THE BENEFITS AND CHALLENGES OF INTELLIGENT SELF-DIAGNOSTIC MODEL FOR FAULT DETECTION IN PHOTOVOLTAIC SYSTEM

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Abstract:

The use of photovoltaic energy systems as an alternative energy source is growing in popularity. The stand-alone PV system must continue to function at its peak level in order to efficiently harness reliable energy. This requires continuous maintenance and monitoring. An intelligent self-diagnostic model for monitoring PV system is needed, nevertheless, to determine faults in the system. An intelligent self-diagnostic model is a system that performs self-diagnosis by monitoring internal signals and operations of the system for evidence of faults. The uncertainty associated with the monitoring and detection of faults in photovoltaic systems could be easily and efficiently solved using the intelligent self-diagnostic model, which are developed using artificial intelligence (AI) techniques. AI-based systems learn and train continuously in order to behave like humans and develop self-reasoning and problem-solving capabilities. Complex problems could be successfully solved by AI tools without the need for more sophisticated mathematical manipulations. As a result, AI has emerged as a promising alternative to conventional approaches to problem-solving. Artificial Neural Networks ANN, Fuzzy Logic (FL), Expert Systems (ES), Natural Language Programming (NLP), and various hybrid approaches are all examples of AI techniques, for this research work, we will base on fuzzy logic system for fault detection. This paper is on the benefits and challenges of intelligent self-diagnostic model for fault detection in photovoltaic system

Key Words: intelligent self-diagnostic model, photovoltaic energy systems, solar energy, fuzzy logic system.

I. INTRODUCTION

Energy is the power created when physical and chemical resources are used, particularly to give light, heat, or operate machines (Székely and Rizzo 2017). Alternative energy sources are needed to prevent the likelihood of a climatic collapse and the rise of warfare over natural resources and to meet the world's expanding energy demand (Svarc, 2020). Energy is a saved amount — the law of preservation of energy expresses that energy can be changed over in structure, yet entirely not made or demolished. The unit of estimation for energy in the world arrangement of units (SI) is the joule (J). In Ristinen, (2022), energy is constantly taken in and released by all living things and is needed for humankind to function. This energy can be obtained from sources like fossil fuels, nuclear fuel or renewable energy. The pursuit of energy sources from natural resources is the primary focus of energy development activities such as the creation of energy from nonrenewable and renewable sources as well as the recovery and redistribution of energy that would otherwise be lost (Jaffe and Taylor, 2018).

Non-renewable energy comes from the source that does not replenish. They are fossil fuels (coal, natural gas, petroleum), which are manufactured from the decay of plants and animals. The fuels are found within the Earth's crust and contain carbon and hydrogen, which may be burned for energy (Ritchie et al., 2020). Fossil fuels can be burned to generate electricity, power engines (like internal combustion engines in automobiles), or provide heat directly for use (like cooking or heating). Before being burned, some fossil fuels are refined into derivatives like kerosene, gasoline, and propane. Fossil fuel combustion on a wide scale has a negative impact on the environment and they release a lot of the greenhouse gas carbon dioxide into the air, which causes global warming effect (Sharma and De, 2018).

Photovoltaic (PV) technology, which is the basis for this research is a renewable energy that converts the sun's radiation, in the form of light, into usable electricity. The term "photo" refers to light, and "voltaic" refers to voltage. Dino Green (2018) stated that a photovoltaic system produces clean, green energy because there are no harmful emissions of pollutants or greenhouse gases during electricity generation. It is a system that is extremely safe to use and has a low cost of maintenance, which is significant if you want something that is simple to maintain and won't cost a lot in repairs. Therefore, by putting in and using a PV system, you are making a sustainable home and improving the environment (Seme et al., 2019). The fundamentals of all PV systems are the same. PV panels first convert sunlight into Direct Current (DC) power, the DC power can be stored in a battery and turned into Alternate Current (AC) power by a solar inverter, which can be used to run household appliances. Excess solar energy can be stored in a variety of battery storage systems or fed into the electricity grid for credits, depending on the system.

The PV system is made up of many different parts such as PV panels, charge controller, batteries inverter and mounting structure, which work together to make it work right and produce electricity (Charfi et al., 2018). In Chermitti et al., (2012), a PV cells are typically made of silicon in a variety of forms and they convert direct light energy into DC electricity. A PV panel is made up of a group of cells that are electrically connected to one another and enclosed to keep them safe from outside forces. In order to generate electricity, PV panels are made to take in the sun's rays. To prevent batteries from overcharging, a charge controller or charge regulator is essentially for voltage and/or current regulator. It regulates the voltage and current that flows to the battery from the solar panels. A battery is a container in which chemical energy is converted into electricity by one or more cells utilized as a power source. Direct current is transformed into the alternating current in an inverter. A photovoltaic system is created by combining the PV panels, charge controllers, batteries and inverters.

The photovoltaic framework falls into two primary classifications – Off-grid and On-grid systems. Off-grid PV systems, as defined by Cheng et al., (2017), use solar power as their primary energy source but are not connected to the electrical grid. As the generated power recharges a battery and is used to meet the required capacity of users, battery storage keeps the electricity at one's disposal. This idea is for users who want to use 100% renewable energy and be completely self-sufficient. Additionally, these systems are utilized in rural areas, particularly those without utility connections. The systems can't send away excess energy because they are only for personal use. Off-grid systems are significantly more expensive than on-grid systems due to the high costs of batteries and inverters. Any excess power will be sent to your battery bank in an off-grid system once the appliances on your property use solar power. When the battery is depleted, the PV panel will no longer supply power to it.

The On-grid system is connected to the public electricity grid and sometimes may not require batteries. The majority of homes and businesses employ on-grid or grid-tied PV systems. Solar inverters or micro-inverters are used in these systems, According to Martin (2016), this one can be set up to export excess solar power to the grid via a meter when the batteries are fully charged. The users typically receive credits or a feed-in tariff (FiT) for the excess solar power they export to the electricity grid. Similar to an off-grid solar system, a hybrid photovoltaic system uses grid electricity as a backup. The idea is to use the grid at night when the sun goes down and the rate of electricity is low, then use renewable free energy when the cost of electricity is very high (Zhu, 2018).

PV systems must be monitored, just like any other energy production system, to improve system performance and to identify faults before they occur. Based on the output of the plant and its characteristics, there are common PV faults that can affect the output efficiency of the system. Faults in Photovoltaic components can arise from either physical or electrical conditions (Dong *et al* 2017). Physical faults include: cell cracks, dust, shading, irradiance temperature, degradation in PV components, aging effect. Electrical faults are open circuit, short circuit and line – line faults. In recent times, numerous businesses, government agencies, and individuals are using PV systems on the grounds that it is 100 percent clean with regard to no ecological contamination. The cost of maintaining a PV system can be relatively low with effective maintenance management or a plan, but it can be frustrating without one. Lack of upkeep can even shorten a PV system's lifespan.

In Hernández-Callejo et al., (2019), the increasing use of PV systems necessitates enhancing their upkeep, operating costs, availability, dependability, safety, life cycle, and other aspects. Baklouti, et al., (2020) highlighted that improper management of a photovoltaic system can severely harm any component and damage household electrical appliances. PV systems can only operate at their best when fault detection and prompt troubleshooting are in place. Early detection of various faults and failures in PV systems is crucial to achieve maximum power production, to minimize energy loss and maintenance expenses, and also to ensure the safe operation of the installed components (Triki-Lahiani et al., 2018).

The use of photovoltaic energy systems as an alternative energy source is growing in popularity. The stand-alone PV system must continue to function at its peak level in order to efficiently harness reliable energy. This requires continuous maintenance and monitoring. An intelligent self-diagnostic model for monitoring PV system is needed, nevertheless, to determine faults in the system. In Garud et al., (2021) an intelligent self-diagnostic model is a system that performs self-diagnosis by monitoring internal signals and operations of the system for evidence of faults. The uncertainty associated with the monitoring and detection of faults in photovoltaic systems could be easily and efficiently solved using the intelligent self-diagnostic model, which are developed using artificial intelligence (AI) techniques. AI-based systems learn and train continuously in order to behave like humans and develop self-reasoning and problem-solving capabilities. Complex problems could be successfully solved by AI tools without the need for more sophisticated mathematical manipulations. As a result, AI has emerged as a promising alternative to conventional approaches to problem-solving. Artificial Neural Networks ANN, Fuzzy Logic (FL), Expert Systems (ES), Natural Language Programming (NLP), and various hybrid approaches are all examples of AI techniques (Solmaz et al., 2020)

Artificial neural networks (ANNs) are computing systems with interconnected nodes that work much like neurons in the human brain (Abiodun et al. 2019). ANN Functions by learning patterns from given inputs such as pictures/images, text or video, etc. It is in form of a multiprocessing computer system with a high degree of interconnection and adaptive interaction between elements. Using algorithms, they can recognize hidden patterns and correlations in raw data, cluster, classify and predict the data. ANNs are frequently used for forecasting, data validation, anomaly detection, customer purchase research, and risk management (Yang & Wang 2020). ANNs do, however, have several important disadvantages: its black box nature, which implies that it's a complex system whose internal workings are hidden or not easily understood and difficult to modify, it requires a very large memory capacity for parallel processing. The ANN architecture has a fixed number of input layers. As such, it can only take a fixed sized input and output for any task (Solmaz et al., 2020).

A Hybrid Model is the combination of two AI techniques. The majority of the problems related to solar energy are solved using hybrid models. The Adaptive Neuro-Fuzzy Inference System (ANFIS) combines the benefits of Fuzzy Logic (FL) and Artificial Neural Networks (ANNs) into a single framework. In order to model complicated patterns and comprehend nonlinear interactions, it offers rapid learning capacity and adaptive interpretation skills. The number of studies focused on hybrid models for the detection and prediction of faults in PV is limited because of their high prediction cost, high computational time, and complexity of algorithms compared with standalone models (Garud, 2021).

Guo et al., (2022) define]d a convolutional neural network (CNN) ss a type of artificial neural network that is primarily utilized for image processing and recognition. Although a CNN is a powerful tool, training requires millions of labeled data points, due to its capacity to recognize patterns in images. There are numerous applications for CNN, particularly those involving images. Image classification, image semantic segmentation, and object detection in images are all examples of applications for CNN.

A probabilistic neural network (PNN) is a feedforward neural network, which is widely used in classification and pattern recognition problems. In applications like classification and pattern recognition, probabilistic neural networks (PNNs) are scalable alternative to back-propagation neural networks. They don't require as many complex forward and backward calculations as standard neural networks do. Additionally, they are able to work with a variety of training data. When applied to a classification problem, these networks make use of the idea of probability theory to reduce the number of incorrect classifications. In order to anticipate solar radiation and the performance of PV systems, generated AI models are tested using statistical analysis. Different statistical factors are included in the statistical analysis to demonstrate how near or off the actual and projected values are (Pirouz *et al.*, 2020).

Fuzzy logic is a form of reasoning comparable to human reasoning. In other words, a system using fuzzy logic is capable of decision-making on an equal level with a person. It includes all middle options between the digital values Yes and No. The traditional logic block has the ability to receive input and produce output as true or false, much like a person would say yes or no. It predicts accurate results for all data points within the ranges of the various parameters since it works with ranges rather than individual data points (Garud *et al.*, 2021). Complex problems can be resolved most effectively using the fuzzy logic system. It is simple to modify the system to alter or enhance performance. Dealing with engineering uncertainty is made easier by the system. This system is primarily used to operate machines, easily adaptable and knowledge can be obtained with ease. Some applications that use fuzzy logic include vacuum cleaners, air conditioners, microwaves, and washing machines.

In this research, fuzzy logic is primarily used with the internet of things technology to monitor and detect faults in PV system. An innovative paradigm change in the IT industry is the Internet of Things. The two terms "Internet" and "Things" were combined to form the phrase "Internet of Things," which is also commonly abbreviated as IoT. Madakam *et al.*, (2015), described the Internet of Things as what will make real-world objects into intelligent virtual objects in the future. The IoT promises to bring everything in our environment under a single infrastructure, allowing us control over the things around us and keeping us updated on their status. The Internet of things IoT describes physical objects with sensors, processing ability, software, and other technologies that connect and exchange data with other devices and systems over the Internet or other communications networks (Gillis 2021).

The IoT is the integration of people, processes and technology with connectable devices and sensors to enable remote monitoring, status, manipulation and evaluation of trends of such devices (Lewis 2022). The main idea of the IoT is to embed short-range mobile transceivers in various gadgets and daily necessities to enable new forms of communication between people and things, and between things themselves (Stallings, William 2016). Monitoring photovoltaic systems is crucial for maximizing their performance. The system suffers from a number of problems that result in energy losses. The monitoring system must recognize a fault before it occurs and identify the component that has the defect. As a result, the researcher proposes a fuzzy logic model for developing an intelligent self-diagnostic system (SDS) based on the internet of things (IoT) that continuously monitors the operation of a PV system and detect fault where necessary. In order to get the most out of the PV system's operational performance and reliability as a whole, it is crucial to have this self-diagnostic system (SDS) that can quickly monitor, detect and anticipate the presence of faults and which can work on real-time recorded data. It is obvious that the accuracy of the real-time trained models is higher than that of models trained with past recorded data.

II. LITERATURE REVIEW

Components of Photovoltaic System

The photovoltaic systems are most of the time composed of photovoltaic panels, charge controller, batteries and inverter.

a. Photovoltaic Panels (PV Panel)/ Photovoltaic Cell

In Balaban, and Oliveira, 2017, a photovoltaic cell is made of semiconductors, often silicon, and the cell has conductors connected to its positive and negative side, forming an electric circuit. The cells are coated to form a positive (+ve) – negative (-ve) structure as an internal electric field. The positive silicon has a tendency to give up electrons whereas the negative accepts electrons. The light contains a photon, which, when it hits the PV cells, causes negative and positive structures to separate into two different directions. Then the electrons move to the negative electrode (N) and the holes move to the positive electrode (P). Finally, when a conducting wire is connected to both +ve and -ve with load, it results in a flow of electrical current. The current, or output, of a PV panel depends on its surface area, its efficiency, and it is directly proportional to the intensity of sunlight striking on the surface (Haba, 2019), Multiple cells connected together is called a PV module, which are then wired together as a PV panel. Multiple modules (PV panels) connected together is called a PV array. Figure 1 and Figure 2 illustrate PV cell, modules and array and what happens inside the PV cells respectively.

Dhole, *et al*., (2016) explained a formula **E = A x r x H x PR** to estimate the electricity generated in output of a photovoltaic system. Where - E is Energy (Kilowatt hour (kWh)), A is total Area of the panel (m^2), r is PV panel yield/ efficiency (%), H is annual average solar radiation on tilted panels and PR = Performance ratio, constant for losses (range between 0.5 and 0.9, default value = 0.75). r is the yield of the PV panel given by the ratio. Electrical power (in kWp) of one PV panel is divided by the area of one panel.

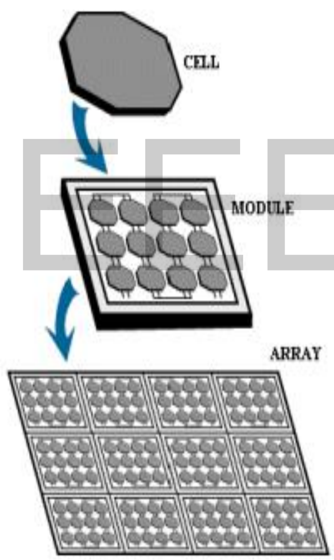

Figure 1: PV cell, panel and array (Kumar, and Gupta, 2021)

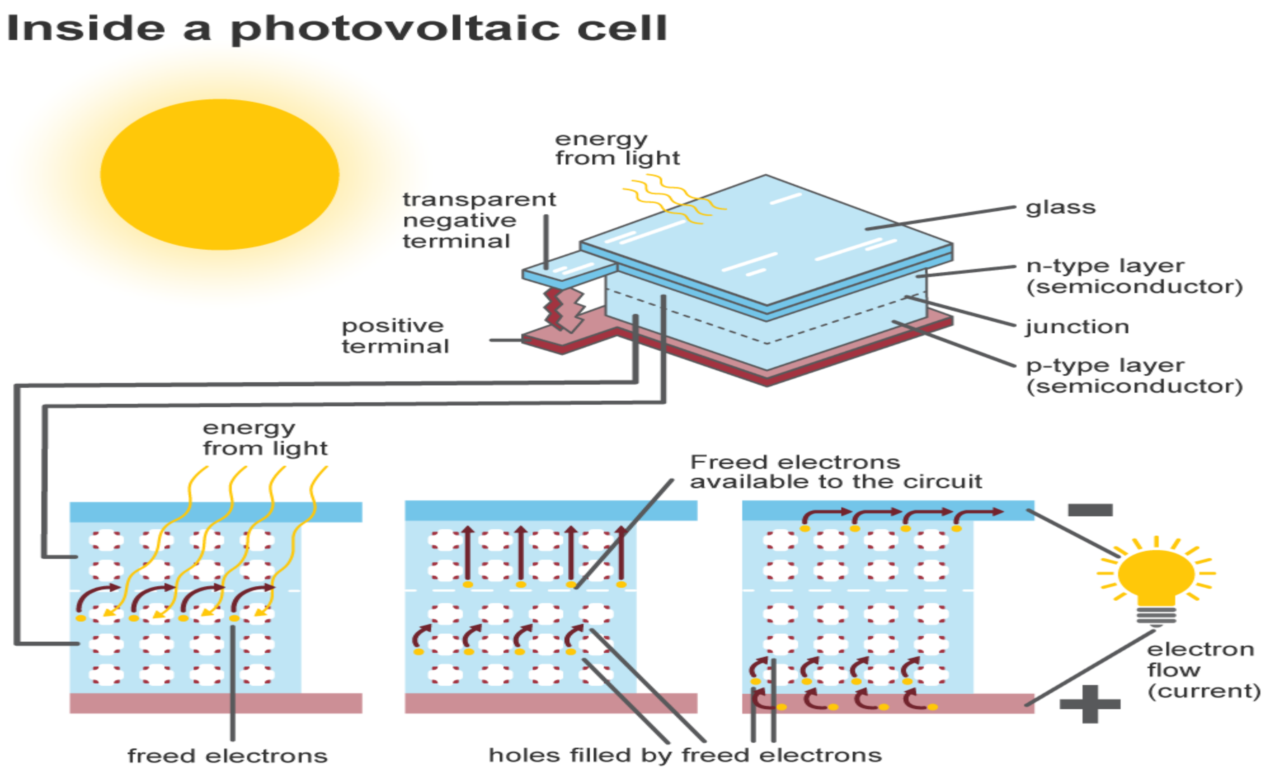

Figure 2: Inside a PV Cell (Kumar, and Gupta, 2021)

The photovoltaic cells in each PV panel are made up of either Monocrystalline solar cell, Polycrystalline Solar Cells or Thin Film Solar Cells. Saga, (2010) explained that: monocrystalline PV cells are made from single crystalline silicon. They have a remarkable distinctive appearance, as they are often colored. The cells themselves also tend to have quite a cylindrical shape. They are cost effective and perform at optimal levels, manufacturers tend to cut out the four sides of the monocrystalline cells. While this gives them their recognizable appearance, it is also quite a wasteful process. They tend to have the highest levels of efficiency and quality. Figure 3 depict the diagram of Monocrystalline PV cell.

Figure 3 Monocrystalline PV cell (Saga, 2010)

Kranz *et al*, (2015) described polycrystalline cells as cells that do not require each of the four sides to be cut off, which results in less waste. Instead of cutting off the four sides, the silicon is melted and poured into square molds, which results in a shaped square cells. The polycrystalline PV panel is considered to be the mid-range panels in terms of price and efficiency out of the three main materials used. Figure 4 shows the diagram of Polycrystalline PV cell.

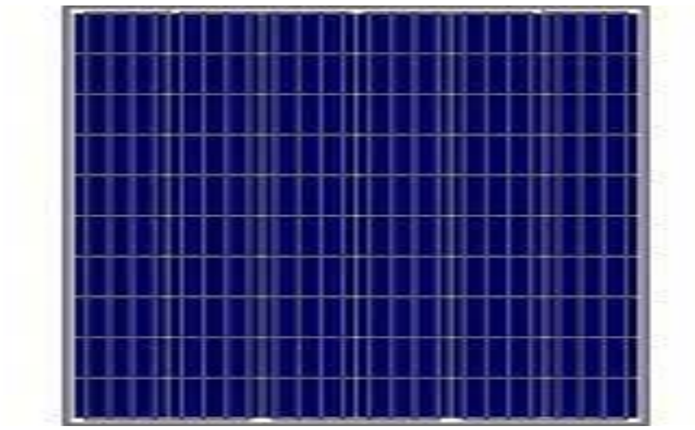

Figure 4: The Polycrystalline PV cell (Kranz *et al*., 2015)

Thin film PV cells are manufactured by placing several thin layers of photovoltaic on top of each other to create the module. There are actually a few different types of thin film PV cell, the types are as follow: Amorphous silicon, Cadmium telluride, Copper indium gallium selenide and Organic PV cells. Thin film PV cells are the cheapest cells and of less efficient. However, thin film PV cells also have the most potential for the future (kranz 2015).

b. Charge controller

A PV charge controller is a device connected between the PV panel and batteries, which controls the flow of the current to and fro the battery and protects the battery from overcharging after reaching its required voltage capacity and over-discharging. The charge controller also determines the life span of the batteries and the efficiency of the entire photovoltaic system (Kurukuru *et al*, 2020). The device is an important component within a PV off-grid system as it strengthens the life of the overall system saving expenses in its technical maintenance. Any system that has unpredictable loads or undersized battery storage or other characteristics that would allow excessive battery overcharging or over-discharging requires a charge controller (Saadeh *et al*, 2018). Loads are electrical devices operated by electrical energy. The loads are connected to the photovoltaic system and they can be both AC and DC devices. Loads with DC loads are recommended for daily household activities. Some such loads are compact fluorescent light bulbs (CFL) or Light Emitting Diode (LED) light bulbs and a radio. For AC loads, an inverter is used to convert DC into AC.

The charge control system is susceptible to loose connections, extreme exhaustion, rusted or burned components, just like other electronic equipment. The overcharge and undercharge protections collapsing is another flaw that could cause the charge controller to malfunction (Rokonuzzaman *et al*., 2020). Reading the controller's LED display and measuring the power output with a millimeter are two of the simplest ways to make sure a charge controller is operating as intended. If there is no voltage output or if it is very low, there may be a problem with the controller.

Figure 5: Charge Controller (https://www.u-buy.com.ng/product/1BGG24CCO-30a-solar-charge-controller-mppt-solar-charger-controller.

c. Batteries/ the Storage of Photovoltaic System Energy

The PV system generates excess energy, which batteries collect, and store for use at night or when there is no other energy source. The effective use of electricity from renewable sources requires large-scale stationary electrical energy storage systems with rechargeable high-energy-density, low-cost batteries. Since off-grid systems are connected to solar power, power production is zero in the evenings, nights, and cloudy days with no sunlight. As a result, battery banks that provide electricity during these times store excess daytime energy. Depending on the requirements of the PV system, a battery bank consists of a number of batteries that are further wired in series or parallel. The evaluation of factors like battery capacity and power ratings, depth of discharge (DoD), and efficiency prior to selecting a storage option makes the process difficult. According to Kurukuru (2019), determining the battery's capacity is crucial because it provides a comprehensive picture of the total amount of electricity stored.

In addition to capacity, the power rating is essential as well because power rating is the amount of electricity that a battery can deliver at a single time. Capacity and power are measured as Kilowatt-hour (kWh) and kW, respectively, where a kWh reflects the total amount of electricity used, whereas a Kilowatt (kW) reflects the rate of electricity usage. These should always be calculated because a battery with a high capacity but low power rating would only provide a limited amount of power for a long time, whereas a battery with a high power rating could power an entire house for a limited number of hours. A battery's depth of discharge (DoD) shows how much of its capacity, has been used. The number of frequently performed charges and discharges also affects the battery's lifespan. A battery should not be completely discharged for optimal performance (Uygun *et al*, 2019).

For PV systems, there are four different kinds of batteries: lead acid, lithium-ion, nickel cadmium and saltwater batteries. Lead acid batteries are the common energy storage devices for PV systems. Lead acid batteries can be either 6V or 12V type in tough plastic container. Amp-hours (Ah) are the units used to measure lead-acid battery capacity. To extend the life of lead-acid batteries, they typically only use 30 to 40 percent of their total capacity each day. The most cost-effective energy storage option is lead-acid batteries because they are the least expensive, reliable, due to their long history, they are simple to recycle and dispose of and require regular maintenance (Jiang and Song, 2022).

Muhando *et al.*, (2010) described a sealed lead acid battery or gel cell as a lead acid battery that has the sulfuric acid electrolyte coagulated (thickened) so it can't pour out and the electrolyte in a sealed or gel battery is immobile. The researcher further explained that the immobilized electrolyte batteries of sealed lead-acid will experience fewer electrolyte freezing issues. Water is transformed into hydrogen and oxygen through chemical reactions at the negative and positive plates during the charging process. Since these gases recombine to form water, there is no need to add water. For the following reasons, lead acid batteries of this kind are suitable for PV applications: easy to transport, and suitable for applications in remote locations due to its low maintenance requirements and lack of water requirements.

In Elsheikh *et al*., (2019), there are two kinds of sealed batteries namely: gelled electrolyte batteries and absorbed glass mat batteries. A gel battery is basically the same as a conventional lead-corrosive battery with the expansion of silica to the electrolyte to make the gel-like substance. This thickening of the electrolyte implies that gel batteries can be introduced in different positions and don't produce as many vapors. When silicon dioxide is added to the electrolyte, it forms a warm liquid that is added to the battery and turns into a gel when it cools. During the charge and discharge processes, the gelled electrolyte's cracks and voids transport the hydrogen and oxygen produced during the charging process between the positive and negative plates. Gel batteries enjoy the benefit of having the option to be utilized in practically any position, since they don't spill and are generally maintenance-free. The batteries are fixed with a valve that eliminates excess pressure. This significantly increases the number of application the gel batteries can be utilized for.

An AGM (consumed glass mat) battery contains an extraordinary glass mat separator that wicks the electrolyte arrangement between the battery plates. This material's design empowers the fiberglass to be immersed with electrolyte and to store the electrolyte in a "dry" or suspended state as opposed to in a free fluid structure. Glass mats are sandwiched between plates in Absorbed GAS MAT (AGM) batteries. The electrolyte is absorbed by these glass plates. Water is produced at the negative plate as the oxygen molecules from the positive plate recombine with hydrogen through the electrolyte in the glass mats. Controlled charging is required for both gel and AGM batteries. Lead calcium electrodes are typically used in these batteries to reduce gassing and water loss (Park *et al*., 2016).

Lithium-ion batteries are regarded as the best type of battery for photovoltaic systems, due to their lower cost, longer cycle life, higher depth of discharge (DoD), and ease of use, lithium iron phosphate (LiFePO4 or LFP) cells are typically utilized in the majority of lithium batteries used for home energy storage (Svarc, 2020). Kilowatt-hours (kWh) are the unit of measurement for lithium-ion battery capacity. Lithium-ion batteries have three times the energy density of Pb acid batteries. Few cells in series will produce the required battery voltage, which will be 3.5V. Lithium-ion batteries are more expensive than *nickel–cadmium* (NiCd) batteries because of this fact. The battery is damaged by further overcharging.

In a lithium battery design, the sealed cells are exclusively fixed and can't move. This implies there is no limitation in the installation position of a sealed-cell lithium battery. It

tends to be positioned on its side or upside down. Photovoltaic users prefer lithium-ion batteries because they can store more energy, hold that energy longer than other types of solar batteries, and have a higher Dept of Discharge.

In saltwater batteries, a liquid solution of salt water is used to capture, store, and eventually discharge energy. The saltwater battery is operated by evolution/reduction reactions of gases (mostly oxygen (O_2), with possible Chlorine (Cl_2)) in saltwater at the cathode, along with reduction/oxidation reactions of Sodium (Na/Na^+) at the anode. The use of salt water and the Na-metal-free anode enables high safety and low cost, as well as control of cell voltage and energy density by changing the salt concentration. Compared to other energy storage batteries, they last longer. The cycle life of saltwater batteries is 5,000 (Nelson, 2017). Additionally, you can use the product beyond the indicated cycles because it is not susceptible to explosions.

Figure 6: saltwater battery (Park *et al.*, 2016)

Figure 7: Lead acid batteries (Svarc, 2020)

According to Kurukuru *et al.*, (2016), lithium-ion batteries are more prevalent due to their physical properties, affordability, low maintenance rate, and ability to supply up to 90% of their available capacity per day when the battery discharge rate falls below 50%.

Figure 8: Lithium-ion battery

d. Electricity Switchboard

In an on-grid solar system, AC electricity from the solar inverter is sent to the switchboard where it is drawn into the various circuits and appliances in your home. This is known as **net metering,** where any solar **excess electricity** generated by the PV system is sent to electricity grid through an energy meter or stored in a battery storage system.

e. Solar Power Inverters

An inverter is an electronic device that converts direct current (DC) electricity that has been generated by the PV panels into alternating current (AC). This is what is used to power our homes and the local transmission. As a result, this component of the PV system allows you to receive and use the electricity that you require for powering even the most basic home appliances (Kurukuru, 2019). AC loads are devices which receives alternating-current (AC) electrical power from a source in an electrical system. Most small devices run with DC, there are only a few appliances that require AC. Small portable devices like flashlights, mobile chargers, LED bulbs, laptops and battery embedded electronic devices use DC power stored in batteries. An inverter is not required in such cases. However, large electrical equipment, generally with three phase wires, need AC to operate (Kurukuru, 2019).

A solar inverter works by taking in the variable direct current, or 'DC' output, from your solar panels and transforming it into alternating 120V/240V current, or 'AC' output. The appliances in your home run on AC, which is why the solar inverter must change the DC output that is collected by your PV panels (Sandy, 2022). Good, and Johnson, (2016). noted that the sun shines on the photovoltaic (PV) cells, which are made of semiconductor layers of crystalline silicon or gallium arsenide. These layers are mixture of both positive and negative layers, which are connected by a junction. When the sun shines, the semiconductor layers absorb the light and send the energy to the PV cell. This energy runs around and bumps electrons lose, and they move between the positive and negative layers, producing an electric current known as direct current (DC). Once this energy is produced, depending on the used system, it is either stored in a battery for later use or sent directly to an inverter. When the energy gets sent to the inverter, it is in DC format but your home requires AC. The inverter grabs the energy and runs it through a transformer, which then spits out an AC output. The inverter runs the DC through two or more transistors that turn on and off super-fast and feed two varying sides of the transformer.

There are several types of inverters that might be installed as part of a photovoltaic system. One inverter (central inverter) for all the panel that converts the energy generated by all panels, which is more cost-effective method. *Micro inverters* are smaller inverters placed on every panel. With a micro inverter, shading or damage to one panel will not affect the power that can be drawn from the others, but micro inverters can be more expensive. In a micro inverter system, each panel has its own micro-inverter attached to the rear side of the panel. The panel still produces DC, but is converted to AC on the roof and is fed straight to the electrical switchboard and then onto your home appliances or the gird. *String* inverters connect a set of panels—a string—to one inverter. The inverter converts the power produced by the entire string to AC. Although cost-effective, this setup results in reduced power production on the string if any individual panel experiences issues, such as shading. The 'smart inverter', it allows for two-way communication between the solar inverter and the electrical utility. This allows for a balance between supply and demand, resulting in a reduction of costs, grid stability, and a decreased risk of losing power in the home. It's also good to measure how much energy you are using and how much you have fed the grid. A utility meter, also known as a net-meter, is connected to the PV system so that you can keep regular and accurate readings of consumption and output (Agarwal *et al*., 2017).

Smart inverter systems use small power optimizers attached to the back of each solar panel. The **power optimizers** are able to monitor and control each panel individually and ensure every panel is operating at maximum efficiency under all conditions (Good and Johnson, 2016). Solar inverters are very sophisticated pieces of equipment that need to operate in extreme indoor environments for up to 10 hours a day. In order to prolong the life of a solar inverter and improve its efficiency, it should be mounted in a sheltered location and out of direct sunlight. The ideal location is in a garage or undercover area that is close to the electrical switchboard.

Figure 9: Solar Power Inverter (Agarwal *et al.,* 2017)

Components of Intelligent Self-Diagnostic Model for Fault Detection in Photovoltaic System

The system is made up of intelligent Detection Algorithm that will monitor each of the behaviors of solar panels, charge controller, batteries and inverters, and be able to detect faults in each of the components of a photovoltaic system. With the internet of things, the system will send real-time messages with respect to the faults detected to the mobile phone of the technician/users and the computer system in the control room, thereby informing the technician/users of the fault/

problem before it will occur. The faults detected will also be saved in a cloud for future analysis by the technician/ users. More so, by the intelligence that is embedded in the system, the technician/engineer/ users will know that the solar panel is no longer producing the required output or that the batteries do not charge fully within the usual interval of time or drain very fast as expected or the inverter is out of frequency. With this, the system will help the technician/ users to know when the photovoltaic system needs maintenance before damages occur.

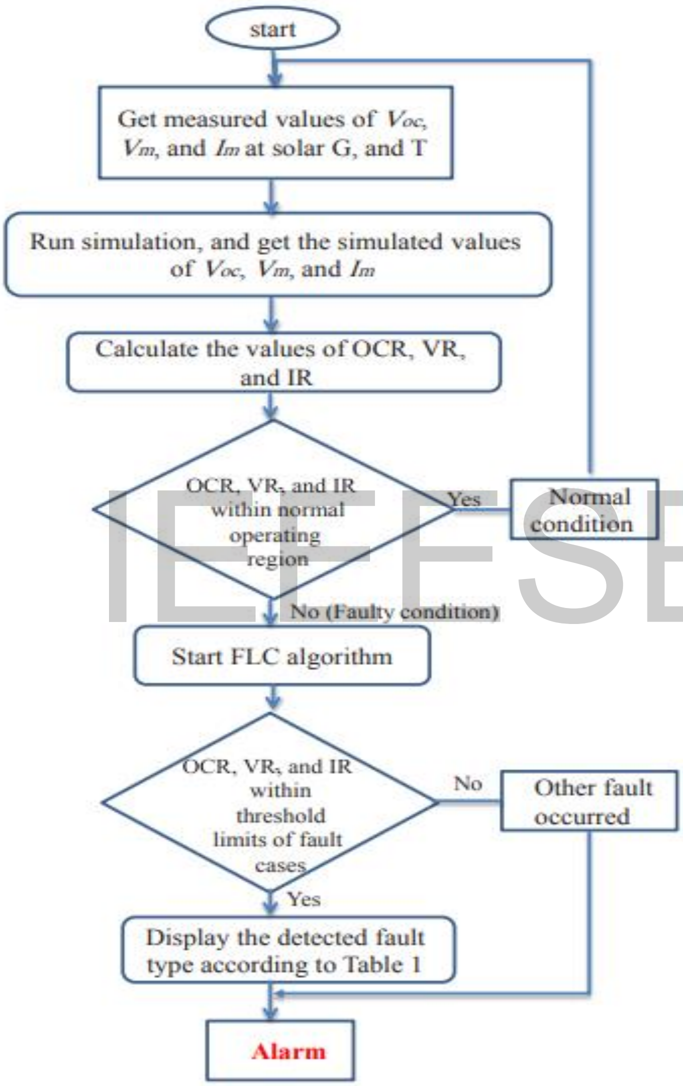

Figure 10: The flowchart of the existing method (Zaki., et al (2019).

It uses the Mandani fuzzy logic approach to monitor, predict and transmit faults in a photovoltaic system. The system will be basically used by the photovoltaic users and engineers to bridge the gap created by the some existing system, which causes lack of effective monitoring of all the PV system. The added components of the system are the temperature, voltage and frequency sensors. The temperature sensor is used to monitor and measure the temperature of the PV panel, the measured temperature is compared with the expected temperature on the datasheet as stated by the manufacturer. The voltage sensor is used to sense the batteries and the output is compared with the main voltage given by the manufacturer. The frequency sensor is used to monitor and measure the inverter. This sensor helps to know when the inverter goes out of frequency range.

The technique has three modules namely, the fuzzification, inference and defuzzification modules. The architecture of the implementation of the fuzzy model is based on the results generated by the various sensors used, which are converted by the fuzzification module into a fuzzy value by making use of the knowledge-base. The inference module chooses which rule to activate based on the input value and also determines the matching degree of the fuzzy input to each rule. The defuzzification module converts the inference engine's fuzzy set into a clear output value, from where the Internet of Things sends the output as a real-time message over the internet and store in a cloud for future analysis.

III. BENEFITS OF INTELLIGENT SELF-DIAGNOSTIC MODEL FOR FAULT DETECTION IN PHOTOVOLTAIC SYSTEM

a. In a conventional photovoltaic system, it was observed that the user of the photovoltaic system finds it difficult to monitor and detects faults before the system breaks down. The user usually knows that the system has a fault when the light goes off but the intelligent self-diagnostic model will detect the fault at the onset.
b. Moreover, most of these intelligent self-diagnostic methods developed with Artificial Neural Network, Convolutional Neural Network are not IOT based and do not monitor PV components such as PV panel, charge controller, batteries and inverters all at a time but the intelligent self-diagnostic model will monitor the overall components.
c. It can easily identify common faults of a PV system and integrate solution using intelligent self-diagnostic model
d. The system also employ a cloud-based system for fault monitoring and diagnosis,
e. The adoption of the system will has a lot of economic benefits due to the preventive measures of the system.

IV. CHALLENGES OF INTELLIGENT SELF-DIAGNOSTIC MODEL FOR FAULT DETECTION IN PHOTOVOLTAIC SYSTEM

1. It is obvious that accuracy of the real-time trained models is higher than that of models trained with past recorded data. Therefore, the accuracy of the system was very low because it was trained with pass recorded/historical data.
2. In a country like Nigeria, global system mobile network is really a big challenge and it will create serious problem on messages transmission at the right time for the system fault detection.

V. CONCLUSION

The research on the benefits and challenges of intelligent self-diagnostic model for fault detection in photovoltaic system was fully conducted, we observed that the benefits of installing and using the intelligent model is greater than the challenges, therefore further research on the analysis, design, implementation and deployment the model will proceed. At the completion of this work, the overall objectives and benefits will achieved for the users' satisfaction.

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