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Enhancing Developmental Resilience: The Role Of Multilevel Inverters And Machine Learning In Addressing Asymmetrical Faults In Photovoltaic Systems

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Abstract
This review paper investigates the application of machine learning techniques for regulating Multilevel Inverters (MLI) in Photovoltaic (PV) systems, specifically in the context of asymmetrical faults. The integration of these technologies is examined not only for their technical merits but also for their broader implications in promoting developmental resilience and energy accessibility in diverse communities. By analyzing existing literature on MLI and machine learning, the paper highlights the strengths and limitations of various methods for detecting and diagnosing asymmetrical faults, which can lead to more reliable energy solutions. Furthermore, the findings underscore the potential of these technological advancements to support initiatives in reattachment therapy and developmental diversity by ensuring consistent energy supply in underserved areas. The paper concludes by identifying critical areas for future research, advocating for a collaborative approach that bridges technology and community development to foster inclusivity and support varied developmental needs.

Keywords: Multilevel Inverter (MLI), Machine Learning, Asymmetrical Faults, Photovoltaic Systems, Developmental Resilience, Energy Accessibility

1. INTRODUCTION

The call for for financial enlargement and the upward thrust in populace has extended the consumption of herbal assets and, as a result, uncooked substances. Energy, mainly electrical energy, is one of the key gamers on this transition process. As demand rises, supply should also circulate in lockstep. The loss of strength ends in shortages, which in flip purpose monetary, technological, and social retraction or stagnation. They inhabit a planet in which sources are constrained, and call for is increasing. Investing in renewable strength sources, particularly photovoltaic and sun thermal, is a viable alternative [1].

1.1 PV machine

The implementation of Photovoltaic (PV)-based standalone energy manufacturing systems in rural areas is gaining reputation and significant attention. PV systems are now legal, promoted, and supported in many nations, which helps with the manufacturing of renewable strength. The function of current strength converter topology has given several [2]. This academic is designed in general for a PV/engine generator hybrid strength system, however it may additionally be applicable to other hybrid electricity systems which have at least one dispatchable strength supply and at least one renewable supply, such as a PV panel. For PV hybrid structures, taper-price settings are advocated to help the battery get geared up for a capacity check. To make sure proper statistics collection, battery characterization, and potential measurements, a take a look at protocol is obtainable. Finally, a procedure is obtainable for reviewing test outcomes and deciding on the right direction of motion for the battery. There are not any cycle-life forecasts made [3]. Additionally, it's far inexperienced, requires no care, and shows increasing promise. The photovoltaic (PV) output strength is erratic and dependent on the climate and the movement of the clouds. During the night, it absolutely vanishes. Matching the various and unpredictable strength call for with the nocturnal and intermittent electricity deliver from the sun is still considered one of the most important problems for PV systems. As a backup, fuel cells are hired to make up for the PVG's erratic electricity output. It turns chemical energy into power, that's then employed in small- and medium-sized power packages [4].
For PV hybrid structures, taper-rate settings are encouraged to help the battery get geared up for a potential test. To make sure right records collection, battery characterization, and ability measurements, a take a look at protocol is offered [5].
As global strength demands keep to upward thrust, the transition to renewable energy sources, specifically Photovoltaic (PV) structures, has turn out to be more and more essential. Among the technologies that enhance the performance and reliability of PV structures, Multilevel Inverters (MLI) have received giant attention because of their ability to limit harmonics, enhance strength quality, and manage diverse operational challenges. However, PV systems are at risk of asymmetrical faults, which can disrupt their performance and compromise electricity reliability. This is in which device studying strategies come into play, imparting revolutionary solutions for fault detection and diagnosis.

The integration of gadget mastering with MLI regulation presents an possibility no longer most effective to decorate the technical performance of PV structures but additionally to cope with broader societal problems. Communities, specially the ones going through developmental demanding situations, frequently warfare with consistent get entry to to strength. Unreliable energy deliver can prevent social and economic development, exacerbating current inequalities. By using gadget gaining knowledge of to enhance the resilience and reliability of MLI inside the face of asymmetrical faults, we are able to create greater stable and sustainable power solutions that support developmental resilience.
This evaluate paper pursuits to discover the intersection of machine studying, MLI generation, and their programs in diagnosing asymmetrical faults in PV systems. We will examine current literature to become aware of the strengths and barriers of diverse approaches, critique modern-day methodologies, and highlight potential areas for destiny research. Ultimately, this work underscores the critical role that technological improvements can play in selling electricity accessibility, helping community development, and enhancing average societal nicely-being.

1.2 Objectives of the Review

1 **To Analyze Current Literature**: This review aims to comprehensively analyze existing research on the integration of machine learning techniques with Multilevel Inverters (MLI) in the context of asymmetrical faults in Photovoltaic (PV) systems. By examining various studies, we seek to synthesize the knowledge surrounding these technologies.
2 **To Identify Strengths and Limitations**: The review will identify the strengths and limitations of different machine learning methods used for detecting and diagnosing asymmetrical faults in PV systems. This analysis will provide insights into the effectiveness and applicability of these approaches in real-world scenarios.
3 **To Critique Current Methodologies**: We aim to critique current methodologies used in the detection and management of asymmetrical faults, highlighting gaps in research and areas needing further investigation. This critique will serve as a foundation for proposing more effective solutions.
4 **To Explore Future Research Directions**: The review will explore potential areas for future research, focusing on how advancements in MLI and machine learning can enhance the reliability of PV systems. This includes considerations for community development and energy accessibility.
5 **To Highlight Societal Impacts**: Finally, we aim to emphasize the societal implications of integrating these technologies, particularly in promoting developmental resilience and improving energy access for underserved communities.

1.3 Contributions of the Review

1. **Synthesis of Knowledge**: This review will contribute to the body of knowledge by synthesizing findings from diverse studies on MLI and machine learning, providing a comprehensive understanding of their intersection.
2. **Framework for Evaluating Fault Detection Techniques**: By identifying strengths and weaknesses in current methodologies, the review will establish a framework for evaluating fault detection techniques in PV systems, guiding future research and applications.
3. **Identification of Research Gaps**: The critique of existing approaches will pinpoint specific research gaps and challenges in the current landscape, encouraging further exploration and innovation.
4. **Promotion of Energy Accessibility**: The review will underscore the importance of reliable energy systems in fostering developmental resilience, linking technological advancements to broader societal benefits.
5. **Guidance for Future Developments**: The exploration of future research directions will provide guidance for researchers and practitioners looking to improve the reliability and performance of PV systems through innovative solutions.

2. MULTILEVEL INVERTER (MLI)

The call for for economic expansion and the upward push in populace has improved the intake of herbal resources and, as a result, uncooked materials. Energy, in particular electric energy, is one of the key gamers on this transition procedure [6].
In this paintings, a photovoltaic module's layout is shown, with solar cells related in collection and parallel to create the panel. Solar panel energy is increased via feeding it to a dual-level improve converter, which then output is delivered to a couple of degrees of cascaded H-bridge inverters. Since the last few decades, electricity electronics have used multilayer inverters extra often. High conversion efficiency multilevel cascaded H-bridge inverters that are simple to integrate with renewable strength sources like solar panels [7].
In the previous, a circuit short may result in a very robust fault cutting-edge so that it will damage any more circuit-connected gadgets. Inverters with many stages of voltage are consequently most appropriate. There are four one of a kind MLI topologies: cascaded H-bridge (CHB), diode clamped (DC), flying capacitor (FC), and neutral factor clamped (NPC). Low THD is good for cascaded H-bridge multilevel inverters. Different MLI topologies range from each other in terms of the source of enter voltage and the switching mechanism [8]. At the instant, renewable strength resources hold a

exceptional area in the world, and they may be used by the majority of Distributed Generations (DGs) inside the related electricity device. Due to the benefits of the use of DG, along with the smooth nature, lack of environmental pollution, and countless nature of renewable resources, extra people are using them to generate electrical electricity in daily life. In this work, customized PWM turned into used to bridge the single-section, three-stage diode clamp of a multilevel inverter (MLI). Because a modest Total Harmonic Distortion (THD) suggests a good voltage, modified PWM is used to produce the voltage with the least amount of THD [9, 10].

A multilayer converter with assumed same DC resources is used in this work. The required power electronics switches are managed by using a multilevel fundamental switching architecture. Additionally, a way is provided where switching angles are calculated in order that the preferred fundamental sinusoidal voltage is generated at the same time as also disposing of some higher-order harmonics [11].

Due to the significant variety of semiconductor switches concerned in power conversion, multilevel inverters have a higher risk of switch faults. Therefore, it is crucial to directly perceive and find flaws. The matrix converter's AC resources may theoretically be switched out for DC resources. The matrix converter is able to produce a stepped output waveform that is much like a multilevel inverter output via utilizing a switching method that is similar to a multilevel inverter switching method and a few amendment to the matrix converter topology [12,13].

A wide variety of appealing traits of multilevel inverters include their capacity to withstand excessive voltage, low output harmonic distortion, low dv/dt, and similar traits. Multilevel inverters have thus been extensively utilized in a number of applications, along with the manufacturing of renewable power, strength storage, the transmission of high-voltage direct modern-day, and the operation of medium-voltage vehicles [14].

For excessive-power, medium-voltage applications, the cascaded H-bridge multilevel topology for inverters has tested to be an tremendous desire because of its modular layout, voltage balancing, separated DC resources, harmonics discount, reliability, and lower stresses on switching gadgets. Phase shifted and degree shifted are the 2 maximum used pulse width modulation (PWM) strategies for cascaded H-bridge multilevel inverters [15].

By cascading 4 H-bridge inverters with a 3-leg inverter, a PWM-unfastened, and the transformer-loose 19-stage three-phase inverter has been successfully developed. Three-phase waveform realization has been carried out by way of deriving a switching series and strategies. Only twenty-two strength switches are wanted, and at an 1800 Hz sampling fee, the synthesized voltage has a THD of roughly 3%. When a unmarried strength supply is hired, the switching approach has also been successfully carried out for voltage law of the capacitor voltages [16].

With numerous DC assets as inputs, a multilevel inverter with fewer transfer counts creates AC output at the best voltage and frequency. Multi-degree inverters are being used greater often these days in commercial settings and coffee- and medium-voltage distribution systems for quite a few motives, which include improved reliability and power quality. Researchers were paying plenty of attention to decreased switch multilevel inverters as a alternative for preferred multilevel inverter topologies for the improvement of medium-voltage multilevel inverters. Solar energy is a dependable source of renewable power considering it's miles ample in nature. Multiple inverters are used in modern solar structures to transform DC power to AC electricity. Multilevel inverters are more effective than complete-bridge inverters because of the low harmonics and coffee leakage modern-day levels [17-19].

In order to adjust and form the power supplied by way of these forms of assets to in shape the demands of the burden, power conversion technology changed into needed. The strength inverter is the most essential component in electricity conversion. The 1/2-bridge inverter, that is used to produce the square or PWM output waveform, has the only inverter shape. Multilevel inverters, but, have the benefit of having lower electromagnetic interference and total harmonic distortion. In addition, MLI is better able to operate at medium and excessive-strength rankings. Three common topologies of MLI can be determined; the first is herbal point clamped, the second one is flying capacitors and the 0.33 is a cascaded hybrid bridge [20].

2.1 Types of multilevel inverter (MLI)

- *Neutral-Point-Clamped Multilevel Inverter:* The Neutral-Point Clamped Multilevel Inverter, also known as the Diode Clamped Multilevel Inverter, is one of the multilevel structures that has attracted significant interest and is frequently employed [21].
- *Flying Capacitor Multilevel Inverter:* The voltages of the power switch chain nodes are clamped by capacitors in the flying-capacitor voltage source multilevel inverter. This circuit has several switching choices for the same voltage level, which is a significant benefit. This allows for flexibility in changing control tactics to get output performance that is optimized. Meynard and Foch originally revealed the topology in the early 1990s. The load current is routed through circuits that incorporate clamping of cell capacitors to achieve intermediate voltage levels while the power switches are operated as complementary pairs [22].
- *Cascaded H-Bridge Multilevel Inverter:* One of the most well-known, most advantageous, much easier, and fundamental methods of multilevel inverter is the cascading H-Bridge multilevel inverter. excellent switching frequencies

and pulse width modulation techniques are needed to provide output voltage and current waveforms of excellent quality with the least amount of ripple [23].

It is further of two types:

- *Cascaded H-Bridge Multilevel Inverter with Single DC Source*: In general, multilevel converters are categorized into diode-clamped, flying capacitor, and cascaded H-bridge. The diode-clamped inverter provides multiple voltage levels through the connection of the phases to a series bank of capacitors. Applications of diode-clamped multilevel converters include high-power ac motor drives in conveyor systems [24].
- *Cascaded H-Bridge Multilevel Inverter with Multiple DC Source*: In comparison to symmetrical and binary asymmetrical structures, an asymmetrical multilevel inverter may generate more voltage levels and a greater maximum output voltage with the same number of bridges. When m number of cells are connected in series, comparing the number of levels (n), switches (Ns), dc sources (Nd), maximum output voltages (VM), number of variations in voltage magnitudes (Nv), and total voltage blocked by switches (Vb) [25].

3. MACHINE LEARNING FOR PV SYSTEM

The sun quarter has skilled a international trend of growth in the course of the last few a long time. As a end result, PV systems have received sizeable recognition for pleasant the necessary energy needs. The sun electricity plant can be scaled up and built with the aid of connecting the necessary quantity of PV modules in both series or parallel. These structures are used to satisfy the desired modern and voltage requirements. However, because the PV modules themselves are liable to a number of defects, the solar electricity manufacturing produced by way of the PV arrays is unreliable. While fault isolation and protection are essential for PV array design, there are numerous greater defects which could move undetected for extended periods of time [26].

Due to the unpredictability of renewable electricity sources like sun photovoltaic (PV) electricity technology, the steadiness of the strength quarter has grown doubtful. Integrating renewable strength into the electrical grid is the ultimate goal of strength amassing. Predicting the entire amount of energy generated through solar cells has come to be essential [27].

Support Vector Machines (SVM) and K Nearest Neighbor are the system studying techniques applied. (KNN). The SVM, which turned into initially created for categorizing binary records, has matured right into a powerful supervised device gaining knowledge of method this is implemented to both linear and nonlinear regression and classification troubles [28].

Defects in photovoltaic (PV) systems lessen output performance, which lowers the go back on funding (ROI) and extends the payback durations for investments. By the usage of Photovoltaic System Monitoring (PVSM) technology, those faults can be minimized. Machine gaining knowledge of techniques (MLT) have currently been used to enhance the performance of PVSM, in addition to to help in PV fault detection, identity, diagnosis, and prognostics. In addition to imparting an prepared list of MLT solutions applied in PVSM, this paintings reviews preceding paintings within the subject of MLT PVSM research and identifies opportunities and obstacles for future studies [29].

With managed battery strength storage, a fashionable control device turned into created to reduce the sporadic swings ofpower era. To reap the intention of smoothing sun PV, the suggested controller applies model predictive manage and system mastering strategies. The controller uses these predictions from the neural network to gain the vital smoothing whilst working inside the set restrictions. The neural community can expect PV power with a excessive degree of accuracy. The output of simulations turned into used to verify the general efficacy of our controller in forecasting and regulating solar electricity. Additionally, the impact at the ramp price and battery country of price was noticed. The created controller is flexible sufficient for use with numerous sporadic electricity sources, such as wind power [30].

In the cutting-edge global marketplace, photovoltaic systems' strength output is relatively tremendous. PV structures are set up for the generation and distribution of energy in a whole lot of settings, from small-scale applications to self-enough agencies. When building a PV plant, safety, monetary effectiveness, and early trouble-detection techniques should be prioritized. This assessment article illustrates the numerous problems which can arise in PV structures and presents facts at the sophisticated gadget-learning strategies that have been evolved to pick out and categorize those problems. In addition, this paintings opinions numerous failure types seen in photovoltaic structures utilizing diverse device gaining knowledge of algorithms, which can be confirmed to be straightforward and sensible for implementation. Use the dataset accumulated from these websites, which incorporates a lot of parameters. Numerical climate prediction (NWP) can rent numerous of these characteristics for short-time period forecasts. The traits are chosen the use of the regression approach and the correlation matrix [14].

Due to the excessive demand for renewable energy resources, the potential of established solar photovoltaic (PV) panels has extended current years. For grid managers, environmental video display units, and disaster mitigation efforts, the locations and spatial volume of these centers are important. Here, a straightforward technique for detecting solar PV in medium-decision satellite tv for pc pix is suggested [31]. The identification of solar panel soiling is a widespread issue because dirty panels generate drastically less power. This work outlines a illness detection collaboration among the

University of Cyprus and Arizona State University. The endeavor is part of the NSF program International Research Experiences for Students on Energy Applications [32].
The indoors patterns of on every occasion series as well as the records of time are each first-class applied in our methods. In order to increase an initial model, our methodologies are quality proper to make huge use of each the inner patterns of whenever series and the facts from time collection throughout many assets. They have carried out hybrid regularization phrases to restrict the intention capabilities of matrix factorization based on this theory. Then it's far recommended to apply temporal dynamic matrix factorization to efficaciously update the firstly trained fashions. To create an effective and green version for dynamic matrix factorization, batch updating, and exceptional-tuning tactics also are used. Numerous exams the use of synthetic and actual-international statistics sets show that the proposed methodologies can drastically boost the accuracy of missing information prediction [33].

4. FAULT DETECTION AND CLASSIFICATION FOR PV SYSTEM

Fault detection and class in sun arrays have emerged as one of the maximum crucial topics for boosting the effectiveness and dependability of these structures in mild of the recent growth within the hooked up potential of photovoltaic structures. Traditional protection techniques can't stumble on faults in solar arrays because of their non-linear nature, their output electricity's high reliance on environmental factors, and the presence of maximum strength factor monitoring. The use of machine learning strategies, that have been greater often employed in in advance research, is one among many techniques which have been provided in current years to get around this difficulty. The noise can intrude with the set of rules schooling procedure while the usage of device gaining knowledge of techniques. On the alternative side, there will be noise in the facts set when amassing facts from solar arrays due to human blunders or device malfunction. With the assist of system studying techniques and the presence of noisy facts, they purpose to offer a technique for fault identity and type in photovoltaic arrays on this paintings [34].

4.1 Unsymmetrical Faults in PV gadget

Photovoltaic (PV)-based totally electricity generation is extra effective than different sun power-primarily based generation, mainly for load-facet generation, due to its modular nature, lack of geographic restrictions, minimum renovation requirement, and simplicity of installation. Therefore, a brand new method of assembly the load requirement has emerged nowadays: PV-based microgrids, each DC and AC. However, the growing technology from PV sources has also introduced up certain safety problems because of its low fault modern contribution and poor reactive power functionality. Additionally, the transformer configuration used after the PV inverter influences how the fault contemporary behaves even as there may be a fault, consisting of the voltage degree of the healthful phases and how the fault propagates whilst there's an unsymmetrical fault.
The PV on a regular IEEE 10-bus machine using Dig Silent/Power manufacturing facility changed into thoroughly analyzed for unsymmetrical faults in this article, and the impact of numerous transformer configurations turned into also examined [17].
The detection of islanding and illness in a PV-penetrated power machine is suggested in this paintings. Based at the MATLAB Simulink tool, an intensive mathematical version of a photovoltaic (PV) array connected to the grid, entire with circuit breakers, 3-phase faults, most energy factor trackers, IGBT bridges, and controllers, is proven. The simple circuit equation for photovoltaic sun cells, which includes the effects of sun radiation and temperature trade, is used to adapt the PV model. When a defect happens or upkeep is necessary, a small part of the grid is isolated from the primary grid. This system is called islanding [18].
For DGs primarily based on PV inverters, a emblem-new brief brief circuit modern detecting method is placed forth in this paintings. The evaluation of the slope (d/dt) and significance of the PV inverter current serves as the inspiration for the advised brief-circuit present day detector. Depending at the grid code that the application is following, it could take one of the following moves as soon as it discovers a problem this is in all likelihood to cause the PV inverter short circuit cutting-edge to exceed the inverter's rated modern: To assist grid voltage, the PV inverter can routinely develop into a dynamic reactive electricity compensator STATCOM (referred to as PV-STATCOM). This work suggests how to stabilize a important induction motor load the usage of this voltage help. From the moment of fault discovery, the total process of DG disconnection or transformation into a PV-STATCOM is anticipated to take among 1-2 milliseconds. This novel controller is proven to reply nicely through modeling of a actual-world distribution machine, regardless of the fault type or position on the distribution gadget [20].
A common structure for integrating dispersed electricity sources into a traditional distribution network is the microgrid. A microgrid shape is made up of various renewable power assets and nonlinear solid-nation interfaces. The presence of non-linear components inside the distribution community may additionally regulate the primary utility grid's behavior in each steady and brief operating states. The temporary behavior of a application grid related to a microgrid is tested on this work below both symmetrical and asymmetrical fault instances. The system underneath research is a microgrid that is fueled through electricity from solar photovoltaic (PV) and wind turbine generator (WTG) resources. The important

grid is attached to the microgrid, which maintains the voltage and frequency on the point of commonplace connection constant. (PCC) [21].
Network operators advise low-voltage experience-via (LVRT) operation and dynamic voltage support as grid ancillary offerings for regions with big PV penetration. An incorporated controller for the LVRT capability of a 3-segment grid-tied PV device linked to an LV grid is proposed on this paintings. Since LV grids frequently have a low X/R ratio, lively strength injection throughout grid disturbances is prioritized above reactive power injection. Reactive energy support with energetic electricity curtailment (RPS-APC) controller for dynamic grid assist, decoupled double synchronous reference frame (DDSRF) based totally superb and bad sequence extractor, dual synchronous reference frame (DSRF) based totally present day controller for unbalanced contemporary injection, height modern-day limiter to modify the contemporary within inverter score, and modified protections based on LVRT curve are all covered in the proposed controller. The effectiveness of the incorporated controller is classed, and simulation outcomes are proven, beneath various symmetrical and unsymmetrical grid faults [22].
A thorough simulation of a grid-connected, -level solar PV system is provided on this paintings. (GC-TS-SPS). The performance of the created model has been examined in the presence of brief circuit defects. The information honestly show that symmetrical faults have a greater impact than unsymmetrical faults. Additionally, the DC Link voltage will increase substantially for the duration of faults, necessitating a machine with sturdy overvoltage safety. A defect at this website might have a terrible effect at the gadget, hence the terminal connections at the inverter output terminal must be regularly tested for any insulation degradation at cable connection lugs/crimps [23].
In order to correctly combine PV structures into the grid, a manipulate strategy need to be green and able to running beneath both everyday and atypical grid situations. An L VRT technique is created in this paintings for grid-included PV systems with asymmetrical faults. Among its many functions, the advanced approach includes the energy set-factor computation scheme to enforce grid code necessities, the PV energy discount model to prevent dc-link overvoltage, the contemporary amplitude restricting characteristic to protect towards converter overload, and a unique modern reference computing scheme to ensure the easy operation of PV structures. A range of simulations are run to test the effectiveness of the developed approach in MATLAB/SIMULINK, and the outcomes show that the plan works efficaciously [24].
This paintings examines how a single-section rooftop solar photovoltaic (PV) machine reacts when symmetrical and unsymmetrical faults arise. The outcomes showed that the manage approach utilized for the electricity digital converter that connects sun PV systems to the grid has a huge effect on how they respond to faults. Past simulations, it has been demonstrated that the solar PV device stops running whilst a fault develops between the road conductors and the floor, but, whilst there may be no floor path, it can bypass beyond the fault. Electromagnetic transients precipitated over currents and over voltages to be visible in the system simply after the fault is fixed. These findings resource in comprehending how solar PV systems behave below fault conditions and can be used to expand extra powerful electricity digital converter controllers and hybrid electricity machine protection plans [27].

4.2 Types of unsymmetrical faults in PV system

Line to ground (L-G), line to line (L-L), and double line to ground (LL-G) faults are the three basic types.

- Single Line to Ground: The most frequent type of unsymmetrical fault is a single line-to-ground (SLG) failure. It could be caused by tree branches, flashovers across dusty insulators during rainstorms, or a vehicle accident that sends one of the phase conductors flying and into touch with the ground.
- Line to Line: A short circuit occurs between two phase wires that are presumed to be phases b and c in a line-to-line (L-L) fault. As a result, there is symmetry in relation to the primary phase a.
- Double Line to Ground: A short circuit between the ground and the two-phase conductors b and c causes a double line-to-ground (2LG) problem. There is symmetry with regard to the principal phase a, just like there is with the line-to-line fault [26].

5. DISCUSSION

This work provides a comprehensive investigation into the challenges of fault occurrences, protection issues, and the consequences of undetected defects in photovoltaic (PV) systems. It critically evaluates a range of fault detection algorithms and techniques that have demonstrated efficacy in PV applications. The increasing reliance on artificial intelligence (AI) highlights its potential as a transformative alternative to traditional maintenance strategies. In this context, AI has emerged as a vital tool for diagnosing and identifying failures within solar PV systems, thereby enhancing operational efficiency and safety.
The comparative analysis of machine learning (ML), deep learning (DL), and hybrid approaches for fault detection and diagnosis emphasizes the superior accuracy of deep learning models, particularly when using infrared thermography images. The developed deep convolutional neural network (CNN) achieved an impressive classification accuracy of 98.70% for both binary and multiclass scenarios, signifying its robustness in identifying common issues affecting PV

modules. Furthermore, the results indicate that deep learning approaches outperformed traditional machine learning methods, underscoring the effectiveness of advanced neural architectures such as VGG-16 in this domain.
Condition monitoring frameworks have seen significant advancements, underscoring the importance of a well-structured maintenance program for ensuring the continuous delivery of electric power from solar systems. This review also delineates various failure modes that PV systems are susceptible to, coupled with essential integrated detection methods and technologies. The role of data-driven paradigms in addressing prediction challenges has been explored, emphasizing the interplay between different learning architectures—traditional, hybrid, and ensemble methods.
Moreover, the survey of recent advancements in AI applications within PV systems illustrates the pivotal role these technologies play in design, control, diagnosis, and output estimation. A comparative analysis of traditional versus AI methodologies reveals significant benefits offered by AI algorithms in optimizing PV system performance. However, the study also highlights the critical need for timely fault detection and diagnosis to mitigate risks associated with component failures, such as fires from arc and ground faults, thereby ensuring the safe operation of PV plants.

6. CONCLUSION

This review has synthesized the application of machine learning approaches for controlling multilevel inverters (MLIs) in the context of asymmetrical faults in photovoltaic systems. The strengths and limitations of various strategies have been outlined, demonstrating the effectiveness of both traditional MLI control methods and machine learning-based approaches for identifying and diagnosing unsymmetrical faults in PV systems. This analysis underscores the importance of accurate fault detection and diagnosis in enhancing the efficiency, safety, and reliability of PV systems.
The integration of MLI with machine learning techniques presents significant opportunities for improving performance and reliability in the face of asymmetric defects. Furthermore, this work emphasizes the necessity for interdisciplinary collaboration and continued research to further advance these technologies. Addressing the challenges outlined herein will be crucial for the future development and implementation of intelligent and efficient energy systems, particularly as the demand for reliable renewable energy sources continues to rise.

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