A METHOD TO DETECT PHOTOVOLTAIC ARRAY FAULTS IN PV SYSTEMS

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Abstract— *Abnormal conditions such as faults and partial shading lead to a reduction in the maximum available power from a photovoltaic (PV) array. Thus, it is necessary to detect partial shading and faults in a PV array for improved system efficiency and reliability. Conventional protection devices fail to detect faults under cloudy and low irradiance conditions, leading to safety issues and fire hazards in the PV field. This paper proposes a method to detect faults and partial shading under all irradiation conditions using the measured values of array voltage, array current, and irradiance. The proposed method enables classification of the status of the PV array into three possible scenarios, viz., normal operating condition, partial shading, and fault.*

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1. INTRODUCTION

In recent years, the huge growth of photovoltaic (PV) capacity has necessitated a foolproof protection system in order to improve system reliability, efficiency, and safety. Conventional protection systems for PV arrays consist of over current protection devices (OCPD), arc-fault circuit interrupters, and ground fault protection devices (GFPD). The challenges in protection for PV arrays includes the negative impact of environmental conditions, maximum power point tracking (MPPT) controller, and blocking diodes in fault detection, along with the inability of OCPD to detect faults under certain conditions.

Faulted and partially shaded PV arrays have reduced maximum power points (MPP) compared with normal operating conditions. Partial shading leads to the presence of multiple peaks in the PV Characteristic. Because of the non-linear output characteristics of PV arrays, a variety of faults may be difficult to detect by conventional protection devices**.** This paper proposes a method to detect the occurrence of faults in a PV under all irradiation conditions using the measured values of array voltage, array current, and irradiance.

2. LITERATURE REVIEW

Use of PV circuit simulation for fault detection in PV array fields by D.Stellbogen, faults are detected by comparing the actual electrical array quantities with expected array quantities. The latter are obtained from simulations, which take in constant inputs of geometrical configuration parameters of the array and variable inputs of meteorological data. However, the deviation threshold for detection of fault is not discussed in this work.

Automatic fault detection in grid connected PV systems presented by S. Silverstre. The measurands considered here are irradiances, the horizontal plane and in PV modules plane, the ambient temperature, as well as electrical quantities at the dc and ac sides of the PV system, which are fed into simulation to calculate the normalized capture losses. Thresholds are defined in this work so as to detect the presence of faults in PV array, but the method does not differentiate between partial shading and short-circuit faults.

Outlier detection rules for fault detection in solar photovoltaic arrays proposed by Y. Zaho. This works presents fault detection method in which all PV string currents are measured and tested under outlier detection rules. The best-performing outlier detection rule for short-circuit faults was found to cause false alarms during normal conditions after and before the occurrence of partial shading. In addition, the method of distinguishing between partial shading and other faults has not been discussed.

3. SOLAR CELL

The Solar energy is a renewable, inexhaustible and ultimate source of energy. If used in a proper way, it has a capacity to fulfill numerous energy needs of the world. The photovoltaic energy is a source of interesting energy; it is renewable, inexhaustible and non-polluting, and it is used as energy sources in various applications. But because of its high cost and low efficiency, energy contribution is less than other energy sources. It is therefore essential to have effective and flexible models.

A. *Principle*

A solar cell or photovoltaic cell is an electrical device that converts the energy of light directly into electricity by the photovoltaic effect, which is a physical and chemical phenomenon. It is a form of photoelectric cell, defined as a device whose electrical characteristics, such as current, voltage, or resistance, vary when exposed to light. Solar cells are the building blocks of photovoltaic modules, otherwise known as solar panels.

B. *Operation*

The operating principle of today solar cells is essentially the same. It is based on the photovoltaic effect. In general, the photovoltaic effect means the generation of a potential difference at the junction of two different materials in response to visible or other radiation. The basic processes behind the photovoltaic effect are generation of the charge carriers due to the absorption of photons in the materials that form a junction, subsequent separation of the photo-generated charge carriers in the junction and collection of the photo-generated charge carriers at the terminals of the junction. In general, a solar cell structure consists of an absorber layer, in which the photons of an incident radiation are efficiently absorbed resulting in a creation of electron-hole pairs A solar cell is a solid-state electrical device nothing but the p-n junction that converts the energy of light directly into electricity (DC) using the photovoltaic effect.

C. Mathematical Model For Pv Module

The equivalent circuit for simplified model of PV cell consists of a current source (I_{pv}), a diode (D), and series resistor (Rs) connected as shown in Fig.3.2.

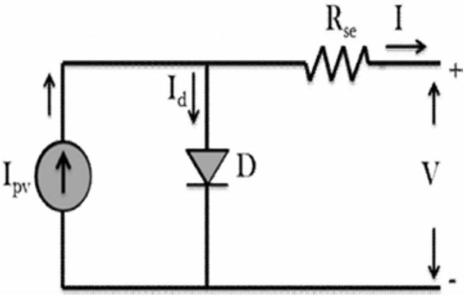

Fig.1: Equivalent circuit of pv module

The output current (I) equation is derived by applying Kirchoffs law in the equivalent circuit. The equation for output current is as follows

$$I = I_{pv} - I_d \quad \ldots (1)$$

Equation (1) can re-written as

$$I = I_{pv} - I_s \left\{ exp\left(\frac{q}{AKT_c N_s} V + IR_{se}\right) - 1 \right\} \quad \ldots (2)$$

where,

$$I_{pv} = [I_{sc} + K_I (T_c - T_r)].G \quad \ldots (3)$$

$$I_s = I_{rs} \left(\frac{T_c}{T_r}\right)^3 exp\left[\frac{qE_g}{A_k}\left(\frac{1}{T_c} - \frac{1}{T_r}\right)\right] \quad \ldots (4)$$

$$I_{rs} = \frac{I_{sc}}{exp\left(\frac{q}{AKT_{c(n)} N_s} V_{oc}\right) - 1} \quad \ldots (5)$$

The general model of the PV cell has a parallel resistor (Rp) in the circuit which is connected across the diode. The value of parallel resistance is very high and thus it is generally neglected in modeling the PV cell Modeling and simulation of The PV is based on the mathematical equations is presented in many literatures. Modeling and simulation of PV module using simple blocks is presented. This model is very primitive, and the user has to change to parameters inside the blocks of the model in order to analyze different PV modules. Therefore, the possibilities of error in feeding the data are high. The PV module model with the masked subsystem and a dialogue box is discussed. This model provides the user with front end dialog box which makes the model more user-friendly to analyze any commercial PV modules.

D. Characteristics Of Solar Cell

PV system naturally exhibits a nonlinear I-V and P-V characteristics which vary with the radiant intensity and cell temperature.

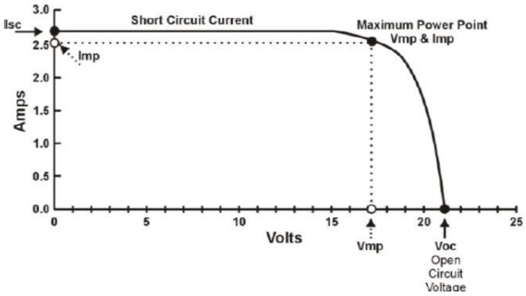

Fig 3: VI characteristics of a solar panel

The curve has drawn (Fig.3) shows how the voltage and current varies with Irradiation and Temperature of PV module. We can find out maximum power by finding out the Vmax and Imax. There are different methods of finding out Maximum power of PV module i.e. Pmax and these are known as MPP Techniques that is Maximum Power Point Technique at that point we get Vmax and Imax.

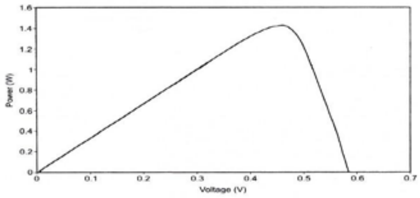

Fig 2: PV characteristics of a solar panel

4. CONVERTERS

A. Dc-Dc Converter

A DC-to-DC converter is an electronic circuit or electromechanical device that converts a source of direct current (DC) from one voltage level to another. It is a type of electric power converter. Power levels range from very low (small batteries) to very high (high-voltage power transmission).

B. Boost Converter

A boost converter (step-up converter) is a DC-to-DC power converter that steps up voltage (while stepping down current) from its input (supply) to its output (load). The DC input to a boost converter can be from many sources as well as batteries, such as rectified AC from the mains supply, or DC from solar panels, fuel cells, dynamos and DC generators. The boost converter is different to the Buck Converter in that it’s output voltage is equal to, or greater than its input voltage. However it is important to remember that, as power (P) = voltage (V) x current (I), if the output voltage is increased, the available output current must decrease.

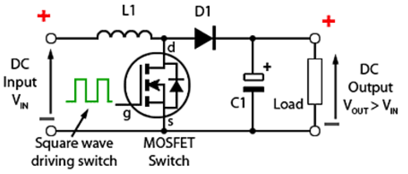

Fig 4:Basic boost converter circuit

Fig.4 illustrates the basic circuit of a Boost converter. However, in this example the switching transistor is a power MOSFET, both Bipolar power transistors and MOSFETs are used in power switching, the choice being determined by the current, voltage, switching speed and cost considerations.

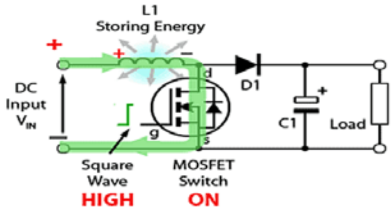

Fig 5: Boost converter operation at switch on

Fig. 5 illustrates the circuit action during the initial high period of the high frequency square wave applied to the MOSFET gate at start up. During this time MOSFET conducts, placing a short circuit from the right hand side of L1 to the negative input supply terminal. Therefore a current flows between the positive and negative supply terminals through L1, which stores energy in its magnetic field. There is virtually no current flowing in the remainder of the circuit as the combination of D1, C1 and the load represent a much higher impedance than the path directly through the heavily conducting MOSFET.

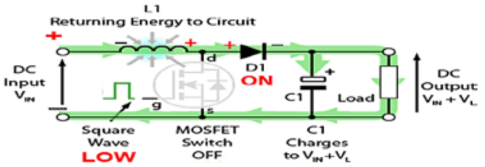

Fig 6:Current path with mosfet off

Fig. 6 shows the current path during the low period of the switching square wave cycle. As the MOSFET is rapidly turned off the sudden drop in current causes L1 to produce a back e.m.f. in the opposite polarity to the voltage across L1 during the on period, to keep current flowing. This results in two voltages, the supply voltage V_{IN} and the back e.m.f.(V_L) across L1 in series with each other. This higher voltage (V_{IN} +V_L), now that there is no current path through the MOSFET, forward biases D1. The resulting current through D1 charges up C1 to V_{IN} +V_L minus the small forward voltage drop across D1, and also supplies the load.

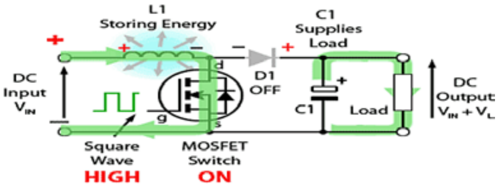

Fig 7:Current path with mosfet on

Fig 7 shows the circuit action during MOSFET on periods after the initial start up. Each time the MOSFET conducts, the cathode of D1 is more positive than its anode, due to the charge on C1. D1 is therefore turned off so the output of the circuit is isolated from the input, however the load continues to be supplied with V_{IN} +V_L from the charge on C1. Although the charge C1 drains away through the load during this period, C1 is recharged each time the MOSFET switches off, so maintaining an almost steady output voltage across the load.

B. Mppt Algorithm

MPPT or Maximum Power Point Tracking is a algorithm that included in charge controllers used for extracting maximum available power from PV module under certain conditions. An MPPT, or maximum power point tracker is an electronic DC to DC converter that optimizes the match between the solar array (PV panels), and the battery bank or utility grid. To put it simply, they convert a higher voltage DC output from solar panels (and a few wind generators) down to the lower voltage needed to charge batteries. The photovoltaic module yields the current-voltage characteristic with a unique point which is known as the Maximum Power Point (MPP). Perturb and Observe (P and O) and Incremental Conductance (INC) algorithms are most widely used, especially for low-cost implementations. The MPP changes as a consequence of the variation of the irradiance level and temperature. Therefore, it is necessary to ensure that the PV system always operates at the MPP in order to maximize the power harvesting in that prevailing environmental conditions. This compares the power measured in the previous cycle with the power of the current cycle to determine the next perturbation direction. If the power increases due to the perturbation then the perturbation will remain in the same direction. If the operating point exceeds the peak power and deviate to the right side of the P-V characteristic curve, the power at the next instant will decrease. Thus, the direction of the perturbation reverses. When the steady-state is reached, the operating point oscillates around the peak power as the MPP will perturb continuously. The flow chart required for P&O MPPT module (subsystem) is shown in Fig.8

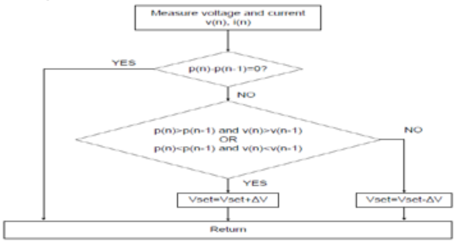

Fig 8:Flowchart of mppt algorithm

P&O is the most widely used algorithm due to the simplicity of implementation practically. In this method, P-V characteristic of PV cell is used. As known, produced power by PV array varies as a function of voltage. In P&O algorithm, a small increase in operating voltage of PV array is realized, and the amount of change in power () is measured. If -value is positive, operating voltage is increased again to reach MPP, thus, sign of power error track by these small voltage errors. Let us assume that a PV array has P-V characteristic and operates at point (A) as shown. By repeating the process above, the operating point moved upwards. After MPP, the value of , the resulting increase in voltage, will be negative. In this case, the direction of voltage adjustment is reversed, and operating point (A) in trying to make it is the closest to MPP. Today, P&O algorithm typically includes digital and computer-controlled applications.

5. TYPES OF FAULTS IN PV SYSTEM

A. Issues In Photovoltaic Systems

There are a lot of studies analyzing different issues present in PV systems demonstrating an interest in detecting faults to the greatest extent as early as possible. The reasons for failure in solar modules:

- Yellowing and browning
- Delamination
- Bubbles in the solar module
- Cracks in cells
- Defects in anti-reflective coating
- Hot spots caused by the panel acting as a load
- Edge-seal delamination
- Newly cracked cells
- Delamination over cells and interconnections
- Split encapsulation over cells and interconnections
- Protruding interconnections

Protection devices commonly present in PV installations known as over-current protection devices (OCPD) and ground protection (GPD) are not sufficient. During certain kinds of faults the MPPT may interfere and lower the current output, which in turn will not trigger the current-based protection devices. Similar issues are present when faults occur during the night .In the context of degradation over time it has been found that dust is a significant problem. These effects are however very dependent on the geographical position and the physical alignment with respect to weather conditions. A study found that early degradation occurs due to wide variety for reasons. The paper ties the measured degradation rates to a specific allowance, based on guarantees from the manufacturer.

B. Fault Analysis In A Photovoltaic Array

In general, faults that occur in PV systems could be classified as line–ground faults, line–line faults, open-circuit faults, and partial shading. Line–ground faults are not treated separately in this paper, as they can be considered to be a special case of a line–line fault, involving a ground point. Further, these can be easily detected and cleared by GFPDs. A line–line fault is similar to a short-circuit fault in the grounded system. Line–line faults can be quantified based on the number of PV modules that have mismatch. It is shown in that a line–line fault with a large number of PV modules mismatched ceases power generation from the faulted PV string, if blocking diodes are used in the PV array. This is similar to an open-circuit fault condition. It is, therefore, clear that it is sufficient to detect line–line faults, as this would automatically detect line–ground, as well as open circuit faults. The above faults are permanent in nature. On the contrary, partial shading is a temporary fault.

C. Ground Fault

Ground-faults in PV arrays could potentially result in large fault current which may increase the risk of fire hazards. To better understand ground-fault scenarios, a typical ground fault in a PV array is introduced, followed by PV current flows explanation and current vs. voltage (I-V) characteristics analysis. To protect PV arrays from damages due to ground-faults, the National Electrical Code (NEC) requires ground-fault protection devices (GFPD) in PV arrays. In most cases, the GFPD is a fuse rated at 0.5-1A within the PV inverter. Finally, the Tech Topic explains how to clear ground-faults by installing fuses and fuse protection characteristics.

Ground fault is the most common fault in PV and may be caused by the following reasons:

1.Insulation failure of cables, i.e. a rodent animal chewing through cable insulation and causing a ground fault.

2.Incidental short circuit between normal conductor and ground, i.e. a cable in a PV junction box contacting a grounded conductor incidentally.

3.Ground-faults within PV modules, i.e. a solar cell short circuiting to grounded module frames due to deteriorating encapsulation, impact damage, or water corrosion in the PV module.

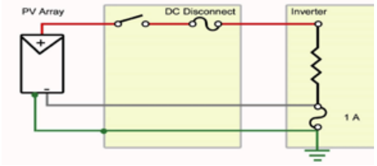

Fig 9:Ground fault in pv array

D. Line To Line Fault

Depending on fault locations, the magnitude of line-line faults in PV arrays could be high enough to damage PV modules and conductors. To better understand the fault scenarios, an example of typical line-line faults in PV arrays is introduced, followed by PV current flow explanation and current vs. voltage (I-V) characteristics analysis. To protect PV arrays from over current damages, Article 690.9 of the National Electrical Code (NEC) requires over current protection devices (OCPD) in PV arrays. Fuses are often utilized as OCPDs in series with PV modules. The NEC passages related to fuses in PV arrays are given in this paper. Finally, this paper will briefly explain how to choose the right size of fuses and fuse protection characteristics.

Line-line faults in PV arrays may be caused by the following reasons:

- Insulation failure of cables, i.e. an animal chewing through cable insulation
- Incidental short circuit between current carrying conductors, i.e. a nail driven unprotected wirings;
- Line-line faults within the DC junction box, caused by mechanical damage, water ingress or corrosion.

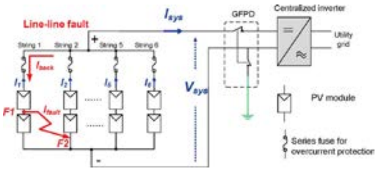

Fig 10:Line to line fault in pv array

6. SIMULATION AND RESULTS

A. Normal Mode Of Operation

The normal mode is nothing but the state where all the conditions such as temperature and output level are met. The normal mode of operation of Solar PV is taken to be threshold values in all cases and it is compared with faulty operations. In normal mode of operation, it is assumed to have the temperature of 25 degree Celsius.

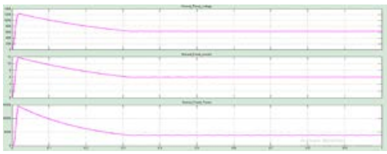

Fig 11: Output graph of normal mode operation

B. Line To Line Fault Analysis

A Line to line fault in a PV array can be said as an abnormal connection of very low impedance between two points of different potential, whether made intentionally or accidentally. This Line to Line fault is also considered to be a short circuit fault, which may cause impedance to be lower and current to increase in a level such that it damages the solar PV panel. These are the most common and severe kind of faults, resulting in the flow of abnormal high currents through the solar pv panel. If these faults are allowed to persist even for a short period, it leads to the extensive damage to the equipment. These faults are caused due to the insulation failure between two Photovoltaic panels.

- This type of fault will have the least losses among all faults (excluding partial shading) due to the least module mismatch . This fault is analyzed with help of *P–V* curves under normal and faulted conditions under standard test conditions. When a permanent fault like line to line fault is found, the Mppt controller immediately shuts down the PV panel. This is done not only by analyzing the duration of faulted condition but also with values of voltage and current obtained during fault condition.
- Thus, it can be seen that the voltage level obtained is less than the voltage obtained during normal operation of Array as well as the output power obtained is also much less when compared to normal operation.

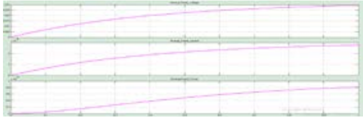

Fig 12: Output graph of line to line fault

C. Open Circuit Fault Analaysis

Open Circuit fault is a type of an Unsymmetrical fault or Unbalanced fault. This Open circuit fault is caused when a fault occurs in one or two solar panels or when the fault occurs in a wire joining the two panels. Though Open Circuit can be tolerated than Short Circuit fault, it must be removed as soon as possible to avoid the greater damage. Open Circuit fault is also considered to be one of the permanent fault in a solar panel. This fault is analyzed with help of *P–V* curves under normal and faulted conditions under standard test conditions. So, When the fault like Open Circuit fault occurs, Mppt Controller shuts down the PV panel.

- Thus, it can be seen that the voltage level obtained is less than the voltage obtained during normal operation of Array as well as the output power obtained is also much less when compared to normal operation.

Fig 13:Output graph of open circuit fault

7. CONCLUSION

This work is proven to be successful in distinguishing between three possible scenarios: normal operation, partial shading, and permanent faults. This algorithm was found to work accurately under fast-moving cloud conditions. The proposed algorithm does not require any ac quantities from the PV system, nor does it require any training data from different conditions. It allows modified MPPT algorithms to be integrated alongside so that losses may be reduced under partial shading with P&O being used under normal operating conditions. Finally, degradation of the PV array may be monitored by measuring the array losses at a particular time on a daily basis.

REFERENCES

[1] U. S. National Electrical Code, “Article 690—Solar PhotovoltaicSystems,” 2011.
[2] Y. Zhao, J. F. de Palma, J. Mosesian, R. Lyons and B. Lehman, “Line–line fault analysis and protection challenges in solar photovoltaic arrays,”IEEE Trans. Ind. Electron., vol. 60, no. 9, pp. 3784–3795, Sep.2013.
[3] D. Stellbogen, “Use of PV circuit simulation for fault detection in PVarray fields,” in Proc. Conf. Rec. 23rd IEEE Photovoltaic Spec. Conf.,Louisville, KY, USA, May 10–14, 1993, pp. 1302–1307.
[4] H. Patel and V. Agarwal, “Maximum power point tracking scheme for PVsystems operating under partially shaded conditions,” IEEE Trans. Ind.Electron., vol. 55, no. 4, pp. 1689–1698, Apr. 2008.
[5] J. Young-Hyoket al., “A real maximum power point tracking methodfor mismatching compensation in PV array under partially shaded conditions,”IEEE Trans. Power Electron., vol. 26, no. 4, pp. 1001–1009, Apr.2011.
[6] M. Boztepeet al., “GlobalMPPT scheme for photovoltaic string invertersbased on restricted voltage window search algorithm,” IEEE Trans. Ind.Electron., vol. 61, no. 7, pp. 3302–3312, Jul. 2014.
[7] G. V.-Quesada, F. G.-Gispert, R. P.-L´opez, M. R.-Lumbreras, andA. C.-Roca, “Electrical PV array reconfiguration strategy for energy extractionimprovement in grid-connected PV systems,” IEEE Trans. Ind.Electron., vol. 56, no. 11, pp. 4319–4331, Nov. 2009.
[8] M. Z. S. El-Dein, M. Kazerani, and M. M. A. Salama, “Optimal photovoltaicarray reconfiguration to reduce partial shading losses,” IEEE Trans.Sustain. Energy, vol. 4, no. 1, pp. 145–153, Jan. 2013.
[9] S. Silverstre, A. Chouder, and E. Karatepe, “Automatic fault detection in grid connected PV systems,” Sol. Energy, vol. 94, pp. 119–127, Aug.2013.
[10] Y. Zhao et al., “Decision tree-based fault detection and classification insolar photovoltaic arrays,” in Proc. 27th Annu.IEEE Appl. Power Electron.Conf. Expo., Orlando, FL, USA, Feb. 5–9, 2012, pp. 93–99.