# A Fuzzy-Based Strategy to Improve Control Reconfiguration Performance of a Sensor Fault-Tolerant Induction Motor Propulsion

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**Abstract**–*This short paper deals with the transition performance improvement of a sensor fault-tolerant controller devoted to automotive applications. Indeed, improvements are brought over a previously developed technique that exhibit abrupt changes in the torque if a sensor fault is detected and after a transition from a control technique to another one [1]. The Fault-Tolerant Control (FTC) system firstly concerns the sliding mode control technique since better performances are obtained with an encoder to get the speed information. In the event of unavailability of the speed sensor, a sensorless fuzzy control technique is applied. In the proposed active fault-tolerant control approach a short and a smooth transition are achieved from the encoder-based control technique to the sensorless one using an appropriate fuzzy logic decision approach.* ***Copyright © 2011 Praise Worthy Prize S.r.l. - All rights reserved.***

***Keywords****: Induction motor propulsion, sensor fault, fault-tolerant control, smooth transition, fuzzy logic.*

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## I. Introduction

The concept of a fault tolerant drive system is that it will continue to operate in a satisfactory manner after sustaining a fault [2]. The term satisfactory implies a minimum level of performance after the fault, and will therefore be heavily influenced by system requirements. This correspondence deals with a flexible and active approach that maintains maximum performance in the event of sensor loss or sensor recovery in the Electric (EV) or Hybrid Electric Vehicle (HEV) induction motor drive. To achieve this goal, a reorganizing controller will adopt the best control methodology depending on the available feedback and operational hardware. Figure 1 shows the proposed flexible architecture for fault-tolerant control purposes. This short paper will be mainly concerned by the Fuzzy Switchover Block (FSB).

## II. Induction motor drive control in EV and HEV

In order to obtain high performance motor drives, modern control strategies should be used. Induction motor drives control techniques are well treated in the literature. However, automotive application drives such as in EV and HEV have some major requirements that are listed in [1]. The main requirement that is related to the electric propulsion control is the ability to operate at constant power over a wide speed range, good overload performance, and high efficiency, especially at light load operation at higher speeds.

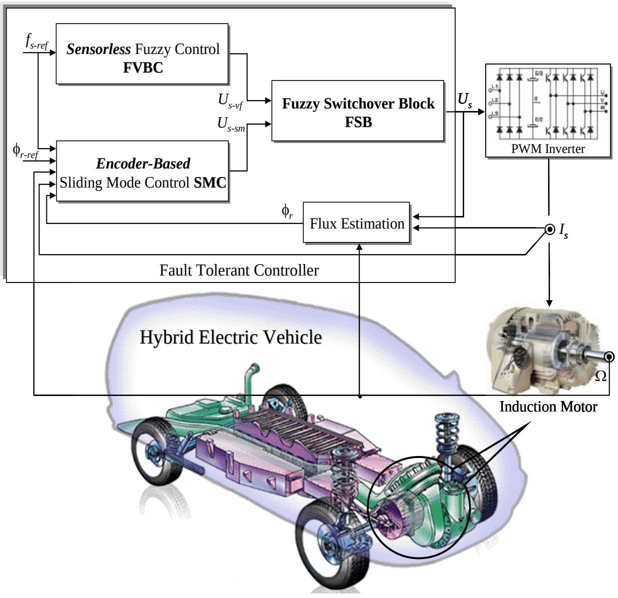


Fig. 1. Fault-tolerant controller configuration.

These characteristics allow the best utilization of the limited battery capacity (extension of the running distance per battery charge) and the minimization of the size and the weight of the motor and the drive. All these aspect call for an efficiency optimized control techniques. Indeed, it should be noted that classical induction motor control techniques, such as vector control are not sufficient to achieve this requirement. Therefore, control techniques that maximize the induction motor efficiency are highly desirable for the fault-tolerant controller. This is why the FTC system firstly concerns the sliding mode control technique since better performance is obtained with an encoder to get the speed information. In the event of unavailability of the speed sensor, a sensorless fuzzy control technique is applied [1].

### *II.1. Sliding Mode Control (SMC)*

SMC is one of the effective nonlinear robust control approaches, since it provides system dynamics with an invariant property to uncertainties once the system dynamics are controlled in the sliding mode.

### *II.2. Sensorless Fuzzy Control (FVBC)*

FVBC (Fuzzy Voltage Boost Controller) has been chosen because it meets EVs or HEVs requirement for optimizing the induction motor drive efficiency. In fact, the losses are minimized when the motor operates at low frequency and with rated torque. Moreover, the starting torque is also greatly improved, increasing the drive capabilities in the low speed region [3].

## III. The Controller Transition Strategy

The switchover block is based on fuzzy logic. Indeed, the controller transition that is a sensitive but complex task is better handled with a fuzzy approach.

The main idea of the FSB is to generate the suitable law $U_s$ in order to compensate for the existing drift between $U_{s\text{-}sm}$ and $U_{s\text{-}vf}$ (transition from SMC to sensorless control) by providing a short and smooth transition between both controllers. The suitable laws $U_s$ can be written as

$$\bar{U}_s = f\left(\bar{U}_{s-vf}, \bar{U}_{s-sm}\right) = (1-SF)\,\bar{U}_{s-vf} + SF\,\bar{U}_{s-sm} \qquad (1)$$

where $U_{s\text{-}vf}$ is the stator voltage generated by the FVBC; $U_{s\text{-}sm}$ is the stator voltage generated by the SMC; and $SF$ is the switching function.

To achieve a smooth transition from SMC to sensorless control, the controller transition follows two steps:

*1) Step 1.* After sensor fault detection, $U_s$ will consist of contributions from both controllers (1). For the FSB design, input/output variables are quantified with a suitable number of fuzzy sets. Simple triangular membership functions have been selected for input variable (time) and constant values (switch function) for output variable. The *Prod-Probor* inference algorithm and the *Wtaver* defuzzification approach are selected to perform the last steps of the fuzzy procedure [4].

*2) Step 2.* The second step greatly depends on the rotor flux angular position in the stator reference frame. Indeed, the calculated flux angles are used for transition from the encoder-based control to the sensorless one.

$$\theta_s = \int \omega_s \, dt \qquad (2)$$

The calculated angles for both control techniques reveal a slight difference that should be managed by the transition strategy [1]. To obtain a smooth transition, this should be done when phase-shift is zero or very close to zero.

The proposed controller transition philosophy is illustrated by Fig. 2. In this case, Region I corresponds to encoder-based control (SMC); Region II to contribution from both encoder and sensorless control (SMC + FVBC); Region III to sensorless control (FVBC); and Region IV to encoder-based control (back to SMC).

## IV. Simulation Results and Comparisons

The controller transition management performances are tested on a 4-kW squirrel cage induction motor in an FTC context.

Simulation results (Figs. 3 and 4) show the controller transition from encoder-based control (SMC) to sensorless control (FVBC or V/F) and back to the encoder-based one. At 0.5-sec, a disturbance in the form of speed sensor missing pulses was introduced and removed at 1.5-sec. The proposed switchover block reconfigures the control from SMC to FVBC with short speed transition (Fig. 3a). In this case, a small torque transition is observed (Fig. 4a). As shown by Figs. 3b and 4b, the proposed switchover block leads to obvious transition improvements.

In term of current transition, Fig. 5 confirms the effectiveness of the proposed transition approach.

## V. Conclusion

This short paper dealt with the transition performance improvement of a sensor fault-tolerant controller devoted to EVs or HEVs. The obtained results obviously show short and smooth transitions in terms of speed and torque.

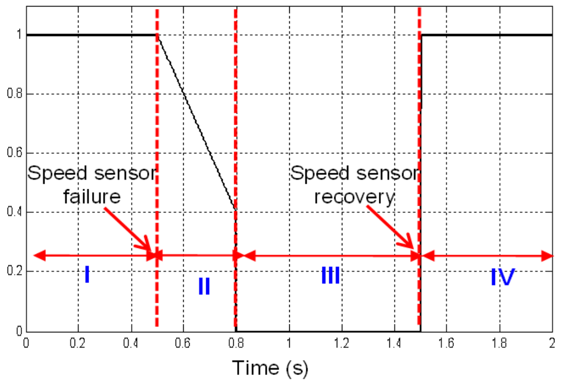
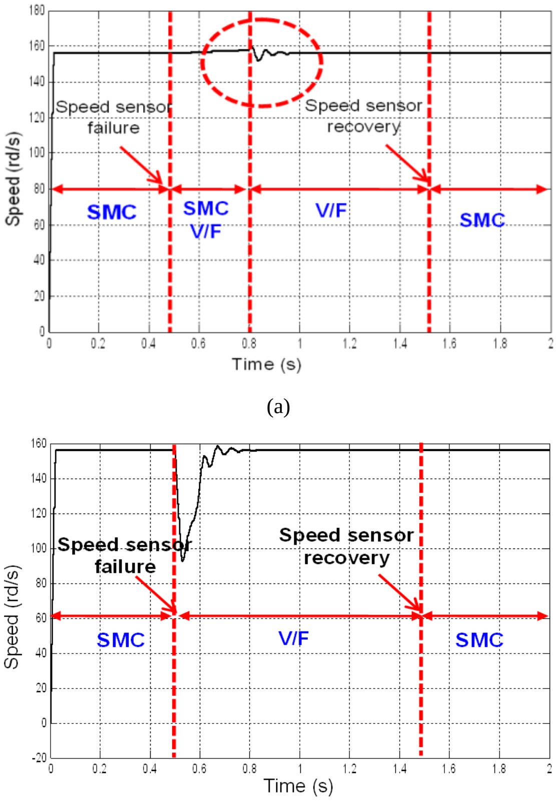


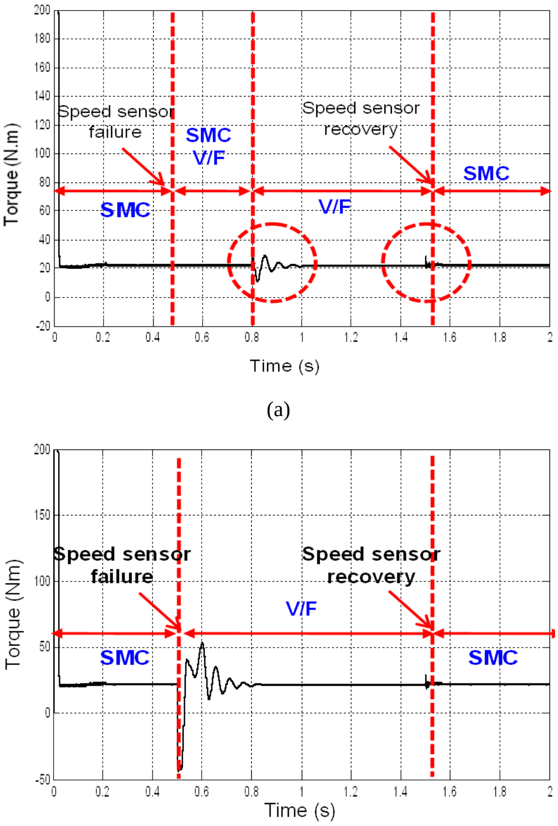
Fig. 2. Controller transition switching function ($U_s$).



(a)

(b) Without transition strategy.

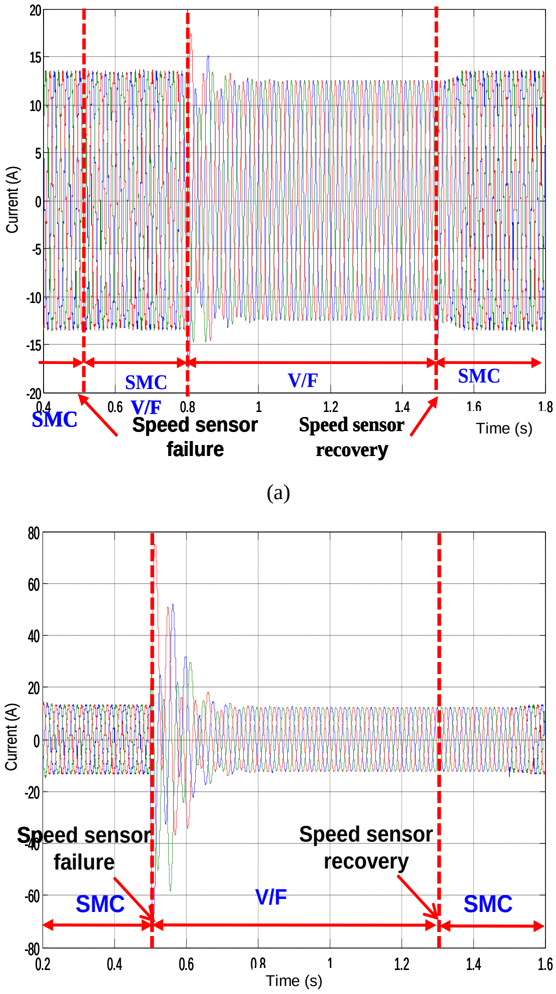
Fig. 3. Induction motor speed performances during transitions.



(a)

(b) Without transition strategy.

Fig. 4. Induction motor torque performances during transitions.



(a)

(b) Without transition strategy.

Fig. 5. Induction motor currents during transitions.

# Appendix

RATED DATA OF THE SIMULATED INDUCTION MOTOR

4 kW, 23.8 Nm, 1500 rpm, $p = 2$

$R_s = 1.125\ \Omega$, $R_r = 1.103\ \Omega$, $L_s = 0.17$ H, $L_r = 0.015$ H, $M = 0.048$ H

$J = 0.135$ kgm², $k_f = 0.00182$ Nms

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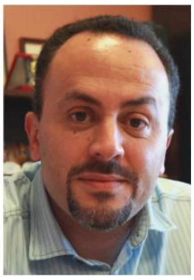

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