handful of advanced fault detection techniques that are efficient to detect, diagnose and localize multiple faults in a PV system have been proposed recently in the last few years. Hence, with a wide spread literature, this paper reviews various fault detection techniques which are proven to be effective and feasible to implement. The proposed study analyzes the performance of each technique with an emphasis on its: 1) Approach, 2) Sensor requirement, 3) Ability to diagnose and localize faults, 4) Integration complexity, 5) Accuracy and 6) Implementation cost. Furthermore, an in depth investigation has been made to analyze various faults occurring in PV systems, their effects on the electrical characteristics, protection challenges and the limitations of conventional protection devices. Rest of the paper is organized as follows; Sub Section 2 discusses various faults occurrences in a PV system, the standard protection schemes recommended for detecting the faults and the protection challenges of the conventional detection techniques. Section 3 provides a detailed study on recent technological advancements in fault detection of PV systems while an overall comparison of advanced fault detection techniques is presented in Section 4. Summary and some suggestions for further improvements are discussed in Section 5.

2. Typical faults in a PV system and protection challenges

Like any other power system, PV generating systems are also very sensitive to fault occurrences. Various faults investigated in this paper as well as all possible faults that can occur in a typical PV power plant can be classified using a tree diagram presented in Fig. 1. The block diagram of a typical grid-connected PV generation system is shown in Fig. 2. As shown, the system comprises of two main stages of power flow viz. the DC stage and the AC stage. In the DC stage, unlike other generating sources, PV systems have the following peculiarities: 1) The voltage and current of a PV module is limited and is highly dependent on insolation level and temperature, 2) Usually, with the presence of MPPTs, all PV panels operate at a point which is very near to its I_{SC} and 80% of its V_{OC}. Hence, any fault occurring in the DC side of PV systems possess disparate characteristics, especially low fault current magnitudes that makes it very difficult to detect and distinguish fault occurrences.

Meanwhile, faults occurring in the distribution side of a grid connected or standalone PV system affects only the AC side; which are easy to detect and isolate using the protection standards specified in [9–11]. For a clear understanding, a PV schematic is depicted in Fig. 3 to show various frequent fault scenarios that occur at different power conversion stages in PV systems. Faults in a PV system can occur due to many reasons [31] and a deep insight is necessary to: 1) Distinguish each fault occurrence, 2) Understand the necessity of fault detection and 3) Analyze the protection challenges. Hence, a detailed analysis of various faults is provided in this section for a better understanding. In short, this section gives an insight to various faults occurring in a PV system, the effects of each fault occurrence on the electrical characteristics,

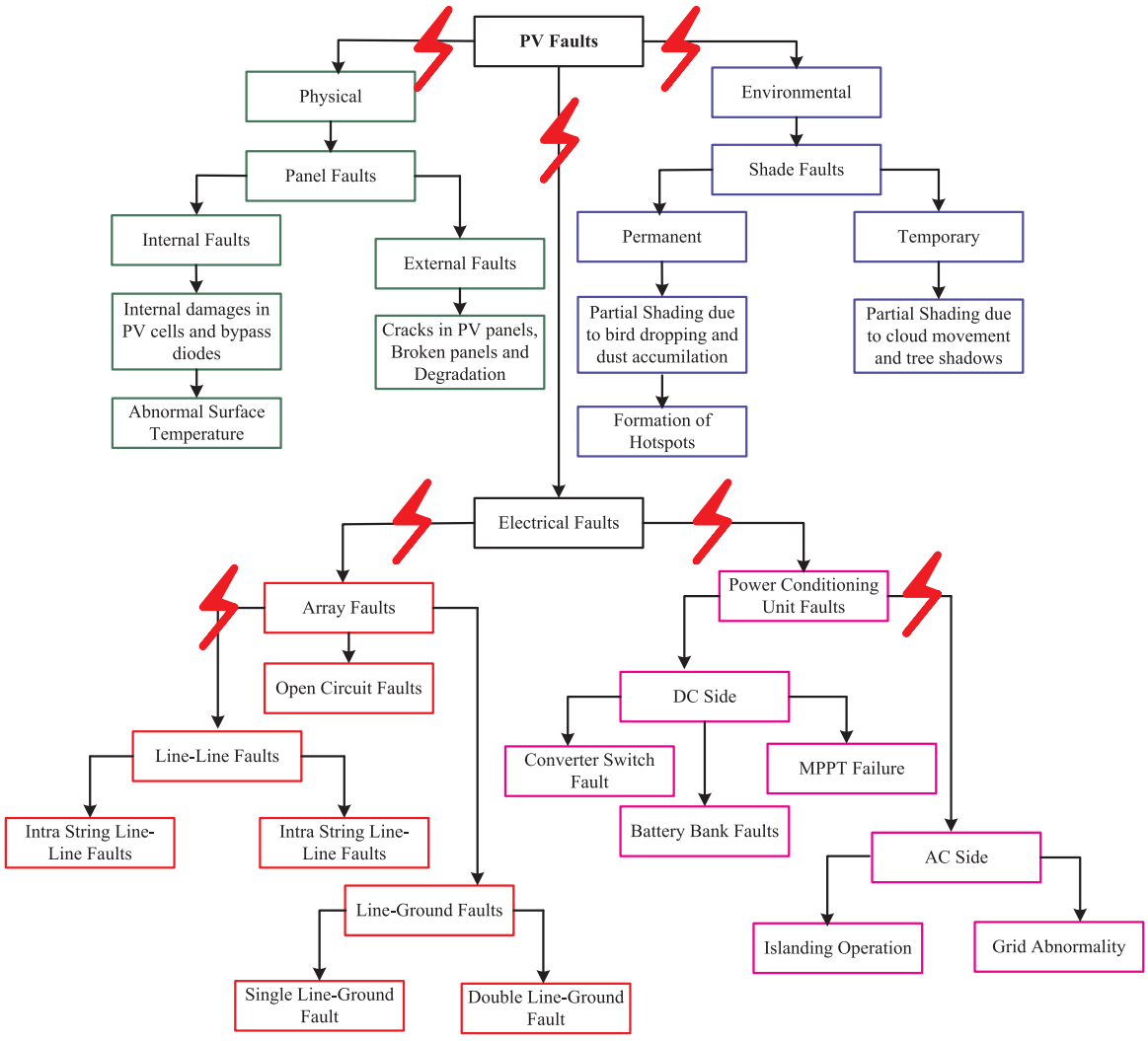

Fig. 1. Classification of faults in PV Systems.