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# A Fuzzy Logic based Sensorless Speed Control of DTC-SVM of an Induction Motor using EKF

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**Abstract:** This paper presents the real-time implementation of a bi input extended Kalman filter (EKF) (BI-EKF)-based estimator in order to overcome the simultaneous estimation problem of the variations in stator resistance *Rs* and rotor resistance *Rr* aside from the load torque *tL* and all states required for the speed-sensorless control of induction motors (IMs) in the wide speed range Performance of the proposed technique is assessed under challenging stator and rotor resistance variation using matlab/simulink. Superior performance has been obtained using the fuzzy logic adaptation mechanisms **.**The proposed robust-intelligent controller improves the low speed performance, the torque and the flux ripple and its dynamic performance of the induction machine as those used in tractions, as they require good torque control performance at considerably lower frequency. A novel stator resistance estimator is proposed. The estimation method is implemented using the Extended Kalman Filter. Finally, extensive simulation results are presented to validate the proposed technique.

**Index Terms**: Fuzzy control, Induction motors, DTC-SVM,EKF.

## I. INTRODUCTION

Induction motors become more and more popular due to their reliable construction. If we intend to use AC induction motor in a low cost application (e.g. mass produced washing machine) it is necessary to optimize production costs. Many applications require precise speed control. The speed sensor is quite expensive device comparing to other parts of the drive. That is why we are trying to develop a reliable control system which estimates the rotor speed from electrical quantities instead of using a speed sensor.The modern induction machines are now replacing DC motors in industry applications, even in the applications where a fast speed and torque response in four quadrants is required. One of the reliable techniques to effectively control the speed of induction motor is the Direct Torque Control (DTC) technique proposed by Takahashi**.** This technique can be considered as an alternative to the Field Oriented Control (FOC) strategy.

In recent years the use of AC drives with DTC technique have gradually increased due to its advantages over the FOC techniques: good dynamic performance, precise and quick control of stator flux and electromagnetic torque, robust against machine parameters variations, no current control loops, and the simplicity of the algorithm. A classical DTC drive system, which is based on a fixed hysteresis bands for both torque and flux controllers, suffers from a varying switching frequency, which is a function of the motor speed ,stator/rotor fluxes, and stator voltage; it is also not constant in steady state. Variable switching frequency is undesirable .At low speed, an appreciable level of acoustic noise is present, which is mainly due to the low inverter switching frequency. Therefore, there will be large torque ripples and distorted waveforms in currents and fluxes. Several solutions have been proposed to keep constant switching frequency. In order to improve the dynamic performance of the classical DTC, a new modified DTC with a Space Vector Modulator (SVM) is proposed. The use of SVM is to ensure a constant switching frequency .Sensorless high performance control of squirrel cage induction machine (SCIM) over a wide range of speeds depends on the knowledg e of electrical and mechanical uncertainties at high accuracy. Induction motor drives without speed sensors have become an attractive and commercially expanding technology for the past few years.The absence of mechanical speed sensors reduces the cost and the volume of the drive motor. DTC is able to produce fast torque,in steady state a mixed DTC- and stator flux response with a well designed flux, torque and speed estimator. In order to reduce the torque and current pulsations SVM control method seems more suitable.

SVM techniques offer better DC link utilization and they lower the torque ripple. The EKF is considered to be suitable for use in high performance RSM drives, and it can provide accurate speed estimates in a wide speed-range, including very low speed. The variation of stator resistance due to changes in temperature or frequency deteriorates the performance of DTC controller by introducing errors in the estimated flux linkage and the electro- magnetic torque.The estimation of rotor resistance *Rr*, which is affected by frequency and temperature variations, estimation of stator resistance *Rs* which is also affected by temperature variations are required in order to reach a correct speed and flux values at high accuracy.The motors (IMs) relies upon how accurately state estimations performance of speed-sensorless control of induction of IM are performed. In fact, these estimations are adversely affected by the temperature and frequency-dependent variations of *Rr* and *Rs* as well as unknown load torque. The variations in *Rr* and *Rs*, while and are easily affected by the *Rs* or *Rr* variations, respectively thus, they still need improved performance under both resistance uncertainties, the

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simultaneous estimation of *Rr* and *Rs* causes instability. *Rs* and *ωm* estimations cannot be simultaneously conducted at no load or when the load torque is not sufficiently high, and a high-frequency signal is also injected on the magnetizing current command in order to perform *Rr estimation*. Moreover, the estimation algorithms in and are only applicable whenever the speed-sensorless control system is in steady state. On the other hand, extended Kalman filter (EKF)-based solutions have been also investigated for the simultaneous estimation problem of *Rr*,*Rs*, and *ωm* regardless of load conditions. Extended Kalman Filter (EKF) based observers are also widely used in order to estimate electrical and mechanical uncertainties of SCIM. in addition to flux and speed estimation (with the use of equationof motion), the load torque and rotor resistance is simultaneously estimated in a single EKF algorithm. The development of this novel induction motor controller can be separated into the following contributed steps: First, Study the classical DTC disadvantages and suggestion of new scheme to overcome them. Second, investigate of a complete dynamic model of the drive systems, relevant controllers, and its dynamic performance using MATLAB-SIMULINK.

## II.MODELLING OF THE INDUCTION MOTOR

Electrical and mechanical equations of the induction motor in the stator reference frame are:

$$v_s = R_s i_s + p\varphi_s$$

$$v_r = R_r i_r + p\varphi_r - j\omega_r\varphi_r = 0$$

$$\varphi_s = L_s i_s + L_m i_r$$

$$\varphi_r = L_r i_r + L_m i_s$$

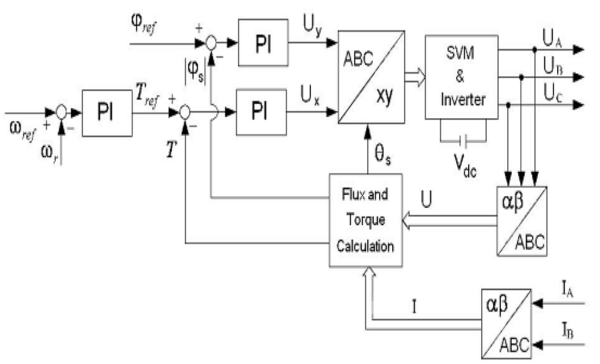
$$T_e = \frac{3}{2}P_p(i_s * j\varphi_s) = \frac{3}{2}P_p\frac{L_m}{\sigma L_s L_r}(\varphi_s * j\varphi_r)$$

$$T_e - T_l = Jp\ \omega_r + \text{F}\omega_r$$

Where $v_s, v_r, i_s, i_r, \varphi_s, \varphi_r$ are the voltages,currents and fluxes of stator and rotor. $R_s$ and $R_r$ are the stator and rotor resistances. $L_m, L_r, L_s$ are the mutual,rotor and stator inductances. $\omega_r, \sigma$ are the rotor speed and leakage coefficient respectively. $P_p, p$ are the pole pair number and differential operator. $T_e, T_l, J$, F are the electromagnetic torque, load torque, inertia and viscous friction coefficient.

## III.USING OF EKF IN DTC-SVM IN INDUCTION MOTOR

The block diagram of conventional DTC-SVM of an induction motor:




The stator flux space vector and the electromagnetic torque are calculated as:

$$\varphi_{s\alpha} = \int(v_{s\alpha} - r_s i_{s\alpha})dt.$$

$$\varphi_{s\beta} = \int(v_{s\beta} - r_s i_{s\beta})\,dt.$$

$$|\varphi| = \varphi_{s\alpha}{}^2 + \varphi_{s\beta}{}^2$$

$$.\theta_s = \tan^{-1}(\varphi_{s\alpha} / \varphi_{s\beta}).$$

$$T_e = \frac{3}{2}P_p\left(i_{s\beta}\varphi_{s\alpha} - i_{s\alpha}\varphi_{s\beta}\right).$$

With DTC-SVM, constant switching frequency of inverter is established. The reference voltage vector for space vector modulator is obtained from stator flux and electromagnetic torque PI controllers. In order to incorporate EKF into induction motor control system, the IM equations are written in the state space from as below:

$$\dot{x} = Ax + Bu + w(t).$$

$$\text{y=Cx+v(t).}$$

Kalman filter algorithm can be written as following:

Prediction of the state:

$$x_{n+1\ n} = \emptyset(n+1, n, x_{n\ n-1}, u_n).$$

Where $\emptyset(n+1, n, x_{n\ n-1}, u_n) = A_n(x_{n\ n})x_{n\ n} + B_n(x_{n\ n})u_n.$

Estimation of covariance matrix:

$$P_{n+1\ n} = \frac{d\emptyset}{dx}|_{x=x_{n\ n}}\ P_{n\ n}\frac{d\emptyset^T}{dt}|_{x=x_{n\ n}} + \text{Q}\ .$$

Computation of filter gain:

$$K_n = P_{n\ n-1}\frac{\partial H^T}{\partial x}|_{x=x_{n\ n-1}}((\frac{\partial H}{\partial x}|_{x=x_{n\ n-1}}P_{n\ n-1}\frac{\partial H^T}{\partial x}|_{x=x_{n\ n-1}} + R))-1.$$

Where

$$\text{H}(x_{n\ n-1}, n) = C_n(x_{n\ n-1})x_{n\ n-1}.$$

State estimation:

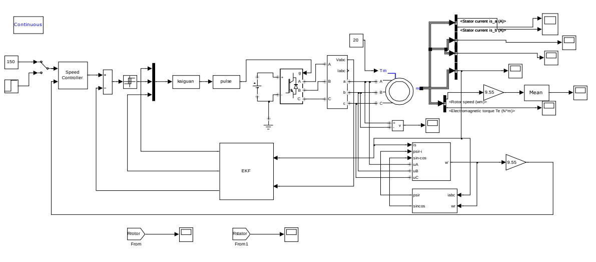
$$x_{n\ n} = x_{n\ n-1} + K_n\left(y_n - H(x_{n\ n-1}, n)\right).$$

Update of error covariance matrix:

$$P_{n\ n} = P_{n\ n-1} - K_n\frac{\partial H}{\partial x}|_{x=x_{n\ n-1}}P_{n\ n-1}.$$

Where $A_n, B_n, and\ C_n$ are the input and output matrices of the system.x,y and u are the system state matrix, system output and system input matrices respectively:

## IV.SVM-DTC WITH EKF BASED ON ROTOR FLUX AND STATOR FLUX




By using single EKF, only one resistance can be changed during the operation of the machine. The variations in *Rr* and *Rs*, while and are easily affected by the *Rs* or *Rr* variations, respectively thus, they still need improved performance under both resistance uncertainties, the simultaneous estimation of *Rr* and *Rs* causes instability.

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So two EKF algorithms with different models are cascaded, so that the final values of the covariance matrix and state matrix calculated at the end of each period and used by the next EKF algorithm as the initial values of that covariance matrix and state matrix.The developed algorithm can estimate the stator and rotor resistance simultaneously to improve the speed sensorless of IM drive especially at lo and zero speed operations.

## V.FUZZY LOGIC BASED DTC-SVM OF INDUCTION MOTOR DRIVE USING EKF

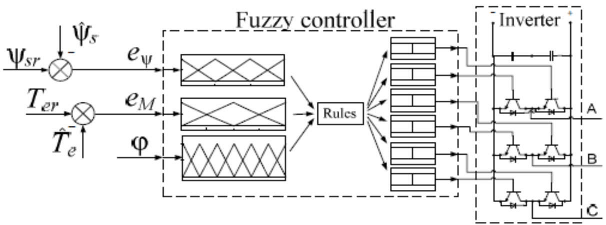
### FUZZY LOGIC CONTROLLER:

The concept of the controller remains the same as in case of the traditional DTC. The fuzzy controller combines the functions of the flux and torque controllers as well. The stator flux magnitude and the developed torque depend on the space vectors of the stator voltage, and could be directly controlled by selecting the proper inverter states As the selected inverter has six switches, the fuzzy controller has six outputs directly controlling each switch separately. The output signal values are limited to 0 and 1. The inputs for both traditional and fuzzy control are the phase angle ϕ and deviation of the stator flux and the electromagnetic torque:

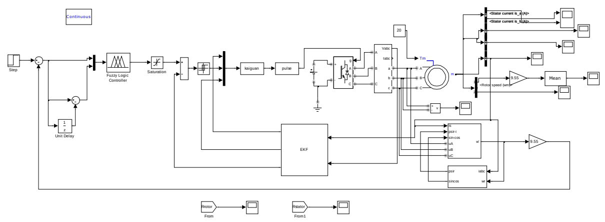
$$e_\psi = \psi_{sr} - \hat{\psi}_s,$$

$$e_T = T_{er} - \hat{T}_e,$$

where $\varphi_{sr}$ is the reference value of the stator flux, $\hat{\varphi}_s$ is the estimated magnitude of the stator flux, $T_{er}$ is reference value of the torque, $\hat{T}_e$ is estimated value of the torque.The output is based on the deviation of the stator flux, electromagnetic torque and phase. The membership functions are the following: PL – positive large, PS – positive small, NS – negative small, NL – negative large, P – positive, Z – zero, N – negative. From S.1 to S.6 there are the membership functions which are equivalent to the sectors of phase.It consists of three major blocks: a fuzzification block, rule base and defuzzification block



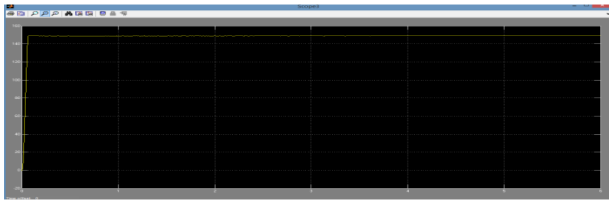

DTFC fuzzy controller is based on Mamdani model with defuzzification using the mean of maximum (mom) method as it allows the discrete output signals, unlike Sugeno model which cannot guarantee the safe use of the inverter.



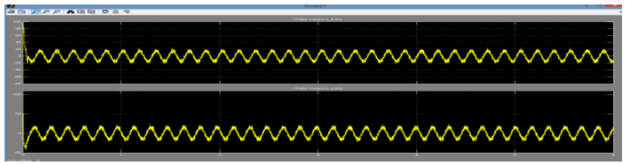
## VI.SIMULATION RESULTS

The speed sensorelss induction motor drive has been simulated and assessed using MATLAB/SIMULINK software. In the simulation stator voltage used by EKF is obtained from the VSI of an induction motor drive. From t=0s to t=2 s, the command speed is changed from 0 RPM to 150 RPM and from t=2s to t=6s,command speed is kept constant at 150RPM.Furthermore the rotor resistance is kept at 0.0435 and from t=2s tp t=6s it is changed to 2*0.0435.The stator currents for phase ‘a’ and phase ‘b’ are shown below.The oscillations of estimated stator flux are about 0.03wb around the average amount of 1.2wb.

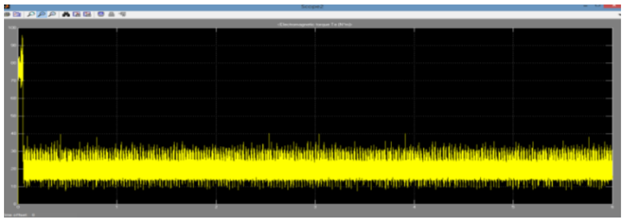
Rotor Speed:



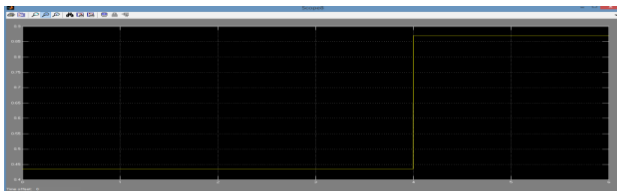
Stator currents for Phase ‘a’ and ‘b’:



Torque:



Stator and rotor resistances:



By using fuzzy logic controller into the IM drive system it is simulated by using MATLAB/SIMULINK model. Hence the rotor speed is obtained at transient conditions. The torque ripples are also reduced satisfactorily.

Rotor speed:

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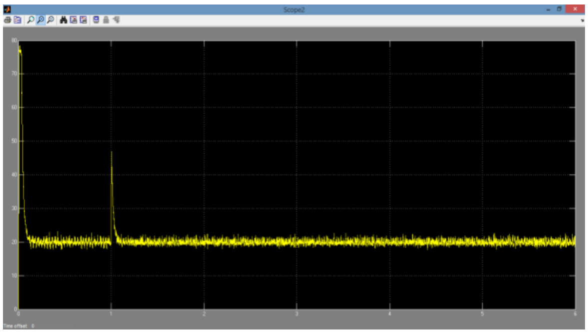
Torque waveform:



## VII.CONCLUSION

A new approach for speed sensorless SVM-DTC for 3-phase Induction motor drive is proposed and evaluated simulations. At low/zero speed, speed sensorless control of induction motor is sensitive to the accurate values of stator and rotor resistances and the proposed algorithm simultaneously estimate the speed, stator and rotor resistances as well as the stator and rotor fluxes and stator currents. The proposed algorithm can also be used for both stator and rotor field oriented schemes. By using fuzzy logic controller e can operate the system in transient conditions. The simulation results showed the good performance of the proposed EKF in the speed sensorless in SVM-DTC of induction motor drive.

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