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# Fault diagnosis and on-line monitoring for grid-connected single-phase inverters

Tamer Kamel*, Yevgen Biletskiy, Liuchen Chang

*University of New Brunswick, Fredericton, New Brunswick, Canada E3B5A3*

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ABSTRACT

The functionality of power electronic converter systems (PECS) is a cornerstone in various industrial applications. One of the key requirements to ensure reliable functions of PECS is the analysis of their behavior during fault conditions. Characterizing the behavior of PECS during the fault conditions can provide a standpoint for enhancing their control and protection algorithms. Moreover, effective solutions for on-line monitoring for PECS are significant in order to improve the system supervision and management. Consequently, this paper presents fault diagnosis and on-line monitoring schemes for grid-connected single-phase inverters in typical commercial PECS utilized for renewable energy distributed generation. The paper provides fault detection, classification and location of the open circuit (O-C) faults which do not trigger the standard protection systems in the single-phase inverters. The proposed fault diagnostic algorithm is implemented by adaptive neuro fuzzy inference system (ANFIS) algorithm and it is based solely on the inverter output current measurements. Therefore, the proposed algorithm requires much fewer inputs compared to the previous research works. Furthermore, the paper implements an on-line monitoring by using a communication interface board which is connected to graphical user interface (GUI) software through transmission control and internet protocols (TCP/IP). The GUI software integrates the on-line monitoring for the electrical signals of the single-phase inverter, as well as incorporates a real time database for these signals.



## 1. Introduction

The power electronic converter systems PECS are significant cornerstones in a wide range of industrial applications, including smart grids, renewable energy applications, motor drives, power systems, and others. As a result, the detailed investigation and analysis of PECS during their fault conditions are critically important in order to improve their reliability and performance. Moreover, due to the wide proliferation of the smart grids with the applications of the renewable energy sources [1,2], the on-line monitoring of the PECS becomes important for such applications. In order to make the monitoring and supervision processes more accessible and easier to use, the human–computer interface must be designed in a systematic way, from the hardware support to the information provided to the user. The choice of technology is very important, as well as presentation of the data. The technology determines the possibilities and the limitations for the design. In addition, the data must be grouped and organized in an intuitive way to allow the user to access the graphical user interface (GUI) easily and to find the required information.

Faults of power switches in PECS are classified as short circuit (S-C) faults, and open circuit (O-C) faults. S-C faults in most cases cause an overcurrent condition that is readily detected and acted upon by standard protection systems, such as over-current, under-voltage or over-voltage protection. However, O-C faults often do not trigger standard fault protection, but rather cause system malfunction or performance degradation. Since the standard protection system may not detect these fault types, their diagnosis become critical for PECS.

This paper demonstrates open circuit (O-C) fault diagnosis and on-line monitoring for grid-connected single-phase inverters. The proposed O-C fault diagnostic algorithm is implemented by adaptive neuro fuzzy inference system (ANFIS) algorithm and it is based solely on the inverter output current measurements. The output of the ANFIS-based fault diagnostic algorithm is utilized as index in order to identify the O-C faults taking place in the single-phase inverter. It also classifies the blocked path for the inverter output current due to the O-C fault. Additionally, it locates the O-C fault either in the switching element of the inverter circuit or in its gate drive circuit. Furthermore, the paper implements an on-line

* Corresponding author. Tel.: +1 506 999 5799.
*E-mail addresses:* t.kamel@unb.ca, tamer.kamel.unb@gmail.com (T. Kamel).

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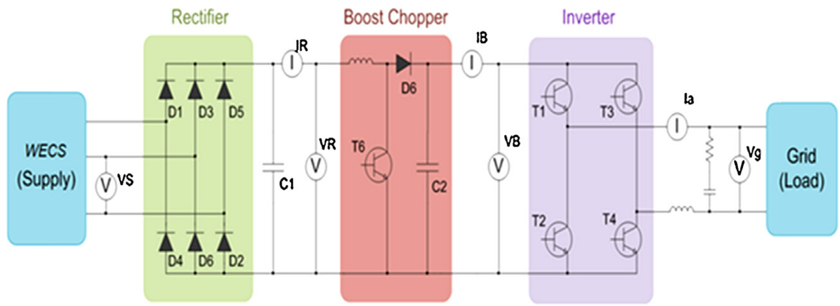


**Fig. 1.** Grid-connected power electronic converter under study.

monitoring using a communication interface board which is responsible for receiving the measurements of the electrical parameters of the inverter. Then, these measurements are sent by the communication interface board to GUI software through transmission control and internet protocols (TCP/IP). The GUI software integrates the on-line monitoring for these different parameters, as well as incorporates a real time database for these parameters.

Regarding the previous research works, FPGA-based power switch fault detection and compensation for PECS is presented in [3], where the proposed fault detection methodology is based on the comparison between measured and estimated voltages across the semiconductors switches. Papers [4,5] utilized the measured three-phase currents and their corresponding reference signals as well as the DC-link voltage to detect the inverter O-C faults. Besides, a fault detection method based on the current Park's vector approach is presented in [6–8]. Park's vector concentrates the information contained in the three-phase currents in one vector, which is used as the basic criteria for identifying the fault. For the single-phase inverters, research [9] uses a magnetic field probe in order to detect the magnetic field near the output inductor of the single-phase inverter. The measured waveform is processed by the peak detector and comparators and is utilized as the diagnostic criterion for the inverter faults. Furthermore, fault diagnosis based on D-S evidential theory and fuzzy logical theory is presented in [10] for fault diagnosis of the single-phase inverter. The inputs to the diagnosis are the output voltage, the input voltage and the temperature of MOSFET. A survey is presented in [11] for the fault tolerant control techniques of the three-phase inverters in order to allow their operation in faulty conditions under certain circumstances. Paper [12] provides a control of three-phase inverter-based distributed generation system during fault conditions in order to avoid the voltage sag problems. Monitoring of the chopped, freewheeling and excitation bus currents is implemented in [13] for the O-C fault diagnosis in the power converters of switched reluctance motors. The proposed fault diagnosis method requires several additional current sensors in particular positions in the converter to obtain the diagnosis result and the fault location by logical analysis with the use of additional logical circuits. A monitoring system, designed to detect O-C faults occurred in the matrix converter topology, is proposed in [14]. This monitoring system is based on the measurements of the three output currents with their neutral current component. Regarding the GUI schemes, some GUI for the electrical power applications have been implemented in previous research works [15–18]. However, they are applied on simulated power systems rather than experimental implementations for a GUI for actual power system applications. Therefore, their interface processes becomes easier and simpler as they are not evaluated in the experimental environments.

The fault diagnostic and monitoring algorithms implemented in the previous research papers require more sensors, hardware, or both in order to identify the fault event. Such additional sensors and hardware are not often implemented in the typical commercial PECS used for the distributed generation. Therefore, additional cost and expenses are required, which cause drawbacks for such commercial systems. Moreover, their protective schemes are not equipped with GUI which leads to restrain the supervisory and management tasks essential for the smart grids technology. On the other hand, the proposed fault diagnostic algorithm in this paper is based solely on the inverter output current measurements. Therefore, the proposed algorithm requires much fewer inputs compared to the previous research works. The minimization of the required sensors and hardware is significant for low and medium-size commercial PECS implemented in distribution generation systems. As a result, the developed fault diagnosis methods can be used directly in existing PECS available on the market.

The paper is outlined as follows. The architecture of the PECS under study is presented in Section 2. The methodology for O-C fault diagnosis for the single-phase inverter is described in Section 3. Then, the proposed ANFIS-diagnostic algorithm is demonstrated in Section 4 and evaluated under normal and fault conditions at different loading and supplying situations. After that, Section 5 provides the factors that could affect the proposed fault diagnosis and how the proposed methodology overcomes such factors. Then, Section 6 describes the communication interface board implemented in this paper as well as the GUI software utilized in this system. Finally, the conclusions of the paper are outlined in Section 7.

## 2. System architecture

The system under study, as depicted in Fig. 1, represents grid-connected power converter, which converts electrical energy in the variable voltage variable frequency (VVVF) form to the fixed voltage fixed frequency (FVFF) form. The supply of the converter is wind energy conversion scheme (WECS), which contains the wind turbine, the gear box, and the synchronous generator. On the other hand, the converter output is a single-phase grid. The main circuits of the converter are: three-phase uncontrolled rectifier, boost chopper, and single-phase inverter.

There are four voltage sensors and three current sensors in the power converter under the study. These sensors are utilized to measure the output voltage and current of each of the main circuit as well as the input line voltage to the rectifier circuit. These sensors are utilized in order to control and regulate the whole power electronic converter under study.

The maximum power point tracking (MPPT) algorithm [19–21] is implemented in this system in order to achieve the transfer of the maximum possible output power to the load. The desired output power ($P_{desired}$) is dependent in this system on the input frequency ($f_i$) to the PECS from the WECS. Fig. 2 illustrates the relationship between the $P_{desired}$ and $f_i$ for the system under study.