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Localization of Faulty Transistor in a Three-phase Inverter

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Abstract: The aim of this study is to develop an accurate model which is able to predict the performance of a three-phase inverter associated to a squirrel cage Induction Motor (IM). The proposed approach is a sensor-based technique using the current measurement. A localization domain illustrated by seven patterns is 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.The simulated results and the spectral analysis of the average vector current contours in the Alpha Beta (α, β) plan have allowed to investigate the voltage inverter state and to locate unambiguously the damaged switch. A data acquisition system card is proposed for practical tests.

Key words: Localization, inverter, induction motors, simulation

INTRODUCTION

The industrial techniques requirements generally need the use of the voltage inverters in the electric systems at variable speed. However, the disfunction of any switch produces inevitably constraints and damages the control device.

Considerable studies have been carried out these recent years dealing with diagnosis in electric drive[1-4]. This increasing interest is explained by the fact that not only such diagnosis gives good results but also has a direct economical impact.

The present study is concerned with the motoring and diagnosis of the voltage inverter associated to a squirrel cage induction motor using the average vector current contours in the α, β plan. The principle of detection and the induction motors model are presented. Then some simulation results illustrate the proposed method in the case of a healthy inverter and in the assumption of a damage of one the six switches. We show clearly the difference between the spectrum of the studied seven cases. A data acquisition system is then proposed to control the inverter in real time.

Principle of detection the faulty transistor: The three-phase voltage inverter is based on three cells of commutation as shown in Fig. 1. Each commutation cell can thus be regarded as a phase of the inverter. This system is controlled by a Pulse Width Modulation (PWM) generator module[5]. The command of the complementary switch of the same cell is assumed unchanged initially. Based on this command, a mean variable voltage is applied to the motor at each commutation period[6-8]. We study the effect of the damage of every switch of the inverter, respectively.

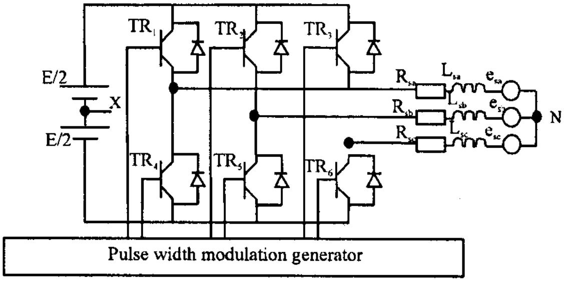

Fig. 1: Voltage inverter

When a damage occurs in a cell switch, the voltage of the corresponding phase is decreased[9] and a continuous current component appeared. Consequently, this yields to the displacement of the current vector contour in a direction which is dependant on the sign of the current variation and thus, gives an information on the localization of the damaged switch.

From Fig. 1, the simple voltage of a motor phase is written in the following way :

$$u_{si} = u_{ix} + u_{xn} i \in \{1,2,3\} \qquad (1)$$

Since the sum of the voltages is equal to zero ($\sum_{1}^{3} u_{si} = 0$), the instantaneous expression can be easily deducted as follows:

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Table 1: Relation between voltage and switches

$\delta_1 = \overline{\delta_4}$	$\delta_2 = \overline{\delta_5}$	$\delta_3 = \overline{\delta_6}$	[Va Vb Vc]	Positions
0	0	0	[0 0 0]	a
0	0	1	[-E/3 -E/3 2·E/3]	b
0	1	0	[-E/3 2·E/ -E/3]	c
0	1	1	[-2·E/3/ E/3 E/3]	d
1	0	0	[2·E/3 -·E/3 -E/3]	e
1	0	1	[E/3 -2·E/3 E/3]	f
1	1	0	[E/3 E/3 -2·E/3]	g
1	1	1	[0 0 0]	h

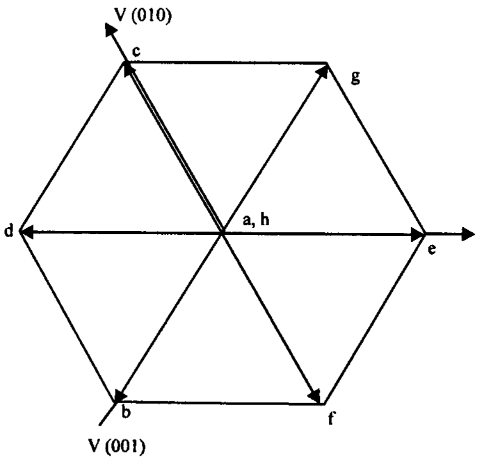


Fig. 2: Vector V_a, V_b and V_c representation

$$\begin{bmatrix} u_{sa} \\ u_{sb} \\ u_{sc} \end{bmatrix} = \frac{E}{6} \begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix} \begin{bmatrix} \delta_1 & - & \delta_4 \\ \delta_2 & - & \delta_5 \\ \delta_3 & - & \delta_6 \end{bmatrix} \qquad \delta_i \in \{0,1\} \quad (2)$$

Where, E is the DC voltage inverter input and δ_i ($\delta_i = 1, 0$) presents the logic state corresponding to the conducting or non conducting state of the switch (TR_i), respectively. In a three-phases system, the vector components are separated from each other by an angle of 120°. We have to mention that the logic state of two switches of the same cell in the inverter is complementary.

Table 1 shows the possible combinaisons related to the logic state of the cells and theire voltage vectors. Then, the positions of the extremities of the resulting voltage vectors are labelled a, b, c, d, e, f, g and h as (Fig. 2).

As an illustration of this method of localization of a damaged switch, we consider that TR_1 is out of work ($\delta_1 = 0$). From Table 1 and Fig. 2 the representation of the extremity of the current vector in α-β plan is located in the domain abcd. However, if the complementary switch TR_4 is damaged the extremity of the current vector is located in the domain efgh.

The same procedure is then applied to determine domains where the extremity of the current vector is located in the case of a possible damage occurring in one of the remaining switches.

INDUCTION MOTOR MODEL

We need an induction motor model which allows to simulate its behavior. For the setting equation, we suppose that winding set out in a manner to give a sinusoidal Magneto Motrice Force (MMF) if it is fed by sinusoidal current. Also, the following assuptions are to be considered: the permeance of iron is infinite, the Foucaul current and winding losses are negligible, the currents and the skin effect are negligible[10,11]. With these assumptions, the voltage equations for the stator can be written as:

$$v_s = R_s.I_s + \frac{d\phi_s}{dt} \qquad (3)$$

Where:

$$\phi_s = L_{ss} \cdot I_s + L_{sr} \cdot I_r \qquad (4)$$

$$I_s = [i_{sa}\ \ i_{sb}\ \ i_{sc}]^t;\ I_r = [i_{ra}\ \ i_{rb}\ \ i_{rc}]^t;\ v_s = [v_{sa}\ v_{sb}\ v_{sc}]^t \qquad (5)$$

The matrix R_s consists of the resistances of each coil. Due to the conservation of energy, the matrix L_{ss} is asymetric. The mutual inductance matrix L_{sr} is an 3 by 3 matrix composed of the mutual inductances between the stator coils and rotor.

$$L_{sr} = \begin{bmatrix} L_{sara} & L_{sarb} & L_{sarc} \\ L_{sbra} & L_{sbrb} & L_{sbrc} \\ L_{scra} & L_{scrb} & L_{scrc} \end{bmatrix} \qquad (6)$$

The second term of Eq. 3 can typically be written in the form:

$$\frac{d\phi_s}{dt} = L_{ss} . \frac{dI_s}{dt} + \omega_{rm} . \frac{dL_{sr}}{d\theta_{rm}} . I_r + L_{sr} \frac{dI_r}{dt} \qquad (7)$$

Where, θ_{rm} is the spatial position of the rotor and the mechanical speed is:

$$\omega_{rm} = \frac{d\theta_{rm}}{dt} \qquad (8)$$

The voltage equations for the rotor are:

$$v_r = R_r.I_r + \frac{d\phi_r}{dt} \qquad (9)$$

Where,

$$v_r = [v_{ra}\ \ v_{rb}\ \ v_{rc}]^t = [0\ \ 0\ 0]^t \qquad (10)$$

The rotor flux linkages ϕ_r can be written as:

$$\phi r_r = L_{rr} \cdot I_r + L^t_{sr} \cdot I_s \qquad (11)$$

Where, the matrix L^t_{sr} is the transpose of the matrix L_{sr}.

The mechanical equation of motion depends upon the characteristics of the load which may differ widely from one application to another. We will assume here, for simplicity, that the torque which opposes that produced by the machine consists only of an inertial torque and an external load torque which are known explicitly. In this case the mechanical equation of motion is simply.

$$T_e = J.\frac{d^2\theta_m}{dt^2} + T_L \qquad (12)$$

Where, T_L is the load torque and T_e is the electromagnetic torque produced by the machine.

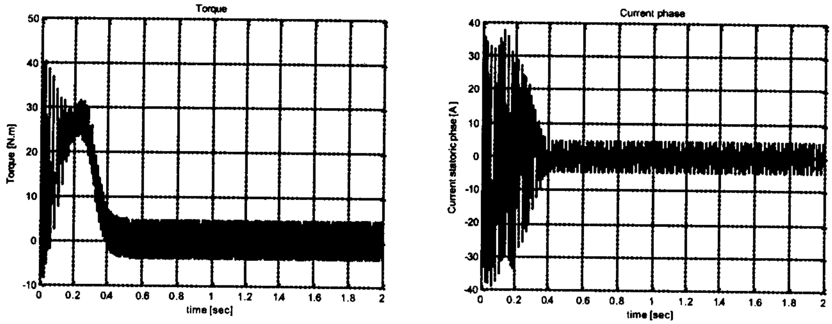
RESULTS AND DISCUSSION

In order to validate this approach of detection and localization of the damaged switch, the detection and the localization process is based on the analysis contour shape of the statoric current of the motor in the α, β plan. In this study seven test cases have been examined. In the first case, we have taken into account the case of an operational healthy inverter. In Fig. 3, we present the magnetic characteristics of the motor. We note that torque, stator current and speed shown respectively in Fig. 3a, b and c are stabilized after a transient state. The shape of the stator current contour inα, β plan is shown in Fig. 3d. It is remarked that a dispersion of the contour exists around zero. Figure 3d will serve as a reference to analyse the contours when we assume that a possible switch is damaged. We consider hereafter in the model that a damaged switch corresponds to an opened position.

Figure 4 shows the evolution of the statoric current in α, β plan considering a possible damage of a switch in the various cells. Figure 4a, shows the spectrum in the case of the damage of TR_1. We note the appearance of an additional spectrum located at the left of the spectrum of the healthy inverter at the negative extension of the α axis (-α). However when TR_4 is damaged we note that the additional spectrum is displaced to the right of the contour corresponding to the healthy inverter. The contours corresponding to the damage of TR_1 and TR_4 are separated by an angle of 180°.

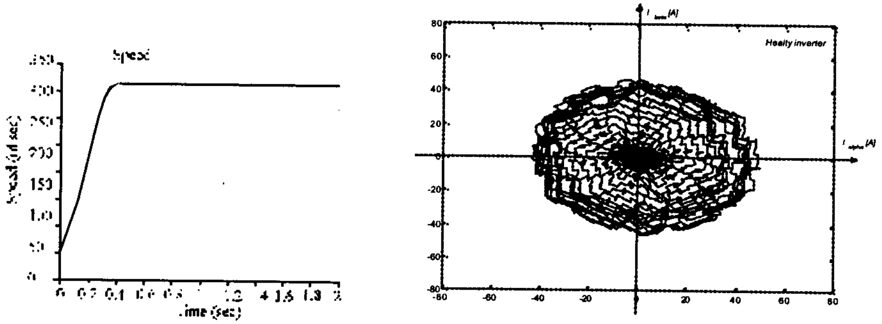
The analysis of the remaining couple of switches of the same cell (TR_2, TR_5) and (TR_3, TR_6) show that the positions of the additional contours change depending on the considered damaged switch (Tr_i).

We conclude that for the same cell, when one of it's two switches is damaged it is remarked that their corresponding additional contours are separed by an



a: Torque

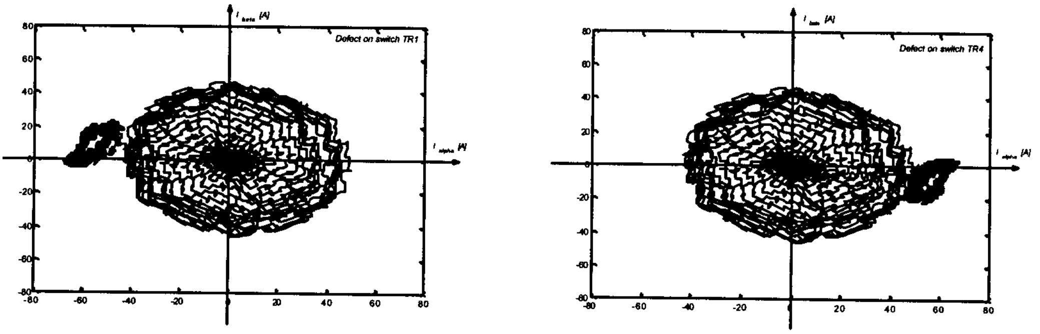
b: Statoric current



c: Rotor speed

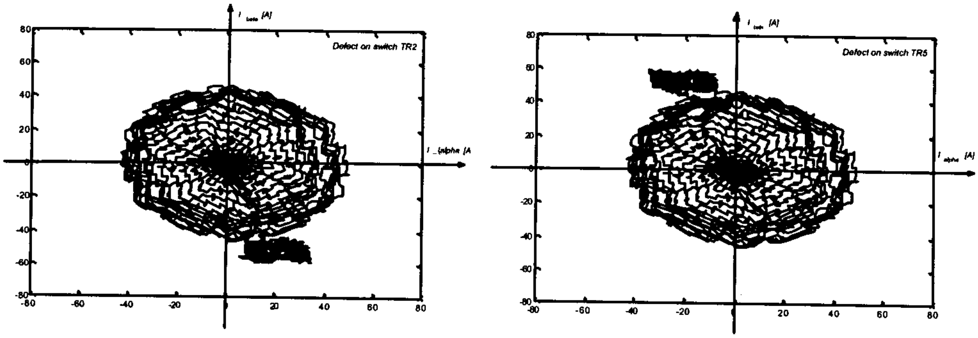
d: α, β plan representation

Fig. 3: Healthy inverter behaviour



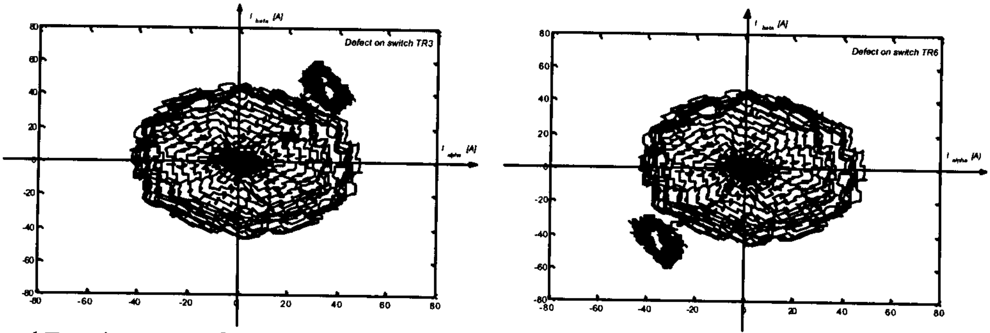
a: Default on TR_1

b: Default on TR_4



c: Default on TR_2

d: Default on TR_5



e: Default on TR_3

f: Default on TR_6

Fig. 4: Defected Transistors in α, β plan representation

angle of 180° (Fig. 4a-f). When a damage is assumed in one of the switches of the top position of the inverter (TR_1, TR_2, TR_3), their corresponding additional contours are separated by an angle of 120° (Fig. 4a-e). The same conclusion is drawn when we consider the case of a damage of one of the switches of the bottom position (TR_4, TR_5, TR_6) in the inverter (i.e., the separation angle between the additional contours is 120°) (Fig. 4b, d and f).

Accordingly, the representation of the stator current in the α, β plan allows to detect a possible damage of a switch in the inverter. The later switch is accurately located knowing the position of the additional contour.

Figure 5, is a schematic representation of the working state of the inverter. The hexagonal centred region defines the healthy state whereas the six other regions predict the damage of one of the switches.

DATA ACQUISITION UNIT SYSTEM

The main parts of a data command of an inverter and control of an induction motors are the following as shown in Fig. 6 the interface to the PC, the command circuit, the Data Acquisition Unit (DAU) which is based on the and A/D Converters and a multiplexer, sensors and actuators.

In this design, the parallel port interface is based on an eight bit buffer to send command, a two- to-four bit

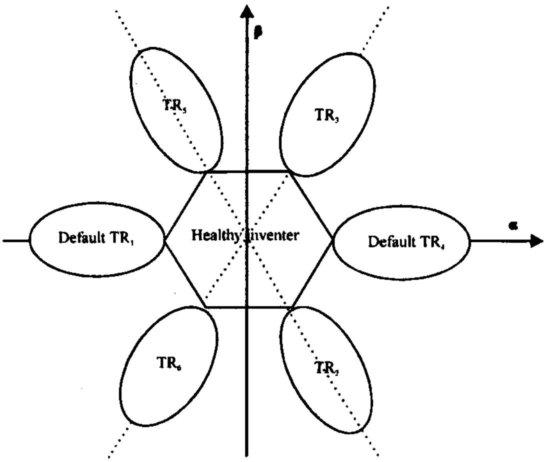


Fig. 5: Division the space of localization of the defects

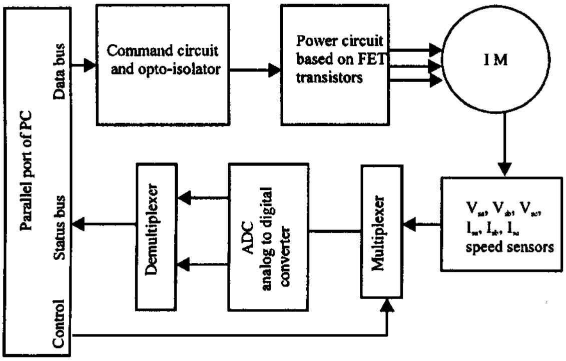


Fig. 6: Data acquisition unit card

three-state buffer to read data from converter and three-to-eight bit decoder to select multiplexer and buffers. A study were done to choose a better rate efficiency-price for the converters choice[12-14].

Thus, in the experimental implementation a simple eight bit A/D Converter of type successive approximation such as ADC-804 with 100 micro second time of conversion were used. It is obvious that voltages, currents and speed of the induction motors are signals rich of information. The digital processing of these signals would give better control and also in advance detection of default within an I M. The main program drives the DAU card. The PWM signals are generated then sent to the command circuit, a dead time is taken into consideration, the sensors provide to the multiplexer (MUX - 4051) with seven analogue signals from the system : the three voltages (v_{sa}, v_{sb},v_{sc}), the three currents (I_{sa}, I_{sb}, I_{sc}) and speed of the rotor. They are selected one by one and presented to the A/D Converter. The result of conversion is read in two steps by de-multiplexing the higher and lower four bits, the data is stored in a file to be processed and plotted on the screen.

In this study, the acquisition of three currents I_{sa}, I_{sb} and I_{sc} were capturel in real-time and the samples of these signals are saved in a file in order to be processed in details off-line. The α, β plan representation of these currents enables to inform us about thevoltage inverter status.

CONCLUSIONS

We developed a method of detection and localization of a possible damage of a switch in a voltage inverter. This method is based on the analysis of the Concordia transformation of the motor measured phase currents.

The analysis of the contour of the average current vector in the α-β representation is proved to be an effective tool for early detection and localization of the damage of a switch in an inverter. Indeed, the appearance of an additional pattern inform on the existence of an actual damage. The position of the pattern indicates accurately the location of the damaged switch.

In order to exploit this method practically, a Data Acquisition Unit is suggested. The PC interface card solution commands the inverter and allows the acquisition of the currents. This is intended to improve the reliability and the efficiency of an electric drive.

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