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Null Vector Period Current Based Sensorless Rotor Flux Estimation of Vector Control Induction Motor Drive

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ABSTRACT

The paper describes a new technique for sensorless rotor flux estimation of vector control induction motor at low speed operation. The sensorless rotor flux estimation at low speed region is difficult mainly due to the terminal voltage acquisition problem and parameter variation effect. The estimation technique proposed here, estimates rotor fluxes without the motor terminal voltages signal. Thus, the problems associated with the estimation of rotor fluxes at low-speed due to terminal voltage measurement can be eliminated. To achieve this feature, the rotor flux is estimated during null or zero space vector (state 8 or 7) periods of Space Vector PWM Inverter. The terminal voltages are zero during null or zero space vector period as motor terminals are shorted through the upper or lower switching devices of the inverter. Thus, the rotor position estimation can be performed using the zero vector period stator currents considering terminal voltages are zero. Theoretically the proposed estimator can estimate the position signal just after the first sampling period of the inverter. The method is simple and easy for implementation. Extensive computer Simulation results are presented in this work to validate the performance of the proposed estimator scheme.

Key words: Vector Control, Induction Motor, Sensor-less Control

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INTRODUCTION

Vector or field-oriented control of induction motor drives are widely used for high-performance speed or position control applications [1-2]. Rotor position or speed signal is required for vector control of induction motors [3-4]. Rotor speed and position information is required for 'Indirect vector' control where in case of 'Direct Vector Control' information of rotor flux position is required, which is estimated based on the rotor speed and stator current signals [4]. Shaft mount optical encoders or resolvers are used to acquire the position or speed information. However, the presence of such position or speed sensor lead to a number of disadvantages such as increased cost, reduced reliability, robustness and noise immunity etc [3-5]. Different methods for elimination of speed or position sensor have been proposed in recent literature, such as speed estimation by slip calculation [3-4], direct synthesis from state equations [5], model reference adaptive systems [6-11], state observer [12-16], EKF observers [3-5], saliency effects [3-18-25-26], sliding-mode observer [19], artificial intelligence [20-22]. In these methods the flux and speed estimations are mainly done based on the motor terminal voltages and currents. However, their performances are very poor at low speed region. The main reasons of poor performance at low speed region are the limited accuracy of stator voltage acquisition, the presence of offset and drift components in the acquired voltage signals, their limited bandwidth, parameter variation, high computational effort, stability problem at low speed region etc. [4-5]. These deficiencies degrade the accuracy of flux and speed estimation at low speed region. Recent researches focus on providing sustained operation with high dynamic performance in the very low speed range, including zero speed start-up.

In this work, a new sensor less rotor flux estimation technique for vector control induction motor using null vector period currents-based estimator is proposed. The rotor flux is estimated during null or zero space vector (state 8 or 7) periods of the space vector PMW (SVM) [24] inverter sampling period. The terminal voltages are zero during the null or zero space vector period as the motor terminals are shorted through the upper or lower switching devices of the inverter. Thus, the rotor flux can be estimated using stator currents considering the terminal voltage as zero during null voltage vector period. In this proposition, the measurements of terminal voltages are not required for the rotor flux estimation during the null or zero space vector (state 8 or 7) periods of the SVM inverter therefore, the problem associated with the measurement of terminal voltage at low-speed operation can be eliminated. Theoretically the estimator can estimate the rotor flux just after the first sampling period of the SVM inverter. Extensive computer simulation results are presented in order to validate the performance of the proposed estimator.

DERIVATION OF ROTOR FLUX ESTIMATION EQUATION

The machine stator flux linkages in d-q stationary frame can be written as follows [4].

$$\Psi_{ds}^{s} = \int (V_{ds}^{s} - I_{ds}^{s}R_{s}) \tag{1}$$

$$\Psi_{qs}^{s} = \int (V_{qs}^{s} - I_{qs}^{s}R_{s}) \tag{2}$$

Where V_{ds}^{s}&V_{qs}^{s} are the stator terminal voltages, I_{ds}^{s}, I_{qs}^{s} are the stator currents and R_S is the stator resistance, all are in static d-q reference frame.

$$\Psi_{dm}^{s} = \Psi_{ds}^{s} - L_{ls}i_{ds}^{s} \tag{3}$$

$$\Psi_{qm}^{s} = \Psi_{qs}^{s} - L_{ls}i_{qs}^{s} \tag{4}$$

Where, L_{ls} stator self-inductance.
Rotor flux linkages are,

$$\Psi_{dr}^{s} = \frac{L_r}{L_m}\Psi_{dm}^{s} - L_{lr}i_{ds}^{s} \tag{5}$$

$$\Psi_{qr}^{s} = \frac{L_r}{L_m}\Psi_{qm}^{s} - L_{lr}i_{qs}^{s} \tag{6}$$

Where, L_r rotor inductance, L_m mutual inductance, L_{lr} rotor self-inductance.

Substituting the value of Ψsdm & Ψsqm from eqn.3 and 4 in eqn. 5 and eqn. 6 gives,

$$\Psi_{dr}^{s} = \frac{L_r}{L_m}(\Psi_{ds}^{s} - L_{ls}i_{ds}^{s}) - L_{lr}i_{ds}^{s} \tag{7}$$

$$\Psi_{qr}^{s} = \frac{L_r}{L_m}(\Psi_{qs}^{s} - L_{ls}i_{qs}^{s}) - L_{lr}i_{qs}^{s} \tag{8}$$

Substituting the value of Ψsds & Ψsqs from eqn. 1 & 2 in eqn. 7 & 8 gives,

$$\Psi_{dr}^{s} = \frac{L_r}{L_m}\left[\left\{\int (V_{ds}^{s} - I_{ds}^{s}R_{s})\right\} - L_{ls}i_{ds}^{s}\right] - L_{lr}i_{ds}^{s} \tag{9}$$

$$\Psi_{qr}^{s} = \frac{L_r}{L_m}\left[\left\{\int (V_{qs}^{s} - I_{qs}^{s}R_{s})\right\} - L_{ls}i_{qs}^{s}\right] - L_{lr}i_{qs}^{s} \tag{10}$$

The rotor flux can be estimated from the eqn.9 and 10 by measuring and processing the stator terminal voltages and currents. However, the stator voltage measurement and processing are very difficult during the low speed operation in practical drive. The Rotor position or unit vector estimation using equation no. 9 &10 without the voltage terms will be discussed in the next section.

NULL VECTOR PERIOD CURRENT BASED ROTOR FLUX ESTIMATION

The SVM Inverter fed synchronous current control scheme based vector control induction motor drive is considered in this work. SVM inverter consists eight (8) distinct switching states. Out of the eight switching states of the inverter, state 1 to 6 produces six active voltage vectors, where states 7 & 8 produces two zero voltage vector [23]. During the zero states the motor terminals are shorted by the upper or lower switches of the inverter, so the terminal voltage during this period is zero [23]. If rotor flux estimation will take place during the zero vector periods of every sampling time then voltage terms of the eqn. 9 and 10 can be substitute by zero, as during this period the motor terminal voltages are zero. The rotor flux estimation eqn. 9 and 10 can be modified as follows.

$$\Psi_{dr}^{s} = \frac{L_r}{L_m}\left[\left\{\int (- I_{ds}^{s}R_{s})\right\} - L_{ls}i_{ds}^{s}\right] - L_{lr}i_{ds}^{s} \tag{11}$$

$$\Psi_{qr}^{s} = \frac{L_r}{L_m}\left[\left\{\int (- I_{qs}^{s}R_{s})\right\} - L_{ls}i_{qs}^{s}\right] - L_{lr}i_{qs}^{s} \tag{12}$$

The above equations are only valid during the zero vector periods. The stator current sample has to be acquired during the zero vector periods only. The unit vector signals can be determined easily by using the following equation.

$$\cos\theta = {\Psi_{dr}^{s}}/{\Psi_r} \tag{13}$$

$$\sin\theta = {\Psi_{qr}^{s}}/{\Psi_r} \tag{14}$$

Where,

$$\Psi_r = \sqrt{(\Psi_{dr}^{s})^2 + (\Psi_{qr}^{s})^2} \tag{15}$$

SOFTWARE IMPLEMENTATION OF THE PROPOSED ESTIMATOR

The structure of drive scheme with proposed estimator is shown in Fig.1. Indirect vector control is implemented here using synchronous current technique in MATLAB/ SIMULINK. The Space Vector Modulation (SVM) technique is used to control the inverter. The motor is a three phase four (4) pole squirrel cage induction motor. To implement the null vector period current based estimation technique, the stator current samples must be acquired during the null vector state (State 7 or 8) of the SVM switching period. The estimator calculation has to be carried out by using these current samples only. To fulfil this criterion, the estimator block is modelled as an enable subsystem block and driven by the state 8 pulse of the SVM block i.e. the estimator block become enable only during the zero or null vector period i.e. during state 8 period of the SVM sampling time. The internal structure of the estimation block is shown in Fig. 2. The parameter of the motor and PI controllers are listed is table -1 and table -2.

Table -1 Motor Parameters

Machine Parameter	Values
Stator Resistance (Rs)	0.435 ohm
Stator Self Inductance (Lls)	0.002 H
Rotor Self Inductance (Llr)	0.002 H
Mutual Inductance	69.31 x 10^{-3} H

Table -2 PI Controller Parameters

Controller Gain		Values
Speed Controller Gain	Kp	2.5
	Ki	1.5
Current Controller Gain	Kp	1.5
	Ki	0.9

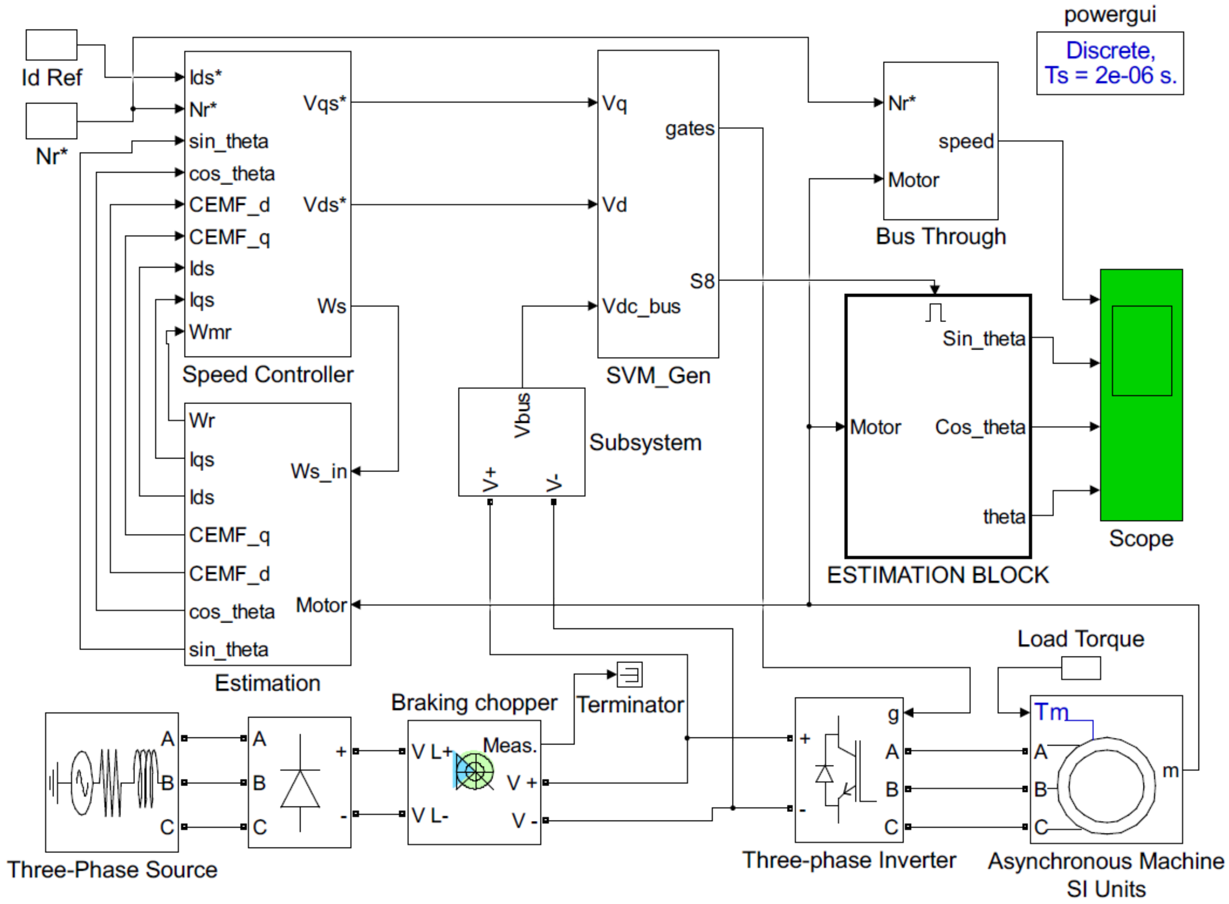

Fig. 1 Structure of drive scheme with the estimator

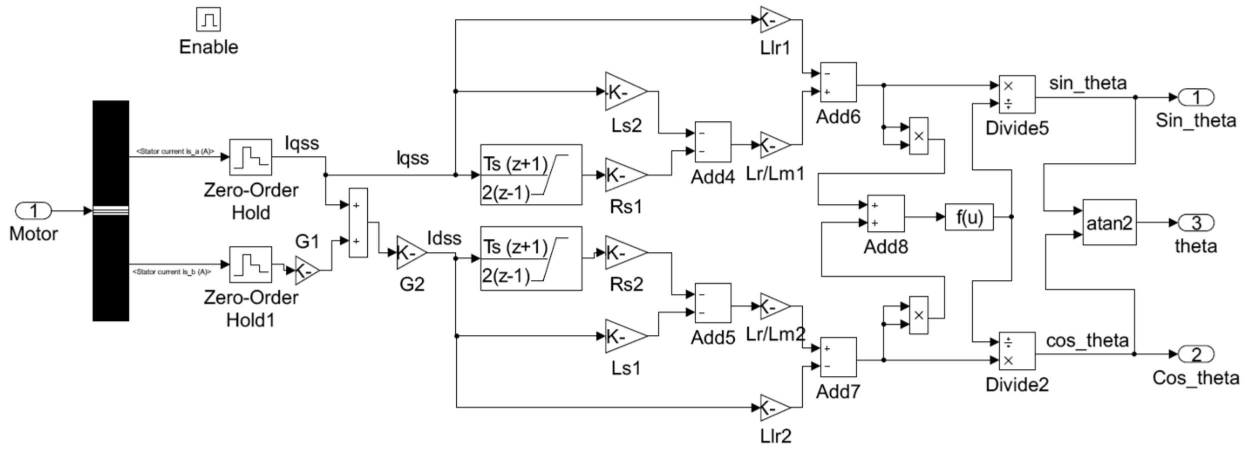

Fig. 2 Structure of Estimation Block

SIMULATION RESULT

The simulation of the proposed estimator is carried out in MATLAB/SIMULINK. The unit vector and rotor flux position estimation are carried out for different reference speed. The drive is run with step speed reference. The rotor flux & unit vector signal is estimated using the estimator shown in Fig. 2. The unit vector is also estimated from the speed signal for comparison. Fig. 3 shows the speed response, Unit vector ($Sin\theta$ & $Cos\theta$) calculated from speed signal & proposed estimator for reference speed 250 rpm (frequency = 8.33Hz) are shown in Fig. 4 –Fig. 7

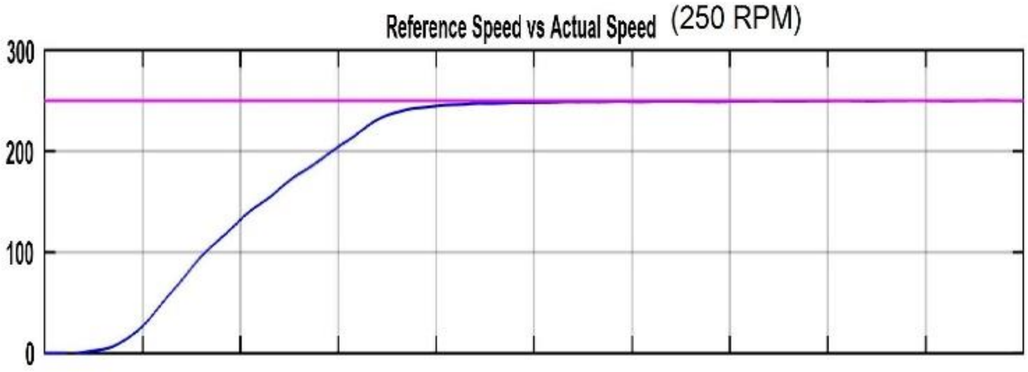

Fig. 3 Reference and Actual speed in rpm (Nr*=250 rpm)

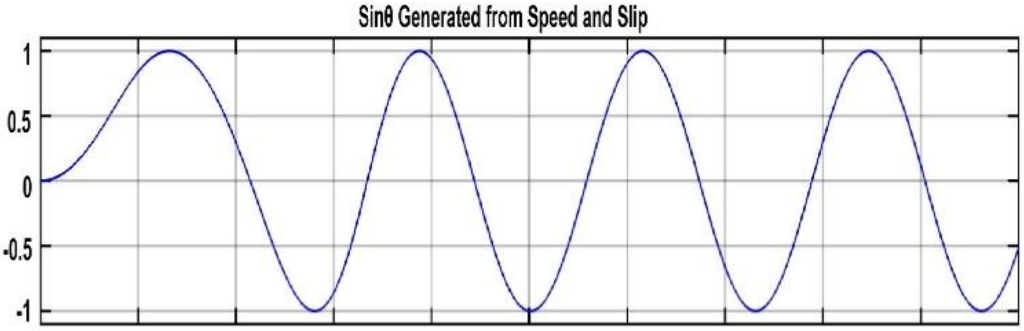

Fig. 4 Unit vector signal ($sin\,\theta e$) directly from speed & slip signal

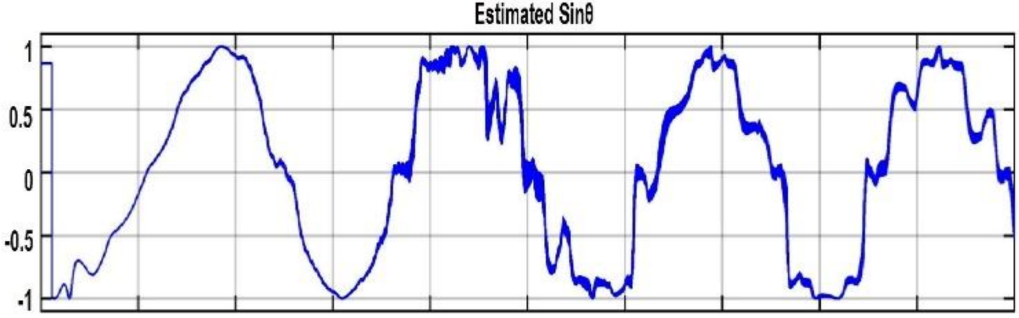

Fig. 5 Estimated unit vector signal ($sin\,\theta e$)

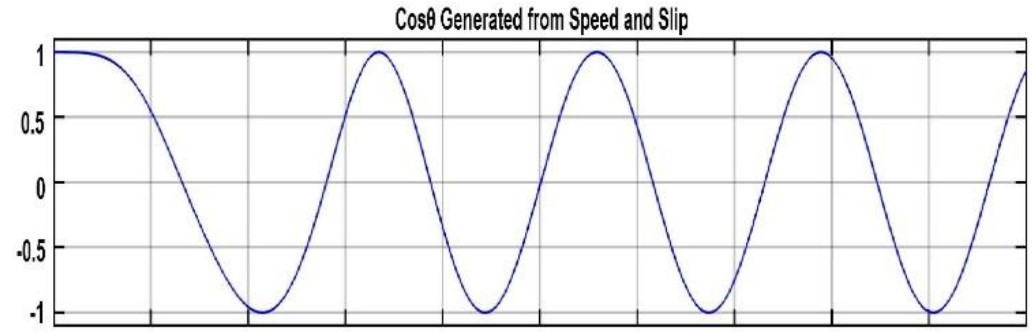

Fig. 6 Unit vector signal ($cos\,\theta e$) directly from speed & slip signal

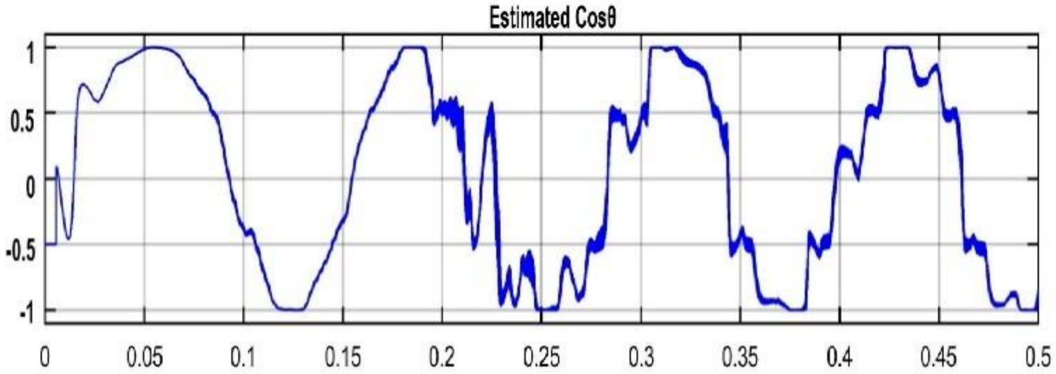

Fig. 7 Estimated unit vector signal ($cos\,\theta e$)

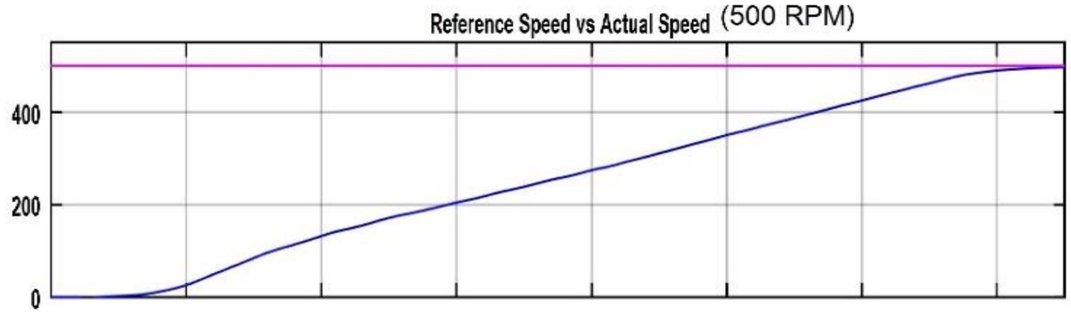

Fig. 8 Reference and Actual speed in rpm (Nr*=500 rpm)

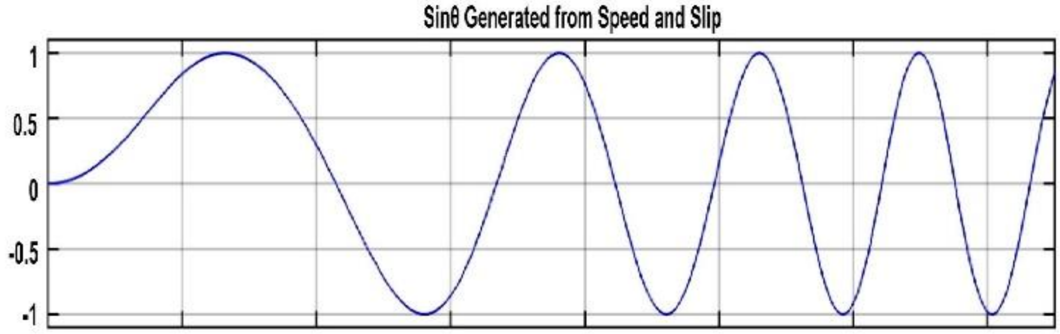

Fig. 9 Unit vector signal ($sin\,\theta e$) directly from speed & slip signal

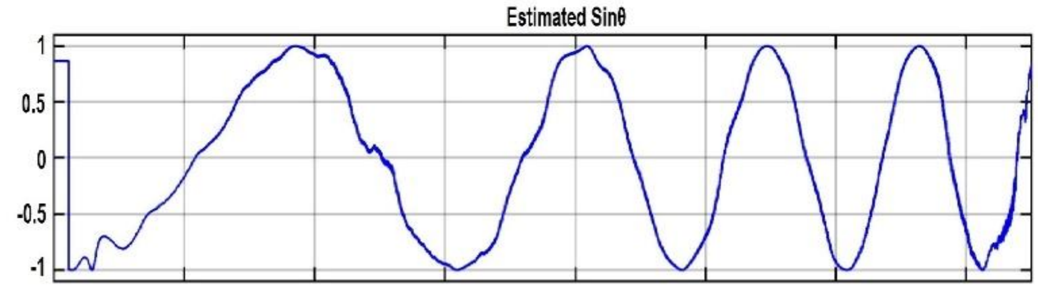

Fig. 10 Estimated unit vector signal ($sin\,\theta e$)

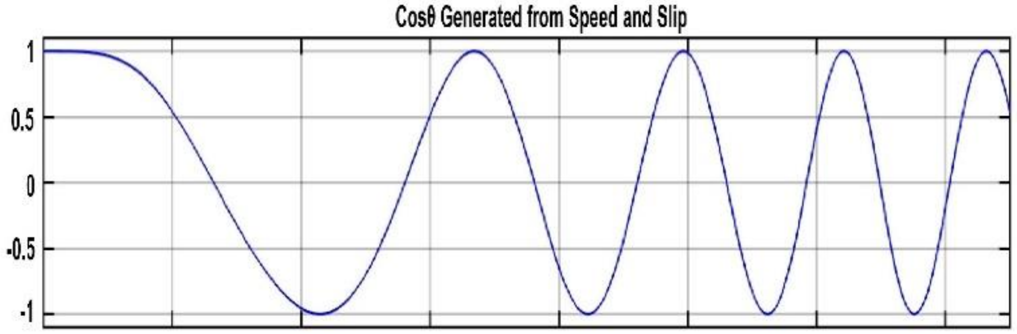
Cosθ Generated from Speed and Slip

Fig. 11 Unit vector signal ($cos\,\theta e$) directly from speed & slip signal

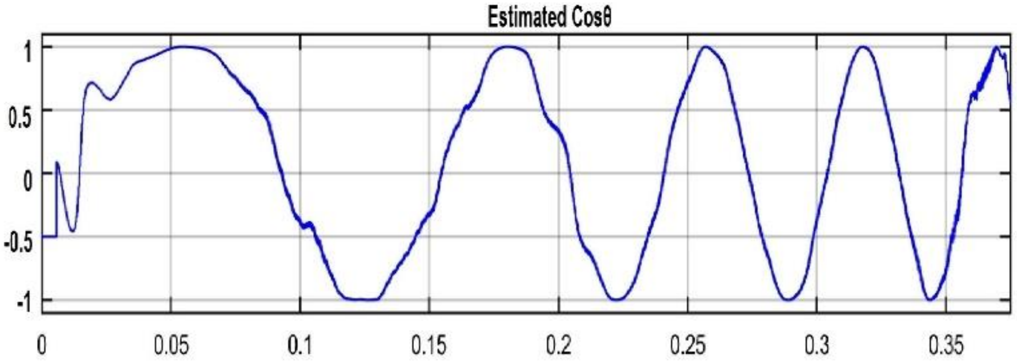
Estimated Cosθ

Fig. 12 Estimated unit vector signal ($cos\,\theta e$)

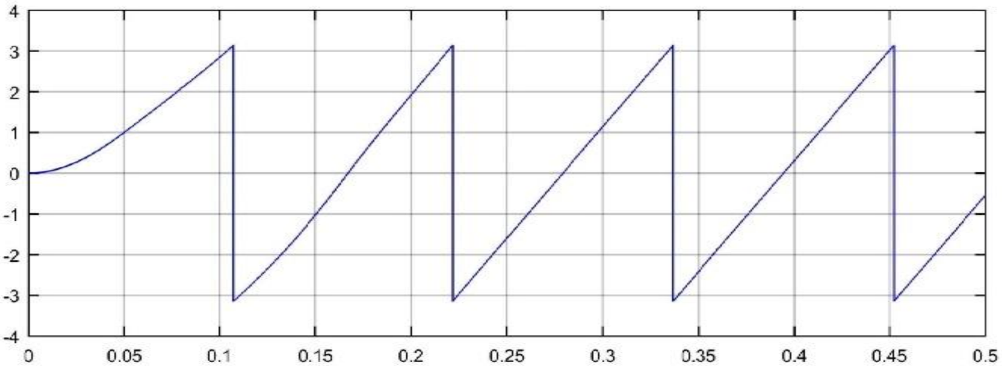

Fig. 13 Rotor flux position genrated from slip and speed signal (250 RPM)

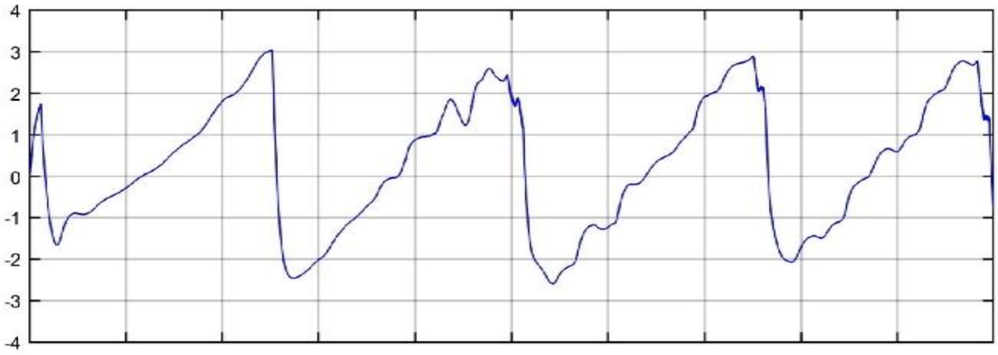

Fig. 14 Rotor flux position signal from the proposed estimator (250 RPM)

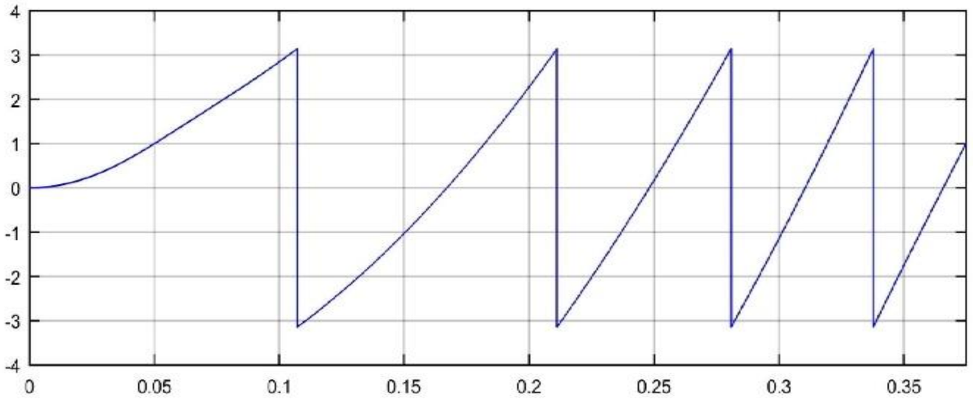

Fig. 15 Rotor flux position genrated from slip and speed signal (500 RPM)

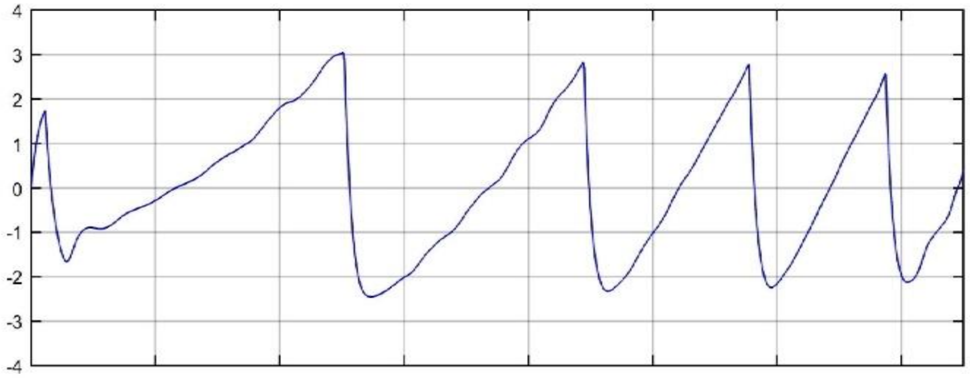

Fig. 16 Rotor flux position signal from proposed estimator (500 RPM)

The same signals are also estimated for reference speed 500 rpm (frequency = 16.66Hz) is shown in Fig. 8. –Fig. 12 The rotor flux position signal is estimated by the proposed estimator for reference speed 250 rpm is compared with the signals obtain directly from speed signal and presented in Fig. 13 - Fig. 14. The signals are also estimated for reference speed 500 rpm is presented in Fig. 15 - Fig. 16.

CONCLUSION

Novel technique for sensorless rotor flux estimation of vector control induction motor in low speed is presented in this work. Motor terminal voltage signals are not required for the estimation method. This future eliminates the problem associate with the measurement of voltage during the low speed region. Extensive simulation results are presented to validate the effectiveness of the proposed scheme. Theoretically the estimator can estimate the rotor position just after first sampling time. The parameter variation effect is not considered in this work, any suitable parameter variation compensation scheme (especially for R_s) from the resent literature may be consider. The device voltage drop and turn off time compensation are to be considered for hardware implementation of the propose technique, especially during low speed operation. At high speed operation the estimation accuracy is degraded as the duration null or zero vector becomes significantly small. However, in high speed region the terminal voltages can be measured easily and any other type of speed estimation technique can be used.

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