Improving Resiliency of Grid Connected PV System Using Machine Learning based Fault Diagnosis

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Abstract: With the exponential growth of global Photovoltaic (PV) power capacity, it is essential to monitor, detect and diagnose the faults in PV arrays for optimal operation. Hence the present faults can see to occur within the PV arrays in PV systems. Online fault detection for the PV arrays is important to improve the system's reliability, safety and efficiency. There are some researches shows the working of the potential faults in order to monitor the faults as well as to make identifications through fault diagnosis that have been elaborated in order to develop and to modify the present problems solving method so to detect early faults in Photovoltaic (PV) system present in the system operators. In this dissertation work author tries to put information precisely taken forward from previous research. The author also explains about the latest trends applied in the PV system fault diagnosis as well as protection system. In this dissertation work a new approach towards literature has been introduced associated with the fault studies present in the PV systems. In this dissertation work author has explained about further discussions over how specific solutions can be provided to make a comprehensive solution to the fault problems of the PV system.

Keywords--Detection and Identification, Fault Diagnosis, Monitoring Systems, Protection Systems, PV Systems.

I. INTRODUCTION

The PV systems are composed by photovoltaic modules and the balance of system (BOS) that includes wiring, switches, a mounting system and solar inverters. In order to avoid PV system downtime and maintain the output efficiency at high levels to shorten investment payback periods, it is essential for the investors, owners and maintenance operators to have access to the input and output data of the PV system. This data can only be acquired through monitoring systems and should be accessible in real-time for the PV system faults to be addressed accordingly to avoid production loss.

Exploration on MLT is famous and has gotten precise because of accessible programming and figuring limit of the new PCs. The two primary model classes utilized in MLT are arrangement and relapse. Characterization is utilized to distinguish and recognize PV issues while relapse is utilized in PV framework diagnostics which takes into account PV framework execution examination or sun oriented yield estimations.

Close by research on PV framework FDD which predicts flow issues, there is additionally continuous examination on Fault Prognostics that anticipate the presentation over the staying helpful life (RUL) of the PV framework and therefore foreseeing conceivable future faults by utilizing relapse MLT. The RUL of a PV framework is controlled by assessing the debasement pace of the PV modules through corruption models that think about UV radiation, temperature, moistness, condition of-wellbeing models and end of life models. By joining PV framework FDD and Fault Prognostics research regions it is conceivable to create PV framework Prognostics and Health Management (PHM) [4] approaches which assists with arranging preventive, restorative as well as condition-based support trips adding to bring down the O&M costs by an expected 20% and therefore abbreviate venture recompense times on the ROI [5].

Condition-based upkeep is the new term related to the prognostics approach, in which the deficiencies are anticipated and the condition-based support trips are made when the faults happen and in this manner brings down the recurrence of deterrent measures and diminishes the effects and expenses of the remedial measures by envisioning disappointments or getting them early.

The Machine Learning research area is vast, but recently Pedro Domingos shared in his book [8] (recommended by Bill Gates) that MLTs can be organized into five "tribes" and that each one is related to a specific master algorithm. This idea assists with sorting out and restricted down the MLTs that are utilized in PV System Monitoring (PVSM) and demonstrate which MLTs that are not being utilized and may can possibly introduce great outcomes in the PVSM research field. Pedro Domingos safeguards consolidating different ace calculations to make one ace calculation. This thought of consolidating diverse ace calculations is now being embraced in the PVSM research field yet in a littler scope by joining a few Master Algorithms and are alluded to as mixture MLTs. Two instances of half and half MLT can be found in [9] and [10] where the main examination a mixture MLT that utilizes the Genetic Algorithm and an Artificial Neural Network which consolidates the ace calculations. The last work tests a half breed MLT that utilizes a scanty Bayesian learning hypothesis and Support Vector Machines which joins the ace calculations.

II. LITERATUE REVIEW

In this section an overview of various intelligent techniques by using the most popular methods in order to solve various types of engineering problems.

Photovoltaic (PV) system malfunctions cause output efficiency to lower which consequently lowers the return of the investment (ROI) and delays investment payback times. These malfunctions can be limited by implementing Photovoltaic System Monitoring (PVSM) solutions. Recently, Machine Learning Techniques (MLT) have been implemented to improve PVSM results and aid in PV performance and PV fault detection, identification, diagnostics and prognostics. This paper provides a review of the work done in the MLT PVSM research field, provides an organized list of MLT solutions used in PVSM, and provides a list of opportunities and challenges to further research in the PVSM field.

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In this paper [1] author introduced a novel approach that utilizes deep two-dimensional (2-D) Convolutional Neural Networks (CNN) to extract features from 2-D scalograms generated from PV system data in order to effectively detect and classify PV system faults. An in-depth quantitative evaluation of the proposed approach is presented and compared with previous classification methods for PV array faults – both classical machine learning based and deep learning based. Unlike contemporary work, five different faulty cases (including faults in PS – on which no work has been done before in the machine learning domain) have been considered in our study, along with the incorporation of MPPT. We generate a consistent dataset over which to compare ours and previous approaches, to make for the first (to the best of our knowledge) comprehensive and meaningful comparative evaluation of fault diagnosis. It is observed that the proposed method involving fine-tuned pre-trained CNN outperforms existing techniques, achieving a high fault detection accuracy of 73.53%. Our study also highlights the importance of representative and discriminative features to classify faults (as opposed to the use of raw data), especially in the noisy scenario, where our method achieves the best performance of 70.45%. We believe that our work will serve to guide future research in PV system fault diagnosis.

In this paper [2] author introduced Faults detection and analysis in PV system are considered critical for ensuring safety and increasing output power of PV arrays. PV faults do not only reduce output power and efficiency but also lessen the working life time of a system. Most common and chronic PV faults are line to line, line to ground, shadowing fault, and arc fault while less common and acute faults are hotspot, degradation, bypass diode, and connection faults. Event of PV fault detection failures, such as most recent in Mount Holly, USA in 2011 evinced the improvement in current fault detection and mitigation techniques to shrink such failures. There are various limitations in the existing fault detection techniques, as identified in this paper, which may cause misdetection of the faults. This paper is focused on mathematical formulation of various PV faults and lead to the latter's critical analysis in terms of efficiency, accuracy, complexity, and reliability. The presented work also helps to identify nature and causes of occurrence of a PV fault. This research work serves as a special set of references and recommendations for researchers and PV manufacturing industry to improve fault detection prospects in solar PV systems.

In this paper author [9] introduced a deep learning that is artificial neural network (ANN) is the most fundamental model used to detect and classify faults occurring in PV systems. This method is very helpful in order to detect the partial shading faults present in the PV systems for the detection done on the basis of various inputs. In this paper author makes a comparison in between the current outputs, current, voltage as well as maximum power point between the ideal model and output estimation from neural network. The use of ANNs is also recognized for monitoring and diagnosing of real-time PV plant management. An ANN knowledge-based diagnosis system has capabilities to estimate the key components that can aid in damage prevention, extend critical components life-time.

Conclusion: This algorithm improve overall system performance and reliability, minimize off-line analysis effort and maintenance costs, and allow remote plant monitoring, diagnosis and evaluation.

Decision Tree Algorithm

In this paper [5] author proposed intelligent technique based machine learning methods have been approached for fault detection and diagnosis that could be the prominent solution for fault detection in PV systems. This work author applied a decision tree algorithm which is then applied to the grid connected PV systems. A learning method based non-parametric model is used to predict the performance of PV systems, while a data set under different climate conditions is collected through acquisition system. The target of this study is to estimate whether the state of PV system is in either normal or faulty conditions. The faulty conditions are classified as string, short circuit or lineline faults. The testing results indicate the high prediction performance and accurate diagnosis that imply the robustness, effectiveness and efficiency of proposed method. Identifying a fault condition in PV systems is quite tricky because the non-linear characteristic of the system outputs is highly susceptible to climate conditions. For PV system diagnostics, common potential problems exist regarding the performance, modelling and sampling of experimental data.

Conclusion: The performance is sometimes not satisfied due to the lack of monitored fault information. The appropriate model is not reached due to less efficient data collection for model training. Also, it is quite difficult to obtain the fault data samples from field experiments.

Therefore, the new approach of fault detection based machine learning methods is introduced using a vector of seven dimensions based on the I-V parameters response to environmental conditions. This vector is proposed as the input to the fault diagnosis model, using the emerging kernel based extreme learning machine (KELM) and this will be described in the next paper.

Kernel Based Extreme Learning Machine

In this paper [6] author introduced KELM which is characterized as having extremely fast learning speed and good generalization performance. The Nelder Mead Simplex (NMS) optimization method is utilized to optimize the KELM parameters which influence the classification performance. Through simulation and experimental results, the optimized KELM approach for fault diagnosis of PV systems is highly accurate, reliable with improved generalization performance. With high efficiency being the main target of PV system development nowadays, there is a trend to increase in PV plant capacity. The provision method for PV fault identification is an important tool in the effort to increase the PV system efficiency.

Conclusion: These methods have achieved successful identification and localization of fault types under different testing scenarios.

III. PROBLEM DEFINITION

1. Fault analysis in solar photovoltaic (PV) arrays is a fundamental task to protect PV modules from damage and to elim- inate risks of safety hazards. Furthermore, fault behavior of PV arrays is highly related to the fault location, fault impedance and irradiance level. Particularly, the proposed examines the challenges to PV array faults:

2. One is a fault that occurs under low-irradiance conditions, and the other is a fault that occurs at night and evolves during “night-to-day” transition. In both circumstances, the faults might remain hidden in the PV system, no matter how irradiance changes afterward. These unique faults may subsequently lead to unexpected safety hazards, reduced system efficiency, and reduced reliability.

3. Also, the faults in the inverter of Grid connected PV system may mislead the protective relays. The different fault scenarios requiring different relaying actions are not distinguished by conventional protection schemes. In this context, an efficient, quick and reliable fault diagnosis strategy based on machine learning techniques has been proposed to address this issue in addition to performing the tasks of fault detection and localization. The proposed work involves the measurement of three-phase voltage and current signals recorded at the grid side to perform the fault diagnosis.

IV. PROPOSED METHODOLOGY

In this section the proposed methodology is described with the 5-level NPC inverter.

Simulation of Grid connected PV system

Multilevel converters are widely considered to be the most suitable configurations for renewable energy sources. Their high-power quality, efficiency and performance make them interesting for PV applications. In low-power applications such as rooftop grid-connected PV systems, power converters with high efficiency and reliability are required.

Simulation of NPC inverter

The NPC inverters have been widely used in grid-connected systems and in high-power industrial applications such as voltage source converter based high-voltage dc transmission, static VAR compensators, and high-power adjustable-speed motor drives.

Since, the number of switches in the NPC inverter is much higher than in a two-level inverter. Therefore, the possibility of a switch fault in the NPC inverter is higher. There are two types of switching device faults: a short-switch fault and an open-switch fault.

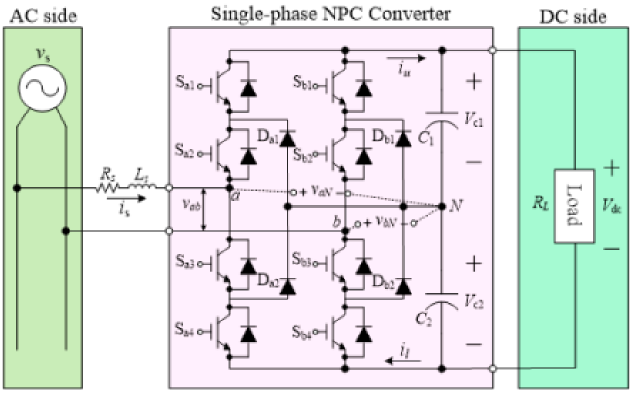

Figure 2: NPC inverter.

Development of protection algorithm

An algorithm that follows the protection concept will be further classified in this section.

Feature extraction using Wavelet transform

Discrete wavelet transform is used to extract characteristics from a signal on various scales proceeding by successive high pass and low pass filtering. The wavelet coefficients are the successive continuation of the approximation and detail coefficients The basic feature extraction procedure consists of

1. Decomposing the signal using DWT into N levels using filtering and decimation to obtain the approximation and detailed coefficients

2. Extracting the features from the DWT coefficients The features extracted from the Discrete wavelet transform (DWT) coefficients of ultrasonic test signals are considered useful features for input into classifiers due to their effective time–frequency representation of nonstationary signals.

Fault detection and classification using K-NN (K nearest neighbor) classifier

The k-NN calculation is a strategy for nonparametric characterization that can create high order exactness in non-ordinary and obscure circulation issues.

K nearest focuses isolating the information and the example are distinguished for a specific example. The Euclidean separation is usually utilized, where the segments of one point are utilized to compare the segments of another point. An information lattice comprising of N lines and M sections is the premise of the k-NN calculation. Boundaries N and M are, separately, the quantity of information focuses and the element of every information point. A question point is given utilizing the information lattice, and inside this information framework, the closest k focuses are looked, which are the nearest to this inquiry point.

Step 1: The work of the proposed algorithm starts from the simulation of the grid connected PV system is done which is the first step.

Step2: In the second step the function call goes at the measurement of the current and voltage samples at the point of common coupling (PCC) will take place.

Step 3: In the third step the control will switch to the extraction of the features from the voltage and the current as well with the help of wavelet transform.

Step 4: In the next step training of K-Nearest Neighbor will be used to obtain an optimal output. The loop will follow the following conditions- if the fault detects then the function control will go to the ANN based fault detector and generate output as –Fault in PV array, fault in inverter and fault in the grid. Otherwise, in second category it will generate outptus as- no fault.

V. SIMULATION SETUP

For the Experimental simulation, the simulation has been done using MATLAB simulation. The MATLAB code was developed using the MATLAB m-file editor toolbox. The test results and performance of the fault algorithm are shown in the following below sections.

PARAMETERS USED

The model is able to analyze the variation of PV parameters such as the ideality factor , Series resistance, thermal voltage and Band gap energy of the PV module with temperature as well as time. Finally a novel intelligent method based on Probabilistic Neural Network for fault detection and classification for PV farm with string inverter technology is proposed.

RESULT ANALYSIS

In this section the outputs obtained at different stages is given-

1. Grid-Connected PV Systm Model

A grid-connected photovoltaic system, or grid-connected PV system is an electricity generating solar PV power system that is connected to the utility grid. A grid-connected PV system consists of solar panels, one or several inverters, a power conditioning unit and grid connection equipment. They range from small residential and commercial rooftop systems to large utility-scale solar power stations. Unlike stand-alone power systems, a grid-connected system rarely includes an integrated battery solution, as they are still very expensive. When conditions are right, the grid-connected PV system supplies the excess power, beyond consumption by the connected load, to the utility grid.

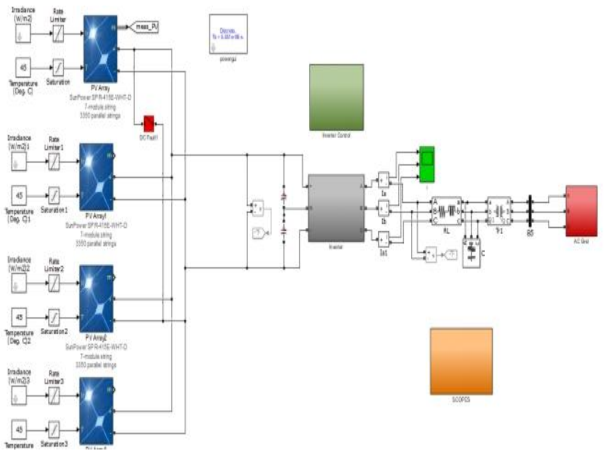

Figure 3: Grid-connected PV System Model.

In the above figure 3 the representation model of the Grid-connecte PV system is shown which is grid-connected photovoltaic system: Mathematical modeling using MATLAB/Simulink.

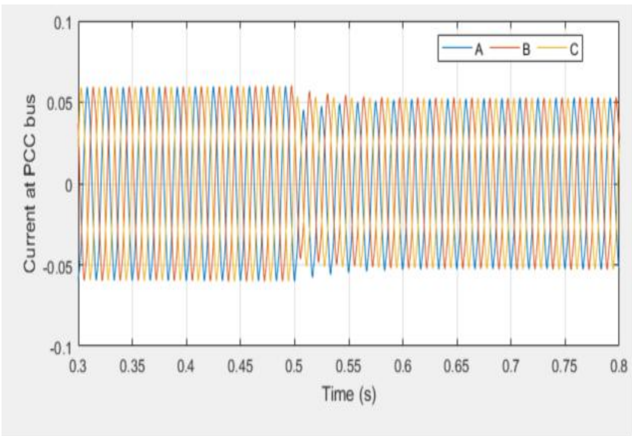

Figure 4: Current waveform at PCC Bus due to PP fault in PV array.

In the above figure 4 the current waveform at PCC Bus due to PP fault in PV array is shown whch represents by time on x-axis and current at PCC bus at y-axisin which requency should be controlled in isolated operation and the power flow through point of common coupling (PCC) should be controlled in the grid connected operation. MATLAB Simulink was used to simulate and analyze both of these situations.

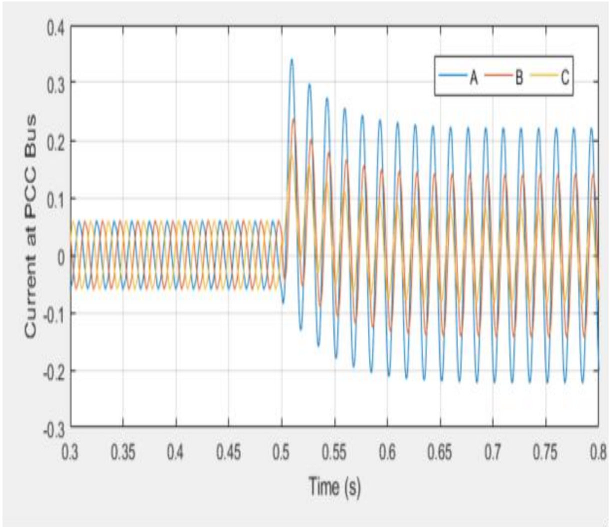

Figure 5: Current waveform at PCC Bus due to line-ground fault in Grid

In the above figure 5 the current waveform at PCC Bus due to line-ground fault in Grid PV array is shown whch represents by time on x-axis and current at PCC bus at y-axis.

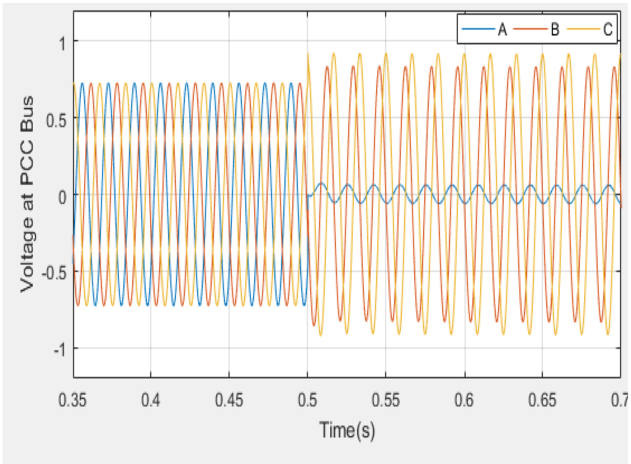

Figure 6: Voltage waveform at PCC Bus due to line-ground fault in Grid

In the above figure 6 the voltage waveform at PCC Bus due to line-ground fault in Grid PV array is shown whch represents by time on x-axis and current at PCC bus at y-axis.

VI. CONCLUSION & FUTURE WORK

Photovoltaic (PV) energy has a fast growing annual rate and is quickly becoming an important part of the energy balance in most regions and power systems. This work aims to study the effects of connecting a PV system to the grid through simulation of the system. Photovoltaic Systems have developed into a mature technology used for mainstream electricity generation. However, they introduce numerous negative impacts into the electrical networks. Studies on three such impacts has been provided. The features extracted from the Discrete wavelet transform (DWT) coefficients of ultrasonic test signals are considered useful features for input into classifiers due to their effective time–frequency representation of nonstationary signals.The k-NN calculation is a strategy for nonparametric characterization that can create high order exactness in non-ordinary and obscure circulation issues. A gridconnected PV test system was considered and simulated. Harmonic content introduced by 4MW PV system with a 3-phase, 2-level DC/AC inverter, at PCC was found to be within the limits. Anti-islanding function of the PV system was studied and found that the critical islanding time of the PV system for the system considered is 125ms. Further, the Performance Ratio of a typical grid connected system in India was calculated in order to compare the performance of the PV system with other systems throughout the world. The studies carried out will help PV power generators and utilities the issues to be studied for a grid connected PV system.

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