Different Techniques for Photovoltaic Solar System Fault Classification: A Review

Namrata Hole[1], Darshana Tajne[2], Dr. G.A. Dhomane[3], Dr. K.D. Thakur[4]

[1]PG Scholar, Governement College of Engineering, Amravati, Maharashtra, India
[2]PG Scholar, Governement College of Engineering, Amravati, Maharashtra, India
[3]Professor, Governement College of Engineering, Amravati, Maharashtra, India
[4]Assistant Professor, Governement College of Engineering, Amravati, Maharashtra, India

---***---

Abstract—*Faults in any parts (modules, connection lines, converters, inverters, etc.) of photovoltaic (PV) systems (stand-alone, grid-connected or hybrid PV systems) will seriously have an effect on the potency, energy yield still because the security and reliableness of the whole PV plant, if not detected and corrected quickly. If some faults persist (e.g. arc fault, ground fault and line-to-line fault) they will result in risk of fireplace. Fault detection and identification (FDD) ways are indispensable for the system reliable, operation at high potency, and safety of the PV plant. During this paper, the categories and causes of PV systems (PVS) failures are conferred, then completely different ways planned in literature for fault classifications and detections of PVS are reviewed, significantly faults occurring in PV arrays (PVA). Special attention is paid to ways which will accurately observe, localize and classify internal and external faults occurring in an exceedingly vinyl resin. The benefits and limits of FDD ways in terms of practicability, complexity, and cost-effectiveness and generalization capability for large-scale integration are highlighted.*

Keywords- Photovoltaic (PV) system, Fault Classification and Detection, Artificial neural networks (ANNs).

I. INTRODUCTION

Solar photovoltaic (PV) growth is greatly increasing worldwide because of its technical, economic and environmental advantages. To satisfy the energy demand, currently, PV is that the most promising supply of property power generation. With the growing energy demand, massive scale PV installations are gaining a lot of attention to satisfy the energy targets. Thousands of large-scale PV plants are within the authorization part to satisfy many giga-Watts of demand. A large-scale PV system includes of awfully sizable amount (hundreds of thousands) of solar modules multifariously interconnected to every different. The failure of one of them will eventually have an effect on the performance of the entire system. The expansion within the capacities of large-scale PV plants entails ways in which to actively monitor and observe any early faults so applicable remedial actions will be taken before any major disruptions happen.

With increasing electricity demand and major environmental considerations about power generation, photovoltaic (PV) systems have gained quality united of the splendid renewable energy sources and it is almost-zero pollution throughout power generation, decreasing prices, advances within the semiconductor devices, straightforward system maintenance, etc. PV watching refers to sleuthing, classifying and locating the fault conditions once system behavior deviates from the expected performance [1-3]. Advantage of system, dynamic environmental conditions and therefore the increased structural complexness of the PV system, fault watching of PV systems has become vital. The study in [4] shows that faults will cause power loss up to 18.9% from the tested PV system.

Generally, the faults are known and solved manually, however, it is not suggested to use this standard methodology as a result of it is long, inaccurate and doubtless dangerous to the operator, particularly within the giant scale PV arrays. Instead, fast and economical machine-controlled fault observance for PV systems is desired.

Locating ground faults in ungrounded systems is inherently troublesome as a result of such faults do not offer extended fault currents for tracing the fault location. Moreover the locating method must be performed whereas the system stay operational, a salient feature of ungrounded power systems. Presently out there fault locating techniques [1]-[4] are either time overwhelming or need giant amounts of dedicated hardware like sensors that increase value and complexness.

A novel ground fault location approach was developed by the authors and conferred in [5]. It is supported the principle of pattern recognition of inherent high frequency noise introduced by the repetitive shift events of power electronic (PE) converters interacting with system parasitic components (such as cable insulation capacitance and stray inductance). The planned approach is applicable to all or any ungrounded systems containing parasitic components to make a ringing circuit through ground and that contain a mechanism to excite that ringing circuit. The initial study conferred in [5] demonstrates the effectiveness of approach through theoretical account of an appropriate system.

II. DIFFERENT TECHNOLOGY FOR SOLAR PV SYSTEM FAULT CLASSIFICATION AND DETECTION

A fault protection and locating methodology for ungrounded DC traction power systems is given [1]. Several DC traction power systems have ungrounded power circuit to extend the escape path resistance. Though ungrounded systems will continue in operation with one ground contact not like solid- or low-resistance grounded systems owing to the terribly low fault current, a second ground fault in another pole can end in a line-to-line fault that might cause vital system harm. However, it is troublesome to sight the primary ground contact thanks to the low ground current and even more durable to find as a result of it will be seen by several detectors within the network. The planned theme during this paper uses a groundwork unit to sight and find the primary single ground fault in ungrounded traction power systems. The probe unit applies probe voltage to sight the fault, and, once the fault is detected, analyzes the response to DC or swept-frequency AC probe voltage to find the fault. The planned ideas are verified with computer based simulations and hardware experiments, and incontestable a self-made performance [6-8].

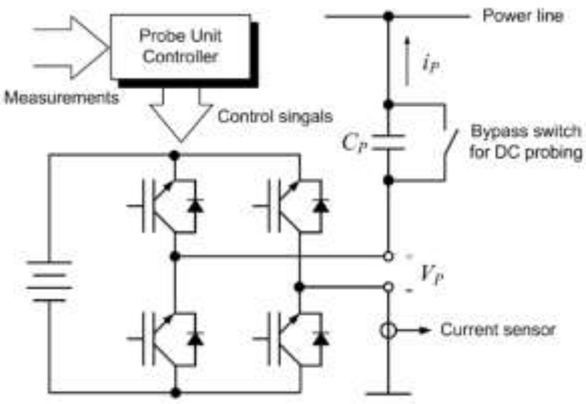

Fig.1. A schematic of probe unit using full-bridge inverter that can generate voltages with arbitrary amplitude and frequency [1]

A ground fault detection and location scheme for ungrounded DC rail power systems has been proposed [1]. Although the ungrounded systems can continue operating with a single ground contact, it is imperative to detect and locate the fault quickly because the second ground fault could cause a destructive line-to-line fault. The proposed protection scheme is capable of detecting the first ground fault by applying probe voltage through the ground connection from a substation. Once a ground fault is identified, the probe unit locates the fault by DC or swept-frequency AC response analysis on probe current. The proposed algorithm can be executed while the traction system is in operation without de-energizing the bus. The proposed method enables fast Time Domain Reflectometry has been used for diagnostic observation of an outsized size photo-voltaic (PV) plant in operation conditions [2]. By analyzing the waveforms obtained once a step-voltage excitation is propagated down the electrical line connecting the PV generators to the inverter, determine and localize the foremost gravity fault conditions, like breaks of the circuit, insulation defects, wiring anomalies. Best compromise between analysis time and preciseness was achieved by testing group of 3 paralleled strings (panels): during this manner this method was ready to find in a very short time whether or not a fault was exists, whereas it is position was singly determined with an honest preciseness by repetition the take a look at on the one strings.

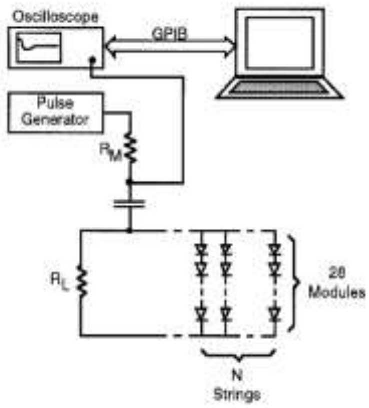

Fig.2. Experimental set-up [2]

A PV arc-fault detection technique victimization spread spectrum time domain reflectometry (SSTDR) technique has been introduced [3]. SSTDR could be a reflectometry technique that has been commercially used for analysis of wiring faults though SSTDR may be probably used for several different applications. Technique used SSTDR for detection of each ground and arc faults during a PV array. It is been clear that SSTDR is used for detection of each series and parallel arcs, and it is the potential to predict the presence of future arc faults by analysis the change in resistance even in absence of sunshine or at terribly low solar irradiance. This technique does not need frequency domain analysis of voltage or current signal and may observe the presence of arc despite the operative state of the inverter.

The projected techniques may be applied for detection of each ground and arc faults and it doesn't depend upon the solar irradiance or measure of DC voltage and current of the PV array. Experiments were performed victimization totally different arc fault resistances and at different fault locations. The projected technique will with perfectly observe the presence of fault resistance no matter the worth of fault resistances and fault locations within the array. Detail analysis of the entire take a look at cases beside the potentials and limitations of the projected arc fault prediction and detections technique has been represented [9-12].

Long term exposure of photovoltaic (PV) systems below comparatively harsh and dynamical environmental conditions may result in fault conditions developing throughout the operational period. This resolution is for system operators to manually perform condition observation of the PV system. However, it is long, inaccurate and dangerous. Thus, automatic fault detection and diagnosing may be an important task to make sure the reliableness and safety in PV systems. The present progressive techniques either cannot give enough careful fault info with high accuracy nor have an excessive amount of quality. One of the techniques [4] presents automatic fault detection and diagnosing technique for string primarily based PV systems. It combines an artificial neural network (ANN) with the standard analytical technique to conduct the fault detection and diagnosing tasks. A two-layered ANN is applied to predict the expected power that is then compared with the measured power from the real PV system. Supported the distinction between the ANN calculable power and also the measured power, the circuit voltage and short current of the PV string determined victimization analytical equations square measure accustomed determine any of the six defined fault sorts. The projected technique contains a quick detection, compact structure and sensible accuracy.

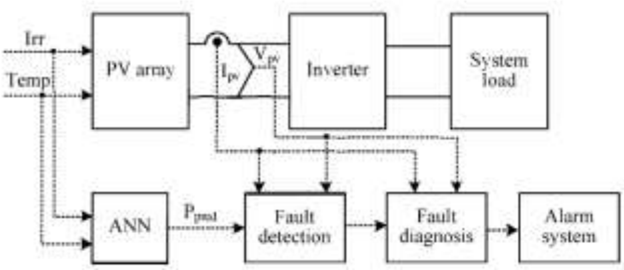

Fig.3. The PV system with fault detection and diagnosis [4]

This method is based on combining the ANN and the analytical methods. The efficient multilayer ANN is used as a predictor to predict the expected power using irradiance and temperature as the inputs.

The estimated power is then compared with the measured power from the real system to detect the occurrence of a fault. After the fault detection, fault diagnosis is conducted by comparing the open circuit voltage of the PV string, which is calculated using the analytical equations, with the measured open circuit value.

This method has a compact structure [4], fast fault detection, good accuracy and no requirement of the inner knowledge of the PV system. The effectiveness of the proposed fault detection and diagnosis method is verified using simulation results. The results show that the proposed method can precisely identify the fault occurrence and types. In our future work, we will implement this method into the experimental setup and test the fault detection and diagnosis method in real PV systems. Since this study only examines the occurrence and types of the fault that regularly in the PV strings, more detailed information of the fault location and other less common faults needs to be further investigated.

In recent years, the advances in power electronics favor DC distribution, particularly for transportation systems like ships. Therefore, this system presents a fault location approach that is predicated on the pattern recognition of inherent high frequency noise related to shift events of converters. This methodology [5] demonstrates the practical approach through hardware laboratory model. Specifically, a low voltage DC system, representative of the salient high frequency behavior of a true Zonal Electrical Distribution System for ships was used. It is over that the approach is possible and might be applied towards the event of a good ground fault location system for convertor dominated DC systems.

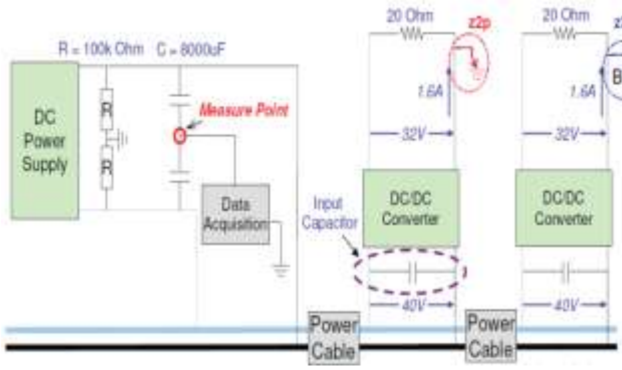

Fig.4. The experimental system [5]

The task of fault detection and diagnosing in massive-scale electrical phenomenon (PV) plants is anticipated to be a significant challenge as additional and additional plants with more and larger capacities still inherit existence. To take care of safety, responsible, and productivity of large-scale PV plants it is essential to develop approaches that permit automatic detection and placement of any mal-operation among thousands of PV modules. Technique was planned associate approach to observe PV plant faults through the generation of fault indicator signals referred to as 'residuals' for every string and also the comparison of residuals with a threshold worth [13]. Moreover, a regression-based approach is planned to estimate fault location as perform of fault current and irradiance level measurements. The planned approach is incontestable by specifically that specialize in intra-string line-line faults. Numerous line-line fault case studies area unit verified through simulations associated valid on an experimental setup in a very star PV plant.

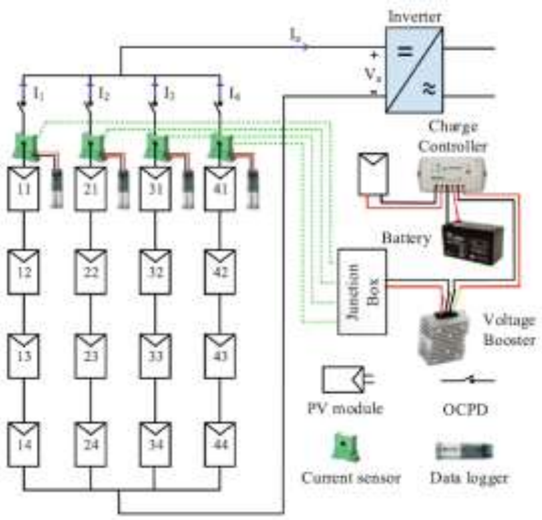

Fig.5. Experimental system used in fault analysis [13]

Through the analysis it is found that string level watching will considerably enhance the visibility on the dc surface of the PV plants notwithstanding the plant size. Noting that the present protection devices are primarily meant to shield inverters and dc facet fires, the projected approach enhances the present protection instrumentation by prompt detection and site of PV faults, eventually benefitting the longevity of PV modules. A natural extension of the projected approach is to create the projected approach adjective to variations in module degradation condition [14-15].

Various faults inevitably occur in electrical phenomenon (PV) array because of the tough external operating surroundings. Therefore, detective work the faults and theirs locations is crucial for the PV array. This can be proposing a way for detective work the faults and their locations supported statistic of PV string current [13]. A time series sliding window (TSSW) is adopted. The local outlier factor (LOF) of every current purpose within the TSSW is calculated. Once variety of LOFs area unit unendingly detected to exceed the edge worth, the PV string may be judged as fault. The experiment results show that the planned technique will sight short fault, open circuit fault and shadow fault for PV string underneath completely different irradiance.

In method, a current sign adjustment detection approach supported LOF is planned to diagnose and find the fault string in PV array. A 1.8kW laboratory grid connect PV system is applied to validate the planned technique. Three typical faults of PV array are conducted, including short circuit fault, shadow fault and open circuit fault.

Arc faults threaten the protection operation of photovoltaic (PV) systems. An arc fault detection and localization approach utilized parallel capacitors is projected [16]. Five capacitors are paralleled with the branches of a PV system. Series and parallel arc faults are tested within the system. The amplitudes and polarities of the capacitance currents are obtained, and separate discrete wavelet transformation (DWT) is applied to the capacitance currents. The results indicate that the distributions of absolute amplitudes, polarities and spectrums of capacitance currents are distinctive underneath totally different fault varieties and locations, which may be want to observe and localize arc faults in PV systems.

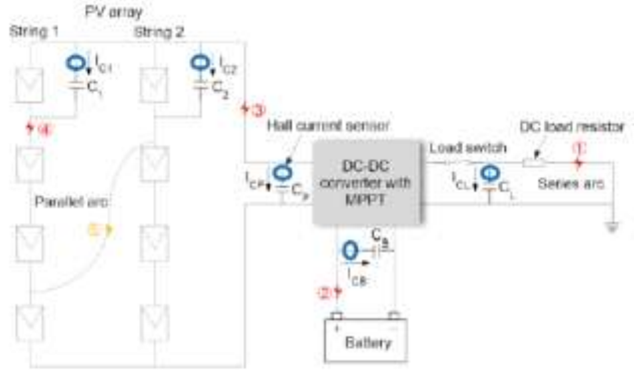

Fig.6. Circuit diagram and arc generation setup [16]

The amplitudes and therefore the spectrums of the currents are analyzed. Once the arc occurred at totally different locations, the amplitudes, polarities and spectrums of the capacitor currents had distinctive distributions. Combining the amplitude, polarity and spectrum distribution diagrams, it is observe and localize series and parallel arc faults within the PV system, and distinguish arc from switch operations.

Quick fault detection and isolation of faulty section are desired in DC micro grid because of the presence of power electronic converters and low cable impedances. The quick disconnection, restricted time and knowledge are on the market for on-line fault distance estimation. A number of the present techniques think about supply capacitors connected at just one finish of the cable; so, assume that the fault current is contributed by just one finish of the cable [17]. This might not be true within the case of multi-source DC micro grids, wherever fault current would be provided from each end. Further, existing communication-based techniques need either knowledge synchronization or quick communication network. To handle these problems, this study proposes an online fault location methodology for multi-source DC microgrid while not victimization communication. The mathematical model of faulted cable section connected to sources at each end come. This model is employed alongside the measurements to see the fault distance. The model consistency with the measurements is quantified victimization the boldness level supported the residual analysis [18-19]. A ring-type multi-source DC microgrid system is taken into account and simulated on period of time digital machine to demonstrate the effectiveness of the projected rule.

Fault location in DC microgrid may be a very difficult task as a result of the quick isolation of the fault, and thus less obtainable information. Further, the presence of DC capacitors at each end of the cable the power electronic converters permits fault current from each the ends of the cable to contribute, in contrast to in typical systems. The voltage and current transients throughout fault are used during this work to style an online fault location technique, while not victimization any communication. A mathematical model of the faulted network springs, that is employed within the rule to estimate the fault location. An estimation-based technique is applied on the model to accurately find the fault and it is associated fault resistance. The calculable values are more confirmed with the calculated level of confidence. The interior faults are situated with error 95%. The planned technique is applicable to each pole–pole and pole-to-ground faults.

Unlike the synchronous generators, the short-circuit current provided by the photovoltaic (PV) sources is restricted by the grid-connected inverters and closely associated with the traditional conditions, that impacts the protection of the power system. This study deals with the protection of the power lines (distribution feeders) that connect the PV power plants (PVPP) to the grid; the primary a part of this study analyses the impact of the grid-connected PV (GCPV) system on the traditional distance protection [20]. A selected co-ordination between the over-current protection of the grid facet and therefore the distance protection of the PVPP surface was wont to eliminate this impact. This coordination needs delaying the gap protection and keeping the electrical converter connected to the grid that was achieved by fault ride-through (FRT) feature accompanied with the inverter management throughout the fault condition [21-22]. The second half studies the chance of mistreatment the double-end-impedance-based fault location on the PVPP power lines, and a few FRT ways were recommended to cut back the impact of the inverter management loops on getting the correct fault location.

The planned coordination methodology between the distance relay within the PVPP facet and also the OCR relay within the grid facet provides the simplest resolution to eliminate this influence by taking advantage of the inverter control like the FRT capability, providing voltage and frequency references throughout the islanding mode, and also the reactive power injection to support the grid voltage throughout the fault condition [10]

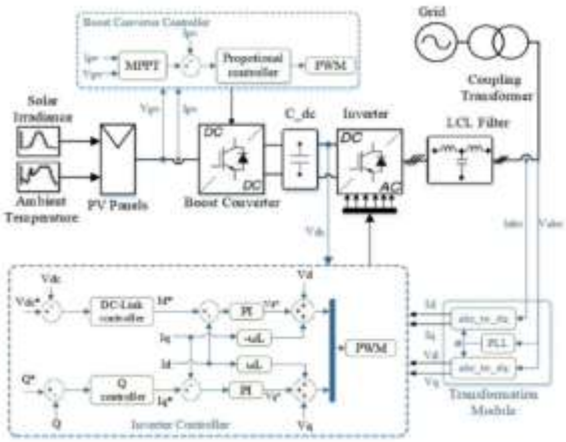

Fig.7. Control structure of the GCPV system [20]

The double-end fault location was enforced and simulated with success with high accuracy, except just in case the grid side transformer capability is comparatively little. That the accuracy of the fault location depends indirectly on the worth of the remote current fed to the grid aspect; however high grid aspect remote current may well be shared throughout fault condition verify by the grid side transformer at the tip of the distribution line. just in case the present fed from the grid is comparatively low (120 kVA), VCCF-FRT provides the most effective accuracy for the doubled finish fault location, as a result of it guarantees the standard of the output currents.

One of methodology [23] investigates a newly-designed fault diagnostic methodology for a PVS consistent with the subsequent 3 steps. First, optimum fault options square measure extracted by analyzing I-V curves from completely different faults, together with hybrid faults of the PVS below the quality check condition (STC). Moreover, the trust-region-reflective (TRR) settled algorithmic rule combined with the particle-swarm-optimization (PSO) met heuristic algorithmic rule is planned to standardize fault options into those below the STC. Additionally, a multi-class adaptive boosting (AdaBoost) algorithmic rule, that is that the stage-wise additive modeling exploitation multi-class exponential (SAMME) loss operate supported the classification and regression tree (CART) because the weak classifier, is used to determine the fault diagnostic model. The effectiveness of the fault diagnostic model might long-run maintain by sporadically change the feature standardization equations to standardize the fault options into those below the STC [24-26]. Numerous forms of the PV modules square measure accustomed validate the generalization of the fault diagnostic methodology.

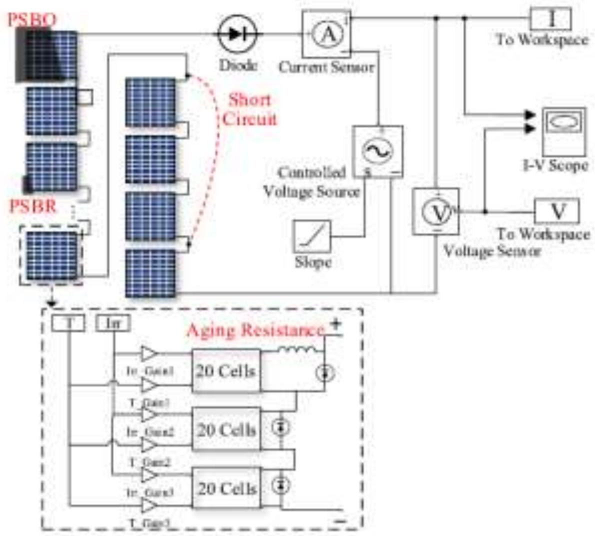

Fig.8. I-V testing circuit and PV module modeling via MATLAB/Simulink [23]

The PV diagnostic model supported the SAMME-CART algorithmic program can do the higher accuracy compared with alternative machine-learning algorisms. Each numerical simulations and experimental results show superior classification and generalization performance than previous researches. The generalization ability is verified by varied modules, and it concludes that the planned fault diagnostic model still will maintain smart accuracy by data from alternative PVS once the fault data is scarce.

III. CONCLUSION

In this paper, an outline of fault detection and classification strategies of PVS is reviewed. Methods are Time Domain Reflectometry method, spectrum time domain reflectometry (SSTDR) technique, artificial neural network (ANN) based technique, time series sliding window, discrete wavelet transform approach. To extend the aggressiveness of PV within the energy market, their reliable, potency and disbursal became crucial factors. As shown during this paper several strategies for fault detection and classification are review.

Methods-based on ANN and Fuzzy Logic are able to distinguish between faults that have constant signature and may classify possible faults. However, the most drawbacks are, they need additional advanced skills with relevance the implementation in real time (experimental realization) and databases (of totally different faults), that don't seem to be invariably offered. In future we will implement fault classification system using artificial neural network and discrete wavelet transform in MATLAB Simulink atmosphere.

REFERENCES

[1] Park, Jae-Do. "Ground fault detection and location for ungrounded DC traction power systems." IEEE Transactions on Vehicular Technology 64.12 (2015): 5667-5676.

[2] Schirone, L., et al. "Fault finding in a 1 MW photovoltaic plant by reflectometry." Proceedings of 1994 IEEE 1st World Conference on Photovoltaic Energy Conversion-WCPEC (A Joint Conference of PVSC, PVSEC and PSEC).Vol. 1.IEEE, 1994.

[3] Alam, Mohammed Khorshed, et al. "PV arc-fault detection using spread spectrum time domain reflectometry (SSTDR)." 2014 IEEE energy conversion congress and exposition (ECCE).IEEE, 2014.

[4] Jiang, LianLian, and Douglas L. Maskell. "Automatic fault detection and diagnosis for photovoltaic systems using combined artificial neural network and analytical based methods." 2015 International Joint Conference on Neural Networks (IJCNN).IEEE, 2015.

[5] Pan, Yan, Michael Steurer, and Thomas L. Baldwin. "Ground fault location testing of a noise pattern based approach on an ungrounded DC system." 2010 IEEE Industrial and Commercial Power Systems Technical Conference-Conference Record.IEEE, 2010.

[6] Zhao, Ye, et al. "Decision tree-based fault detection and classification in solar photovoltaic arrays." 2012 Twenty-Seventh Annual IEEE Applied Power Electronics Conference and Exposition (APEC). IEEE, 2012.

[7] Zhao, Ye, et al. "Line–line fault analysis and protection challenges in solar photovoltaic arrays." IEEE transactions on Industrial Electronics 60.9 (2012): 3784-3795.

[8] Zhao, Ye, et al. "Outlier detection rules for fault detection in solar photovoltaic arrays." 2013 Twenty-Eighth Annual IEEE Applied Power Electronics Conference and Exposition (APEC). IEEE, 2013.

[9] Mirhosseini, Mitra, and Vassilios G. Agelidis. "Performance of large-scale grid-connected photovoltaic system under various fault conditions." 2013 IEEE International Conference on Industrial Technology (ICIT).IEEE, 2013.

[10] Johnson, Jay, et al. "Crosstalk nuisance trip testing of photovoltaic DC arc-fault detectors." 2012 38th IEEE Photovoltaic Specialists Conference.IEEE, 2012.

[11] Bonsignore, Luca, et al. "Neuro-fuzzy fault detection method for photovoltaic systems." Energy Procedia 62 (2014): 431-441.

[12] Hu, Yihua, et al. "Online two-section PV array fault diagnosis with optimized voltage sensor locations." IEEE Transactions on Industrial Electronics 62.11 (2015): 7237-7246.

[13] Dhoke, Amit, Rahul Sharma, and Tapan Kumar Saha. "An approach for fault detection and location in solar PV systems." Solar Energy 194 (2019): 197-208.

[14] Zhang, Wenying, et al. "Weather prediction with multiclass support vector machines in the fault detection of photovoltaic system." IEEE/CAA Journal of AutomaticaSinica 4.3 (2017): 520-525.

[15] Ali, Mohamed Hassan, et al. "Real time fault detection in photovoltaic systems." Energy Procedia 111 (2017): 914-923.

[16] Xiong, Qing, et al. "Arc Fault Detection and Localization in Photovoltaic Systems Using Parallel Capacitors." 2018 IEEE 7th World Conference on Photovoltaic Energy Conversion (WCPEC)(A Joint Conference of 45th IEEE PVSC, 28th PVSEC & 34th EU PVSEC). IEEE, 2018.

[17] Meghwani, Anju, Suresh C. Srivastava, and SaikatChakrabarti. "Local measurement-based technique for estimating fault location in multi-source DC microgrids." IET Generation, Transmission & Distribution 12.13 (2018): 3305-3313.

[18] Dhimish, Mahmoud, et al. "Multi-layer photovoltaic fault detection algorithm." High voltage 2.4 (2017): 244-252.

[19] Dhar, Snehamoy, Rajesh Kumar Patnaik, and P. K. Dash. "Fault detection and location of photovoltaic based DC microgrid using differential protection strategy." IEEE Transactions on Smart Grid 9.5 (2017): 4303-4312.

[20] Mohammedsaeed, Elshiekh K., Mohamed A. Abdelwahid, and KeJia. "Distance protection and fault location of the PV power plants distribution lines." The Journal of Engineering 2019.16 (2019): 2710-2716.

[21] Sarikh, S., et al. "Fault diagnosis in a photovoltaic system through IV characteristics analysis." 2018 9th International Renewable Energy Congress (IREC).IEEE, 2018.

[22] Yan, Ke, Yang Du, and ZixiaoRen. "MPPT perturbation optimization of photovoltaic power systems based on solar irradiance data classification." IEEE Transactions on Sustainable Energy 10.2 (2018): 514-521.

[23] Huang, Jun-Ming, Rong-Jong Wai, and Wei Gao. "Newly-Designed Fault Diagnostic Method for Solar Photovoltaic Generation System Based on IV-Curve Measurement." IEEE Access (2019).

[24] Yi, Zhehan, and Amir H. Etemadi. "A novel detection algorithm for line-to-line faults in photovoltaic (PV) arrays based on support vector machine (SVM)." 2016 IEEE Power and Energy Society General Meeting (PESGM).IEEE, 2016.

[25] Mellit, Adel, Giuseppe Marco Tina, and Soteris A. Kalogirou. "Fault detection and diagnosis methods for photovoltaic systems: A review." Renewable and Sustainable Energy Reviews 91 (2018): 1-17.

[26] Chen, Guodeng, et al. "Location for fault string of photovoltaic array based on current time series change detection." Energy Procedia 145 (2018): 406-412.

[27] Ducange, Pietro, et al. "An intelligent system for detecting faults in photovoltaic fields." 2011 11th International Conference on Intelligent Systems Design and Applications.IEEE, 2011.

[28] Zhao, Ye, et al. "Graph-based semi-supervised learning for fault detection and classification in solar photovoltaic arrays." IEEE Transactions on Power Electronics 30.5 (2014): 2848-2858.