Real-Time Switches Fault Diagnosis for Voltage Source Inverter Driven Induction Motor Drive

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Abstract—**Induction machine is the frequently used for electrical drive applications in almost many industrial processes due to its simple and robust construction. Speed control of induction machine is required depending on the type of application. Speed of the induction motor can be varied by varying frequency or by variation of the terminal voltage. Variable voltage can be fed to induction machine using the voltage source inverter which is found efficient technique of controlling induction motor drive. The potential faults that occur in inverter are the open and short circuit switch fault. The cost of this schedule can be high, and this justifies the development of fault diagnostic methods. In this paper we present a reliable strategy for diagnosis and detection of open and short circuit switch faults in plush width modulation of voltage source inverter (PWM-VSI) using the fuzzy logic approach. The principle of the proposed approach is based on the acquisition of stator currents, to calculate the average absolute values of currents (AAVC), which allows the real-time detection and localization of inverter IGBT open or short-circuit faults using just the motor phase currents. A model of the system is built using MATLAB/SIMULINK. Simulation results are presented showing the monitoring approach performance under distinct operating conditions.**

Index Terms—**Open circuit fault, short circuit fault, fuzzy logic, modeling, simulation.**

I. Introduction

The plush width modulation of voltage source inverter (PWM-VSI) has become the usual in industrial applications for variable speed operation systems such as energy conversion system, electrical motor drives, active power filters, and even traction of hybrid electric vehicle. These inverters mostly use power electronics switches based on the insulated-gate bipolar transistor (IGBT), due to its advantages features which include sinusoidal input current with unity power factor and high-quality of output voltage [1], [2] The reliability of the power conversion systems have been always important issue. So, fault diagnosis methods of the system are required to improve reliability and guarantee scheduled maintenance [3]. In literature the several statistical researches are introduced to prove the components the most susceptible to failures. These researches show that about 38% of the failures in variable speed AC/DC/AC drives systems in industry are mostly found in power electronics equipment and 53% in the control circuits [4]-[6].

The open switch faults of the system do not cause system shutdown contrary to short circuit faults, but degrades its performance. Such degradations in return represent the source of secondary faults. If such state of abnormal operation lasts for extended period of time, accumulated fatigue under unstable operation may generate malfunctions in several devices of the system. Accordingly, there is high probability of secondary faults occurrence in the load, grid, and converter system [7].

Short-circuit switch faults, also called transistor latch-ups, are one of the most common failures in semiconductor switches. When a short-circuit fault occurs the switch becomes closed and remains in the on state regardless to the gate control signal. The first problem occurring after a short-circuit fault is a very high current flowing in the two switches of one phase leg and the dc source, as soon as the other switch of the leg is turned on. These faults can cause severe damages to the battery or the load connected to the inverter [8].

Therefore, diagnosis techniques of power conversion systems are required for monitoring and detecting of open and short circuit switch faults [9]. The suggested approach in this paper is based on the fuzzy logic technique, last that used as input to fuzzy system the Average Absolute Values of Currents (AAVC), in the aim to increase the efficiency and the reliability of the monitoring of detection and localization IGBT open and/or short circuit fault of PWM-VSI. The models based on artificial intelligence approach as well as the global model are implemented by using MATLAB®/SIMULINK software.

II. Three Phase PWM Inverter

The Fig. 1 presents the structure of PWM voltage source inverter feeding an induction motor [10], [11].

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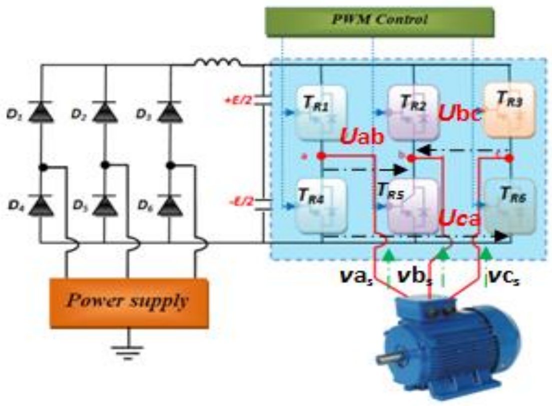


Fig. 1. Structure of PWM-VSI feeding induction motor

III. Fault Diagnosis Approach

A. Fuzzy Monitoring Systems

The fuzzy logic is used for the diagnosis of open and short circuit switches faults in PWM-VSI feeding induction machine. The diagram of the suggested approach is shown in Fig. 2.

The measured motor phase currents are normalized using the modulus of the Park's Vector defined as [12]:

$$\begin{cases} i_d = \sqrt{\frac{3}{2}}i_a - \frac{1}{\sqrt{6}}i_b - \frac{1}{\sqrt{6}}i_c \\ i_q = \frac{1}{\sqrt{2}}i_b - \frac{1}{\sqrt{2}}i_c \end{cases} \quad (1)$$

where i_a, i_b and i_c are the stator currents of the induction motor, i_d and i_q are the components of the Park' vectors. The Park's vector modulus $\bar{i}_s$ is can be expressed by:

$$\left|\bar{i}_s\right| = \sqrt{i_d^2 + i_q^2} \quad (2)$$

The normalized stator phase currents of induction motor are given by [13]:

$$i_{nN} = \frac{i_n}{\left|\bar{i}_s\right|} \quad (3)$$

where n=a, b, and c.

Therefore, haughty that the induction motor is fed by a healthy inverter generating a perfectly balanced three phase sinusoidal current system, that can be given by:

$$i_n = \begin{cases} i_a = I_m \sin(\omega_s t + \varphi) \\ i_b = I_m \sin(\omega_s t - 2\pi/3 + \varphi) \\ i_c = I_m \sin(\omega_s t + 2\pi/3 + \varphi) \end{cases} \quad (4)$$

where I_m is the current maximum amplitude, ω_s is the motor current frequency, and φ is the initial phase angle. Then the new expression of the Park's Vector modulus can be defined by:

$$\left|\bar{i}_s\right| = I_m\sqrt{\frac{3}{2}} \quad (5)$$

The normalized stator currents will always get values within the range of $\pm\sqrt{2/3}$, independent of the measured motor phase current amplitude, as [14]:

$$i_{nN} = \begin{cases} i_{aN} = \sin(\omega_s t) \\ i_{bN} = \sin(\omega_s t - 2\pi/3) \\ i_{cN} = \sin(\omega_s t + 2\pi/3) \end{cases} \quad (6)$$

The average absolute values of the three normalized motor phase currents i_{nN} are be given by:

$$\omega_s \int_0^{1/\omega_s} \left|i_{nN}\right| dt = \frac{1}{\pi}\sqrt{\frac{8}{3}} \quad (7)$$

Lastly, the three input monitoring variables in fuzzy system inference $e_n(e_a, e_b, e_c)$, are obtained from the errors of the normalized currents average absolute values as:

$$e_n = \varepsilon - \left|i_{nN}\right| \quad (8)$$

where ε is a constant value equivalent to the average absolute value of the normalized motor phase currents under normal operating conditions presented by equation (7), that given as:

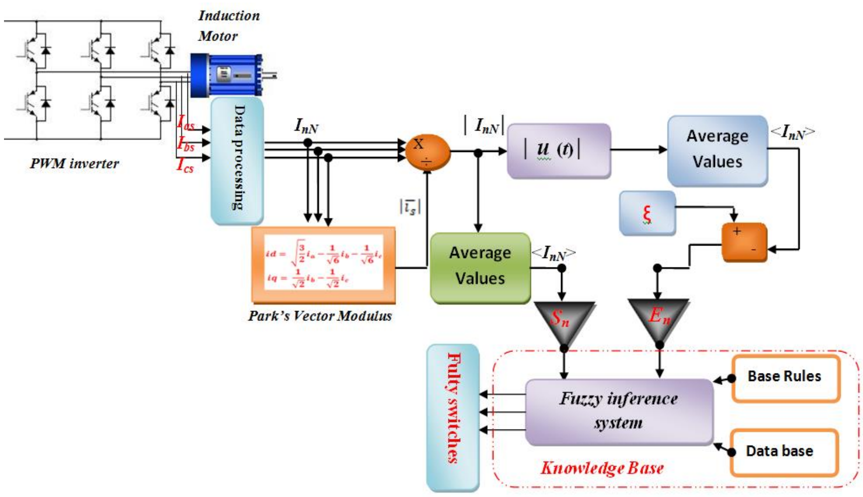


Fig. 2. Diagram of proposed diagnosis approach

$$\varepsilon = \frac{1}{\pi}\sqrt{\frac{8}{3}} \approx 0.5198 \tag{9}$$

The values taken by E_n and S_n allow generating a distinct fault signature which corresponds to a specific faulty operation condition, to achieve this, fault symptom variables can be formulated according to the following expressions [15]:

$$E_n = \begin{cases} N & \text{for } e_n < 0 \\ P & \text{for } e_n < 0 \end{cases} \tag{10}$$

$$S_n = \begin{cases} N & \text{for } i_{nN} < 0 \\ P & \text{for } i_{nN} > 0 \end{cases} \tag{11}$$

B. *Fuzzy System Input and Output Variables*

The values of E_n (E_a, E_b and E_c) and S_n (S_a, S_b and S_c) are selected as input variables of the fuzzy system. The diagnosis inverter state (CM_O) and (CM_CC), are selected as output variables of the fuzzy system. All these variables are defined by using the fuzzy set theory.

Fig. 3 shows that CM_O interprets the state (Open circuit switch) of the inverter as a linguistic variable, which could be T(CM_O)={O_TR1, O_TR2, O_TR3, O_TR4, O_TR5, O_TR6, HI}.

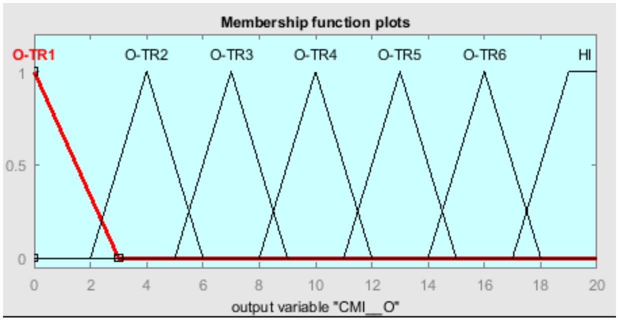


Fig. 3. Membership functions for output variables (Open circuit switch fault)

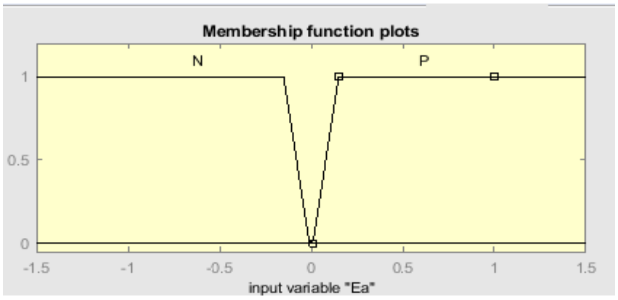


Fig. 4. Membership functions for input

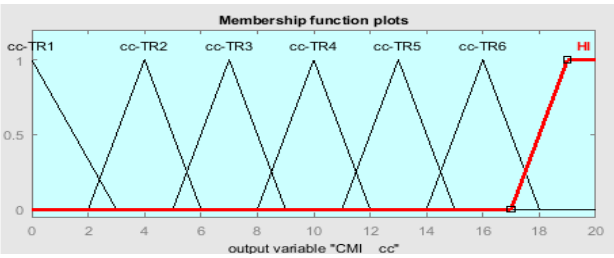


Fig. 5. Membership functions for output variables (*short circuit switch fault*)

The input variables (E_a, E_b and E_c) and (S_a, S_b and S_c) are also interpreted as linguistic variables, with $t(Q)$={Positive (P), Negative (N), as it is showing in Fig. 4. Fig. 5 shows that CM_CC interprets the state (*Short-circuit switch*) of the inverter as a linguistic variable, which could be T(CM_CC)={CC_TR1, CC_TR2, CC_TR3, CC_TR4, CC_TR5, CC_TR6, HI}. The uzzy rules membership functions for the input and the output. These rules are then defined, as follows.

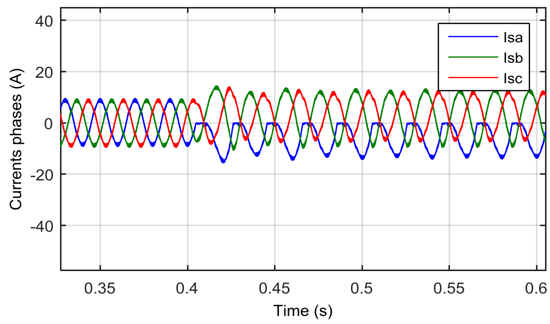
IV. Case of Study

The three phase stator currents I_{sa}, I_{sb} and I_{sc} in the faulty case of open switch fault in T_{R1} are presented in Fig. 6 (a), in this case of fault, it is noted that the stator phase currents are unbalanced at the moment of failure (t= 0.4s), and the cancellation of the positive sequence of the phase current. In the Fig. 6 (b), we note that the three diagnostic variables are the position (E_a=Positive, E_b=Negative, E_c=Negative). The Fig. 6 (c) shows the stator currents average absolute values are taking the position (S_a= Negative, S_b = Positive, S_c = Positive).

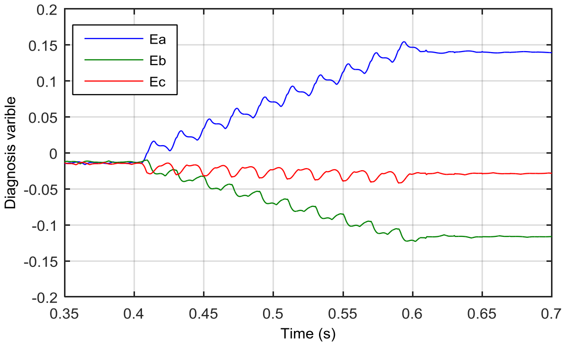
These positions of the input variables of E_n and S_n presented in Fig. 6 (b) and Fig. 6 (c) are corresponding to the rule number 1 of Table I. Based on these position states, the fuzzy inference system made the decision that the TR1 is faulty, as shown in Fig. 6 (d).

TABLE I: Fuzzy Rules Member Ship Function

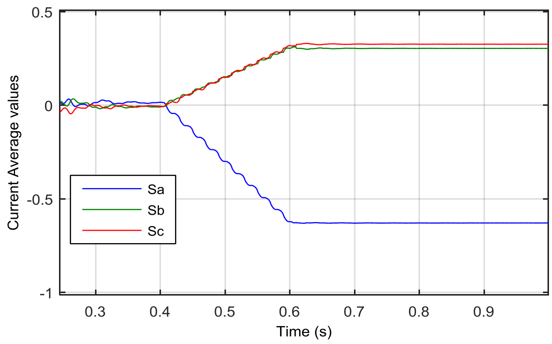
Open Switch Fault Of PWM Inverter (CM_O)									
Rules	If E_a	and E_b	and E_c		If S_a	and S_b	and S_c		is
Rule (01)	P	N	N		N	P	P	Then CM_O	OpenT_{R1}
Rule (02)	P	N	N		P	N	N		OpenT_{R2}
Rule (03)	N	P	N		P	N	P		OpenT_{R3}
Rule (04)	N	P	N		N	P	N		OpenT_{R4}
Rule (05)	N	N	P		P	P	N		OpenT_{R5}
Rule (06)	N	N	P		N	N	P		OpenT_{R6}
Short Circuit Switch Fault Of PWM Inverter (CM_CC)									
Rule (07)	N	P	P		P	N	N	Then CM_CC	Short-circuit TR1
Rule (08)	N	P	P		N	P	P		Short-circuit TR2
Rule (09)	P	N	P		N	P	N		Short-circuit TR3
Rule (10)	P	N	P		P	N	P		Short-circuit TR4
Rule (11)	P	P	N		N	N	P		Short-circuit TR5
Rule (12)	P	P	N		P	P	N		Short-circuit TR6
Rule (13)	P	P	P		P	P	P		Healthy Inverter



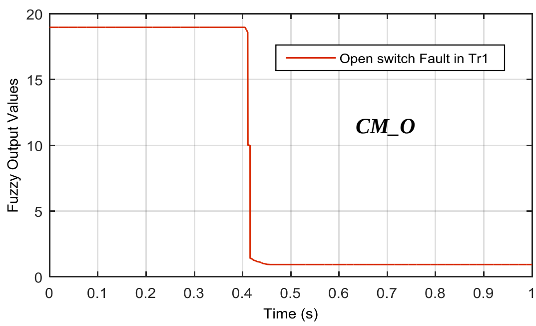
(a) Three stator phase currents



(b) Input diagnosis variables of fuzzy system



(c) Input currents average values of fuzzy system



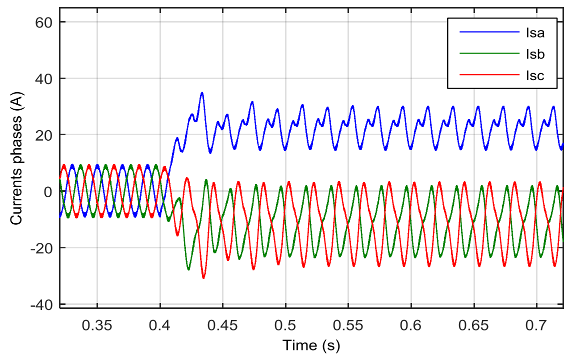
(d) Output fuzzy values (case of fault in switch TR1)

Fig. 6. Case of open switch fault in TR1.

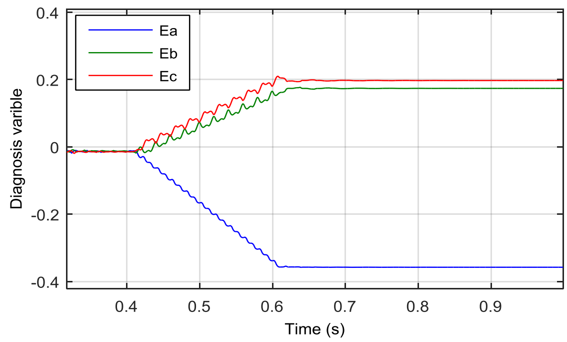
The three phase stator current I_{sa}, I_{sb} and I_{sc} in the faulty case of short circuit switch fault in TR4 are presented in Fig. 7 (a), in this case of fault, it is noted that the stator phases currents are unbalanced at the moment of failure (t=0.4s), and the sequence of the three phase current are decaled.

In Fig. 7 (b), we note that the three diagnostic variables are taking the position (E_a =Negative, E_b = Positive, E_c = Positive). Fig. 7 (c) shows the stator currents average absolute values are taking the position (S_a= Positive, S_b= Negative, S_c= Negative).

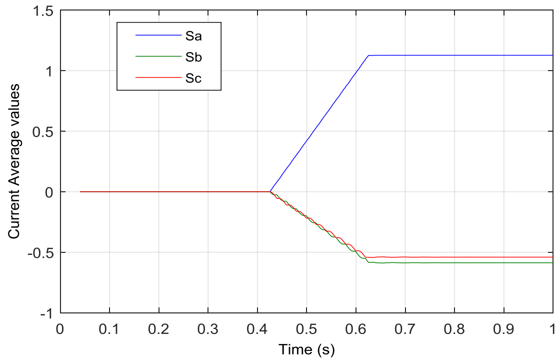
These positions of the input variables of E_n and S_n presented in Fig. 7 (b) and Fig. 7. (c), respectively, are corresponding to the rule number 7 of Table 1. Based on these position states, the fuzzy inference system made the decision that the TR1 is faulty (short-circuit fault), as shown in Fig. 7(d).



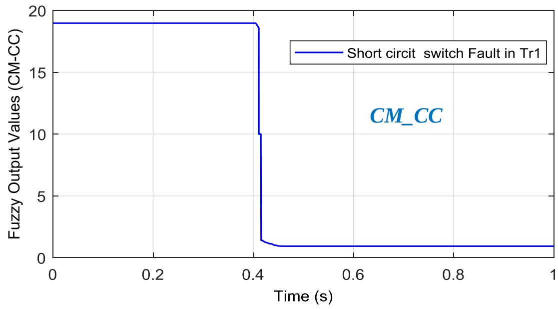
(a) Three stator phase currents



(b) Input diagnosis variables of fuzzy system



(c) Input currents average values of fuzzy system



(d) Output fuzzy values (short circuit fault in switch TR1)

Fig. 7. Case of short-circuit switch fault in TR1.

V. Conclusion

This paper analyzed the open and the short-circuit switch fault in DC/AC inverter and proposed a reliable strategy for detection and localization fault of open and short-circuit switch fault in Plush Width Modulation of Voltage Source Inverter (PWM-VSI) induction machine faults using the fuzzy logic approach by supervising the stator currents phase.

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