

# DIFFERENT OPEN-SWITCHES FAULTS AUTOMATIC DETECTION AND LOCATION IN TWO LEVEL THREE PHASE VOLTAGE INVERTER

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**Abstract:** *The faulty performance of two level three phase voltage inverter is studied under one and two simultaneous open-switches conditions. This inverter is three phase two level six IGBT voltage source inverter feeding a three phase balanced resistive-inductive load. The inverter three phases currents zero harmonic components and their harmonic distortion rate are used as diagnostic indices. A knowledge algorithm is based to get information on which IGBT is in open-switch fault condition. This algorithm testing shows that the system could not only detect the open-switch fault, but also identify the faulty switches. Presented simulation results confirm the effectiveness of the proposed methodology.*

**Key words:** *Two level three phase voltage inverter, Fault diagnosis, IGBT, Alternative current, Zero harmonic component, Min and Max value, Logic functions, Boolean value.*

## 1. Introduction

Automatic fault detection of electric machines and drive systems is a challenging task that has recently attracted increasing attention. An intelligent regime of online condition monitoring leading to fault identification, fault location, and fault-severity evaluation represents the far goal. Precise diagnosis and early detection of incipient faults help avoid harmful, sometimes devastating, consequences of the fault. Repair requirements and the time frame could be preset based on the automatic diagnostics, which reflects lower cost. Temporary remedial actions, which allow the machine to continue running under fault, are firmly based on the online diagnostics and highly recommended for fault-tolerant systems.

Certain procedures are to be followed in order to achieve the automatic diagnosis mission. Studying system performance under specific fault conditions, and comparing it to healthy performance, yields one or more characteristic waveforms that could identify the fault. Features extracted from the characteristic waveform(s) are used as input data to the online diagnosis process.

Various techniques for open-switch fault detection in voltage source inverter (VSI)-fed pulse width-modulation (PWM) asynchronous motor drives were

presented in [1]. Monitoring voltages at key points of the system, and comparing them to respective references, could successfully diagnose the fault. Temporary remedial actions under similar faults on permanent-magnet (PM) synchronous motor drives were prescribed for fault-tolerant operation [2]. A converter topology with eight switches helped the machine produce more torque under fault than the classical six-switch configuration.

Expert systems, artificial neural networks (ANNs), fuzzy and adaptive-fuzzy systems, and genetic algorithms (GAs) represent the modern AI tools, which have been used in the area [3-4]. Adaptive neuro-fuzzy inference systems (ANFIS) are composed of fuzzy inference systems implemented in the framework of adaptive networks [5]. Pattern classification through learning, nonlinear mapping, and utilization of human expertise are examples of the powerful features of ANFIS. New and promising research horizons in the area of motor fault detection could be explored using fuzzy inference systems implemented on neural architectures [6].

Tahar Bahi, Mohamed Fezari, George Barakat and Nasr Eddine Debbache [7], Friedrich W. Fuchs [8] used a localization domain illustrated by seven patterns built with the stator Concordia mean current vector. One pattern corresponds to the healthy domain and the remaining six patterns are linked to the state of each inverter switch.

All works mentioned previously study the case of one open-switch fault condition. Case of simultaneous two open-switches fault is not widely studied.

The present work introduces a simple diagnostic technique for one and simultaneous two open-switches faults on the inverter bridge of voltage-source inverter (VSI)-fed three phase balanced load. Healthy and faulty system were simulated in PLECs / MATLAB program. Fault impact on each one of the three phases currents mean values and maximum and minimum values are observed to conceive the appropriate diagnosis algorithm basing on the value and the polarity of both the currents mean values and maximum and minimum values under fault condition.

This technique testing shows its effectiveness in detecting and locating the open-switch fault and even the simultaneous ones. Implementation of the proposed method should be straight forward on a processor loaded with three currents sensors.

## 2. Studied System

The VSI-fed three phase balanced resistive-inductive load considered in this work is presented in (fig. 1.). The system consists of the following components:

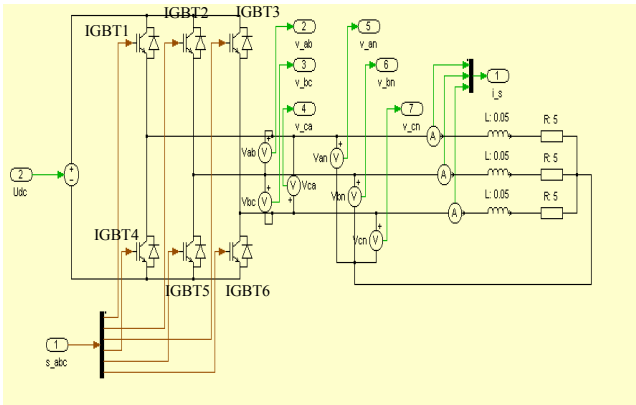


Fig. 1. Schematic diagram of the drive system.

- 1) DC supply 550 V;
- 2) IGBT-based three-phase inverter bridge controlled in PWM strategy with modulation index ( $0 < m < 1$ ) of 0.85, carrier frequency of 1080 Hz and sinusoidal fundamental frequency of 50Hz;
- 3) Three current sensors;
- 4) Three-phase balanced resistive-inductive load ( $R=5$  Ohm,  $L=0.005$  H).

The switching logic of the inverter is set by the open loop controller. Fig. 2. shows the switching sequence of the inverter IGBTs that goes through six different switching states in safe and open switch fault condition (T1 open switch fault condition and simultaneous T5, T6 open switches fault condition). Line to line voltages waveforms and Line to neutral point of the three phase load voltages waveforms are presented in (fig. 3.), phases currents waveforms with their mean values and maximum and minimum values are presented in (fig. 4.).

## 3. Simulation

The system was modeled using a PLECS / MATLAB program. The load was represented by three phase balanced resistance and inductance in series for each phase. Each switch was represented by a nonlinear resistor that attains a very low value when the switch is ON and a very high value when it is OFF.

**A. Proposed Method principle (Change detection of phases currents)**

Simulation results under both normal and faulty conditions will be used eventually to conceive the diagnosing algorithm basing on currents zero harmonic components and their maximum and minimum values and their polarities. Normal operating condition is characterized by, theoretically, a nil zero harmonic component value and specific maximum and minimum values of each phase current. As remarked on (fig. 4.). In normal operating condition, currents zero harmonic components values are almost nil (0 A). A change in phase currents waveforms is defined as the instant at which a sudden increase or decrease is observed in zero harmonic components values of three phases currents. A change is considered to have occurred in three phases values when they exceed or falls below a given band ( $\pm 0.5$  A).

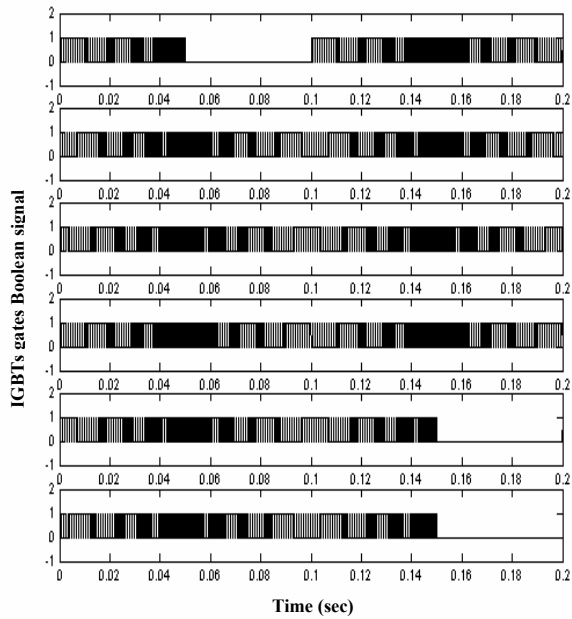
Basing on zero harmonic components values may not be sufficient to make difference between one open-switch fault of an upper IGBT of one leg and simultaneous open-switch fault of lower IGBTs of other legs. In both cases, one phase current zero harmonic component is of a sign that is different from the other two phases currents zero harmonic components ( $i_{s1\text{mean}} = 0$  A to  $-15$  A to  $0$  A to  $-20$  A,  $i_{s2\text{mean}} = 0$  A to  $+7.5$  A to  $0$  A to  $+9.6$  A,  $i_{s3\text{mean}} = 0$  A to  $+7.5$  A to  $0$  A to  $+10.4$ ) (fig. 4.).

The diagnostic system Boolean output signals in safe and open switch fault condition (IGBT1 safe and open switch fault condition and simultaneous IGBT5, IGBT6 safe and open switches fault condition) are presented in figure 5.

Therefore, another parameter is introduced to make the difference between one open-switch fault of an upper IGBT of one leg and simultaneous open-switch fault of lower IGBTs of other legs. This parameter is the minimum values of currents. In case of one open-switch fault of an upper IGBT of one leg, minimum values of the other phases, linked to safe legs, currents are negative. But, in case of simultaneous two open-switch fault of the lower IGBTs of the other two legs, minimum values of the other phases, linked to these legs, currents are nil ( $i_{s1\text{min}} = 0$  A to  $-49.5$  A to  $0$  A to  $-49.2$  A to  $0$  A to  $-50.5$  A,  $i_{s2\text{min}} = 0$  A to  $-49.5$  A to  $0$  A to  $-42$  A to  $-49.5$  A to  $0$  A,  $i_{s3\text{min}} = 0$  A to  $-49.5$  A to  $0$  A to  $-38.7$  A to  $-49.5$  A to  $0$  A) (fig. 4.).

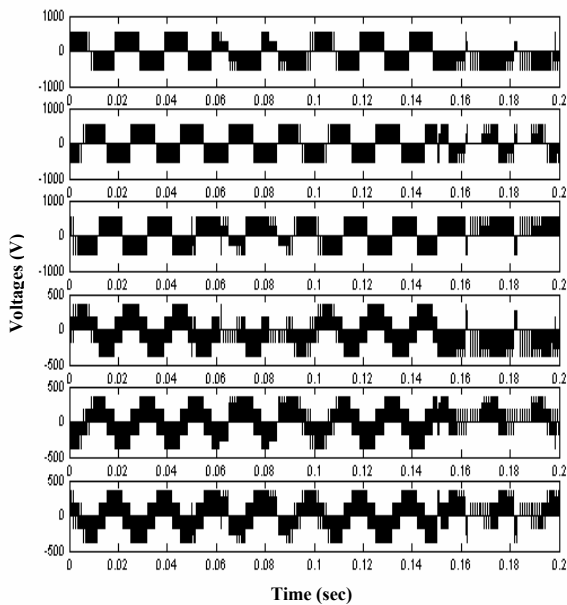
In case of one open-switch fault of a lower IGBT of one leg and simultaneous open-switch fault of upper IGBTs of other legs, currents maximum values will be used to make the difference between these two fault conditions (fig. 6.), (fig. 7.).

Currents zero harmonic components are calculated by using the discrete variable-frequency FFT calculation block in Simulink / Matlab with sample time of 0.0001s and input signal (phase current) frequency of 50 Hz.



From the top to the bottom: IGBT1, IGBT2, IGBT3, IGBT4, IGBT5, IGBT6.

Fig. 2. Six different IGBTs Boolean firing signals in safe and open switch fault condition (IGBT1 safe and open switch fault condition and simultaneous IGBT5, IGBT6 safe and open switches fault condition).



From the top to the bottom:  $v_{ab}$ ,  $v_{bc}$ ,  $v_{ca}$ ,  $v_{an}$ ,  $v_{bn}$ ,  $v_{cn}$  (V).  
 Fig. 3. Line to line and line to neutral point of load voltages waveforms in safe and open switch fault condition (IGBT1 safe and open switch fault condition and simultaneous IGBT5, IGBT6 safe and open switches fault condition).

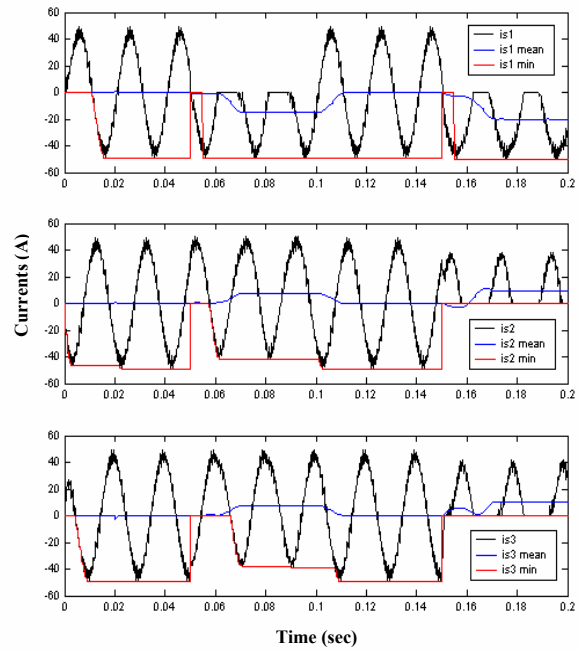
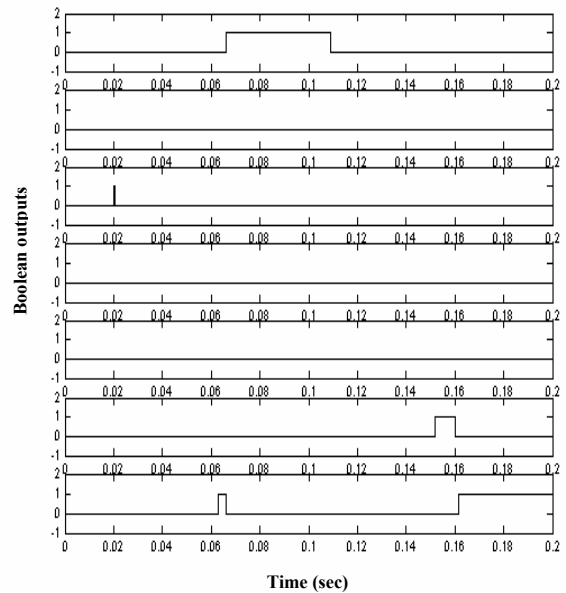
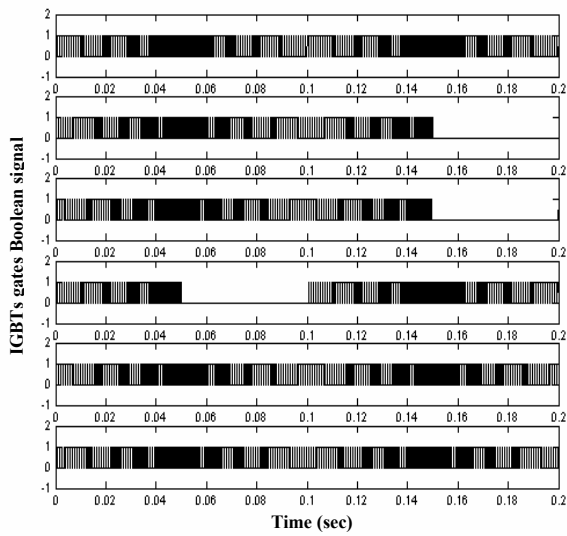


Fig. 4. Phases currents waveforms in safe and open switch fault condition with their mean values and their minimum values (IGBT1 safe and open switch fault condition and simultaneous IGBT5, IGBT6 safe and open switches fault condition).



From the top to the bottom T1, T2, T3, T4, T5, T6, simultaneous T5 and T6 open-switch fault.

Fig. 5. Diagnostic system Boolean output signals in safe and open switch fault condition (IGBT1 safe and open switch fault condition and simultaneous IGBT5, IGBT6 safe and open switches fault condition).



From the top to the bottom: IGBT1, IGBT2, IGBT3, IGBT4, IGBT5, IGBT6.

Fig. 6. Six different IGBTs Boolean firing signals in safe and open switch fault condition (IGBT4 safe and open switch fault condition and simultaneous IGBT2, IGBT3 safe and open switches fault condition).

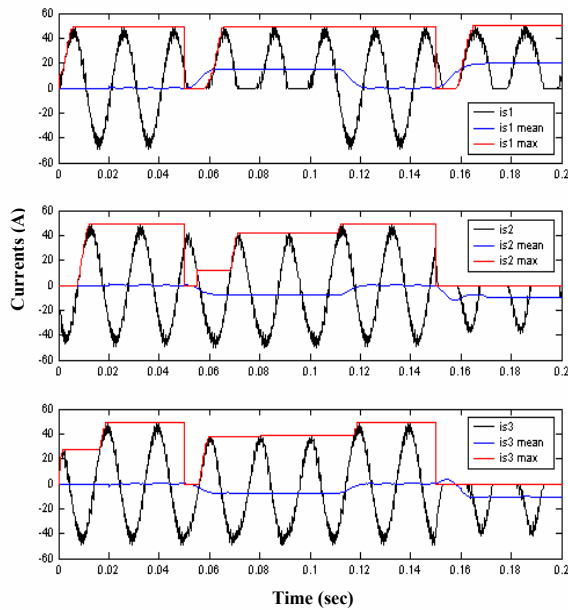
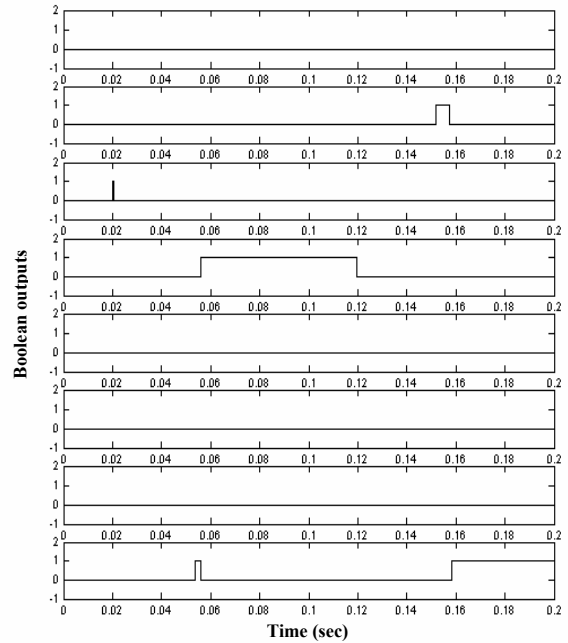


Fig. 7. Phases currents waveforms in safe and open switch fault condition with their mean values and their maximum values (IGBT4 safe and open switch fault condition and simultaneous IGBT2, IGBT3 safe and open switches fault condition).

The diagnostic system Boolean output signals in safe and open switch fault condition (IGBT4 safe and open switch fault condition and simultaneous IGBT2, IGBT3 safe and open switches fault condition) are presented in figure 8.



From the top to the bottom T1, T2, T3, T4, T5, T6, simultaneous T5 and T6 open-switch fault, simultaneous T2 and T3 open-switch fault.

Fig. 8. Diagnostic system Boolean output signals in safe and open switch fault condition (IGBT4 safe and open switch fault condition and simultaneous IGBT2, IGBT3 safe and open switches fault condition).

Phases currents characteristics to be used to identify the faulty device, as classified in Table 1.

The important remarks from this table to be noted are:

- 1- If the faulty switch is one of the up switches of inverter, mean value of current of the linked phase will be negative and positive for two other phases currents.
- 2- If the faulty switch is one of the up switches of inverter, minimum values of current of the linked phase will be negative as well as for two other phases currents.
- 3- If the simultaneous faulty switches are in the down part of inverter, mean values of currents of the linked phases will be positive and negative for the other phase current.
- 4- If the simultaneous faulty switches are in the down part of inverter, minimum values of currents of the linked phases will be at least nil and negative for the other phase current. Which constitute a difference comparing to the case of faulty switch in the up part of inverter.
- 5- In the cases of one faulty switch in the down part of inverter and simultaneous two faulty switches in the up part of inverter, both of mean value of phases currents and their maximum values will be used to make the difference between these two cases.

Table 1

Phases currents mean values and their max, min values polarities corresponding to faulty open circuit IGBT.

Faulty Device	is123 zero harmonic component polarity			is123 Min Values polarity			is123 Max Values polarity		
	Phase1	Phase2	Phase3	Phase1	Phase2	Phase3	Phase1	Phase2	Phase3
IGBT1	negative	positive	positive	negative	negative	negative	nil	positive	positive
IGBT2	positive	negative	positive	negative	negative	negative	positive	nil	positive
IGBT3	positive	positive	negative	negative	negative	negative	positive	positive	nil
IGBT4	positive	negative	negative	nil	negative	negative	positive	positive	positive
IGBT5	negative	positive	negative	negative	nil	negative	positive	positive	positive
IGBT6	negative	negative	positive	negative	negative	nil	positive	positive	positive
IGBT 5,6	negative	positive	positive	negative	nil	nil	nil	positive	positive
IGBT 4,6	positive	negative	positive	nil	negative	nil	positive	nil	positive
IGBT 4,5	positive	positive	negative	nil	nil	negative	positive	positive	nil
IGBT 2,3	positive	negative	negative	nil	negative	negative	positive	nil	nil
IGBT 1,3	negative	positive	negative	negative	nil	negative	nil	positive	nil
IGBT 1,2	negative	negative	positive	negative	negative	nil	nil	nil	positive

Simulation results show that when the base drive open circuit fault (IGBT<sub>i</sub> i=1 to 6) is introduced and phases currents are examined as a function of failure mode, there will be six different phases currents corresponding to the individual transistor base drive open-circuit fault of IGBT1, IGBT2, IGBT3, IGBT4, IGBT5 and IGBT6. In all six cases, this fault introduces a non-nil zero harmonic component values in three phase currents with polarity specified to each IGBT fault condition. This technique allows only individual transistor open-switch fault detection.

In case of simultaneous two open-switch fault IGBTs, another parameter is introduced to make the difference between one open-switch fault of an upper IGBT of one leg and simultaneous open-switch fault of lower IGBTs of other legs and vice versa.

#### 4. Conclusion

This paper presents systematically the novel simple approach to detect the inverter faults of one and simultaneous two open switches fault condition. The zero harmonic component values of phases currents as well as their Max/Min values have been used to identify the inverter faults. Implementation of this technique requires only three currents sensors, signal acquisition system and calculation processor.

The results are extremely important for the monitoring and fault detection of the inverter in drives system. The work can be extended to other converter configurations or drives.

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#### Biography



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