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Classification and Detection of Faults in Grid Connected Photovoltaic System

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Abstract – An integration of distributed generations (DGs) to the utility grid has raised the need for good power quality, safety operation and islanding protection of the grid interconnection. This paper presents the classification and detection of faults in a distributed generation, particularlyphotovoltaic (PV) grid-connected system. The initial step in fault detection of PV system is recognition, investigation and classification of all possible faults that maybe occur in the system. The classification, simulation and discussionof all possible faults in both AC and DC side of PV system are presented, where 100 kW array connected to a 25 kV grid via a DC-DC boost converter and a three-phase three-level Voltage Source Converter (VSC).

Keywords **-100 kW PV array, 25kV grid, AC and DC side Faults, Grid connected PV system.**

I. INTRODUCTION

Power generation based on PV sources has gradually increases during the last few decades [1]. This development has been matched with research into more efficient solar panels. Efficiency is calculated as the ratio of incident sun energy to the maximum attainable output power, with the recent record being an efficiency of 44.7% [2]. Along with research into solar panels, there is also an interest in the adjacent equipment. The efficiency of solar panels naturally range throughout the system, since any losses will disturb the final efficiency of the whole system. The standard configuration of a Grid Connected PV System (GCPV) is shown in Figure 1.

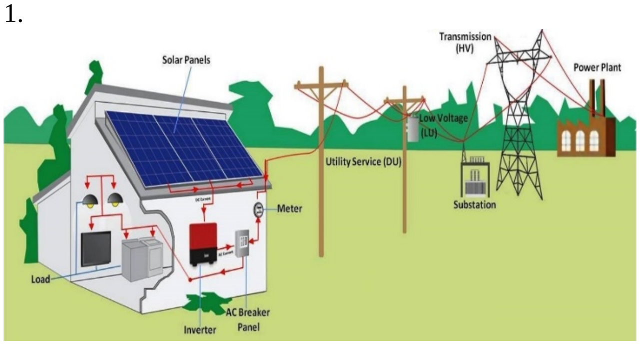

Fig. 1 Standard configuration of a Grid connected PV system

Recently, the area PV inverters has progressed to distributed systems of inverters,where a small inverter module is connected to every panel [3]. This is favorable since each panel can be enhanced locally, thereby improving the energy harvest. Besides increased efficiency, this also allows individual measurements of solar panels. These new capabilities make new possibilities in monitoring of the health of solar panels that is technically termed as fault detection. The output power degradation not only depends on the PV panels. The occurrences of faults in any other components such as Maximum Power Point Tracking (MPPT), inverter, Voltage Source Converter (VSC) and grid in the power system may results in output power change.

II. LITERATURE REVIEW

Currently, many identification techniques are established for possible faults detection in PV systems. Some of these do not need climate data such as the earth capacitance measurement (ECM) developed in [4], which having an electrical method for locating the disconnection of PV module in a string. The time-domain reflectometry (TDR) that measures the electrical characteristic of a transmission line, which can detect not only the disconnection in the string, but also the impedance change due to degradation is presented in [5]. A statistical method based on the ANOVA (Analysis of Variance) test and nonparametric Kruskale-Wallis test thatdisplays a high level of accuracy and is fast in fault diagnosis is proposed in [6]. A remote monitoring and fault detection method of small GCPVsystems is presented in [7], where climate data from satellites observation that replaces on-site measurements is used. Then, the expected energy yield is computed and compared with the measured one. The expected system's energy yields do not have the same accuracy than yields calculated from real measured data and values with root mean square error (RMSE) of about 10% have been stated for irradiance estimated using these methods[8]. Using this different types of faults can be identified: constant energy losses, variable

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energy losses [9] and losses due to the presence of snow. Other researchers used climate data measured by local sensors on the plants. A three layered feed forward neural network, to identify the short-circuit location of PV modules in one string is proposed in [10]. An intelligent system for automatic detection of faults in PV fields based on a TakagieSugenoeKahn Fuzzy RuleBased System (TSKFRBS) is described in [11]. The results show that the system can identify more than 90% of fault conditions, even when noisy data are introduced. Learning methods [12], for monitoring system simplifies the operation and maintenance of the PV systems, even if it needs many measurement sensors, whichidentify shading and inverter failure. A technique [13] that used only few measurement sensors, which can categorize the energy losses in four different types: sustained zero efficiency faults, brief zero efficiency faults, shading, and nonzero efficiency non-shading faults.

A simple investigative method to identify the number of open and short-circuited PV modules in a string with a small number of sensors is presented in [14]. Line to line fault that occurs under low irradiance conditions and occurring in PV arrays where blocking diode have been used is stated in [15]. A fault identificationmethod based on the extended correlation function and the matter element model has been presented in [16]. The results shows that the proposed fault diagnosis method detects the malfunction accurately and quickly. The (-dI/dV)-V characteristic to detect the partial shadow phenomenon is proposed in [17]. The fault detection and classification method based on decision trees (DT) is presented in [18].

A fault detection algorithm acting on the power conditioning system of the PV plant using wavelet transform is proposed in [19]. This method detects the fault and its location without any additional hardware. But this method has high cost and re-design problem if the inverter specification has been changed. An automatic fault detection method based on the power losses analysis is proposed in [20]. This method detect faults that occur only on the DC side of the PV system. The method canidentify four different types of faults: faulty modules in a string, faulty string, false alarm andcombined faults such as partial shadow, ageing, and MPPT error. In this paper, the classification and detection of all possible faults in both AC and DC side GCPV system are presented, where 100 kW array connected to a 25 kV grid via a DC-DC boost converter and a three-phase three-level VSC.

III. CLASSIFICATION OF FAULTS IN GCPV SYSTEM

Faults in PV system can be identified in two side of the system: DC side and AC side, the interface between this to part is DC/AC inverter that connected to grid.The classification of faults is shown in Figure 2.

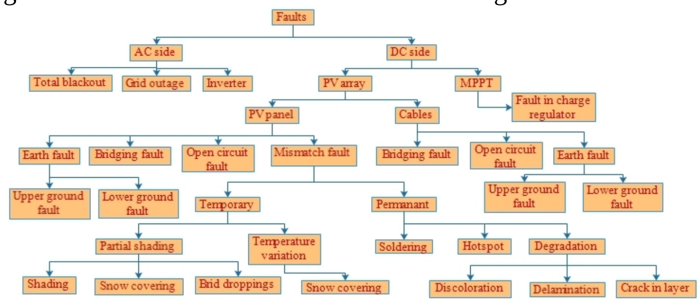

Fig. 2. Classification of faults

A. *Faults in DC side*

The faults occurs in DC side of the GCPV system are classified into two major types: Fault in PV array and Fault in MPPT.

A.1. Faults in PV Array

Faults in PV arrays involve two main groups, PV panel fault and cabling. The most common types of fault in PV Panel/Module are Earth Fault, Bridge Fault, Open Circuit Fault and Mismatch Fault.

a) PV panel/Module Faults

1) Earth Fault

Earth fault occurs when the circuit develops an unintentional path to ground.Two types of grounding shall be provided for PV system such as system grounding and equipment grounding. In system grounding, the negative conductor is grounded through the Earth fault protection device (GFPD) in the PV inverter. The exposed non-current-carrying metal parts of PV module frames, electrical equipment, and conductor enclosures should be grounded in equipment grounding.Two types of Earth faults namely Lower Earth fault and Upper Earth fault can occur.In Lower Earth fault, the potential fault point is upper than half of the maximum voltage power point. And the Upper Earth fault will create large backed current and very high Earth-fault current. Without any sensor, these faults areidentified, when the sign of the monitored primary current of the solar inverter is changed. When the primary current becomes negative, the solar inverters initiate a controlled internal short circuit [21].

2) Bridging fault

When low- resistance connection recognized between two points of different potential in string of module or cabling, the bridging fault will occur. Insulation failure of cables such as an animal chewing through cable insulation, mechanical damage, water ingress or corrosion cause these faults.

3) Open Circuit Fault

An open circuit fault occurs, when one of the current-carrying paths in series with the load is broken or opened. The poor connections between cells, plugging and unplugging connectors at junction boxes, or breaks in wires cause these fault.

4) Mismatch Fault

When the electrical parameters of one or group of cell are changed from other, the mismatches in PV modules will occur. These fault results in irreversible damage on PV modules and large power loss. These faults can be classified into permanent and temporary mismatches.

Temporary mismatches occurs when a part of the panels array are shaded by shade from the building itself, light posts, chimneys, trees, clouds, dirt, snow and other light- blocking obstacles [22]. Non- uniform temperature can identified due to snow covering.

Permanent mismatch occurs due to faults in hotspot, soldering and degradation. Hot spot heating happens when the operating current exceeds the reduced short circuit current of a shadowed or faulty cell or group of cells within the module [23].

Soldering fault can be identified in resistive solder bond between cell and contacted ribbons. Discoloration, delamination and transparent layer crack result in degradation fault.

b) Fault in cables

Bridging Fault, Open-Circuit fault and Earth Fault are occur in power line carrier and cabling system. An aged connection box at the back side of a solar panel or in the corner and bend aria of cable cause bridging fault[24]. Upper earth and lower earth faults occur between panels and ground. It results in dropped output voltage and power, and can be dangerous if the leakage currents are running through a person.

A.2. MPPT fault

MPPT increases the power fed to the inverter from PV array. The performance of MPPT degrades when the failure occurs in the charge regulators. The output voltage and the output power reduces when fault occur in MPPT.

B. Faults in AC side

In AC side two types of faults can be identified: total black out which measured as exterior fault for system, lighting and unbalanced voltage or grid outage for AC part defect such as weaker switch, over current or over voltage and etc. Meanwhile most PV inverters having transformers that could give good galvanic isolation between PV arrays and utility grids and perfect electrical protections.

The AC output power will become low and DC output power remains the same, when there is a fault in the inverter. This details confirms that there is no possibility that a wire between modules/strings and inverter was broken or a breakdown occurs in strings and/or modules. So, fault in the inverter is the reason for power loss.

IV. SIMULATION RESULTS AND DISCUSSION

All the possible faults in both AC and DC side GCPV system are simulated with 100 kW array connected to a 25 kV grid, using MatLab Simulink model. The details of GCPV system is given in Table I.

TABLE I Details of GCPV system

Components	**Specification**
PV array	100-kW capacity, 330 SunPower modules (SPR-305), 66 strings of 5 series connected modules, (66*5*305.2 W= 100.7 kW)
Single PV module	No. of series connected cells : 96, Open circuit voltage: Voc= 64.2 V, Shortcircuit current: Isc = 5.96 A, Voltage and current at maximum power : Vmp =54.7 V, Imp= 5.58 A
Boost Converter	5-kHz, Increase 272 V DC to 500 V DC
MPPT	Incremental Conductance + Integral Regulator technique
VSC	1980-Hz (33*60) 3-level 3 phase VSC, converts 500 V DC to 260V AC and keeps unity power factor, 10-kvar capacitor bank filtering harmonics produced by VSC
Grid	100-kVA 260V/25kV 3 phase coupling transformer, 25 kV distribution feeder + 120 kV equivalent transmission system

The simulation for fault identification have been done under six different fault conditions such as no fault, fault in PV panel, fault in cables, MPPT fault, inverter fault and grid fault. The developed Simulink model of GCPV system to identify faults in MatLab is shown in Figure 3.

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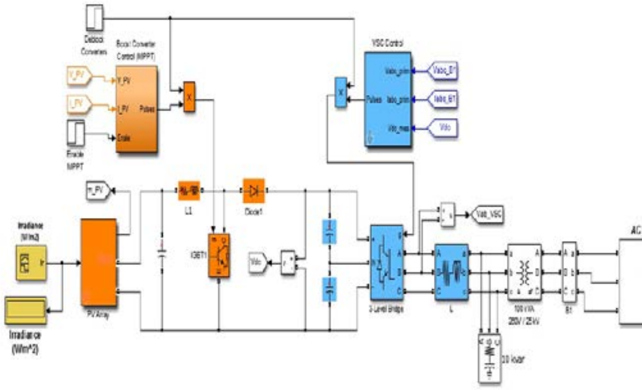

Fig. 3. MatLabsimulink model for GCPV system

A. No fault condition

The output power available at grid under normal operating condition is shown in Figure 4.

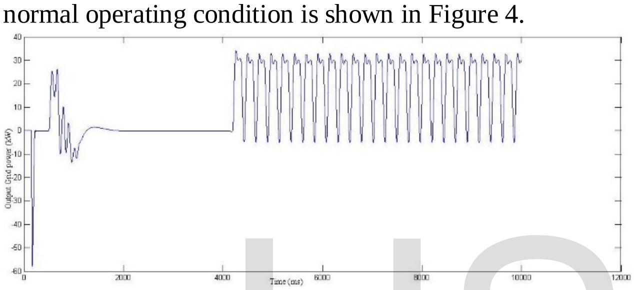

Fig. 4. Output power at grid under no fault condition

The GCPV system can able to provide the maximum power of 34 kW at grid, under no fault condition. The availability of the grid power is also consistent throughout the operation. Figure 4 shows that there is no possibility of breakdown or malfunctioning of modules, strings, or inverters.

B. Fault in DC side

The faults can occur in DC of the GCPV system can be classified as PV array fault, cable fault and MPPT fault.

B.1.Fault in PV array

In order to detect the fault in PV panel, ten PV array have been disconnected. The output power available at grid when fault occurring in PV array is shown in Figure 5. It shows that the output power becomes very low due to the failure in PV array.

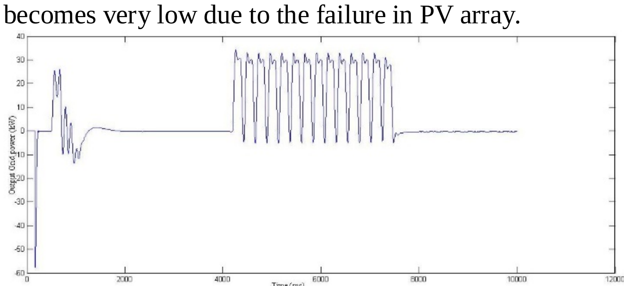

Fig. 5. Output power at grid when fault occurring in PV array

B.2. Fault in cables

Fire can probably occur when there are faults in cables and soldered joints. These faults results in reduced output power as shown in Figure 6.

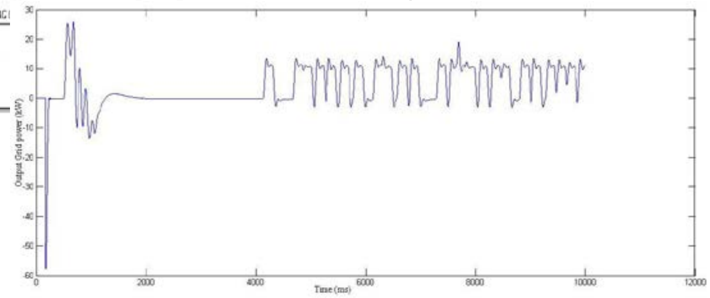

Fig. 6. Output power at grid when fault occurring in cables

B.3. MPPT fault

The maximum power tracking ability will loss when the fault occurs in MPPT. The output power becomes too low in this case. Figure 7 shows the reduced output power at grid under MPPT fault condition.

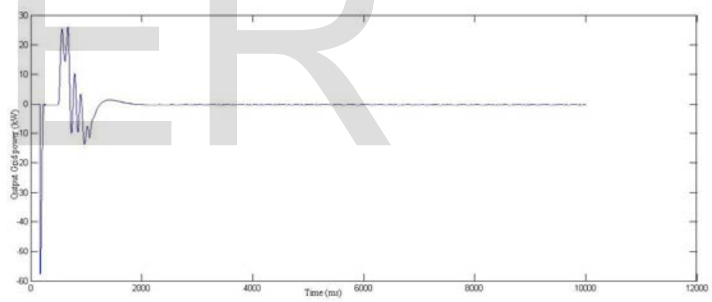

Fig. 7. Output power at grid under MPPT fault condition

C. Fault in AC side

The failure happens in inverter and grid coming under AC side fault of GCPV system. In this case the DC power remains same as the power in no fault condition.

C.1. Inverter fault

Under inverter fault condition, the output AC power at grid is lower than the AC power recorded under no fault condition, but the DC power are same for both cases. The output AC power under inverter fault condition is shown in Figure 8.

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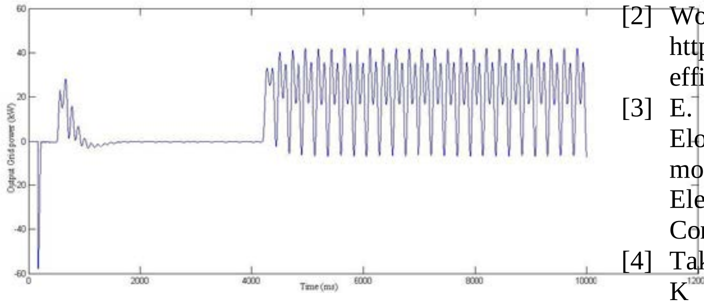

Fig. 8. Output power at grid under inverter fault condition

Figure 8 confirms that there is no possibility of occurring fault in DC side. So, fault in the inverter is the reason for power loss.

C.2. Grid fault

Faults at power stations, damage to electric transmission lines, substations or other parts of the distribution system, a short circuit, or the overloading of electricity mains are considered as grid fault. A three phase fault is created at grid to measure the output power and is shown in Figure 9. It shows that the output power at grid varies continually from maximum to minimum value.

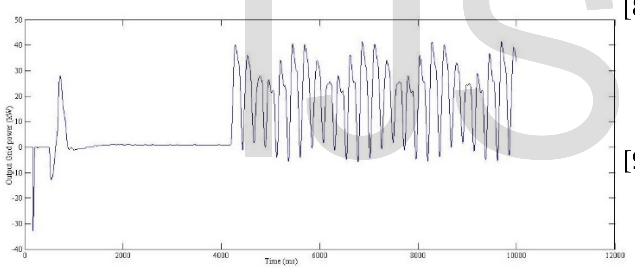

Fig. 9. Output power at grid under grid fault condition

V. CONCLUSION

The classification, simulation and discussion of all possible faults in both AC and DC side of a GCPV system is presented. The output power waveforms are plotted under different fault conditions. The fault can be easily identified by comparing the output powers with no fault condition.This procedure has been simulated for 100 kW GCPV plant using MatLab Simulink model.

In the future, we aim to develop an automatic procedure to detect and locate fault in GCPV system with LCD display and flash alarm to alert users about the fault in real time.

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