Fault Detection and Diagonois Scheme for PV Arrays in the Grid Connected PV System

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Abstract: The PV frameworks has arisen as mainstream elective rather than ordinary assets utilized underway of an electrical energy. The sun based energy is accessible in wealth and attributable to effortlessness of PV framework it tends to be introduced anyplace where as the other environmentally friendly power assets are unevenly spread over the wide topographical zone. The little working and upkeep cost of the PV framework empowers the client to recuperate the venture cost and diminish the compensation time-frame after the establishment of the framework. It has additionally altogether decreased the carbon impression during the cycle of the creation of the power. The solitary burden of PV framework is that proficiency of change of sun oriented energy into electrical energy is as yet bad. The new examination is centered around improving the proficiency utilizing various materials in manufacture of sunlight based boards. Aside from this the accentuation is on expanding the productivity of the activity of the framework. It is similarly critical to decrease the vacation of the framework because of event of the shortcomings. To achive this target a technique is required that can identify, order, find and clear the issue quickly. This paper presents the condition of workmanship on such strategies that can be utilized for issue location and diagonosis.

Keywords—Detection, Classification, Reflectometery, Fault Diagnosis, Protection System, PV Systems, Support Vector Machine, k- Nearest NeigbourAlogorithm.

I. INTRODUCTION

In an oder to meet the deficiency between the age of electrical expanding and dramatically rising interest for it, the part of PV frameworks has gotten critical as they can be placed into service at anyplaceconvieniently. PV system has a capacity to work in islanded mode providing supplying nearby loads and can be effectively amalgamated with primary gridso as to fulfill the need that may emerge over wide gepgraphical region. The plan and design of PV frameworks are not intricated and henceforth the costrealated to its operation is nearly negliglble. The biggest limitation of solar panel is that they have very poor efficiency of conversion of solar energy into electrical energy which is approximately 45% . The erratic and variable changes in the environment duirng the operation of the PV panels influences the proficiency of electrical energy production[2,3]. The dessipation of energy take place in the solar panels because of different faults happening in it, for example, short circui, open circuit, shading and ageing of panels. This may likewise raise the security concerns. On the off chance that these deficiencies go unnoticed it might hamper the proficiency of the panels radically. For recognition of such faultsa infrared detection can be used to locatethe point of fault.The fault occuringin the PVpanels results in to rise in temperature and this cuases the heating of panels. The ascent in temperature can be identified with the assistance of the thermal scanner.For improving the general efficiency of the systemit is essential to improve the effectiveness of the elements of the system, for example, power converters, battery chargers, batteries and the operation of the PV system. For this it is expected to recognize the concealed faults in the system and categorize them so that reasonable protection plan can be implemented to clear the faults and avoid repition of the same in future.

Various machine learning & artificial intelligence based techniques have emerged recently that are used in fault detection and diagonosis. Normal to each one of these methodis the assortment of data identified related voltages and current by measureing them at different strategic points in the PV system. These collected signals are utilized to frame the data base for learining. At that point information mining strategy is utilized to recognize the concealed patterns in the leariningdata base which is additionally used in order of data. Toward the end this data helps in making a choice of with respect to control startegy and protection method which may be alarms or automated commands to initiate sequence of action.

II. LITERATUE REVIEW

FouziHarrou et al [15] proposed the statistics basedmethodology that includes the beneficial features of the one diode model and the exponentially weighted moving normal (EWMA) for recognition and categorization of faults occurring at the DC side of the PV frameworks. The set of residuals of the current, voltage and force is formed by estimating the temperature and irradiance levels which is additionally used in deciding the imbalance among estimated and the anticipated value for the Maximum Power Point (MPP) and afterward utilize this as a markers of the faults. After this multivariate EWMA is applied to these residuals for identifying the

faults yet it doesn't give any data about the fault type which can be additionally recognized by applying univariate EWMA chart. The issue of unnecessary alert messages and unidentified fault recognition due to failure of satatistical analysis can be evaded by multi scale representation to generalized likelihood ratio test (GLRT)and considering its temperament fluctuation [16]. MS-WGLRT is assessed dependent on estimated and reenacted information of PV system. It is then used to plot graph in aorder to identify faults. In this paper [20] author proposed a procedure that assess the shortcomings dependent on multi class reinforce vector machine (SVM) examination through online computation. Multiplication models are utilized to address the photovoltaic modules and are execute to look at the line-to-line fault and unpredicted debasement shortcomings.Ali, M. H. et al [21] presented a strategy for methodical observation and summing up the insufficiencies in PV system. The proposed methodology depends on assessment done withaid of investigation of differential development in connection with broken photovoltaic module and its exact model.

Mahmoud Dhimish et al [34] introduced the technique in which the set operation of PV system is reproduced via simulation and statistical examination is completed on information estimated in the system. The measurable t-test is utilized in contrasting the hypothetical and praticaloutput power and which is then used as an identifying the faults. The point of the fault is eatimatedby ascertaining the ration of the deliberate and hypothetical DC power and voltage. The strategy is capable in identifying various faults ordered under eight distinctive fault categories on numerous strings. Factual investigation is utilized to deterine whether the PV modules output is influenced by fracture on the sun panels. Electroluminescence is noticed ceaselessly for recognizing the potential faults in such situations [29]. Karim, I. A. et al [37] assessed the decrease in the productivity because of issues related with Solar PV cell and modules. They brought up the burdens of petroleum derivatives to be utilized underway of power and various points of interest of executing sustainable power hotspots for practical creation of electrical energy.

Table 1: Summary of Computational Methods.

Authors	Methods	Purpose	Tasks
V.S.B Kurukuru [1]	Feature extraction competence of wavelet transform and classification traits of RBFNs	Fault detection & diagnosis	Enhancement in stability & operation of PV system
M. Muttilo [2]	Thermographic inspection	Identification of fault and losses without disturbing the operation of PV system	Analysis of the efficiency drop in PV system due to faults
Elyes Garoudja [20]	Exponentially weighted moving average (EWMA)	Early fault detection	Detection of faults at DC side of the system due to shading of PV modules
Siva Ramakrishna Madeti [14]	k-nearest neighbors rule	Classification and detection of faults on real time basis	Open circuit, L-L faults, partial shading of PV modules considering both cases of bypass diode presence and absence and faults due partial shading considering inverted bypass diode
FouziHarrou [15]	Univariate and multivariate EWMA	Detection & diagnosis of fault	Fault monitoring at the direct current side of the system
Majdi Mansouri [16]	Multi scale weighted generalized likelihood ratio test	Monitoring & detection of Faults	Reduction in false alarm and missed identification rates
Kashyap, N., & Gautam, A. [23]	State machine model	Detection of fault in DC converter	Adherence to Peak Current Mode control procedure

			along with inordinate slope signal.
Mahmoud Dhimish [34]	Statistical *t*-test method	Detection of multiple fault on multiple array	To compare the measured and standard output power for indicating the faults.
A Grid Connected PV System Fault Diagnosis Method [35]	Nikolaos Sapountzoglou, Bertrand Raison/IEEE/2019	Creation of the fault signature table based on response of system to various fault scenarios	The fault diagnosis method generates alarm signal in 60 ms

III. PROBLEM DEFINITION

The PV systems having intermittent output when integrated to main utility gridraises poses threatsassociated with stable operation of grid. These treats may include issues related to quality of power, inconsistency in output of system due to unpredictable availability of solar energy, need of energy stotrage elements, requirement of placing the DERs for achieving optimal operation, avoidance of anti-islanding and the faults occurring in the system.

There are faults occurring in PV framework may go unidentified. It results into damage and malfunctioning of the PV system and influences the proficiency and productivity apart from raising protection and safety related issues in the system. It is needed to have inclusive strategy which can carry out the assignment of identification, location, categorization, disengagement and clearances of faults. Citing the abouve said problem this paper has an objective of characterizing the different faults that may happen in a PV system and explain the limits of conventionaltecjniquesfor recognition and concealment of faults in PV system connected to main grid.

IV. PROPOSED METHODOLOGY

This segment details the methodology adaopted based on decision tree classifier to achieve the objective elaborated in last section.

Simulation Pv System Connected To Utility Grid

The model of PV system connected to the utility grid is developed and simulated using MATLAB Simulink. Inverters are used to connect the PV modules is DC in natur to the utility grid as the ouptput of PV moudules is DC. The control objectives of the inverter includes the boosting of power generation to the maximum and to maintain the active and reactive power to be maintained constant at AC bus.

Decision Tree Based Protection Scheme

Decision tree incorporates the assortment of sufficient data from the PV system which is additionally utilized as the information base for learning. At that point model is developed and its assessment and interpretaionis done by determining the concealed patterns in the learning data set by utilizing the data mining engine. Than the information collected is utilized in categoriization of data that is further utilized for choosing appropriatecontrol strategy that might be suggestions or actions.

Flowchart of Algorithm

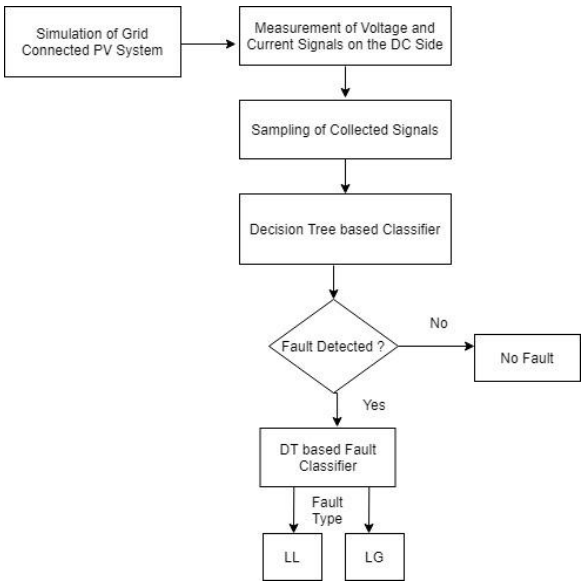

Figure 1. Algorithm flowchart

The flowchart of the proposed algorithm is shown in Fig.1. It involves the following steps:

1. The modelof PV system integrated to main grid is designed and proposed. It uses DC/DC boost converter for connecting the PV panels to the DC bus and then DC/AC inverter for connecting it to AC grid
2. For discrete class decision tree classifier is used while regression tree is used for the continuous values. However the predicator vectors may consists of both numerical variables and categorical variables
3. The detection & classification of fault is carried out by using fault classifier based on Decision Tree method.

V. SIMULATION SETUP

This section elaborates the simulation models utilized in this study

1. MATLAB Simulink model of Grid Connected PV System

PV system consisting of PV arrays is integrated to main grid utilizing 3 Level VSI, inverter controller, Loads & coupling transformer. The system is competent of producing the electrical energy in islanded mode catering the local demand within well defined electrical boundary as well as in grid connected mode when the production of electrical energy is in surplus.

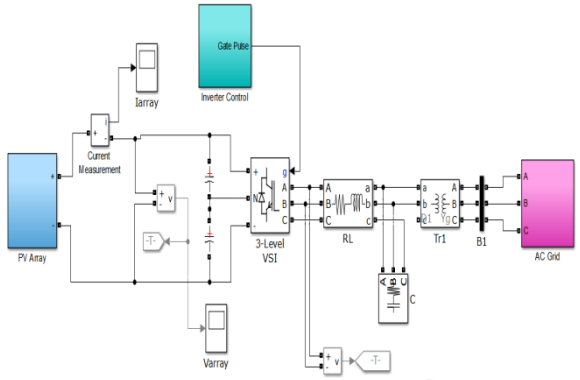

Figure 2. Simulink Model for PV System Connected to the main grid

2. Simulink Model of Series Parallel Distributed Arrangement of PV System

It constitutes of number of PV modulesalongwith their bypass diode connected in series parallel combination. This facilitatesthe simulation of faults occurring within PV module arrays. MATLAB Simulink has been used in developing the model of the said arrangement as asshown in Figure 3.

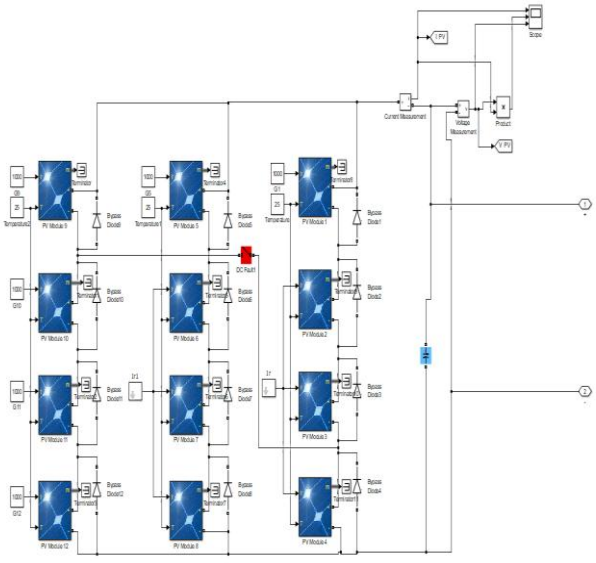

Figure 3.PV array arranged in Series-parallel combination

The Figure 4 shows the MATLAB Simulink Model of the Closed Loop Inverter Control

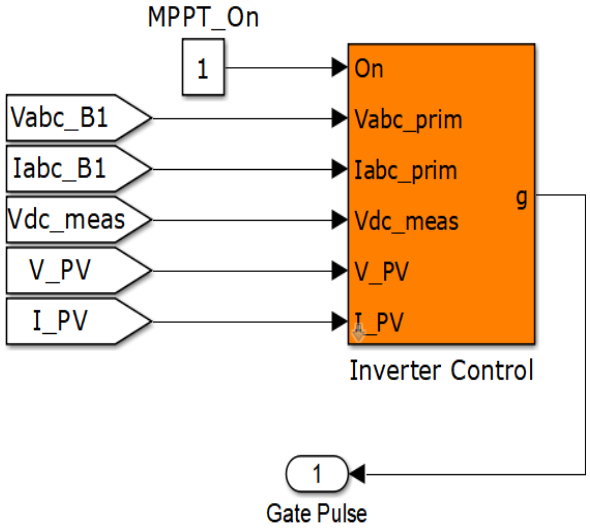

Figure 4. Simulink Model of Close Loop Inverter Control

The Simulink model of PV system connected to the AC Grid consisting of 12kV 2500 MVA generator, with 120kV/25kV, 47 MVA step down transformer, the feeder lines the connected loads are shown in Figure 5.

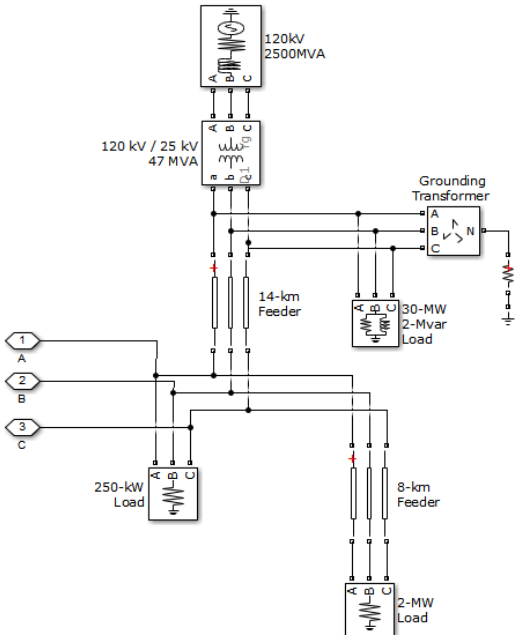

Figure 5. Grid connected PV System

3. I-V and P-V Charateristics of PV Array

I-V characteristic of the PV array represents the relationship of current and voltage forspecific irradiance conditions. The necessary information neededto configure the PV system for achievingits optimal operation close to peak power input can be determined using I-V Characteristics. Figure 6shows the I-V and P-V characteristics of the PV array (Sun Power SPR X20-250-BLK) taken in this study. These characteristics enables to find out the magnitude of current, voltage, maximum power point (MPP) under range of irradiance level.

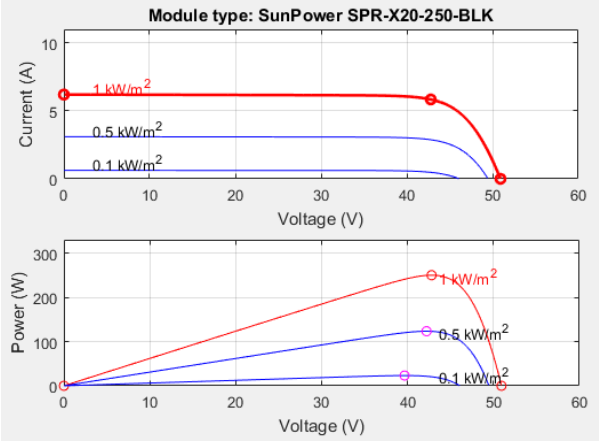

Figure 6.I-V and P-V characteristics of the PV module at different irradiances levels

Irradiance Level	Power (W)	Voltage (V)	Current (A)
1 kW/m^2	250	45	6
0.5 kW/m^2	110	44	4
0.1 kW/m^2	10	40	1

Table1: Comparative study of power, voltage and current for different levels of irradiance level

Table 1 presents the comparative analysis of the Maximum Power Point (MPP) under different levels of irradiance Sun Power SPR X20-250-BLK considered for study.

VI. RESULT ANALYSIS

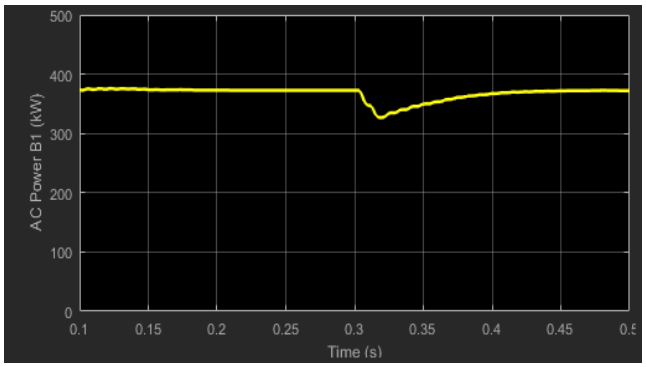

Figure 6. Waveform of Power (in kW) during fault (Pole to Pole) at t = 0.3 s at irradiance of 0.8kW/m^2 in Bus B1

Figure 6shows the waveform of power corresponding to line–line fault occurred at String #1 of bus B1 under low irradiance condition. The time base is 0.05 s/div, for voltage V_{sys} upper trace is 8000 V/div, and for current lower trace is 0.5 A/div.On occurrence of fault the MPPT acts swiftly and reducesVsysto optimized output of the PV array. The previous value of voltage is restored after 0.3 s as MPPT clears the fault.For the same fault as compared to high irridance condition no negative peak of I_{Back} has been observed. Thereforesimulation result exhibits that there is increment in I_{Back} under high irradiance condition has and this prevents the melting of PV modules.

Figure 7. shows the waveform of voltage corresponding to low irradiance condition for line–line fault occurring at String #1. The time base is 0.5 s/div, upper trace is 600 V/div for voltage V_{Sys}.MPPT respond rapidly after fault occurred at t = 0.3 s and reinstate the PV array operation at optimum output level by decrementing the V_{Sys}. It also limits the value of I_{Back} even under high irradiance conditions thereby avoiding the melting of modules.

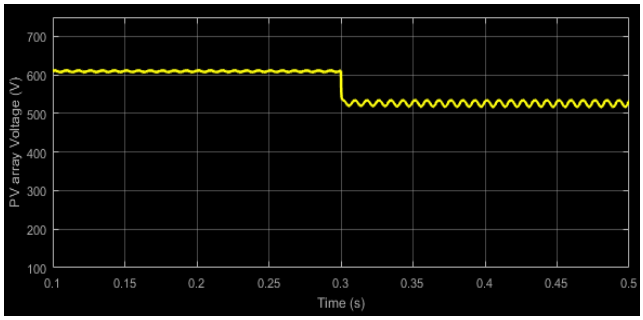

Figure 7. Waveform of Array voltage at irradiance of 0.8kW/m^2 for Pole to pole fault occurring at t =0.3 s

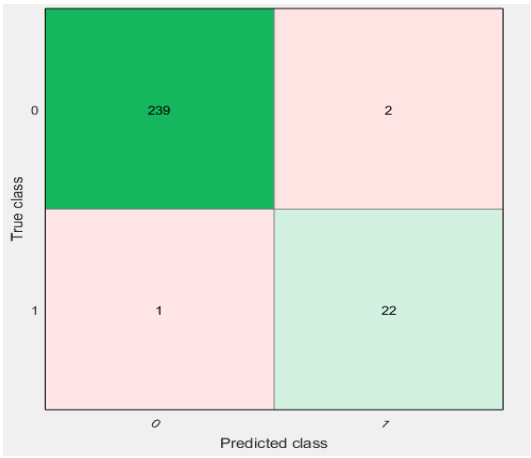

Figure 8. Confusion Matrixfor Pole to pole and pole to ground fault occurring at t =0.3 s

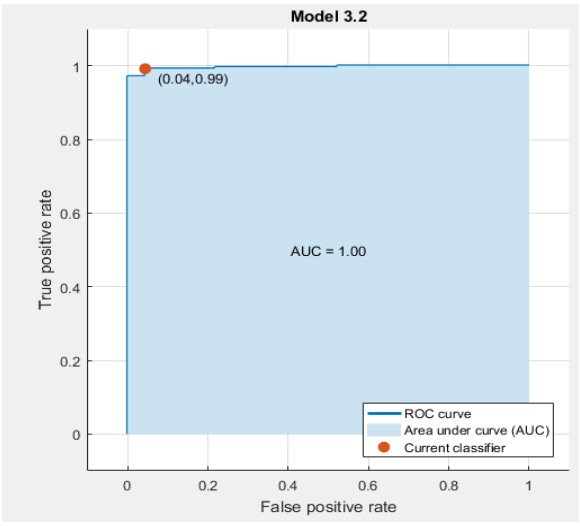

Figure 9.ROC curve for the proposed model.

VII. CONCLUSION AND FUTURE SCOPE

Owing to numerous advantages PV systems have gained popularity over other other resources in production of electricity. The input to such system i.e. sunlight is available in abundance, simplicity of system architecture, ease of operation and maintenanceand feature of integrating with main uitility grid are the few make the PV system indespensible choice. Howeveroperating in gid connected mode PV system give rise to issues realted to stability of the grid.The solar panels have intermittent output and this may cause faults that may go unidentified &lead to catastrophic failure. This paper intended to recognize, locate &clear the faults with the help of machine learning. The grid connectdPV system constituting arraysconnected in series and parallel combination has been taken for the study. The simulation of line to line fault is carried out on proposed model for the irradiance level of 0.8kW/m2. The waveforms of power and array voltage were recorded and considered for further analysis. It is concluded that MPPT acts rapidly as the fault occurs at t = 0.3 s reduces the system voltage i.e.V_{sys} and this helps in achieving the optimal operation of the PV system. The value of AUC as observed from the ROC curves of PG & PP Classes is shown in fig. 8 and fig. 9 respectively.The proposed strategy for detection and classification of fault has shown its efficacy in realizing the defined objective however some modifications still can be made which are listed as below:

1. Only grid connected PV system has been considered for the study, The effectiveness of the proposed scheme can be checked for other DERs such as wind turbines, Fuel cells etc integrated to grid.
2. The analysis of line to line faults have been carried out in this study.Other faults such as all line to ground (L-L-G), line to line (L-L) faults can also be analyzed.
3. A detailed comaparative analysis can be made by applying different machine learning techniques for the same problem

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