3rd International Conference on Automation, Control, Engineering and Computer Science (ACECS'16)
Proceedings of Engineering & Technology (PET)
pp. 389-393

Identification of the fault leg in a three phase voltage source inverter

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***Abstract*— Nowadays, inverters are power electronics devices used in the renewable energy conversion systems and also to fed induction motors, therefore the continuity of service of power converter has been a major concern. This paper presents a new approach of open circuit fault detection in a pulse width modulation three phase voltage source inverter. The fault occurrence detection was based on the standard deviation of the measured current vector and the localization of the fault leg where the open circuit fault occurred was achieved analyzing the current vector in d-q frame system. The reliability of this technique was confirmed in a real time simulation.**

***Keywords*— inverter, IGBT, power converter, induction motor, current vector**

I. INTRODUCTION

In many industrial applications, inverters are power electronics device used to control the speed of induction motors and to convert energy from natural renewable sources to an electrical network. Generally, induction motors are fed from pulse width modulation (PWM) voltage source inverter. Much research in recent years has focused on the reliability of inverters. In fact, switching devices of power converters such as IGBT insulated gate bipolar transistor are the weakest components. Switching device faults in power converters are short circuit and open circuit fault, short circuit generates abnormal over current and the system is immediately halted for safety.

For open circuit faults in power converter unbalanced currents results and healthy switches are overstressed which can damage the system if the fault is not immediately compensated. Rui and Huang cover the causes of IGBT insulated-gate bipolar transistor open circuit [1].

Different fault detection methods have been proposed. Ribiero proposed four techniques using extra voltage sensors at specific points to minimize time of fault diagnosis [2]. A simple hardware have been proposed by Trabelsi to detect single and multiple open circuit faults in a maximum of one switching period analysing the PWM switching signals and line to line voltage levels [3].

A much methods based on the analysis of the current vector have been suggested and introduced by Fuchs and Peuget which proved its effectiveness [4-5].

Peuget technique requires only one period to detect and isolate the fault after its occurrence, in the other hand, Fuchs detection is achieved in one fourth of a cycle. The current vector approach is used also for two level voltage inverter [6] and three parallel power converters [7-8].

Zidani used only two current sensors for simplicity and cost-effectiveness based on the Concordia current pattern with a fuzzy diagnosis [9] while Diallo suggested a pattern recognition approach based also on Concordia stator mean current vector [10]. Further, Caseiro published on the fault diagnosis using the average current vector [11].

One of the biggest challenges in open circuit fault diagnosis is to minimise the fault detection and localization time, most techniques require one period to detect the fault occurrence, the present paper propose a fault diagnosis technique for single IGBT open circuit fault based on the analysis of the current vector, the fault is immediately detected and the fault leg where the open circuit fault occurred is defined in a maximum of one current period and half without any additional sensor or complex training algorithm.

II. SYSTEM DESCRIPTION

The voltage source inverter is a power electronic device which converter energy from a direct current (DC) to alternating current (AC), used in many applications such in renewable energy systems and in the industrial field to fed an induction motor. Therefore the reliability of power converter is extremely important. A fault diagnosis technique must be developed to detect in a short time the faulty leg and isolate it to avoid possible damages in the system. The configuration of the VSI considered in this study has been developed in Matlab/Simulink as shown in fig.1, the pulse width modulation (PWM) was used to control the output voltage of inverter.

ISSN: 2356-5608

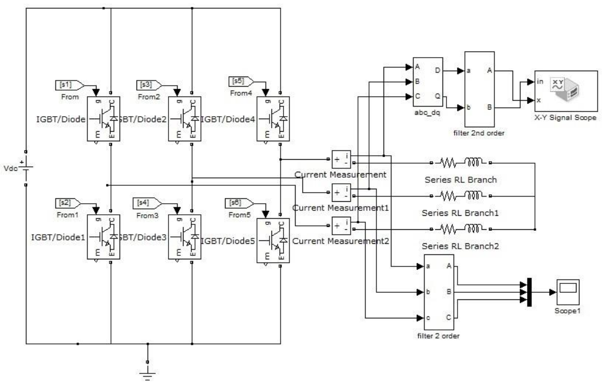


Fig.1: Matlab-Simulink model of a power inverter

A. Open circuit fault detection

The proposed fault diagnosis detects the open circuit fault immediately after its occurrence; this technique requires the measurement of the output inverter currents then the currents are expressed in the d-q frame on which the horizontal-axis is signified by id and the vertical-axis is signified by iq

The current in the d-q frame are expressed as follow:

id =square root(1/6)*(2*ia-ib-ic) (1)

iq =square root(1/2)*(ib-ic) (2)

A new variable x is introduced, this variable in healthy mode changes in the same interval but once the fault occurs this variable diverges and changes in a larger interval which indicates the fault occurrence at this specific time. Therefore x is used to detect an open circuit fault in the inverter.

x= square root (id^2+id^2) (3)

Fig.2 shows the patterns of the current vector in the healthy mode and in the faulty mode and fig.3 indicates the the fault occurrence simulated at t=0.028 sec is visible.

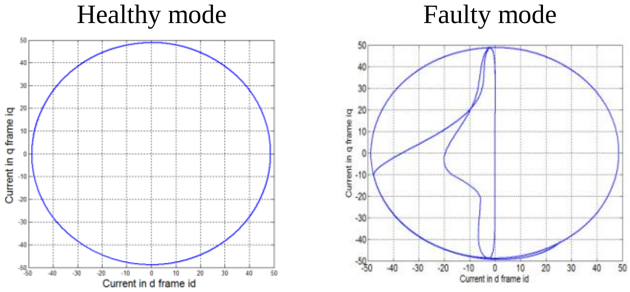


Fig. 2: Current patterns in healthy and faulty mode

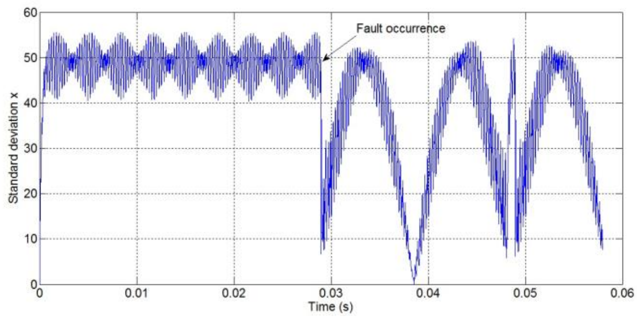


Fig. 3: values of x before and after fault occurrence

B. Fault leg identification

To identify the fault leg , the current in the d frame id was analysed, when a fault occurs after one period and half the maximum and the minimum of the current id are calculated, three cases are to discuss, if the maximum of id is zero or the minimum of id is zero the faulty switch is in the third leg otherwise the sign of the current in q frame is obtained for the maximum of the current in d frame id , if the sign of iq is positive the open circuit fault occurred in the second leg , in the contrarily if the sign of the current iq is negative the first leg must be isolated. The flow chart diagnosis below resume the fault localization approach proposed. Therefore, a regression tree was built.

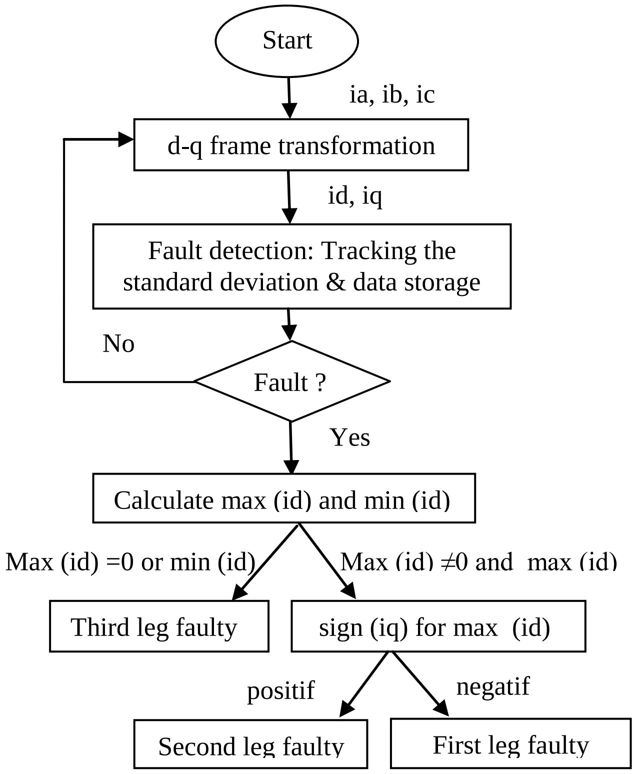
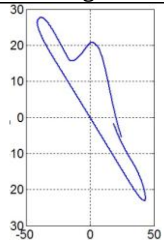
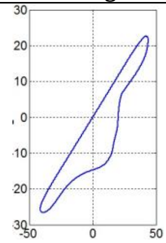
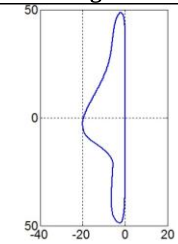
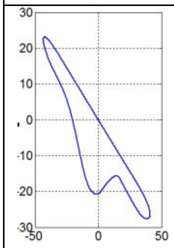
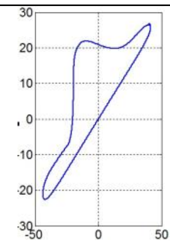
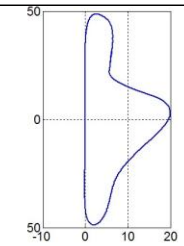


Fig. 4: Flow chart fault diagnosis system

Rigorously, the patterns of one current period were analysed for every open circuit fault and were obtained after one period and half of the fault occurrence. The measured current data were stored in the data storage step. For each leg the patterns of the two open circuit fault possible are represented in the following table:

TABLE I

Specific faulty leg		
First leg	**Second leg**	**Third leg**
		
		

Other researchers used the analysis of the current vector in d-q frame; almost the same patterns were obtained in this study. To detect the open circuit fault is to detect the faulty leg which was the purpose of this research. Although, the technique proposed identify the fault leg only for one open circuit fault.

III. RESULTS AND DISCUSSION

As mentioned earlier, the aim of this study is to introduce a new approach based on the analysis of the current vector in d-q frame; to detect the fault leg where the open circuit fault occurred. In this study the fault occurrence was immediately detected and the identification was achieved by a regression tree; to detect the fault occurrence the variable x was introduced which is the standard deviation of the currents in d-q frame , if the parameter x changes in a larger interval than usual an open circuit fault occurred . In the other hand the localization was based on the maximum and the minimum of the current id, if both are equal to zero than the fault occurred in the third leg otherwise, the sign of the current iq is determined for the maximum of the current iq , if it is positive the second leg is faulty else ways the first leg is faulty.

Simulation results were obtained using Simulink/ Matlab real time simulation, for each open circuit fault a particular shape was obtained as shown in table 1. The current vector in d-q coordinate system in healthy mode and faulty mode were represented in fig.2, the fault occurrence is visible in fig.3. The T4 switch experiences an open circuit at t=0.028sec, the faulty phase currents are illustrated in fig.4 and the currents in d-q frame can be found in fig.5. The fault occurrence is obvious which show a fairly consistent detection.

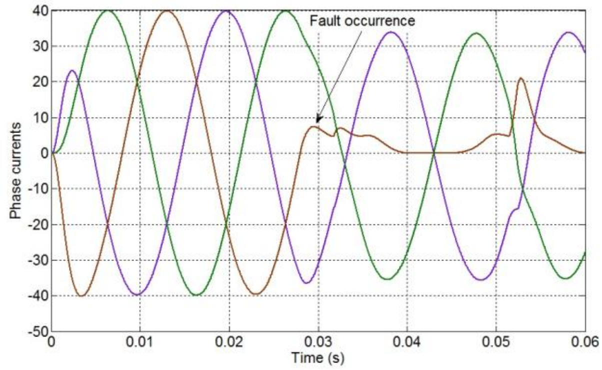


Fig.4: Phase currents in faulty mode

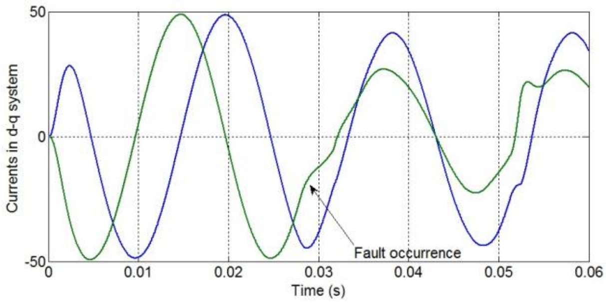


Fig.5: Currents in d-q system in faulty mode

Special patterns are also found in other researches using the analysis of the current vector by Peuget, Trabelsi and Fuchs which confirm and support the results obtained.

Most techniques require one period cycle to detect the fault occurrence and the open circuit fault is identified within a maximum of two periods, this technique detects immediately the fault occurrence and the localization of the fault leg is achieved in a short time, one period and half. Ideal shapes of the vector currents were obtained after one period and half of the fault occurrence and the currents in d-q frame for one period were analysed. This technique was achieved without any additional sensor or complex training algorithm. However, detection of multiple open circuit fault were not explored in this study, nevertheless it can be introduced in a future work. Only simulation results using simulink were obtained, experimental results were not achieved, although simulink is a real time simulation and the results were repeatedly and accurately obtained.

IV. CONCLUSION

A new approach for open circuit fault detection was introduced; this method was based on the analysis of the current circuit in d-q system, which detected the fault leg where the open circuit fault occurred in a short time, one period and half of the current vector. The technique was verified through simulation. A multiple open circuit fault detection and a fault tolerant and compensation system will be presented in a future work.

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