Int. j. inf. tecnol. (May 2022) 14(3):1595–1602
https://doi.org/10.1007/s41870-021-00847-z

ORIGINAL RESEARCH

Modified MRAS approach for sensorless speed control of induction motor for reliability improvement

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Received: 4 August 2021 / Accepted: 2 December 2021 / Published online: 5 February 2022

Abstract This paper proposes an innovative approach in sensorless speed control of induction motor which easily fixes the system at lower cost with high reliability. The conventional Model Reference Adaptive System (MRAS) approach is usually built on the model of voltage and flux linkage in which the accuracy of the speed estimation is affected by the deviations in stator parameters. In the proposed modified MRAS method, to avoid the impact of motor quantities on the performance of speed calculation. Imaginary power in fixed coordinate without speed information is used in the reference model and the imaginary power in the revolving coordinate contains the speed data. The proposed method developed in the MATLAB/Simulink environment and simulation results shows the accuracy and reliability of the speed estimation under the various running conditions.

Keywords Modified MRAS · Sensorless speed control · Induction motor drive · Reliability improvement

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1 Introduction

In many industrial applications induction motor drives are commonly preferred because it has many advantages like low cost, easy maintenance, robust construction and reliable operation over the other motor drives. For high performance and fast dynamic response of operation vector control scheme can easily implement in this drive but it requires the knowledge of speed and if the speed sensors like tachometer, rotary transformer etc. are used to acquire the speed pulse, installation and its cost will be the main difficulty and additionally reliability will also be decreased [1]. Now in this regard as a remedy to these problems sensorless speed estimation technique is introduced to calculate the speed in real time without help of the any speed sensing device. Thus in recent years so many sensorless speed estimation techniques are studied and applied. [2, 3]. While applying these techniques, so many practical issues need to be addressed like sensitivity with parameter variations [4, 5], speed estimation accuracy and stability at low speed etc. therefore finding an appropriate speed estimation technique has been a big challenging task.

2 Literature review

The technique based on MRAS has most popular technique among the sensorless speed control since it has reliable operation, easy control and greater performance. MRAS proposed by Han et al. [6] has reference model consist of flux linkage of voltage model independent of speed whereas the adaptive model builds by flux linkage current model with speed. Since this technique uses model of voltage and flux linkage and Wubin et al. [7] improved the correctness of speed estimation influenced by the stator parameter variation most commonly variation in stator resistance also the term of pure integrator in the voltage model affects the speed estimation performance mainly at small speed.

To minimize difficulties related with conventional MRAS method, several research works has been accompanied like Rashed et al. [8] uses the back Electromotive Force (back- EMF) in place of flux linkage to eliminate the term of pure integrator but the presence of stator resistance in the model affects the accuracy of speed calculation so Peng et al. [9] suggested to replace reactive power in air gap with back- EMF so as to stator resistance can be removed but it leads to MRAS becomes highly sensitive to the noise.

This problem of speed calculation using reactive power in air gap can be resolved using a new technique was proposed by Malti et al. [10, 11] where real power from the induction motor is replaced by the air gap reactive power. This technique successfully eliminates all above mentioned problems and improves the speed estimation performance considerably. But in this method adjustable model contains parameters like flux leakage coefficient, inductance etc. which may have the impact on the speed calculation under running condition.

The performance of MRAS under low speed and frequency is an another problem and it has been tried to resolve by Chen et al. [3] and Zhang et al. [2] but still there is lot of scope for improvement.

In this section an innovative speed estimation technique is proposed where to avoid the impact of motor parameters on the speed estimation performance, reactive power in stationary coordinate is used in the reference model without speed information and the imaginary power in the revolving coordinate contains the speed data.

3 Methodology

In this section two methods for speed estimation are discussed. Initially conventional MRAS technique is presented and then modified MRAS technique is suggested with mathematical changes such that stator resistance will not affect speed estimation.

In the **conventional MRAS** method the reference model build without speed to be calculated and the adjustable model involves the speed within it [6]. The mathematical modeling of the reference model can be expressed as

$$\frac{d}{dt}\psi_{dr} = \frac{Lr}{Lm}[V_{ds} - (R_s + \sigma SL_S)i_{ds}] \tag{1}$$

$$\frac{d}{dt}\psi_{qr} = \frac{Lr}{Lm}\left[V_{qs} - (R_s + \sigma SL_S)i_{qs}\right] \tag{2}$$

And the adaptive model can be built from Eqs. (3) and (4)

$$\frac{d}{dt}\psi_{dr} = \frac{Lm}{Tr}i_{ds} - \omega_r\psi_{qr} - \frac{1}{Tr} \tag{3}$$

$$\frac{d}{dt}\psi_{qr} = \frac{Lm}{Tr}i_{qs} - \omega_r\psi_{dr} - \frac{1}{Tr}\psi_{qr} \tag{4}$$

If the speed (ωr) is known then the flux from stator current can be calculate using above equations. At idle condition $\Psi^s_{dr} = \widehat{\Psi}^s_{dr}$ $\Psi^s_{dr} =$ $\Psi^s_{dr} =$ $\widehat{\Psi}^s_{dr}$ $\widehat{\Psi}^s_{dr}$ and $\Psi^s_{qr} = \widehat{\Psi}^s_{qr}$, where $\widehat{\Psi}^s_{dr}$ and $\widehat{\Psi}^s_{qr}$ are the adjustable model outputs. For the tuning of speed and to make the error ξ = 0 an adaptation algorithm along with P-I control is used. The Structure of conventional MRAS method for speed estimation based on above equations is shown in Fig. 1.

It can be seen in the above method of speed estimation contains the parameter like stator resistance which can be influence the accuracy of speed estimation due to parameter variation also the presence of pure integration term leads to integral drift which hampers the correctness of speed calculation at low speed [12].

To implement **modified MRAS technique**, mathematical model of voltage in d-q frame are considered as,

$$\begin{aligned} v_{ds} &= R_s i_{ds} + \sigma L_s \frac{di_{ds}}{dt} + \frac{L_m}{L_r}\frac{d\psi_{dr}}{dt} - \sigma L_s\omega_s i_{qs} - \omega_s\frac{L_m}{L_r}\psi_{qr} \\ v_{qs} &= R_s i_{qs} + \sigma L_s \frac{di_{qs}}{dt} + \frac{L_m}{L_r}\frac{d\psi_{qr}}{dt} + \sigma L_s\omega_s i_{ds} - \omega_s\frac{L_m}{L_r}\psi_{dr} \end{aligned} \tag{5}$$

where $v_{ds}, v_{qs}, i_{ds}, i_{qs}$ are the stator voltages and currents, Ls, Lr are the inductance of stator and rotor respectively; Lm is the mutual inductance, Rs is the stator resistance, ωs is the synchronous speed and ωr is the rotor speed. The instantaneous value of reactive power obtained from induction motor can be specified as,

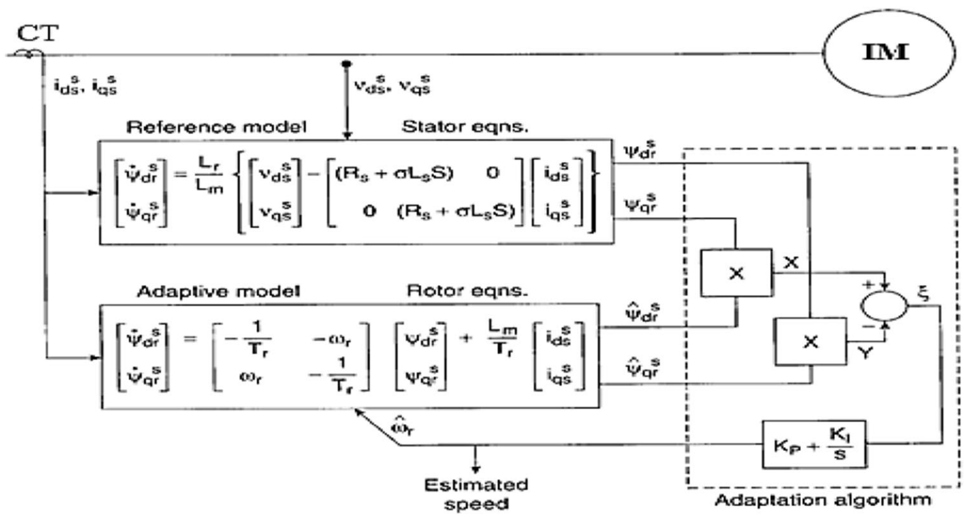
$$Q = v_{qs}i_{ds} - v_{ds}i_{qs} \tag{6}$$

Inserting Eq. 5 into 6:

$$\begin{aligned} Q = {} & \sigma L_S\left(i_{ds}\frac{di_{qs}}{dt} - i_{qs}\frac{di_{ds}}{dt}\right) + \sigma L_s\omega_s\left(i^2_{ds} + i^2_{qs}\right) \\ & - \frac{L_m}{L_r}\left(i_{qs}\frac{d\psi_{dr}}{dt} - i_{ds}\frac{d\psi_{qr}}{dt}\right) + \omega_s\frac{L_m}{L_r}\left(i_{qs}\psi_{qr} + i_{ds}\psi_{dr}\right) \end{aligned} \tag{7}$$

It is clear from Eq. 7 that there is no parameter of the stator resistance in the equation of reactive power obtained from the induction motor therefore deviation in the stator resistance will not affect the speed estimation also the absence of pure integration term greatly help to increase the accuracy of speed calculation at small speed [13, 14].

Fig. 1 Structure of conventional MRAS method for speed estimation



Above equation of reactive power is the equation under transient condition but when the induction motor is at steady state condition $\Psi_{rd} = L_m I_{ds}$ and $\Psi_{qr} = 0$ so the Eq. (7) is modified to Eq. (8)

$$Q' = \sigma L_s \omega_s \left(i_{ds}^2 + i_{qs}^2 \right) + \omega_s \frac{L_m^2}{L_r} i_{ds}^2 \tag{8}$$

So the structure of reactive power based MRAS for speed estimation as shown in Fig. 2 is built from Eq. (7) and Eq. (8).The reference model is built from Eq. (7) and adjustable model built from Eq. (8).

To ensure the stability of the system error signal treating unit is added to the speed calculation system to process the reference model and error signals obtained from the adjustable model.

The reactive power based MRAS method can improve the performance of speed calculation to some extent because still it contains the parameters that may affect the accuracy of speed estimation like inductance and so on [14]. To solve this problem reactive power is stated in static reference frame in the reference model and imaginary power in revolving frame is stated in adjustable model. Reactive power in reference model does not contain speed information whereas the reactive power in adaptable model depends on the speed information. In this way motor parameter influence can be eliminated completely to improve the overall performance and system reliability [14].The real power loss reduction can also be achieved in future using various optimization methods [15, 16]. The basic structure of modified MRAS technique based on the reactive power is shown in Fig. 3.

Mathematical expressions for reactive power in reference model and adjustable model can be expressed as Eqs. (9) and (10) respectively.

$$Q_{ref} = v_s \beta i_{s\alpha} - v_s \alpha i_{s\beta} \tag{9}$$

$$Q_{ad} = v_{qs} i_{ds} - v_{ds} i_{qs} \tag{10}$$

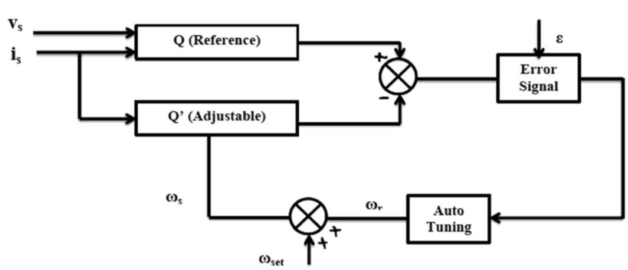


Fig. 2 Structure of reactive power based MRAS for speed estimation

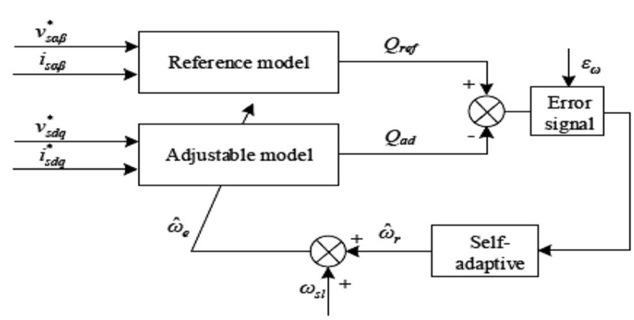


Fig. 3 Structure of reactive power based modified MRAS for speed estimation [14]

4 Experimental results

In this section, speed is estimated under three different conditions using conventional MRAS technique and modified MRAS technique.

4.1 Conventional MRAS technique for speed estimation

- **Case – 1: Zero load torque.**
  Here the set speed of induction motor is 100 rad/s with the load torque of 0 Nm. At start, induction motor acts as short circuit at secondary i.e. rotor winding. It results in very high current at start which is normally 5 to 7 times to that of steady state current. During this transition starting torque due to motor inertia increases from zero to its peak. The change in rotor speed is observed as 0 to 50 rad/s during 0 s to 0.08 s at 0.08 s. the value of torque is maximum that is approximately 50 N-m. After 0.08 s Torque reduces to zero from 0.08 to 0.25 s. and the variation in the speed during 0.08 to 0.25 s. is from 50 rad/s to approximately 100 rad/s. The speed of the motor reaches steady state value in time period of 0.25 s (Fig. 4).
- **Case – 2: Change of speed from 100 rad/s to − 100 rad/s.**
  Here in this condition induction motor is operating at zero load and the command of speed reversal is functional at 0.4 s the decay in speed starts at 0.4 s from 100 rad/s and steady state speed in opposite direction is obtained within 0.22 s. At 0.4 s torque increases in negative direction and reaches to steady state situation in order to achieve required rated speed. Figure 5 shows the simulation results in which the Speed changes from 100 rad/s to − 100 rad/s.
- **Case – 3: At low speed**
  Here set speed of induction motor is very low i.e. only 20 rad/s and the motor is operating at zero load condition. From the simulation results shown in Fig. 6 it can see that more than 0.5 s are required to reach at steady state condition and due to large torque fluctuations, induction motor runs with large noise and vibrations.

4.2 Modified MRAS technique for speed estimation

- **Case-1: Zero load torque.**
  The change in rotor speed is observed as 0 to 50 rad/s during 0 s to 0.08 s at 0.08 s. the value of torque is maximum that is approximately 50 N-m. After 0.08 s. Torque reduces to zero from 0.08 to 0.18 s. and the variation in the speed during 0.08 s to 0.18 s is from 50 rad/s to approximately 100 rad/s. The speed of the

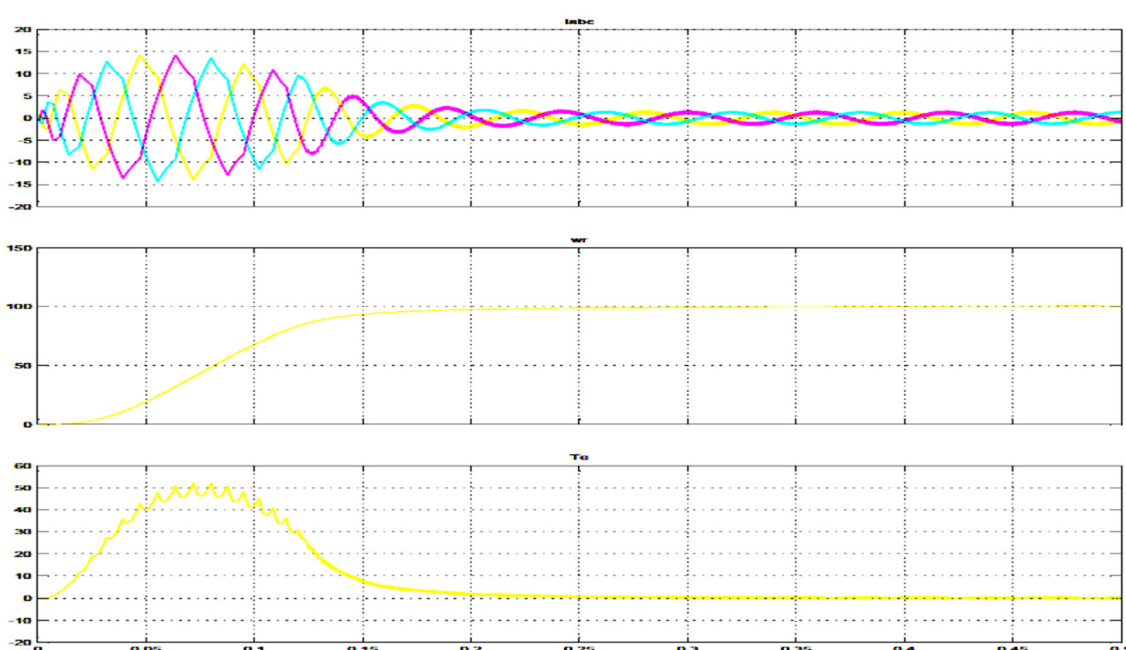


Fig. 4. 3-ϕ currents, rotor speed, and developed torque at zero load torque with set speed of 100 rad/s

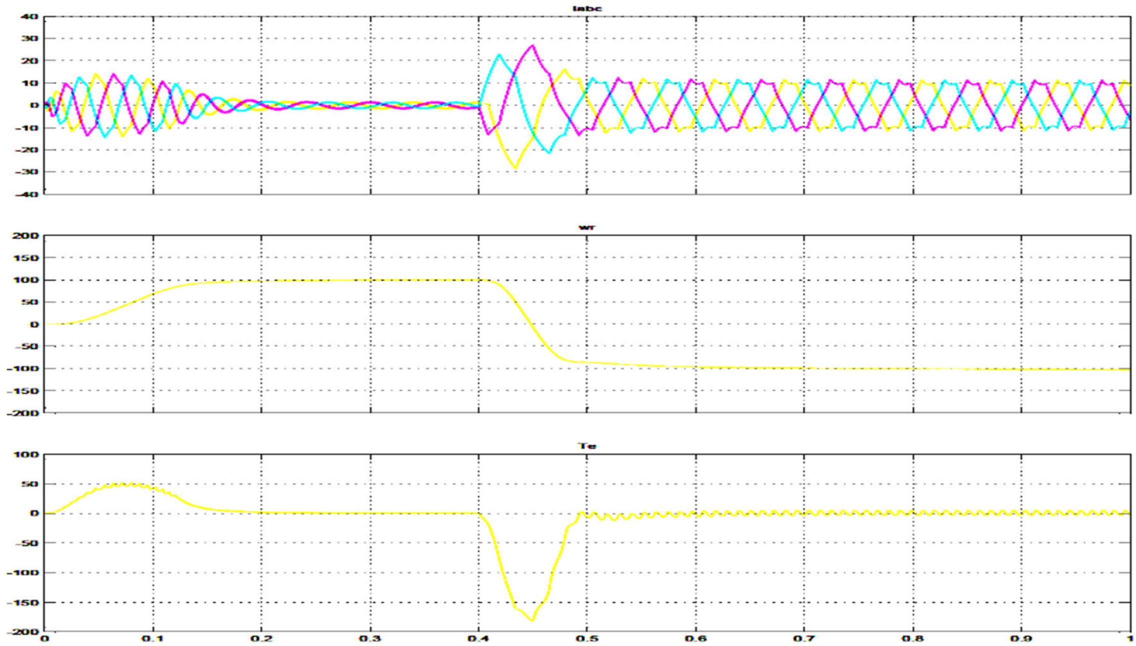


Fig. 5. 3-ϕ currents, speed, and torque for change of speed from 100 rad/s to − 100 rad/s

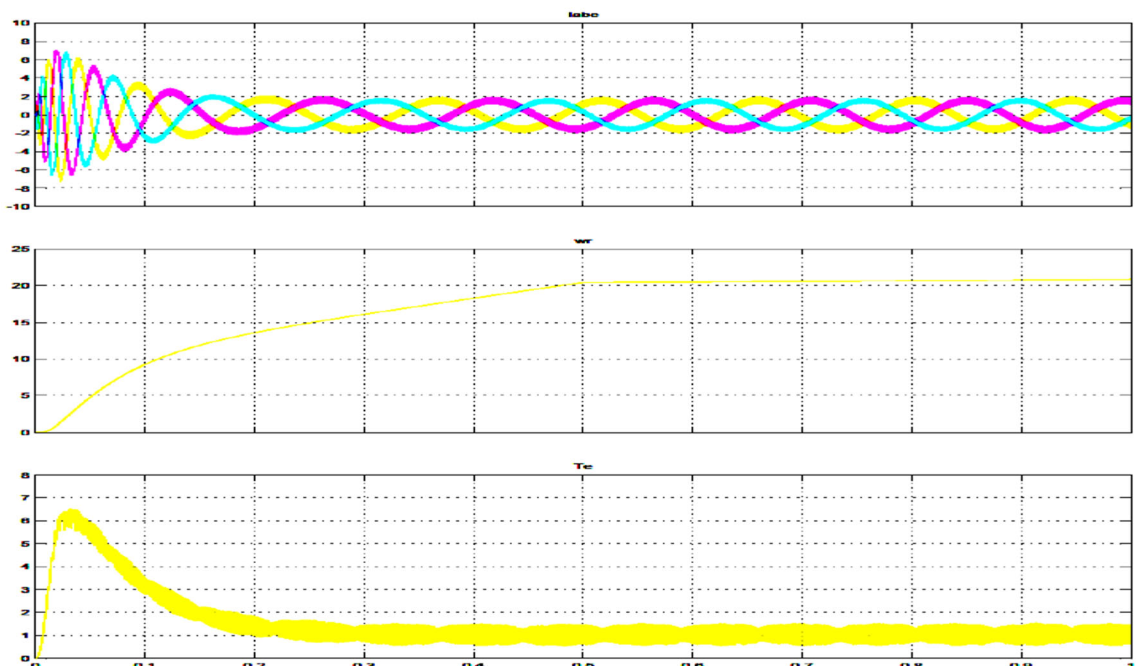


Fig. 6. 3-ϕ currents, speed, and torque for zero load torque with set speed of 20 rad/s

motor reaches steady state value in time period of 0.18 s (Fig. 7).

- **Case-2: Change of speed from 100 rad/s to − 100 rad/s.**
  Here in this condition induction motor is operating at zero load and the command of speed reversal is functional at 0.5 s the decay in speed starts at 0.5 s from 100 rad/s and steady state speed in opposite direction is obtained within 0.19 s. At 0.5 s torque increases in negative direction and reaches to steady state situation in order to achieve required rated speed.

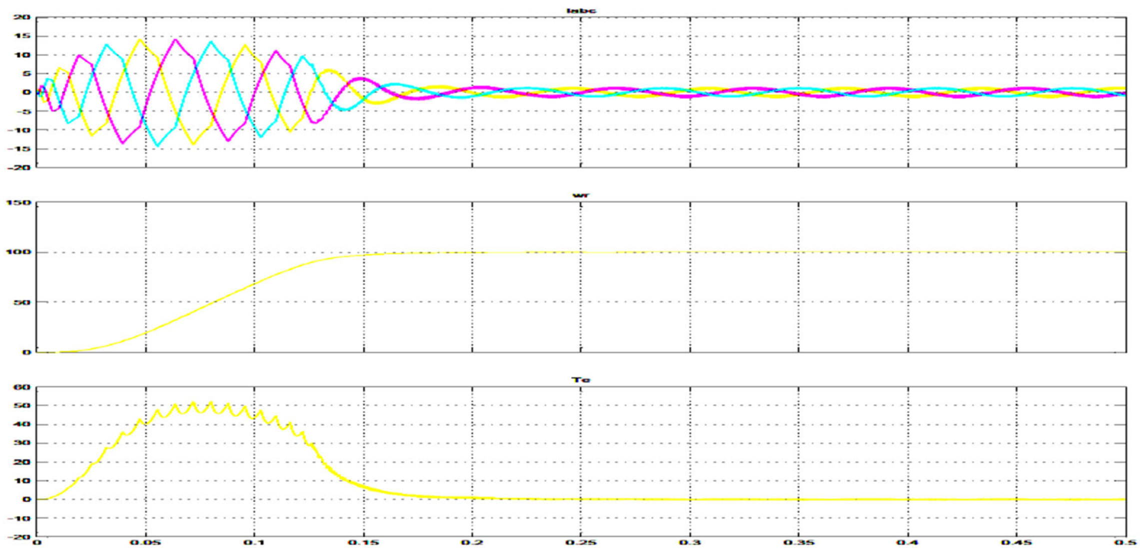


Fig. 7. 3-ϕ currents, rotor speed, and developed torque at zero load torque with set speed of 100 rad/s

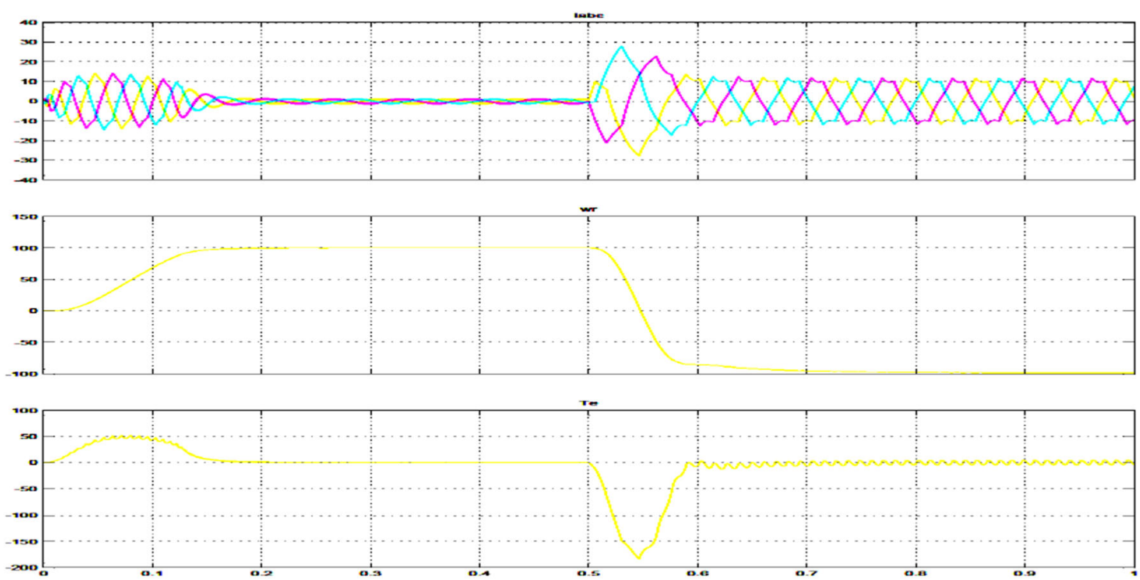


Fig. 8. 3-ϕ currents, speed, and torque for change of speed from 100 rad/s to − 100 rad/s

Figure 8 shows the simulation results in which the Speed changes from 100 rad/s to − 100 rad/s.

- **Case-3: At low speed.**

Here set speed of induction motor is very low i.e. only 20 rad/s and the motor is operating at zero load condition. From the simulation results shown in Fig. 9 it can see that only 0.2 s are required to reach at steady state condition and torque fluctuations are also reduced which causes reduction in noise and vibrations.

The comparative analysis between conventional and modified MRAS method is summarized in the Table 1.

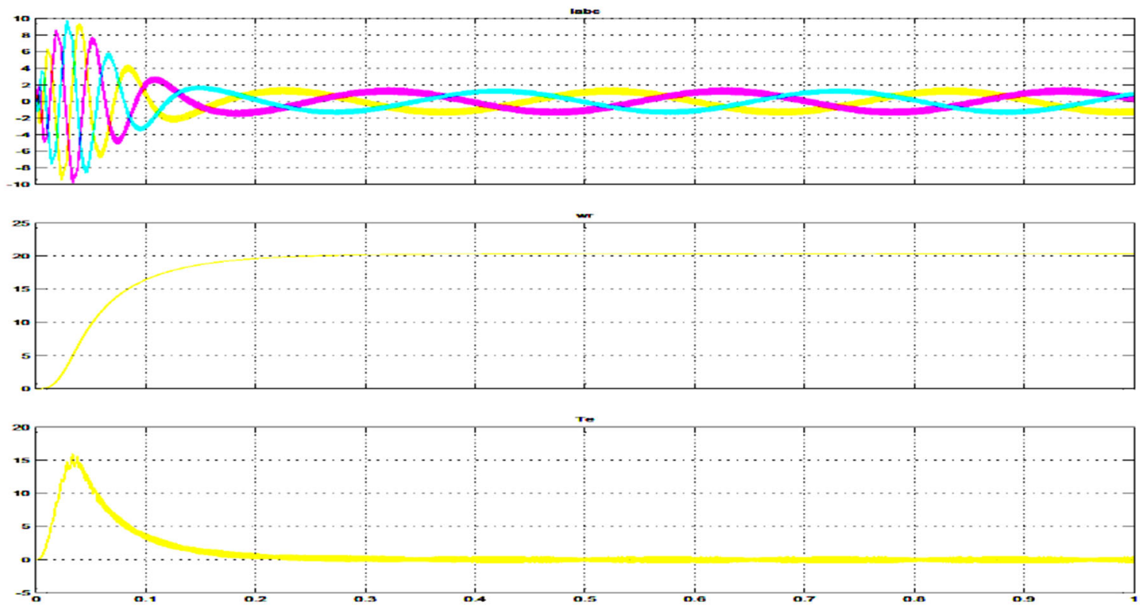


Fig. 9: 3-ϕ currents, speed, and torque for zero load torque with set speed of 20 rad/s

Table 1 Summary of comparative analysis between conventional and modified MRAS method

Speed/Torque condition	Conventional MRAS			Modified MRAS		
	Time to reach at steady state value (s)	Speed deviation W.R.T. set speed	Fluctuations in the developed torque	Time to reach at steady state value (s)	Speed deviation W.R.T. set speed	Fluctuations in the developed torque
Zero load torque	0.25	±1%	±2 – 3%	0.18	±1%	±2 – 3%
Reversal of speed	0.22	±2%	±2%	0.19	±1%	±2%
Low speed region	0.52	±3 – 4%	±7 – 10%	0.2	±2%	±3 – 4%

5 Conclusion and future scope

To eliminate the problem of parameter sensitivity of the conventional MRAS, modified MRAS method is proposed in which the model of flux linkage is exchanged with reactive power achieved from the induction motor. It can see from the simulation results of the conventional MRAS speed calculation and modified MRAS speed estimation that the speed estimation by modified MRAS technique tracks the actual speed signals more accurately than the conventional MRAS method which also helps to improve overall performance and reliability of the system. Also it shows the better accuracy and speed response in the region of low speed. The torque fluctuations are also reduced at great extent which provides noise free operation. Parameter optimization is possible by using genetic online PID controller instead of conventional PID controller also the use of self tuning PID controllers [17, 18] may help to improve its overall performance in its future scope.

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