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Fault Tolerant Control in Z-Source Inverter Fed Induction Motor

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Abstract

This paper discusses about the detection and replacement of the switches in inverter under fault. The detection of switch is done through measuring the phase and line voltages of inverter. The replacement of the open switch is done through the extra arm provided in the circuit. The firing of the extra arm is done by detecting the open switch fault and interrupting the processor to provide the firing to the extra arm switch. This paper gives simple and effective detection and replacement of open switch. The replacement of switch will be done without stopping the whole system and saves the unspecified time. Simulation results are provided to demonstrate the detection and replacement. A feasible test is implemented by building a proto type three-phase impedance source inverter, which is designed and controlled on the basis of proposed considerations. It is verified from the practical point of view that this new approach is more effective and acceptable to minimize the distortion.

Keywords: *SMPS – Switch Mode Power Supply, pulse width modulation (PWM), VSI –Voltage Source Inverter.*

1. Introduction

The inverters are largely used in industries to drive ac motors. The faults in the inverters are open switch fault; short-circuit of switches, short circuit of dc-link capacitor, line to line short circuit, single line to ground and short circuit of dc link to ground [1]. When any one of the fault occurs, it is required to stop the whole system for an unspecified time. The cost to replace the system fault will be high. So it is required to minimize the cost by replacing the faults. The various faults occurs in the inverter can be detected using the comparator [2]. The replacement can be done through the study of the system and some modifications can be done to the system to rectify the fault. In this paper we discuss about the open switch fault and replacement of the faulted switch. When this fault is occurrs the phase and line voltages of the inverters get decreased. This will lead to reduction of torque and speed of the motor [2]. This voltage may or may not be sufficient to drive the motor. This fault occurs when the gate voltage is not switched. Measuring phase and line voltages of the inverter do the detection of open switch fault [3]. Earlier the current decides the detection of various faults. R.L.Araujo Ribeiro gives the various detection techniques to detect the open switch fault. Rene Spee discusses about the various faults and the healthy drive of the motor when the faults are occurred with the some remedial actions. Raphael Peuget detects the faults by knowledge-based rules. F.Blaabjerg gives the detection of faults like short circuit of two output phases, short circuit in dc link and ground or earth fault. In this paper we provide the replacement of this fault through an extra arm placed in this circuit.

This paper presents the fault detection and identification of open switch using the inverter pole voltage measurement technique, which measures the voltages at various places and comparing the voltages. The detection and identification of open switch can be done in very lesser time. To introduce such strategies in motor drive systems as practical entities, hardware and software must perform the following tasks: fault detection, fault identification, and remedial actions.

A basic requirement to all fault tolerant development is a comprehensive understanding of the regular system operation so that its behavior can be compared to that one at the onset faults. The different types of faults normally verified in the switching power stage are indicated as F_1….. F_6. Depending on the nature of the fault, closure or opening of switches the occurrs, which can be classified as:

Dc link short circuit to ground (F_1)
Dc link capacitor bank short circuit (F_2)
Open circuit damage of switch (F_3)
Short circuit damage of switches (F_4)
Line to line short circuit at machine terminal (F_5)
Single line to ground fault at the machine terminal (F_6)

The protection scheme of the drive system is usually designed to prevent the damage of the switching power converter. Such a scheme includes the circuitry to prevent over voltage and under voltage of the dc link bus as well as the over current of the inverter. Fuse relays protect the input side against over current and thermal ones protect the electrical machine against overheating. A circuit breaker interrupts currents in the case of overload in the systems. But the protective circuit will not rectify or detect the open switch damage in the inverter. So the open switch damage fault is selected. The various detection techniques are used to detect the fault occurrence.

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The detection techniques employ a direct comparison of the measured voltages to their reference voltages obtained from the reference signals. They are classified as follows.

Technique 1 – Inverter pole voltage measurement
Technique 2 – Machine phase voltage measurement
Technique 3 – System line voltage measurement
Technique 4 – Machine neutral voltage measurement

In these cases, the voltage error ϵ_{ij} (i, j =1, 2, …. , 6) are the variables used for both the detection and identification of the faulty switch of power inverter. Such error can be expressed as

$$\epsilon_{ij} = v^{*}_{ij} - v_{ij} \quad (1)$$

The fault diagnosis for techniques T1 to T4 is accomplished in three steps as follows.

1) Measurement of voltages (v_{ij})
2) Generation of the voltage error (ϵ_{ij})
3) Determination of the faulty condition and identification of faulty condition

Technique 1 uses the comparison of voltages between the reference voltage and inverter pole voltage. This technique is faster than the other techniques. The time required to detect and identify the open switch fault is smaller than the other techniques. Technique 2 uses the comparison of voltages between the reference voltage and machine phase voltage. Technique 3 uses the comparison of voltages between the reference voltage and system line voltage. Technique 4 uses the comparison of voltages between the reference voltage and machine neutral voltage. This technique will detect the faulty condition when it is combined with the other techniques.

Earlier the faulty condition is detected by the current measurement. The identification of fault cannot be done using current measurement which was used earlier. It will take one fundamental cycle to detect the fault. Now the detection and identification of faulty condition is done by voltage comparison method. The above mentioned problems will be rectified by using voltage measurement. The detection of fault is quicker than the current measurement. Technique 1 is selected for the detection and identification of open switch fault because this technique has the above said advantages and takes lesser time than the other techniques.

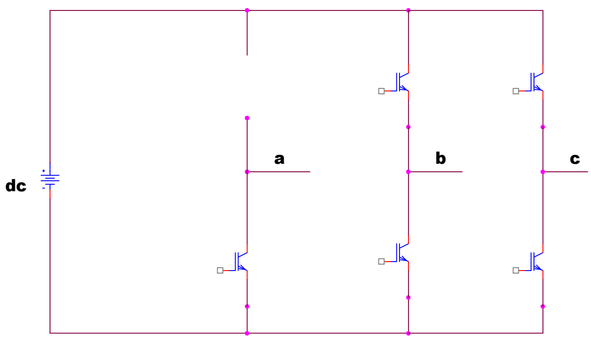

Fig 1 Equivalent circuit when open switch fault occurred

Technique 1 is used to detect and identify the open switch faults. The circuit shown in Figure 1 is used to detect and identify the open switch in the upper arm of the three phase bridge inverter.

2. Circuit Description

Fig.2 shows the detection of the open switch faults in the upper arm switches. Here the phase voltages are measured and compared with the reference voltage (dc voltage). When the open switch fault occurs, the comparator output will be zero or a dc voltage (constant value). This specifies the open switch fault. The three comparators are placed at each arms of the inverter to do the identification of faulted switch .The replacement of the switches can be done through an extra arm placed in the circuit

Figure 3 shows the detection of the open switch faults in the lower arm switches. Here the line voltages are measured and compared with the reference voltage (dc voltage). When the open switch fault occurs, the comparator output will be zero or a dc voltage (constant value). This specifies the open switch fault. The comparators identify the faulted switch.

The replacement arm can be activated when the open switch fault is occurred. The gating pulse should given to the extra switches which is done by interrupting the processor to run the program. When the open switch fault is occurred for example, switch 1 is faulted then the gating pulse is given to the extra switch present in the upper arm. This gating pulse is achieved by interrupting processor via comparator output. The extra arm is connected to the load or motor by manually to the arm where the fault is occurred. Programmable switches can be used instead of manual changing.

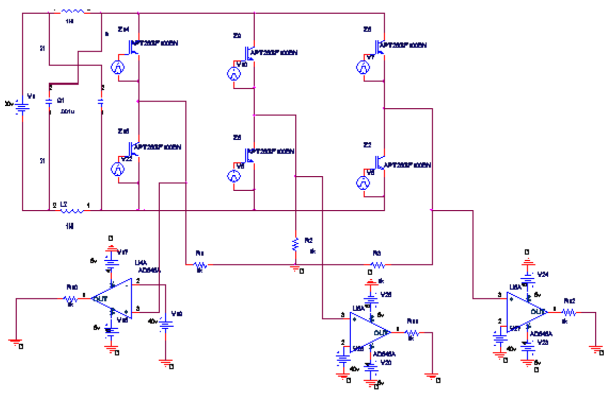

Fig.2 Circuit for fault detection in upper arm switches.

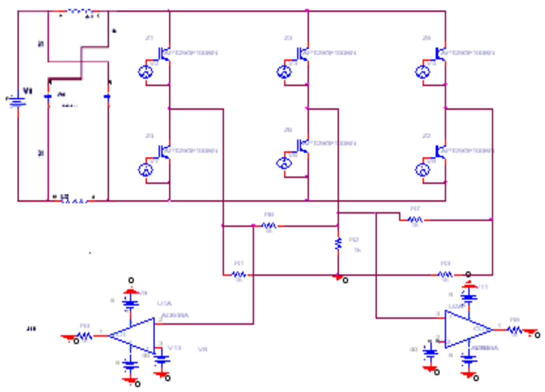

Fig 3 Circuit for fault detection in lower arm switches

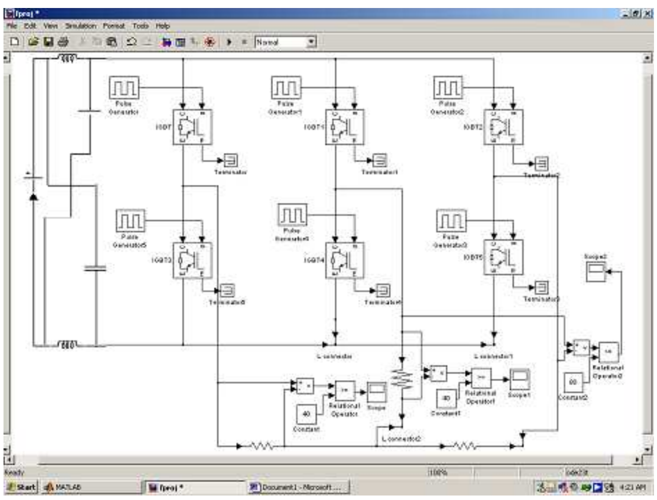

Fig 4 Inverter circuit with the replacement switches

3. Result Analysis

The circuits shown in the previous chapters are simulated using the ORCAD-PSPICE. The simulations results are shown below.

Simulations of circuits:

- Results with and Without Faults
- Detected and Identified Faults Results

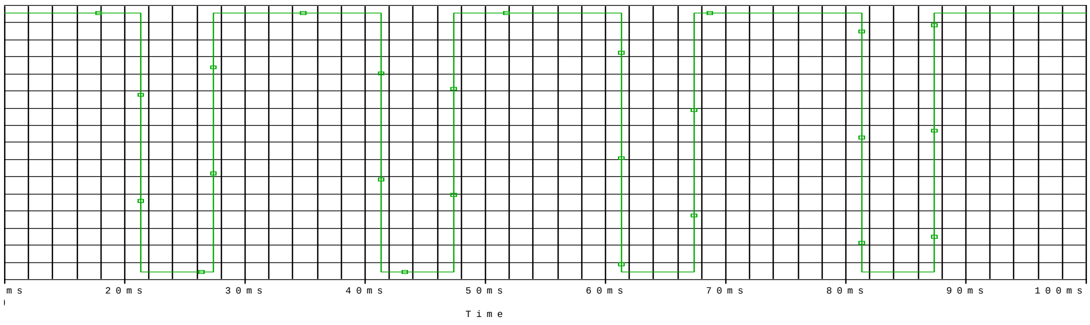

Figure 5 Output of comparator when fault is not occurred

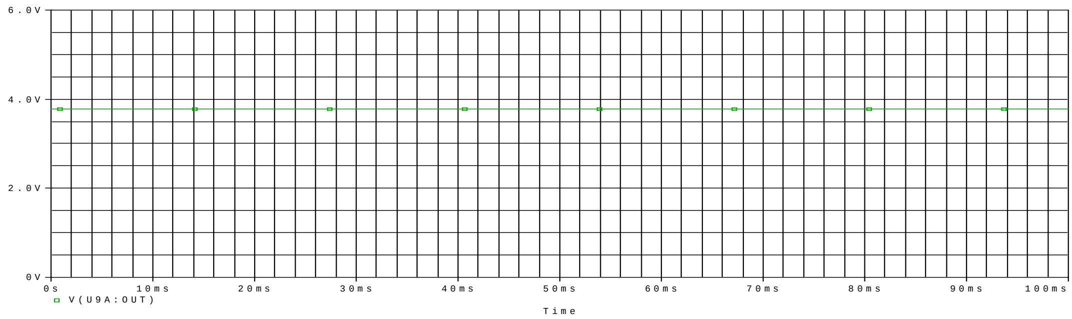

Figure 6 Output of comparator when the switch is faulted

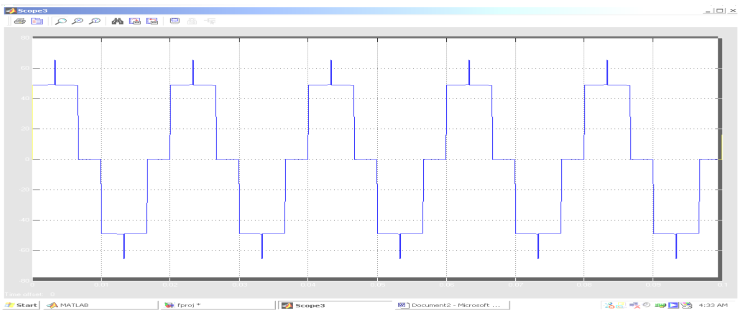

Fig 7 Phase Voltages of Inverters without Open Switch Fault

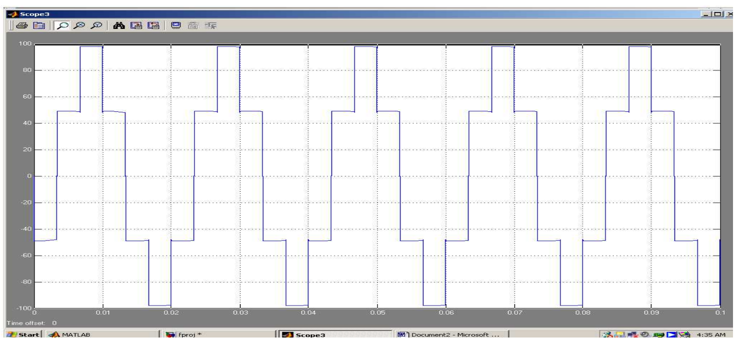

Figure 8 Line Voltages of Inverters without Open Switch Fault

The results shown here are the detected and identified open switch fault in an inverter. The circuits referred previously are simulated using the MATLAB. The simulations of the results are shown here. Simulations of Circuits:

- Results With and Without Faults
- Detected and Identified Faults Results

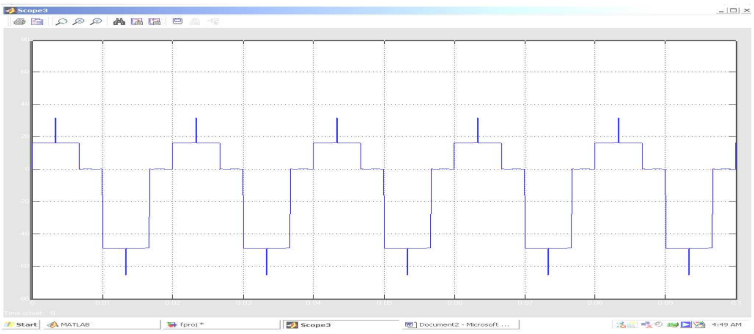

Fig 9 Phase Voltages when Open Switch Fault occurs

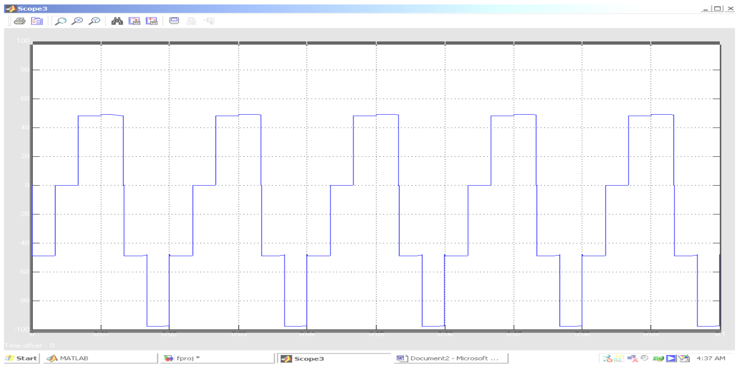

Fig 10 Line Voltages when Open Switch Fault occurs

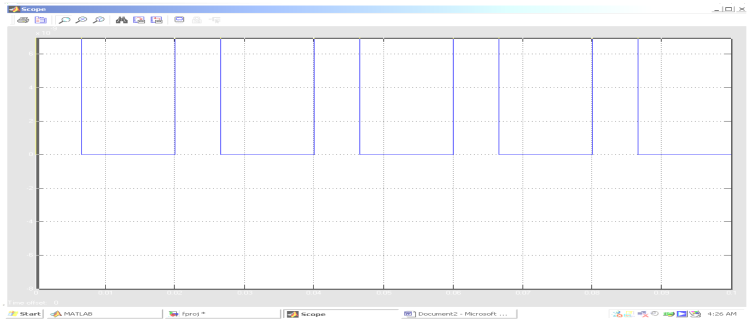

Figure 11 Output of Comparator when fault is not occurred

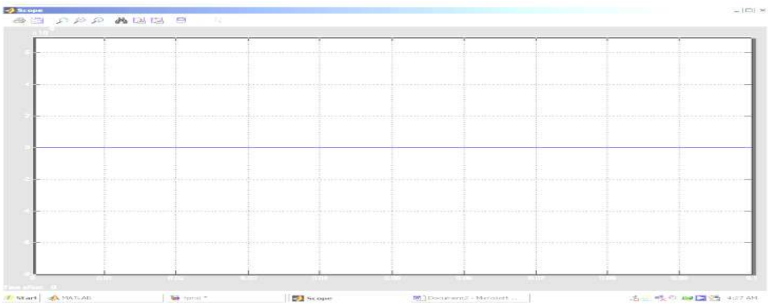

Fig 12 Output of comparator when the switch is at fault

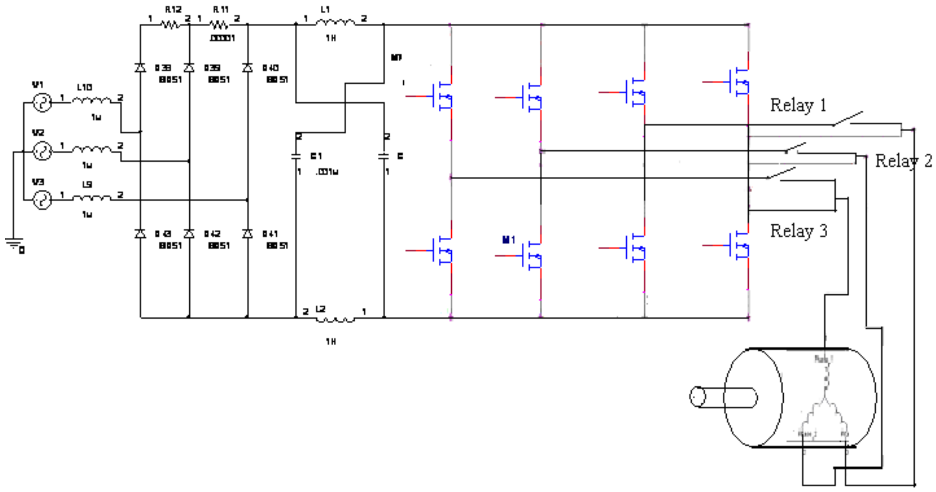

Fig 13 Circuit Diagram of the Hardware Setup

The output voltage of inverter when fault is occurred is also shown in Figure12. The output of inverter when the fault is occurred will contain the pulsating dc voltage that is positive only. The comparator is used to detect and identify the open switch fault. When there is no fault the output of comparator is a square voltage. When the fault is occurred the output of the comparator must be zero or constant voltage. But this output obtained in inverter is due to the change in output voltage of the inverter. Detection of the fault in the upper arm switches is done by measuring the phase voltages and compared with the reference value. The replacement of the switches can be done through an extra arm placed in the circuit as shown in Fig.13.

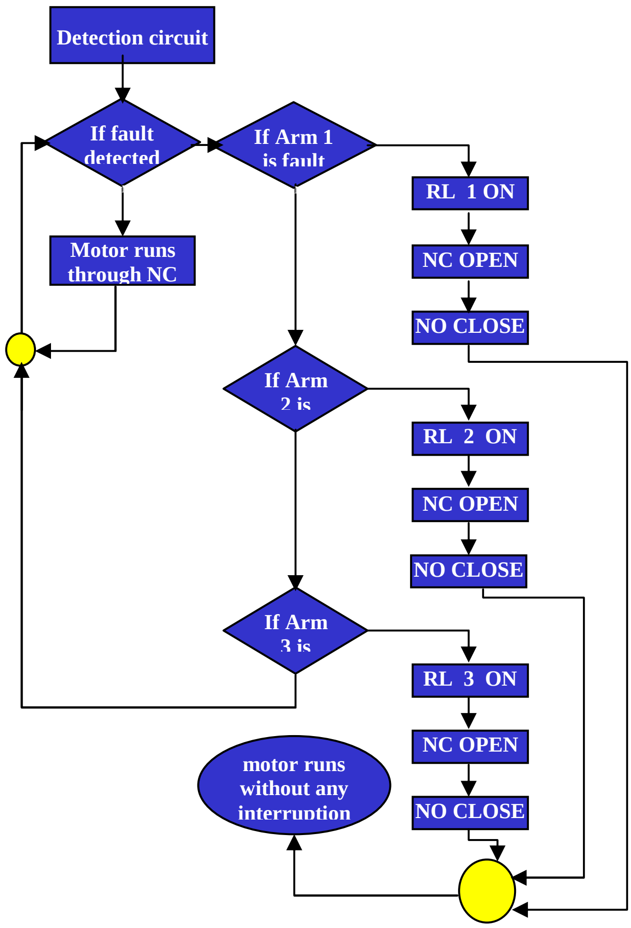

Fig 14 Operation Flow chart

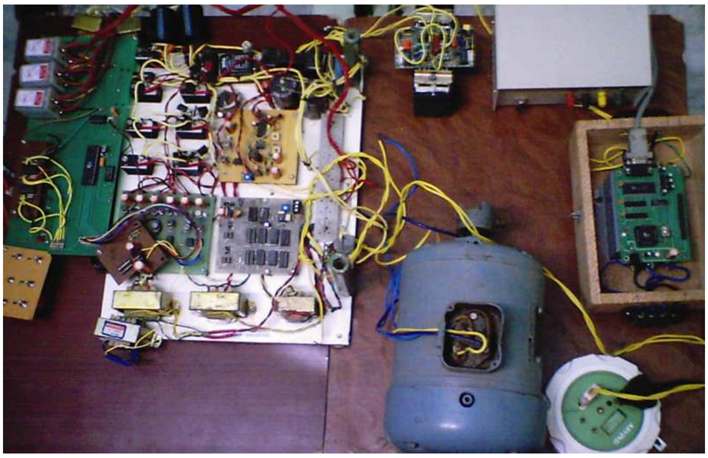

Fig. 15 Photo of the Experimental Setup

4. Conclusion

The detection and replacement of the switches discussed in this paper is done by measuring the line and phase voltages of inverter and comparing it with the reference voltages which is used to interrupt the processor to provide the gating pulses of faulty switch to the extra arm. This extra arm is connected to the load manually. This project can further improved by making the manual changing of switches to a programmed one

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