

Short and open circuit faults study in the PV system inverter

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ABSTRACT

The inverter is the principal part of the photovoltaic (PV) systems that assures the direct current/alternating current (DC/AC) conversion (PV array is connected directly to an inverter that converts the DC energy produced by the PV array into AC energy that is directly connected to the electric utility). In this paper, we present a simple method for detecting faults that occurred during the operation of the inverter. These types of faults or faults affect the efficiency and cost-effectiveness of the photovoltaic system, especially the inverter, which is the main component responsible for the conversion. Hence, we have shown first the faults obtained in the case of the short circuit. Second, the open circuit failure is studied. The results demonstrate the efficacy of the proposed method. Good monitoring and detection of faults in the inverter can increase the system's reliability and decrease the undesirable faults that appeared in the PV system. The system behavior is tested under variable parameters and conditions using MATLAB/Simulink.

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1. INTRODUCTION

Photovoltaic systems have become an environmentally friendly solution to generate electricity in our modern life. They only depend on solar radiation energy, which is a source of energy inspired by nature and considered a source of sustainable energy. Several types of research in the field of solar energy have been elaborated in the last two decades by studying the increasing the efficiency of the PV systems while ensuring the minimum cost of installation [1], [2].

The efficiency is dependent on the components of the PV systems, namely on the efficiency of panels, batteries, and inverters. Also, better monitoring leads to an adequate PV system. However, faults can decrease and even block the well-functioning of the PV system [3]-[7]. A shaded or broken panel, batteries fail and inverter dysfunctions cause losses in the produced energy as well as the economic effect of the PV system. The inverters represent the intermediary device between DC and AC sides. They are used to supply the AC loads. It's based on the commutation between its switchers situated in its arms. This commutation delivers the sinusoidal shape of the output current that feeds the AC loads [6], [8], [9]. The switches are the principal element in the conversion operation and any failure in their work breaks the inverter outputs. Hence, faults in the inverter are known as a big problem that causes damages to the functionality of the

DC/AC converter, AC loads, or other PV system parts. For that, inverter monitoring is an essential task for all PV systems functioning. In [10] they have studied the increasing of the vehicle power train reliability regarding insulated gate bipolar transistor (IGBT) open-circuit failures, 4-wire, and 4-leg pulse width modulation (PWM) inverter topologies investigated and their performances discussed in a vehicle context [4]. In [11] it has been investigated on faults that may occur on the DC link of an inverter fed induction motor and the effect of the capacitor short circuit. It also deals with the effects of the short-circuited capacitor on the freewheeling diode. And, in [12], [13] they have determined the location of the fault, the ratio between DC and AC power. They have developed a software tool to identify different types of faults like fault in a photovoltaic module, fault in a photovoltaic string, fault in an inverter, and a general fault that may include partial shading, PV aging, or maximum power point tracking (MPPT) error. In [5], [14], [15] they have carried out the field measurement for current harmonics. In particular, for a two-stage inverter that assumes the DC-link voltage is constant, the DC-link voltage ripple is identified as the source of a series of odd harmonics. A new periodic time-varying model is proposed by including the DC-link voltage ripple into the conventional current control loop model. In [16]-[18] have focused on the inverter of photovoltaic systems and their characterization. They have obtained a model from a detailed study of main loss processes in small-size PV inverters in the market. The main advantage of the used method is to obtain a model that comprises two antagonistic features since both are simple, easy to compute and apply, and accurate. However, no one of these papers studied the faults that occurred in the structure of the PV system inverters. Hence, this paper tries to explain the inverter faults effects and gives a general idea of the behavior and the changes in the PV system outputs. It is based on the studying of the PV system functioning in the normal operation and under faults in the inverter. For that, we have proposed in this paper a method that can detect short and open circuit faults in the inverter.

Firstly, we tried to study the short circuit fault in the inverter that is the most known problem in the PV system power conversion. The short circuit fault is dependent on the inverter switch commutation and influences the PV system outputs by decreasing the DC/AC converter parameters which reduce the PV system efficiency. Secondly, we presented the open circuit failure, when one of the inverter switches is opened and stays blocked in its position. This kind of fault affects the PV system continuity and breaks the AC loads supplies.

The rest of this paper is organized as being as. Section 2 shows the PV system device modeling. In Section 3, we present the methodology used in this work to study the failures in the PV system inverter. In Section 4, we have simulated the results obtained from the proposed approach in the case of absence and presence of failure in the PV system inverter. The last section is dedicated to the conclusion and perspective the future work.

2. METHODOLOGY

The monitoring of PV system devices is an important part to generate the power produced by these systems. For that, the inverter is presented as an intermediate between the DC and the AC side, and its functioning should be in the correct way to ensure the optimum efficiency. In this regard, a proposed simulation method has been created based on the MATLAB/Simulink environment to study and treat faults in the inverter. In this work, we are interested to study the behavior of the inverter under some specific faults; precisely the short circuit and the open circuit faults. Firstly, the components of the PV system are introduced by relying on the diode photovoltaic cell model. Secondly, a three-phase inverter is modeled where the two types of faults (short circuit and open circuit) to study the behavior are introduced. The proposed structure is shown in Figure 1.

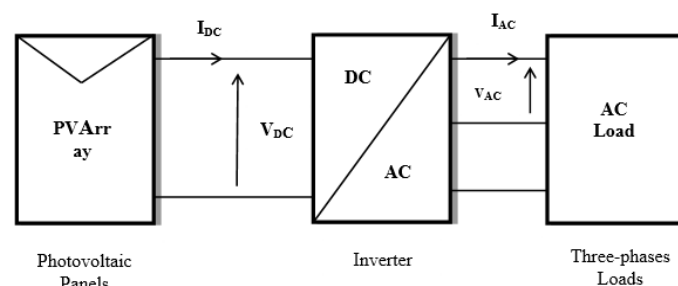


Figure 1. Flowchart of the proposed methodology

2.1. Description of PV system devices

The PV system used in this work consists of eight YL80P-17b 2/3 polycrystalline solar panels. They are connected in parallel and their parameters are summarized in Table 1. The Foshan Tanfon energy technology inverter is used in this study and its characteristics are developed in Table 2.

Table 1. The YL80P-17b 2/3 panel parameters

Technology	Polycrystalline Si
Peak power	80W
Open circuit voltage	22V
Short circuit current	5.04A
Peak voltage	17V
Peak current	4.71 A
Max system voltage	50V

Table 2. Foshan tanfon energy technology inverter characteristics

Features	Values
Output power	1KW-100KW
Nominal voltage	380V/415V/440V.
Maximum efficiency	>85%
Maximum DC voltage	384V
Nominal DC current	156A

2.2. Modeling of PV array

As presented in a previous paper published by [6], [18], [19], [20], the DC output powers, the output currents, and voltages of the PV array have been calculated using a double diode PV cell model as expressed in (1) [14], [18].

$$I = I_{ph} - I_{01} \left(\exp \left(\frac{V + R_s I}{n_1 V_t} \right) - 1 \right) - I_{02} \left(\exp \left(\frac{V + R_s I}{n_2 V_t} \right) - 1 \right) - \frac{V + R_s I}{R_{sh}} \quad (1)$$

where I_{ph} is the current generated by the incident light. I_{01} , I_{02} is the reverse saturation currents of the diodes D1 and D2 respectively. V_t is the thermal voltage. n_1 , n_2 are the ideality factors of diodes D₁ and D₂. R_s and R_{sh} are the series and shunt resistance respectively. V and I are the output PV module voltage and current respectively.

2.3. Modeling of the inverter

To obtain the efficiency of the DC current and voltage converters into the AC current and voltage, we have modeled this inverter with the standard method given by the next equation. This model expresses the efficiency as a function of the input power P_{in} [6], [21], [22].

$$\eta_{DC/AC} = y_0 + c_1(1 - \exp(-c_2 \times P_{in})) + c_3(1 - \exp(-c_4 \times P_{in})) \quad (2)$$

The parameters y_0 , c_1 , c_2 , c_3 , and c_4 are shown in Table 3, these parameters can be obtained using the least square algorithm, minimizing the quadratic function:

$$S(w) = \sum_{i=1}^N (P_{in} - \eta(P_{in}, w))^2 \quad (3)$$

Table 3. Estimated parameters using least square algorithm [10]

Parameters	y_0	c_1	c_2	c_3	c_4
values	1.0733	1.6817	0.0721	-1.8440	0.4069

3. INVERTER FAULTS STUDY

The DC/AC converter represents a principle device in the PV system due to its most important work in the production line, when, it ensures to supply the load by the AC power converted from the DC one [23], [24]. The inverter reliability depends on good efficiency, where it cannot be obtained if this converter is not well functioning. Thus, in this study; we have tried to monitor the inverter behavior in the case of good functioning and other cases when we have introduced some faults (we are interested in this approach in the short circuit of one of the inverter arms and the open circuit at the same converter arm) [14], [25], [26], [27].

3.1. Short circuit fault

The short circuit is the most current problem in the PV system converters, and it has caused big damages in the photovoltaic installations. However, studying the consequences and the results of this fault provides the knowledge of how this event occurred [22], [28], [29]. The normal functioning of the inverter is started when the first switch S1 of the first arm A1 is closed, which means the current passes throughout S1

and S4. And the second step is when S3 is closed, then the current will be passed onto S3 and S6. And the last step is when S5 is turned on, which means the current will pass between S5 and S2 as demonstrated in Figure 2.

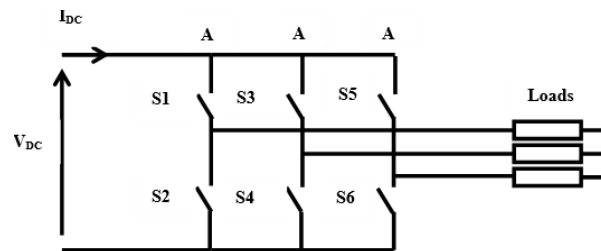


Figure 2. Flowchart of the used inverter in the proposed methodology

3.2. Open circuit fault

The open-circuit represents a harmful fault that appears in the DC/AC converter level and it has influenced the PV system efficiency. Hence, the inverter functioning behavior will be changed in this case. This kind of fault depends on the inverter switches commutation and their mode control.

The open-circuit fault is happening in the DC/AC converter when all of its switches are opened. This case could be arriving if one or more switches are opened and stay blocked. The example took in this methodology is when the switch S1 and S4 are opened and the switch S1 stay opened, but the problem is when the switches S5 and S2 become opened. In this state, the open circuit fault is appeared in the switches S1 and S2, and also the switches S5 and S6. This means that the arm A1 and A3 are in case of open-circuit failure. Thus, the PV system efficiency is automatically influenced by the appearance of this in the solar inverter [19], [27], [30].

4. SIMULATION RESULTS AND DISCUSSION

The objective of the present work is to study the inverter in normal and under faults functioning. For that, we have used eight YL80P-17b 2/3 polycrystalline solar panels connected in parallel to get more output voltage and they supply the PV system by 550 Wp, the PV module parameters are given in Table 1. The inverter used in this study is a three-phase Foshan Tanfon energy technology and its characteristics are mentioned in Table 2. In all figures, the blue line represents the inverter outputs with normal functioning and the green line show the DC/AC converter outputs with different kinds of failures under study (the short circuit and the open circuit).

4.1. PV system inverter functioning without failure

Figure 3 explains the average output power inverter with good operation when this power is in constant value due to a constant solar radiation PV array input and no problem in the inverter commutation switches. Hence, the inverter output power represents the PV system efficiency rate; in this case of normal functioning without faults, the PV system efficiency is in the highest value. In Figure 4 and Figure 5, the curves represent the outputs inverter voltage and current respectively of the first phase of the DC/AC converter used under study. However, both figures are in a sinusoidal form and the current curve is the image of the voltage curve. Thus, we take these curves as a reference to compare them with those of the failure inverter functioning.

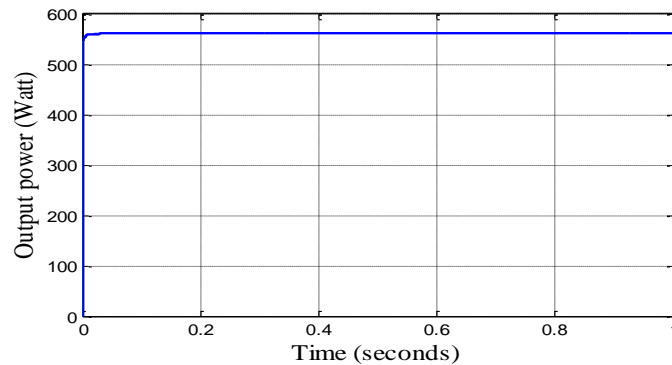


Figure 3. PV system output power with normal functioning (without faults)

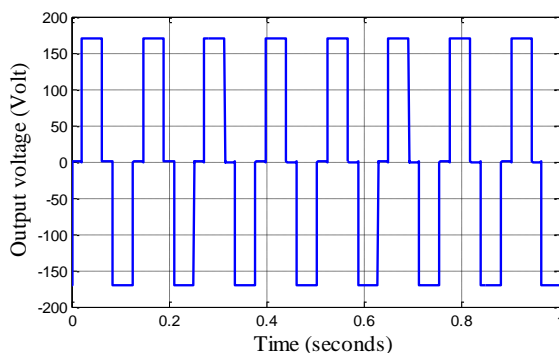


Figure 4. PV system output voltage with normal functioning (without faults)

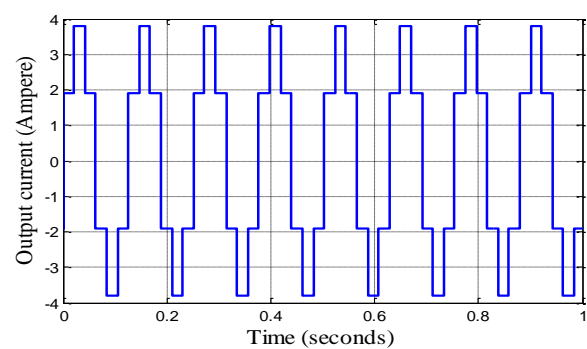


Figure 5. PV system output current with normal functioning (without faults)

4.2. PV system inverter functioning with short circuit fault:

Figures 6-8 show the effect of the short circuit in the PV system inverter by the curves of the power, the voltage, and the current respectively. Figure 6 explains a considerable reduction in the output power and no stability in its signal that could damage the device under study or the load supplied by this power. Figures 7 and 8 are the output voltage and the current of phase 1 of the inverter. However, the current curve is the image of the voltage curve. We observe just the negative part of the current phase in the short circuit case comparing with the normal functioning that means there is a reverse current in the PV system inverter when the arm A1 is short-circuited. For that, it appears just the negative current and voltage form. The three parameters (power, voltage, and current) are linked between them, then one of them changes all of the rest diverge.

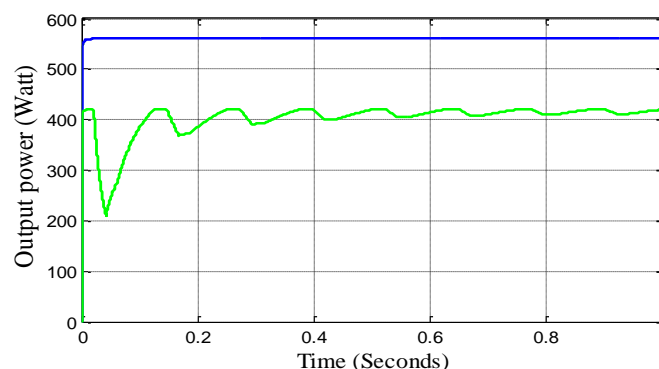


Figure 6. PV system output power under short circuit fault in the inverter arm

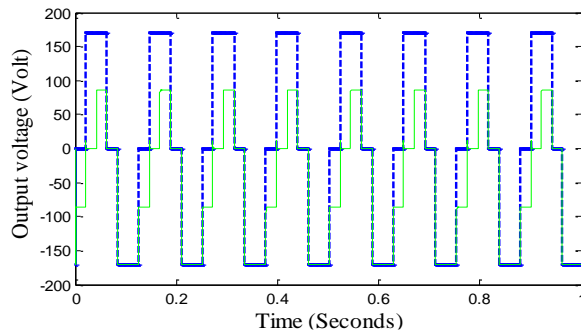


Figure 7. PV system output voltage of the first phase under short circuit fault in the inverter arm

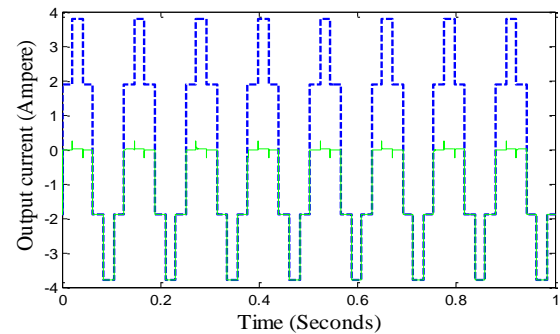


Figure 8. PV system output current of the first phase under short circuit fault in the inverter arm

4.3. PV system inverter functioning with open-circuit fault

In this kind of fault, we could notice that in Figure 9 the output power curve drops its values when the open circuit fault is applied and its allure signal still floating. The effect of the open-circuit fault is the decrease of the total PV system efficiency, which causes another deformation in the inverter structure. Figures 10 and 11 explain the output voltage and current respectively of the first phase of the output inverter. The shape of curves shows the profound effect of the open circuit faults in the sinusoidal form of the voltage and the current results. Besides, the open-circuit fault is introduced by opening two switches in the same inverter arm that changes the voltage and the current allures. The current becomes zero at the moment between 0.06 and 0.08 seconds. At this moment, the first open circuit is introduced and it affects the rest of the signal allure. The same thing in the voltage curve, which remains constant at this moment.

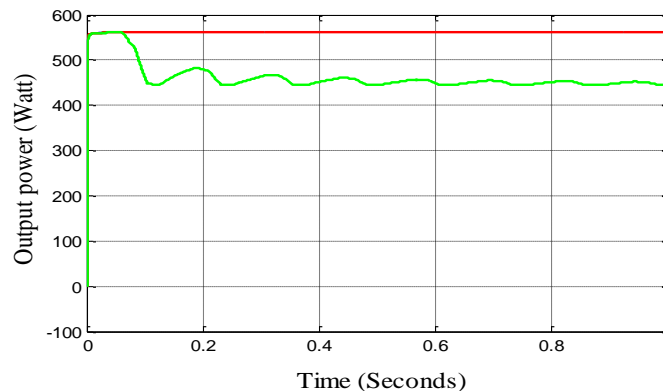


Figure 9. PV system output power under open circuit fault in the inverter arms

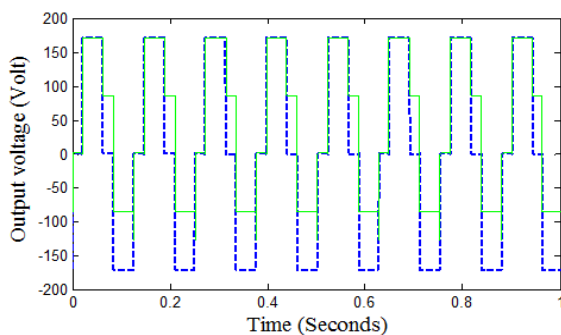


Figure 10. PV system output voltage of the first phase under open circuit fault in the inverter arms

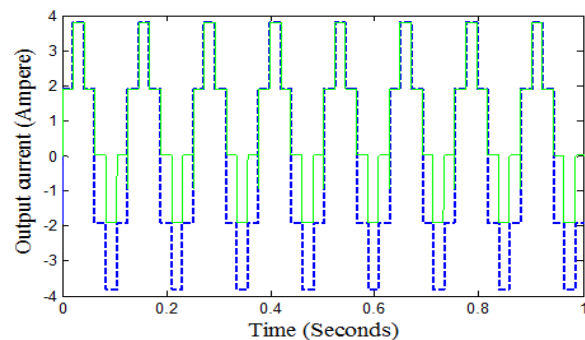


Figure 11. PV system output current of the first phase under open-circuit fault in the inverter arms

5. CONCLUSION

In this paper, we have studied faults that occurred in the inverter especially faults of the short and open circuit of switchers of the inverter. The methodology consists of modeling all the parts of the PV system, namely the panels and the inverter. Then, a description of the inverter with and without faults is presented. The simulation results have shown that a closed blocked switch of one arm of the inverter causes the short circuit fault that leads to a decreasing of the output power with a deformation of the sinusoidal form of the current and voltage outputs. On the other hand, an open circuit fault which occurs when a switch of one arm of the inverter is open and stays blocked in its position causes a zero current value. These faults influence decreasingly the PV system global efficiency. The obtained results showed the efficacy of the proposed method that leads to optimal functioning of the PV system.

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