Detection Faults for Induction Machine Sensors Based on Fuzzy Logic Techniques

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Abstract—This paper concerns the development of the detection of faults the sensors of an induction machine by estimation methods for systems modeled in the form of state representation. The sensors monitors in our case are those of speed.

To achieve our objective, many of the techniques of artificial intelligence have been used to fault sensors detection of rotating machinery, where several selection techniques have been explored during the construction of the detection process.

We develop and combine the model reference adaptive system (MRAS) method with fuzzy logic approach to achieve our objectives. This type of estimation is applied to the supervision of the speed sensor in the system; this is done in order to give more robustness of the overall process, the second one is to study and develop an intelligent adaptation method based on the fuzzy logic algorithms, keeping the same performances. The new presented approach improves the performances of our system compared to the usual methods.

Finally, the validity of the proposed scheme is demonstrated by a series of computer simulations and the obtained results show that the designed system can achieve satisfactory performances.

Keywords — Induction machine, model reference adaptive system MRAS, fuzzy detection, fault of sensors

INTRODUCTION

Many industrial applications require fault tolerance and continuity of service. [1] This is due to the growing need to improve the availability of systems. Therefore, strategies are defined in the early stages of design, to facilitate fault detection, localization and reconfiguration of the order. For this, several recent works [2, 3] deal with fault tolerant control of electric drives.

In this article, we focus our study on the induction machine (IM), conventionally designed for constant speed applications, has become, Due to its simple, robustness structure and the evolution of electronics power and control of the control vector machine most commonly used for variable speed drives. This machine has the advantage of being more robust and less expensive, with equal power, as other machines. However, it has drawn backs. This allowed the opening of various lines of research on its control and power [4, 5, 6].

We introduced in this work, an approach widely used for the detection and isolation of faults based on the method of estimator [7, 8], the main components of a tolerant control strategy to defects (CTD) sensor. It is divided into three stages: detection, isolation and reconfiguration.

A novel estimator schemes based on fuzzy logic algorithm for the speed estimation where derived using Lyapunov's stability theorem [6,9,10]. Several strategies have been proposed for the estimation in the vectorial induction motor drives [6,9,11]. Among these techniques, model reference adaptive systems (MRAS) schemes are the most common strategies employed due to their relative simplicity and low computational effort[9,11].

Can be seen, the majority of estimation schemes described in the literature for MRAS observer employ a PI controller to generate the desired value. However, due to the continuous variation in the machine parameters and the operating conditions, in addition to the nonlinearities present in the inverter, the PI controllers may not be able to provide the required performance. Not much attention has been devoted to study other types of estimation scheme [9,11,12].

In this article, the performances of the diagnostic of sensors, the detection of faults and the fuzzy estimation of speed for the induction machine are analyzed by digital simulation. To achieve our objective, this paper is organized as follows. Section I presents the control of the asynchronous machine; the rest of the paper is organized as follows. Sections 2 and 3 present the control of the IM and the MRAS algorithm using to estimate the speed. Section 4 depicts fuzzy logic algorithm for the estimation. Section 5 provides and discusses the simulation results and Section 6 sketches some conclusions.

II. CONTROL OF ASYNCHRONOUS MACHINES

A. Control Scheme of an Asynchronous Machine

Fig.1 shows a simplified block diagram illustrating the essential of our control system. This system consists of a dc power source, a dc link filter, a voltage source inverter, an induction motor, and same circuit of control system. The dc power source converts the constant-frequency ac power to dc power by a three-phase, full wave diode bridge rectifier; the dc
voltage is smothered by a smoothing capacitor dc link filter and then applied to a three-phase bridge inverter witch converts dc power to variable voltage variable frequency ac power supply to the motor. The two control parameters required are frequency and voltage, the frequency command also generates the voltage command through a volts/hertz ratio.

$$V_{ds} = \sigma * L_s * \frac{d i_{ds}}{dt} - \frac{1}{(\sigma * L_s)} - R_s * i_{ds} + \omega_s * \sigma * L_s * i_{qs} = \frac{L_m}{(L_r * T_r)} * \omega_f$$

$$V_{qs} = \sigma * L_s * \frac{d i_{qs}}{dt} - \frac{1}{(\sigma * L_s)} - R_s * i_{qs} - \omega_s * \sigma * L_s * i_{ds} + \frac{L_m}{(L_r * T_r)} * \omega_f$$

$$\frac{d \delta r}{dt} = \frac{L_m * i_{ds} * 1}{T_r} * \delta \phi + \left( \frac{\omega_s - \omega_r}{\omega_r} \right) * \delta \phi$$

$$\frac{d \delta q}{dt} = \frac{L_m * i_{qs} * 1}{T_r} * \delta \phi + \left( \frac{\omega_s - \omega_r}{\omega_r} \right) * \delta \phi$$

$$\text{Cem} = \frac{P * \text{Lm}}{T_r} \left( i_{qs} * \delta \phi - \delta \phi * i_{ds} \right)$$

$$\frac{d \Omega_r}{dt} = \frac{1}{T_r} \left( \text{Cem} - C_r * K_f * \Omega_r \right)$$

It is noted that rotor flux depends only on the satatoric current is and iq. that the electromagnetic couple describes only on the quadratic current iq.

III. The Structure of Model Reference Adaptive System MRAS

The aim of this technique of control is to replace the speed sensor by a speed estimator. Into our study, we introduced a speed estimator of type MRAS (Model Reference Adaptive System). The latest replace the mechanical sensor without changing the dynamics of our machine.

The principle of the method MRAS speed estimation rests on the comparison of the sizes obtained in two different ways. One model of such a method is the voltage one (or stator equation) and the other is current model (or rotor equation); because the voltage method doesn't include rotor speed then it does not depend explicitly of speed (model of reference) and the other includes rotor speed (adjustable adaptive model). Fig.2 illustrates the derived MRAS scheme for speed adaptation.

A. Reference Model

One uses the equations of the currents (2) of the IM, the current expressed in the reference fixed to the stator. The two equations of the model of reference become:
\[
\begin{align*}
\frac{d\phi_{\alpha}}{dt} &= \frac{L_r}{L_{sr}} \left[ V_{\alpha \nu} - \sigma L_s * \frac{d\omega}{dt} - R_s * i_{\alpha} \right] \\
\frac{d\phi_{\beta}}{dt} &= \frac{L_r}{L_{sr}} \left[ V_{\beta \nu} - \sigma L_s * \frac{d\omega}{dt} - R_s * i_{\beta} \right]
\end{align*}
\]  

(3)

**B. Adjustable Model**

To establish the adaptive model, we expressed the current in the reference fixed to the stator, the fluxes expressed with the rotor sizes in a reference $\alpha\beta$ are:

\[
\begin{align*}
\frac{d\phi_{\alphaad}}{dt} &= \frac{1}{T_r} \phi_{\alphaad} + \frac{L_{sr}}{T_r} * i_{\alpha} - P * \Omega_{est} * \phi_{\betaad} \\
\frac{d\phi_{\betaad}}{dt} &= \frac{1}{T_r} \phi_{\betaad} + \frac{L_{sr}}{T_r} * i_{\beta} - P * \Omega_{est} * \phi_{\alphaad}
\end{align*}
\]  

(4)

**C. Adaptation Mechanism**

The entry of an adaptive mechanism is activated by the error between the reference field and adaptive field. By carrying out the difference between the reference model and the adjustable model, we obtain the following system of equations which govern the adaptive mechanism.

\[
\begin{align*}
\frac{de_{\alpha}}{dt} &= \left[ -\frac{1}{L_r} - \omega \right] + (\omega - \omega_{lad}) \frac{\phi_{\alphaad}}{\phi_{\betaad}} \\
\frac{de_{\beta}}{dt} &= \left[ \omega - \frac{1}{L_r} \right]
\end{align*}
\]  

(5)

The adaptation law chosen to ensure the convergence of $\omega_{lad}$ towards $\omega$ is:

\[
\omega_{lad} = T_p * \delta e + T_i \int_0^t \delta e * dx
\]  

(6)

The adaptive mechanism has an integral proportional form:

\[
\omega_{est} = \frac{1}{P} \left( T_p * e + T_i \int e * dt \right)
\]  

(7)

Where $T_p$ and $T_i$ are positive gain.

**IV. THE FUZZY LOGIC ADAPTATION**

**A) Control by Fuzzy Logic**

Fuzzy logic technique makes it possible to control nonlinear systems and complicated models [10,11,12]. In fact, the calculation of the parameters of the system is not necessary to carry out this control [10,11,12].

On opposite of the adaptation of the traditional techniques; the fuzzy logic does not treat a mathematical relations well defined, but uses inferences with a several rules, being based on variables linguistic.

These inferences are treated by operators suitable for fuzzy logic [10,11,12]. Fig.3, shows the structure of a fuzzy regulator with two input (X1 and X2) and one output (Xr).

So, we can note that the calculation of the control is carried out starting from three fundamental stages: an interface of fuzzification; a mechanism of inference (rules); and an interface of defuzzification.

![Fuzzy Control](Fig.3: Functional diagram of the fuzzy control)

1. **THE FUZZIFICATION**

The entries and exits are defined of the fuzzy are defined by membership functions with 7, 5 or 3 sets. The various sets are characterized by standard designations [9,11,12]:

Negatives Big NB, Negative Medium NM, and Negative Small NS, Zero Z, Positive Small PS, Positive Medium PM, Positive Big PB.

2. **INFERIENCE MECHNISM**

It is well know that the realizations of the matrix of the rules are deduced by experiment, the experiment of the human operators and rests on the analysis of the system.

This analysis must take into account the trajectory which one wants to give to the system [9,11,12].

3. **THE DEFUZZIFICATION**

By this stage; the return to the sets of real exit will be made. It is a question of calculating, from the degrees of membership of all the sets variable of output, the coordinate which corresponds with the value of this exit. Various methods are used [9,11,12].

**A. The Fuzzy Logic Adaptation Mechanism Principle**

A fuzzy logic controller as shown in (Fig.4) will replace the structure of the proposed PI controller used in the adaptation mechanism.

![Fuzzy Logic Adaptation Mechanism](Fig.4: Synoptic diagram of a fuzzy adaptation)

In our work, we adopted seven sets for the two variables of input (En and dEn), and a same number of sets for the variable of output dUn. The rules of the controller can be presented in a
matrix with seven sets known as matrix of inference shown in table (1):

Table 1: The Fuzzy Rules (a regulator with 5 sets).

<table>
<thead>
<tr>
<th>dU_n</th>
<th>dE_n</th>
</tr>
</thead>
<tbody>
<tr>
<td>NG</td>
<td>NG</td>
</tr>
<tr>
<td>NP</td>
<td>NG</td>
</tr>
<tr>
<td>EZ</td>
<td>NP</td>
</tr>
<tr>
<td>PP</td>
<td>NP</td>
</tr>
<tr>
<td>PG</td>
<td>EZ</td>
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<tr>
<td></td>
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</tr>
</tbody>
</table>

In this article, the memberships function are chosen as the triangular type and trapezoidal, and the method of reasoning is considered as the max-min method, the defuzzification stage is done based on the gravity centre method, as it is frequently quoted in the literature and because they requiring less time computing will be also adopted in our work [10,11,12].

A. The Basic Rules of the Fuzzy Controller

The first step in the design of fuzzy controller is to generate fuzzy rules based on the knowledge of the expert. According to the expert, three situations can be distinguished for the constant time estimation, above, around and below the reference desired.

In our control, in order to determine the rules table that generates a command that will be presented later Based on Fig 5.

V. THE MECHANISM OF THE DETECTION ON THE SPEED SENSOR

To diagnose the speed sensor, a MRAS estimator is used as an observer. Then, an algorithm for selecting is used to enable the detection of defects and perform the selection between the measured signals and the estimated signals.

So, to validate the performances of the MRAS, the proposed simulation of the dynamic behaviour of the machine has been done using the MATLAB/SIMULINK and that for the following conditions.

With, the value of the torque is fixed to zero and the field is fixed to 1Wb. To highlight the influence of speed variations and uncertainties, particularly those of the control process, we gave reference speed of 100 rad/s. Fig. 7.

Afterwards, constant field and a reference speed $\Omega_{ref} = 100$ rad/s, the field rotor field is fixed to 1Wb, the initial values of the torque assumed by the machine is zero, and between 1s and 2.5s, one will apply a nominal torque load (10 N.m). Fig. 8.

Finally, we will use our estimator to diagnose faults sensor for speed exceeds the rated speed to a value of the torque is fixed to zero, the field is fixed to 1Wb and the initial values of the speed assumed by the machine is zero, and between 1s and 2.5s, we will apply variations. Fig. 9.

VI. SIMULATION RESULTS

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According to the simulation results we can say that the MRAS technique of detection provides an effective solution to the problem of diagnostic. We can say that our objective here has been successfully achieved.

The results presented on the previous figures, show that the dynamics of the flux magnitude are presented can highlight the decoupling role of the flux controller where the flux tracks its nominal value of 1.1 Wb for all speed ranges.

Numerical simulations are performed and shown good results for tricking the faults. Implementation of the proposed algorithm can be used for the control speed issues suitable for IM applications requiring high-performance torque control and faults detection.

The performance of the estimator, based on fuzzy regulators, is verified. We can say that our objective here has been successfully achieved.

VII. CONCLUSION

The work that we presented contributes to the analysis and the synthesis of a robust diagnostic applied to the induction machine. The MRAS is employed for the detection of the faults of sensor speed. The use of the fuzzy logic is a powerful tool in realization of the robust and reliable diagnostic.

We have proposed a method for detection faults of sensor speed using the MRAS and the fuzzy logic algorithm, to ensure a good diagnostic of induction machines. The method proposed in this paper is applicable to a large category of induction motor drives with a gradually varying load torque. The tests of robustness show clearly that the performances of the diagnostic in the presence of estimator, type MRAS, for the tracking of the faults is always fast.

The validity of this method is checked by several tests. The results obtained show that the model suggested for the MRAS adapts perfectly to all the diagnostic of the IM.

The next step of this work is the integration of a real induction motor and estimator MRAS for testing the diagnostic is required for the practical case.
VIII. ANNEXES
The parameters of the induction machine cage used are shown below:

- Rated power: 1.5 Kw
- Nominal voltage: 220/380 V.
- Rated power factor: 0.8.Rated
- Speed: 1420 rev/ min.
- Nominal frequency: 50 Hz.
- Stator resistance: 4.85Ω.
- Rotor resistance: 3.805Ω.
- Stator cyclic inductance: 0.274 H.
- Cyclic inductance of Rotor: 0.274 H.
- Cyclic mutual inductance: 0.25 8 H.
- Number of pole pairs: 2.
- Moment of Inertia: 0.031Nm-s² / rad
- Friction: . 0.008 Nms /r

IX. NOMENCLATURE

- Ls: Stator inductance [H].
- Lr: Rotor inductance [H].
- Lm: Mutual magnetizing inductance.
- Lsr: Mutual Inductance between the stator and rotor [H].
- Kf: Friction coefficient [N.s/rad].
- J: Total inertia [kg.m2].
- P: Number of pole pairs.
- ωs: Synchronous Pulsation [rad/s].
- ωr: Electrical angular Pulsation [rad/s].
- Cem: Electromagnetic torque [N.m].
- Cr: Resistive torque [N.m].
- Tr: Rotor time constant [s].

X. REFERENCES


