An Overview of Fault Tolerant Methods in power Circuits of Photovoltaic Applications

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Abstract - *In this paper an overview of the research work done in fault tolerant power electronics circuits in photovoltaic applications has been presented. The demand of renewable energy is growing and solar PV modules are preferred choices for renewable energy. Solar power is abundant on earth and it can be converted to electrical signal by using PV modules. Considering this lot of research has been done in design and development of converter and inverter circuits. Large numbers of topologies are suggested which provides efficient power however since the optimized power processing circuits are used in these topologies, any fault in component particularly power switches malfunctions the circuit. This requires repairing, replacement etc. Researchers worked on development of fault tolerant topologies, this paper reviews the techniques used to obtain fault tolerant capacity.*

Key Words: fault tolerant power electronic circuits, PV power fault tolerant circuits, fault tolerant converters/ inverters, PV power stations, fault diagnosing converters

1. INTRODUCTION

In photovoltaic applications PV modules convert solar energy to electrical energy, this electrical energy is converted to different power level using converters. Inverters convert the DC electrical power to AC power. Power switches like MOSFET or IGBT are important components for conversion of electrical energy. Apart from this other components like diode, capacitor, transformers and inductor are also used. Among all these components power switches are found to be more prone to failure. Due to this many topologies are suggested to provide fault tolerant competency in converters and inverters. Multilevel converters are also proposed for fault tolerance enhancement. Moreover PV modules are also found fault prone, some techniques are also suggested to detect and recover faults in PV modules.

In this paper overview of the fault tolerant techniques is presented. Section 2 describes the power electronic circuit arrangement in PV systems, section 3 discusses the reports of surveys, literature etc. regarding the device failures. In section 4 selected fault tolerant schemes are described.

2. PV SYSTEM ARRANGEMENTS

Different architectures / topologies are used in PV systems. Few of them are presented here to explain the role of converter and other power electronic circuits. Fig. 1 shows a typical standalone PV power system used for domestic / official purposes. This system is used for lower power generations.

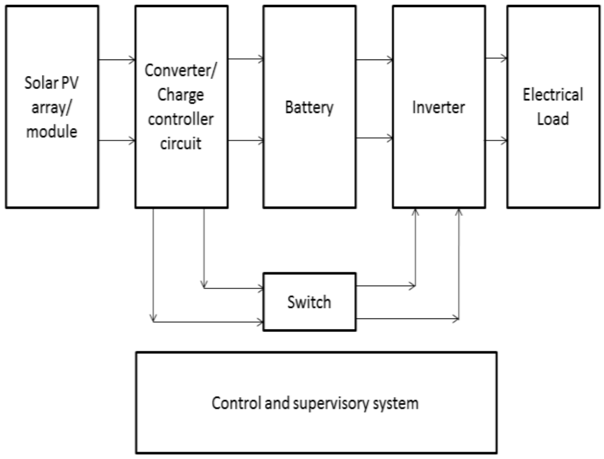

Figure 1- Typical standalone system

Control and supervisory system monitors the status of battery, PV module electrical load etc. and switches the source i.e. PV source or battery.

Fig. 2 shows a typical PV power generation system which is used in high power generation plants. In this large number of solar PV modules are used which are connected in series and parallel combinations to achieve desired power levels. The input power is converted to regulated DC and AC depending upon requirement. Power management is regulated by intelligent supervisory control and management system.

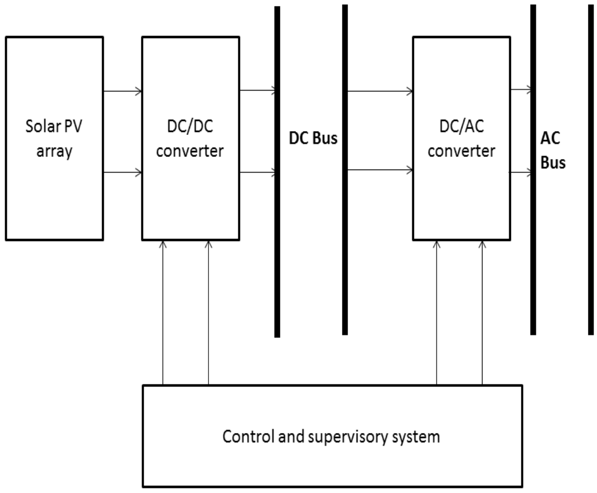

Figure 2- Typical high power PV system

The converters, inverters uses power processing components of different ratings. MOSFETs, IGBTs, SCRs or other power switch modules are used. High power capacitors, transformers are also used. Few topologies are designed [23],[25] in which inverters without transformers are developed, due to lack of isolation the components face higher electrical stress, while [28] and [32] deals with design of converters for PV systems, soft switching topology is also preferred to minimize electrical stress. These devices work in varying environmental conditions, different power levels etc. Also they suffer due to transient currents voltages etc.

3. FAILURE PRONE NATURE OF POWER ELECTRONIC DEVICES AND CIRCUITS

Many case studies, reports and literature have suggested about the failure prone nature of power electronic components as these components process large power. Improper circuit design criteria, device power levels etc. May lead to faults in circuits. An industrial survey was conducted by Yang et al [1] to observe the failure prone nature of the power electronic components and it focused on different power levels, reasons of failure, environmental reasons, temperature fluctuations, load variations etc. It is reported that respondents of this survey highlighted the power switches as most failure prone devices. Also other devices like capacitor, diodes, inductors and resistors were found to be conditionally fault prone.

Reliability based survey of power electronic systems have done by Song et al [2] in which need of reliable power electronic systems is expressed. Authors suggested the use of different reliability indicators, consideration of thermal and electrical issues in system design.

Challenges and problems in photovoltaic systems and their power circuits are described in ref. [3]. It is stated that the environmental factors, electrical factors affect the system performance. The problems in PV array, converters, batteries etc. are discussed in [3]. Reference [4] suggests to continuously monitoring the condition of the device for earlier detection of the fault. Further reference [5] also highlights the need of failure resistant power circuits. Inverters also malfunction due to the failure of power switches, therefore fault diagnostic and protection methods focusing only IGBT are discussed in [6]. Reliability based study of the PV systems in grid power systems is also presented in [7]. Reasons of failure prone behavior of power electronic components are discussed in ref. [8]-[11]. Use of model based approach for diagnosis of fault in converters of PV systems is presented [18] in which it is suggested to model the system behavior and then to find the fault precursors. After thoroughly studying the faults and their nature, fault tolerant system can be designed. Details of power electronics component fault, diagnosis methods and fault tolerant actions is presented [19]. Reliability analysis of power circuits in presented in [24],[26],[27].

Surveys, reports and literatures states about the fault prone nature of power electronic components, due to this studies and research has been done to overcome the issues in power electronic circuits. Several factors are associated for the faulty behavior of power electronic components.

4. FAULT TOLERANT TECHNIQUES IN POWER CIRCUITS

Considering the failure prone nature of power circuits several fault monitoring, tolerant techniques, circuit topologies are suggested. This section discusses the selected fault tolerant techniques in power circuits.

Redundancy based 3 level boost converter having fault tolerant capacity is described [12] in which the circuit is designed for OC power switch fault. In this semiconductor Triac is used to switch the alternate path further PV module, capacitor and inductor are also used. The converter developed in this work has three states which are described as normal state (fault free state) , faulty state (OC semiconductor power switch) and rebuilt state (fault recovered).

Costa et al [13] developed a fault tolerant converter circuit in which full bridge converter is operated in half bridge mode on occurrence of power switch fault. Here 2 numbers of split capacitors and 1 power switch are used additionally to achieve fault tolerance competence. The use of parallel power switch is not required in this topology.

In reference [14] redundancy based fault tolerant circuit is developed in which switch SC failure is detected using the current at transformer primary. Diode and power switch are used at output side. The circuit is capable to deliver continuous output power to the load. Author states that there is slight decrease in efficiency due to addition of diode at output. Reference [15] deals with a converter topology in which input is in parallel while output is in series. In this total 4 converters are used to achieve fault tolerant competency.

One different approach is presented [16] in which two converter circuits are paralleled i.e redundant converter is used for fault tolerant operation, according to authors the converter input and output current ripples are reduced and power ratings of the components are also reduced. In [17] a system is presented in which fault is detected from transformer primary pulses. The converter presented here is operated in 4 states, different additional components are required to achieve fault tolerant competency.

PV power generation stations are remotely located and they occupy very large area of the land. In such case if fault occurs in any converter or inverter module then it's very difficult to locate the fault. Also this process is very time consuming, further the availability of spare components can't be guaranteed, and therefore authors in ref. [20],[30] suggested developing web based scheme to remotely monitor the status of the power station. This will locate exact fault and will reduce the time.

Architecture is presented [21] in which input side of the circuit is connected in series and output is in parallel. This needs additional converter for fault tolerant competence. Multilevel converter topology with PWM strategy is presented in [22], this topology needs additional diodes, power switches, current sensors and bidirectional switches. One other technique is presented [31] in which input side is in series and output modules are parallel, control strategy developed here maintains the fault tolerant scheme. [33] Represents fault tolerant converter in which additional transistor switch is used. Technique for reliability enhancement of an inverter in PV system is presented [34].

5. CONCLUSION

In this work overview of the fault prone nature of power electronic circuits, diagnostic techniques and selected fault tolerant methods is presented. Several techniques are implemented for fault detection and to achieve fault tolerance competence. Device performance and circuit status monitoring systems, redundancy based systems will help to enhance the power circuit reliability. Cost effective and optimized methods are needed for power circuit reliability improvement.

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