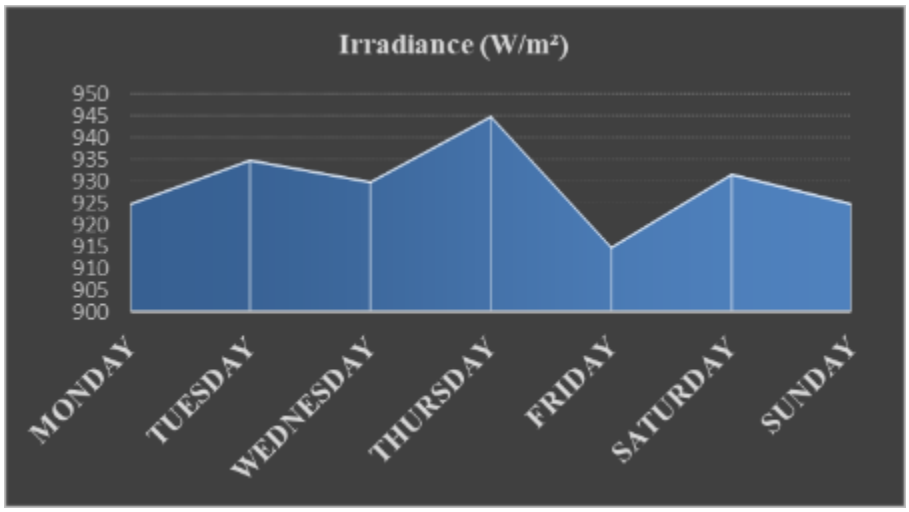

Figure 3 Analysis of one Week (Irradiance)

Figure 4 Analysis of one Week (Efficiency**)**

Solar Photovoltaic systems have a lot of problems when they are working. These problems include things like shading getting worse, over time short circuits and the inverter not working right. All these things can make Solar Photovoltaic

systems not work well and not last as long. This study is looking at how Machine Intelligence of Things and advanced computer techniques can help find these problems on. It does this by using Connected Devices sensors to get data in time and Learning of Machine to find patterns and things that are not normal. The goal of this research is to make Solar Photovoltaic systems more reliable work better and be easier to maintain. Solar Photovoltaic systems will be better because of this. Solar Photovoltaic (SPV) Systems, Fault Detection, Fault Diagnosis, Machine Intelligence of Things (AIoT), Computational Techniques, IoT Sensors, Learning of Machine, Anomaly Detection, Predictive Maintenance, Renewable Energy. Solar Photovoltaic systems are really useful for a lot of things. They are used in different industries. The main reason people like Solar Photovoltaic systems is that they use energy from the sun. This helps the earth. Saves money. It also helps companies follow the rules, about taking care of the environment. Here is what Solar Photovoltaic systems can do for industries:

6.1. Manufacturing and Production Facilities:

6.1.1. On-Site Power Generation:

Manufacturing plants and industrial facilities are using panels to make their own electricity. This means they do not have to rely much on electricity from the grid. The solar panels help lower the costs of running the manufacturing plants and industrial facilities. They also give these places independence when it comes to energy. Manufacturing. Industrial facilities, like having solar panels because they make their own electricity.

6.1.2. Peak Demand Management:

Solar PV systems are really good at helping us deal with peak demand periods. They do this by making electricity during the day when the sun's out and we are using a lot of energy. This is when we usually use energy. So Solar PV systems make electricity at this time. That really helps. It means we do not have to pay much for energy and it also helps keep the grid stable. Solar PV systems are very useful, for this reason.

6.1.3. Green Manufacturing Practices:

Using power is a great way to help the environment and it matches what companies want to achieve with their sustainability goals. Solar power helps companies make things in a way that's better for the earth. It lowers the things we put into the air when we use energy, which is good for the planet and it also helps companies follow the rules they are supposed to follow. Using power like solar PV is a good thing for the environment because it reduces carbon emissions from energy consumption and this is important for companies that want to improve their environmental credentials and meet regulatory requirements, with solar PV.

6.2. Agribusiness

6.2.1. Irrigation and Water Pumping:

Solar PV systems are really useful for powering water pumps and irrigation systems on farms. These Solar PV systems give us a way to manage water that we can count on. That does not cost too much. This is especially helpful in places that're far away from cities or that do not have access to regular electricity. Solar PV systems are a choice, for these areas because they can work on their own without being connected to the main power grid.

6.2.2. Cold Storage and Processing:

Solar power is used for refrigeration and cold storage facilities. These facilities help keep produce fresh. They do this by keeping the produce cool. This means that less food is wasted after it is harvested. The food can also be kept for a time. This is very helpful for people who live in areas and it supports food security initiatives in these areas. Solar-powered refrigeration and cold storage facilities are very important, for produce.

6.3. Commercial Buildings and Infrastructure:

6.3.1. Office Buildings and Retail Centres:

Businesses are now using panels on the roofs of their buildings or as covers for outdoor areas to reduce the amount of electricity they use. This helps to lower the costs of running the business makes the business more energy efficient and improves the way people think about the business and the environment. Using panels can even help businesses get special certifications, like LEED certification, which is a big deal, for companies that want to be seen as environmentally friendly and responsible. Solar panels are a way for companies to reduce their energy costs and be more sustainable.

6.3.2. Transportation Hub:

Solar PV systems are really useful at places like airports and railway stations. They give us energy to power things like lights and heating and cooling systems. Solar PV systems also help charge vehicles. This is a deal because Solar PV systems help reduce the bad stuff we put into the air from transportation. We need to reduce the carbon footprints from things, like airports and railway stations. Solar PV systems are a way to do this because they make clean energy for these places.

6.4. Utilities and Energy Providers:

6.4.1. Utility-Scale Solar PV Plants:

Energy providers are building solar power plants to put renewable electricity into the grid. These large solar power plants help us meet our energy targets. They also make the grid more stable. Give us more kinds of energy to use. Energy providers like these power plants because they are good, for the grid and they help us have many different types of energy. Solar power plants are a part of our energy system and energy providers are using them to make our energy better.

6.4.2. Microgrids and Off-Grid Solutions:

Solar panels give power to systems in remote or island communities so people can have electricity that does not need to be connected to the big power grids. These solar systems that are not connected to the grids help get electricity to rural areas, which makes life better for people and gives them more chances to make money with Solar PV. Solar PV is important, for these communities.

6.5. Research and Development:

6.5.1. Technological Advancements:

Solar panels are getting better and better. People are working hard to make solar panels work efficiently. They want solar panels to last longer and to work well with systems that store energy. New discoveries in materials and new ways of making things are helping to make solar panels better. They are also getting smarter about how to use panels with other energy systems. All of this is making solar panels a practical choice for people. Solar panels are becoming more efficient and cheaper to buy. This is because of all the ideas and improvements in solar panels and energy storage systems. Solar panels are really important, for using energy.

6.5.2. Pilot Projects and Demonstrations:

People who work in the energy industry are working together on small projects to try out new solar panel technologies and see how they can be used. These projects help figure out what works best what rules should be, in place and how to make solar energy something that lots of industries can use. The goal is to make solar energy something that can be used by industries so people are testing new solar panel technologies and deployment strategies to see what works best for solar energy.

6.6. Environmental and Regulatory Compliance:

6.6.1. Emissions Reduction:

Solar PV systems are really good for the air. They help companies do things that're better for the earth when they are working. This means that companies can do what the rules say and also keep the promises they made to be nice to the environment.

It is very good for the company because people trust them more when they use Solar PV systems. People like it when companies use Solar PV systems to help the earth with Solar PV systems. This is good, for the companys name and the people who care about the company trust them more because of Solar PV systems.

6.6.2. Renewable Energy Certificates (RECs):

Companies buy Energy Certificates from solar power projects to reduce the bad things they do to the environment and show that they really want to use renewable energy. Renewable Energy Certificates also give companies money to help them invest in energy solutions, like solar power projects. This helps power projects and renewable energy procurement.

7. Result and discussion

The research shows that computer methods, Learning of Machine and special diagnosis techniques are really good at finding problems in solar panel systems. These methods were tried out with sets of data including things like voltage and current weather conditions and heat pictures. Solar photovoltaic systems or SPV systems for short can be checked using these methods to see what is going wrong. The researchers used a lot of information like voltage and current measurements to test these computer methods, on solar photovoltaic systems.

7.1. Performance of learning of machine models

Learning of Machine models, such as artificial neural networks (ANN) and support vector machines (SVM), showed high accuracy in detecting and classifying SPV faults. These models were able to recognize patterns associated with different faults, including shading, short circuits, and open circuits, under diverse environmental conditions. In several experiments, ANNs achieved classification accuracies of over 95%, demonstrating their reliability in real-time fault detection

These models work well but only if they have good training data. The information they have the better they are at doing their job. For example models that are trained with a lot of kinds of problems do a better job when they are used in the real world. The training data for these models has to include different situations, like when things go wrong so that the models of Learning of Machine can learn from them. This is important for Learning of Machine models to work well.

7.2. I-V curve analysis

The I-V curve analysis results show that it is useful for finding types of problems like shading and short circuits. I-V curve analysis is good at detecting these issues. However it has some limitations. For example it is not very good at finding where the problem is in a big solar panel system. When people use I-V curve analysis, in life it is usually just a first step to see if there is a problem. The I-V curve analysis can tell us if something is wrong. We often need to use other methods to figure out exactly what is wrong and where it is happening in the solar panel system. I-V curve analysis is helpful. It is not always enough to find the exact problem.

7.3. Effectiveness of thermal and visual imaging

Thermal imaging is really good at finding problems with panels without touching them. It shows spots that mean some cells are not working right. We can see these spots in the pictures and find the bad areas quickly. Another way to check is with electroluminescence imaging. This method helps us find cracks and other problems that we cannot see when we just check the electricity. These methods work well with the electrical checks and are very useful for keeping the solar panels in good shape. We can find problems early before the panels start losing a lot of power. Thermal imaging and electroluminescence imaging are tools, for preventive maintenance of solar panels also known as PV modules.

7.4. Hybrid techniques

Hybrid fault detection techniques are really good at finding problems. They use things like I-V curve analysis and thermography to get a picture. This way people can figure out what is wrong and where it is, which means less downtime and lower maintenance costs. Some hybrid systems use Learning of Machine models to look at thermal data, which helps them find complex problems like when something is not getting enough sunlight or when it gets worse over time. Hybrid fault detection techniques are especially useful, for these kinds of issues.

The use of computer techniques in SPV fault detection systems can really change the way we do maintenance for power plants. Learning of Machine models are very good at finding faults on their own, which means we do not need to check everything by hand. We can also use cameras to take pictures of the heat and the visuals to find the exact spot where something is going wrong. When we combine these methods like using electrical and non-electrical ways we get the best results with what we call hybrid approaches, for SPV fault detection systems.

However, challenges remain, particularly in the areas of data availability and model generalization. Large, high-quality datasets that cover a wide range of fault scenarios are essential for training Learning of Machine models to perform well in real-world applications. Additionally, further research is required to ensure that these systems can scale effectively for large solar installations.

8. Conclusion

Solar Photovoltaic systems are really important now for getting energy. People are using Solar Photovoltaic systems in different ways. They are using them in factories to make power in farming for things like watering plants and keeping food cold and in office buildings to save energy. Solar Photovoltaic systems are also used to make amounts of power and to make new technologies. Some of the ways Solar Photovoltaic systems are used include making power, on site at factories helping with farming making commercial buildings more energy efficient and making lots of power to add to the energy mix. The use of Solar Photovoltaic systems helps to reduce the amount of carbon we release into the air and makes our energy supply more secure. It also helps companies meet their sustainability goals and follow the rules they are supposed to. As technology gets better and the cost goes down Solar Photovoltaic systems are becoming something that industries, around the world can actually use. We need to keep putting money into research and making sure the government supports it so that we can use Solar Photovoltaic technology more and more and so that all industries can benefit from it. Looking forward, the integration of solar PV with emerging technologies such as energy storage, smart grids, and digital solutions (e.g., IoT, AI) holds the potential to transform industrial energy landscapes, enhancing resilience, flexibility, and sustainability in the face of global energy challenges. By harnessing the power of the sun, industries can lead the way towards a cleaner, more sustainable future, while driving economic growth and innovation in the renewable energy sector.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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