An Inclusive Evaluation on Types and Detection of Fault Related to Photo Voltaic Cells

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ABSTRACT: ***According to US NEC Article 690.5, every PV system with a system voltage more than 50 V needs ground-fault prevention. In most PV arrays in the United States, an electric connection is made between earth and one of the CCCs through a ground fault detection and interruption (GFDI) fuse, which is referred to as "system grounding". Alternative ground-fault prevention methods, such as residual current monitoring devices (RCDs) and DC insulation resistance measurements, are more prevalent outside the United States. These ground-fault prevention devices are often employed on ungrounded ("floating") PV systems that do not have a ground connection. Ground faults, line-to-line faults, and arc faults are the three most common catastrophic failures in photovoltaic (PV) arrays. Although there haven't been many such failures, recent fires in Bakersfield, California, on April 5, 2009, and Mount Holly, North Carolina, on April 16, 2011, suggest that current fault detection and mitigation techniques, as well as amendments to existing codes and standards, are needed to prevent such accidents. The impact of defects on the functioning of PV arrays is investigated in this paper, as well as the limits of current fault detection and mitigation techniques. A review of cutting-edge defect detection and mitigation methods, as well as commercially available devices, is also provided.***

KEYWORDS: ***Arc Fault, Fire, Ground Fault, Line-To-Line, Photovoltaic (PV).***

1. INTRODUCTION

Recent photovoltaic (PV) array fires highlight the importance of understanding catastrophic failures in PV systems. Shutting down the PV generation system under various fault conditions necessitates a variety of mitigation techniques and, in most cases, prior knowledge of the fault type [1]. This paper discusses the major faults that can cause damage to a PV array (catastrophic faults), as well as the causes, detection schemes, and protection techniques for these faults. Ground fault, line-to-line fault, hot spot formation, polarity mismatch, arc fault, open fault, bypass diode failure, and dust/soil formation are among the many possible faults in a PV array. Ground fault, line-to-line fault, and arc fault are reported to be the major causes of catastrophic failures resulting in electrical fires [2]. This paper examines the PV system's electrical behavior during those faults, as well as the possible causes of any failure and the most up-to-date detection and mitigation techniques for each type.

There are unique technical challenges to detection and mitigation in each fault case. Standards are reviewed in this paper, and recommendations are made to ensure more reliable PV arrays. This paper does not discuss flaws. in the rest of a PV system's components ac isolation failure, inverter failure, dc signal injection into the ac side of the inverter, faults inside battery modules, and so on [3]. A PV array typically has several noncurrent carrying (NCC) metals/conducting parts exposed (module frames, mounting racks, metal enclosures, distribution panels, end-use appliance chassis, and power converters). During normal operation, these conductors do not carry any current. However, there is a potential risk of electric shock hazard from these exposed NCC conductors when an electrical connection is established between the current carrying conductors (CCCs) and NCC conductors due to a fault (e.g., corrosion, loss or melting of insulation, wire cutoff, and wrong wiring). As a result, a conductor known as an "equipment grounding conductor" connects all of these NCC conductors to the ground or earth (EGC). Article 690.43 of the National Electrical Code (NEC) mandates equipment grounding to protect people and other living creatures from electrocution [4].

Similarly, any unintentional connection between a CCC and the EGC/earth can result in a significant current flow to the ground circuit, which is referred to as a "ground fault." In the event of one or more ground failures, effective grounding is needed for any electrical system to provide sufficient people and system safety [5]. The voltage and current limits for electrocution of a live creature have been suggested as 75 V and 100 mA, respectively, and the following conditions must be fulfilled to prevent an electric shock. The operating voltage, plant size, style of installation (ground mount, roof-top, building mounted, etc.) and geographic location all influence how PV systems are grounded. Fig.1, illustrates the schematic diagram of photo voltaic arranged in different arrangements.

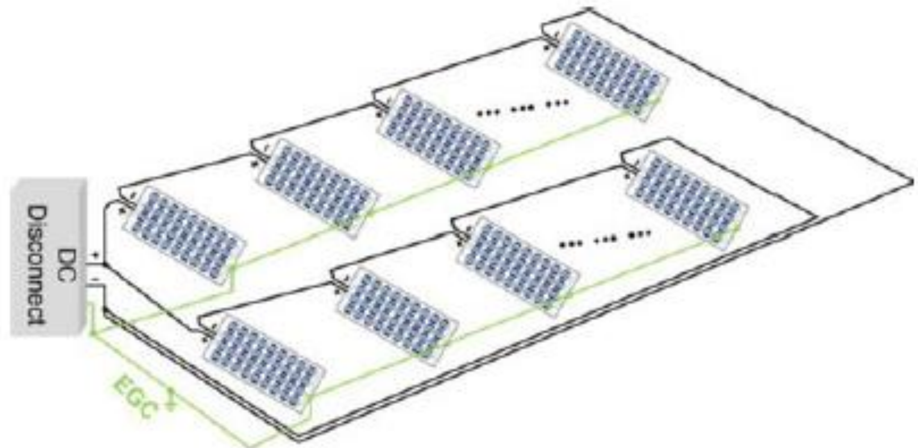

Fig. 1: Illustrates the schematic diagram of photo voltaic arranged in different arrangements [6].

A comprehensive electrical model of a PV array is required to evaluate various ground problems. Unfortunately, electrical characteristics differ across PV systems owing to differences in PV module design (e.g., size, material, and ground connection), as well as differences in location and physical architecture. GFDI protection systems have the unwanted consequence of providing an electrical route for leakage current to return to the PV conduction line through the ground-fault detection fuse [7]. Leakage current is strongly influenced by relative humidity, temperature, array voltage, and array size. Furthermore, in an ungrounded system, impedance from a CCC to ground varies with various meteorological variables (temperature and humidity), and the design of fault detection devices for both ungrounded and grounded systems necessitates a safe estimation of detection parameters to avoid system shutdown under normal operating conditions.

A ground fault creates an unintended low impedance route between one of the CCCs and the ground/earth, and the cause of the fault is often destroyed by a big fire in a PV array [8]. There have been many theories proposed as to why ground faults occur. During a fault situation, system grounding provides an intended circulation route for the ground current, and the fuse melts if the current exceeds a safe threshold current limit. If the fuse is opened, the inverter must be switched off right away to isolate the PV array from the rest of the electrical supply and allow for fault investigation. A fuse with a rating is placed within the PV inverter in most grounded PV systems. The ground-fault fuse's upper limitations are defined by UL 1741. In the event of a ground fault, a sensor within the inverter checks the fuse continuity and turns off the system [9].

The fuse rating should be high enough to prevent nuisance tripping caused by leakage current, but low enough to trip during genuine ground faults. In, a leakage current estimate for modules running at 600 V that satisfy the specification is given. The maximum leakage current for 1.2-m2 crystalline Si modules is predicted to be 11 A/kW for a seven-module string, resulting in 56 mA of leakage current from a 500-kW array. The sensitivity of the GFDI fuse is influenced by the leakage current of the PV array, and several papers have investigated the effect of various parameters on the leakage current, including ambient temperature, relative humidity, salt mist, electromagnetic interference, and grounding conductor resistance. Through the positive and negative CCCs, RCDs may detect the difference in current entering and exiting the PV system.

The existence of an alternative current route may open the CCCs utilizing switching relays in the presence of any residual magnetic field. RCDs may be set up for each string individually or for the whole array. The sensitivity of an RCD, on the other hand, should be determined by the leakage current of the PV modules. The set point of differential current at which an RCD indicates a ground fault is suggested in. A fuse has a threshold current for detecting a ground fault, and if the resulting ground fault current is less than this limit, the fault may go unnoticed. The fault current is extremely minimal if a ground fault occurs on a grounded CCC or at a point in the array where the potential to ground is low. Fig. 2, illustrates the line to line fault found in the photovoltaic arrays used for electricity generation.

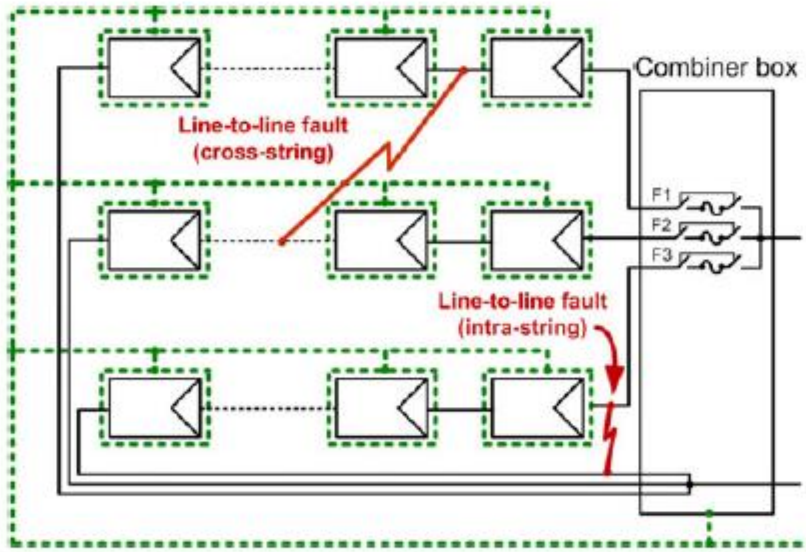

Fig. 2: Illustrates the line to line fault found in the photovoltaic arrays used for electricity generation [10].

In such situations, a failure that does not trigger the GFDI may occur. The "blind area" in conventional ground-fault detecting fuses is what it's called. Because the ground fault in the array stays unnoticed for an extended period until otherwise disabled, any ground fault that results in a blind area presents a substantial danger. Because any future ground fault will result in a fault current that may circumvent the GFDI fuse, a blind area is critical for the PV array's safety. The whole array current may run via the grounding wire, causing the array to be severely damaged. On April 5, 2009, in Bakersfield, CA, USA, and April 16, 2011, in Mount Holly, NC, USA, undetected ground faults within blind spot range were followed by another ground fault that allowed a large amount of current to flow through the grounding wire, resulting in two well-investigated ground-fault events.

2. DISCUSSION

The initial ground fault caused a current to flow through the GFDI fuse with a fault current amplitude that was below the threshold limit, and the fault went unnoticed for an unknown amount of time. However, given the magnitudes of the ground-fault current recorded in the following ground fault resulted in a flow of an estimated 952 A through the EGC, which started a fire before being cleared by the over current protection fuse, adding RCDs would have been more beneficial. Ground-fault detection systems are often based on passive fuses, isolation impedance measurements, or differential current measuring techniques, and these devices have a number of drawbacks, as mentioned before. Due to poor insolation, ground-faults may occur inside the blind spot range, such as at night, on a cloudy day, or under partial shade, and go unnoticed. During the night, a double ground fault may form, resulting in high fault current and arcing within the array during the day. External electrical noise may cause RCDs to trip, resulting in system nuisance tripping. The possibility of installing AFDs at three different locations, i.e., module level, string level, and array level, is discussed in, and it is reported that AFDs are able to detect faults regardless of whether they are located at the string, between the combiner and re-combiner, or at the central inverter, in order to optimize the accuracy, cost, and annual production from a PV generation unit.

Installing AFDs in recombines in bigger PV systems, on the other hand, may be hampered by the severe attenuation problem. As a result, AFDs may be used in combiner boxes, whereas AFCIs can be used at the inverter or recombine. AFDs used at the string level may disconnect the damaged string or strings while the remainder of the strings continue to function normally. However, compared to array-level protection, this is a costlier solution that may suffer from “crosstalk” noise, which occurs when arc noise from one string propagates to unaffected strings. An AFCI must reenergize the arc quickly enough to prevent a fire from igniting, as well as be durable enough to prevent nuisance tripping. A spurious arc signature was identified in a nonacid string in a two-string array owing to noise from a parallel defective string during an average delay of 19.5 ms, according to the researchers. However, it is anticipated that string-level detection would work better with a high number of parallel strings since the arc energy in each healthy parallel string will be smaller. Furthermore, quicker detection methods may be more successful in reducing crosstalk noise.

Among all of these mounting methods, module-level AFD/AFCIs seem to be more reliable (although a costly alternative) and more suitable for PV modules with dc/dc converters or micro inverters. Furthermore, hybrid architectures in which the AFDs are placed at the module/string/combiner and the AFCIs are located at the string/combiner/recombine/central converter may be adapted. Further research is needed to compare all of these architectures in terms of cost and dependability. Parallel arcs to ground are the most frequent, and such faults are likely to include GFDI or OCPDs. Furthermore, the 2014 NEC's enhanced ground-fault detection capabilities will handle the overwhelming majority of parallel arc-fault hazards in big systems. During PV operation, a broad range of variations in solar irradiance/cell voltage has an impact. Some arcing risks are inherent in normal PV plant operation, such as inverter operation in the morning or evening, low voltage shutdown due to clouds or partial shade, or contact arcing at junction boxes during maintenance operations. In the situations described above, an intelligent AFCI should be able to prevent annoyance tripping. Apart from the general techniques described in such as recorded voltage/current, maximum power point, temperature, irradiance, power loss, fill factor, and so on, this section summarizes methods proposed in the literature for detecting, mitigating, and differentiating different fault types using different numerical and data-processing techniques.

In, a multilayer artificial neural network (ANN)-based algorithm was proposed, in which irradiance, cell temperature, voltage, and current at maximum power point are used as input to estimate the voltage across each module of a two-string array, which is used for short line-to-line fault detection and location. However, no data on how well the method performs with other kinds of failures (ground or arc faults) has been published. A decision tree-based supervised technique is proposed in to detect and classify four fault conditions based on PV array voltage, current, operating temperature, and irradiance: line-to-line fault with short circuit, line-to-line fault with 20- resistance, open circuit fault, and partially shaded condition. This technique, like other supervised learning algorithms, needs appropriate training data for each defective situation as well as data from the PV array under normal working circumstances. The accuracy of this method is determined on the size of the tree and the number of leaves utilized. Due to the algorithm's self-training capacity, a graph-based semi supervised learning method was employed in to address the disadvantage of huge training data, resulting in comparable accuracy with a smaller training dataset.

Fault detection methods based on the change in string currents of a PV array have been developed that need less processing. There are three distinct rules for detecting outliers. 3-sigma, To identify line-to-line faults (short circuit and 20-resistance), open faults, series resistance faults, and partial shading, these techniques do not need prior training data. The Boxplot rule, on the other hand, was shown to be the most effective in detecting errors, whereas the 3-sigma technique failed to find any problems. Although this technique cannot distinguish the kind of fault, it is used to detect defective string/strings by comparing string current to maximum string current working in parallel. When the main current turns negative at the beginning of a parallel line-to-line or arc fault, certain inverters are intended to shut down automatically. Because parallel circuits contribute to the fault in big systems, reverse current detection at the feeder inputs of a recombine box or inverter is a useful way of identifying parallel line-to-line or arc faults.

It is suggested to eliminate parallel arc faults by connecting all positive and negative CCCs to ground. PV defect detection was characterized as a clustering issue, and a minimal covariance determinant (MCD) estimator-based approach was developed. To assess the existence of a defect, this technique calculates the likelihood of detection as well as the probability of false alarms. The method was claimed to be capable of detecting PV series arc faults and ground faults in a single module based on simulation results. PV problems are detected using differences in power losses between simulated and real-world data. However, no convincing research has been done to establish the comparative performance indices of the above-mentioned suggested methods. By comparing the actual power measurement data with the predicted power from the algorithm, fuzzy rule based power estimation using temperature and irradiance data is used to identify problem in a PV.

Several additional arc-fault detection methods based on time-domain signature have been suggested in addition to the arc detection approaches based on frequency content of current and voltage signals discussed in Section IV. The unpredictability of the output from the FIR filter is quantified in terms of variance, and the voltage signal of a PV module goes through a finite impulse response band pass filter (FIR filter). An arc fault is present when the variation exceeds a certain threshold. The detection of arcs is suggested utilizing two resonant circuits tuned at a few hundred kilohertz, based on the premise that there would be no significant signal in the PV array at those frequencies unless there is an arc. A discrete wavelet transformation (DWT) for current-based arc-fault detection has also been suggested. Because DWT examines both the time and frequency characteristics in the arc signal, it is more computationally efficient than Fourier transformation.

Reflectometry-based fault detection has long been used to identify defects in long transmission lines, and various reflectometry techniques have been modified for use in PV array fault detection. A step/pulsed voltage signal is transmitted via the two CCCs (or one CCC and EGC) in time-domain reflectometry (TDR) detection techniques to monitor any variation in voltage signal reflection owing to short or open faults. Positive reflection occurs when a high impedance (open fault) is compared to the normal characteristic impedance, and the amplitude of the voltage signal at the receiving terminal rises. When comparing characteristics impedance to reduced impedance, the opposite impact is seen (short-circuit fault). Spread spectrum time-domain reflectometry (SSTDR) generates an autocorrelation plot utilizing incident and reflected signals using a pseudorandom binary noise modulated high-frequency sine wave. The autocorrelation plot may be used to find out whether there is a problem. SSTDR has a benefit over TDR in that it may be utilized without the inverter being disconnected. However, in order to identify the existence of faults, both reflectometry-based fault detection methods need a baseline for comparison.

The system operator must identify the location of the line-to-line fault, ground fault, or arc fault after the problem has been identified in order to repair or replace the defective component. With high PV, this procedure may be extremely complex and time consuming. Identifying intermittent connections and problems is a difficult task. It will be much more difficult to identify the defective component if the problem is not persistent. Table IV examines the various methods and commercially available items that may be used to detect defects in photovoltaic systems. Positive reflection occurs when a high impedance (open fault) is compared to the normal characteristic impedance, and the amplitude of the voltage signal at the receiving terminal rises. When comparing characteristics impedance to reduced impedance, the opposite impact is seen short-circuit fault. Spread spectrum time-domain reflectometry (SSTDR) generates an autocorrelation plot utilizing incident and reflected signals using a pseudorandom binary noise modulated high-frequency sine wave. The autocorrelation plot may be used to find out whether there is a problem. SSTDR has a benefit over TDR in that it may be utilized without the inverter being disconnected. However, in order to identify the existence of faults, both reflectometry-based fault detection methods need a baseline for comparison.

3. CONCLUSION AND IMPLICATION

This article examines ground faults, line-to-line faults, and arc faults in depth. To avoid fires, both grounded and unground PV arrays use several commercial fault detection and mitigation methods. Ground faults, on the other hand, may go unnoticed owing to limitations in traditional detection methods, causing significant damage to the PV array and surrounding environment. In the event of line-to-line problems, similar scenarios may occur. Different mitigation methods must be used depending on the kind of arc fault. As a result, detecting the existence and kind of arc is critical. This article provided an overview of several state-of-the-art detection and mitigation approaches, as well as a literature review of additional suggested methods and suggestions for future advancements in PV fault detection, localization, and mitigation.

REFERENCES:

[1] J. Kamala and B. Umamaheswari, “Reconfigurable smart controller and interface architecture for Photo-voltaic Energy Storage System,” *Comput. Stand. Interfaces*, 2016, doi: 10.1016/j.csi.2016.01.003.

[2] M. Bianchi, C. Ferrari, F. Melino, and A. Peretto, “Feasibility study of a Thermo-Photo-Voltaic system for CHP application in residential buildings,” *Appl. Energy*, 2012, doi: 10.1016/j.apenergy.2012.01.049.

[3] D. E. Collier and T. S. Key, “Electrical fault protection for a large photovoltaic power plant inverter,” 1988, doi: 10.1109/pvsc.1988.105863.

[4] M. Cotterell, “Installation Guidelines: Electrical,” in *Practical Handbook of Photovoltaics*, 2012.

[5] J. Johnson, W. Bower, and M. Quintana, “Electrical and thermal finite element modeling of arc faults in photovoltaic bypass diodes,” 2012.

[6] J. Flicker and J. Johnson, “Electrical simulations of series and parallel PV arc-faults,” 2013, doi: 10.1109/PVSC.2013.6745127.

[7] G. S. Seo, H. Bae, B. H. Cho, and K. C. Lee, “Arc protection scheme for DC distribution systems with photovoltaic generation,” 2012, doi: 10.1109/ICRERA.2012.6477374.

[8] X. Yao, L. Herrera, S. Ji, K. Zou, and J. Wang, “Characteristic study and time-domain discrete-wavelet-transform based hybrid detection of series DC arc faults,” *IEEE Trans. Power Electron.*, 2014, doi: 10.1109/TPEL.2013.2273292.

[9] N. Gokmen, E. Karatepe, B. Celik, and S. Silvestre, “Simple diagnostic approach for determining of faulted PV modules in string based PV arrays,” *Sol. Energy*, 2012, doi: 10.1016/j.solener.2012.09.007.

[10] G. E. P. Jr and C. J. Warren, “System and method for monitoring photovoltaic power generation systems,” *US Pat. 8,204,709*, 2012.