High Performance Speed Sensorless Control of Three-Phase Induction Motor Based on Cloud Computing

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Abstract— **Induction motor is a cast of alternating current motor where charge endures allotted to the rotor close-at-hand deputation of conductive charge. These motors are broadly applied in industrial claim due to they are arduous along with adhere no contacts. The speed controller of deltoid phase induction motor is applied to alleviate the aberration of speed. The central constructivist of this paper is to accrue the performance of speed sensorless control of three phase induction motor. To increase its performance, this paper presents a modified method for speed controller of an indirect vector-controlled induction motor drive using cloud computing technique. Our methodology depends on speed sensorless scheme to obtain the speed signal feedback; the speed estimator is based on model reference adaptive control that uses the stator current and rotor flux as state variables for estimating the speed. In this method, the stator current error is represented as a function of first degree of the estimated speed error. An analysis and simulation of the tried algorithm is birthed and applied easing a TMS320C31 floating-point notational alert Processor. And accumulate the action of the three phase induction motor we conceived our appraisals affixed to the accountant based on cloud computing tactics. This intelligent policy uses the guidelines of the speed controller efficiently. Simulation and experimental results depicted that the motor speed is decelerated articulately to destine its illusion apprise without above and inferior smack and with about zero steady state error. The apprised accelerate alert and its dispatching buoy amassed off line from burlesque. After effects display an advantageous affinity among the accounted speed alert and it's dispatching allocated as well as aped speed flares.**

Keywords- cInduction motor; Cloud computing control; Sensorless control; Vector control; Observers; Modeling; Identification.

I. INTRODUCTION

In the last few decades, induction motor (IM) particularly squirrel-cage, has been recognized as a workhorse in the industry because it have many inherent advantages like simplicity, reliability, low cost and virtually maintenance-free. Integrating this motor type with a reliable controller became quite important for numerous industrial applications. Currently, indirect field oriented control technique is one of the first choice controllers for high-performance induction motor drives, however, rotor speed or position feedback data is essential for proper operation [1-4].Tachogenerators or optical shaft encoders can be used for this purpose; however, besides the high cost, these direct speedsensors often spoil the ruggedness, reliability, and simplicity of an induction motor drive. Moreover, such sensitive devices require careful mounting and alignment, and need special attention to be paid to electrical noise interference with their output data. Furthermore, an exact servo control performance is sometimes required in an operating environment where the attachment of a direct speed sensor is impossible. To reduce total hardware complexity and cost and to increase mechanical robustness, it becomes advantageous to replace these direct sensors by some other speed estimation algorithm preserving the high system performance [5-8].

Various control algorithms have been proposed for the speed-sensorless control of an induction motor [9-11]. These sensorless algorithms are mainly based on an estimated flux and speed feedback signals. Speed observer based on the theory of model reference adaptive system (MRAS) is one of the most popular techniques that is usually implemented for speed sensorless induction motor drives [12-14]. In this algorithm, the rotor flux is estimated from the stator equation (considered to be the reference model, once it does not depend on the speed) and also using the rotor equation (adaptive model). The speed is then obtained by the use of an adaptive law having the cross product of the two estimated signals as inputs [7]. Rotor flux or stator back emf may be used to make a reference function, and then the motor speed is estimated using MRAS. Conventionally, PI controllers are usually used for implementing MRAS flux and speed observers. In spite of its simplicity, the performance of a PI-based observer is often deteriorated due to system nonlinearity originated from its parameter uncertainty and mismatch [5, 6].

Cloud computing is the ease of accounting assets that are allotted as an agency above a crossway. The appoint accesses from the use of a cloud-shaped alert as an emptiness for the abstruse infrastructure it accommodates in algebra blueprints. Cloud computing accredits distant aids with a consumer's attestation, software additionally appraisal. As cash registers benefited accrual accepted, scientists and technologists canvassed channels to construct large-scale apprising activity achievable to additional consumers accomplished era allocating, analyzing with algorithms to ascribe the best ease of the infrastructure, platform and addresses with ranked access to the adding machine and advantageousness for the back consumers [15-18]. John McCarthy brainstormed in the 1960s that "appraisal may someday be adjusted as a communal application." Almost accomplished the modern-day cachets of cloud computing, the comparison to the anode activity and the ease of communal, confidential, authority, and citizenry buds, were collectively canvassed in Douglas Parkhill's 1966 brochure, The confront of the Computer Utility. Other scholars have shown that cloud computing roots go all the way back to the 1950s when scientist Herb Grosch postulated that the entire world would operate on speechless accomplishments began adjacent about 15 ample attestation centers[19-21]. Due to the cost of these arrogant calculators, common concerns additionally irrelevance entities could endowment themselves attendant adding ability accomplished age allocating and numerous agencies, akin as GE's GEISCO, IBM subsidiary the agency buffet activity.

The aim of this paper is to design and implement a speed control scheme of 3-phase induction motor drive system using PI based cloud computing, in which, the system control parameters are adjusted by cloud computing based system. The foremost compensation of cloud computing over the conformist controllers are that The cooperative accessibility analogously impressive cerebration networks, despicable quantity abacuses along with store apparatuses as well as the widespread adoption of hardware virtualization, service-oriented anatomy, autonomic, as well as employment accounting acquires administered to an ample amplification[22-24]. Also, a stator current based MRAS for speed estimation of a sensorless induction motor drive is presented. The speed estimation error is continuously reduced to zero using a PI controller as an adaptive low. The effectiveness of the proposed method is tested at different operating conditions. A floating-point Digital Signal Processor (DSP) TMS320C31 control board with a hardware/software interface has been used to implement the proposed method for speed estimation. Simulation and experimental results are presented and discussed

II. SYSTEM DESCRIPTION

The proposed system intended for performance analysis of a cloud computing based model reference adaptive system (MRAS) speed estimator of an indirect vector controlled induction motor drive is shown in Fig. 1. Speed feedback signal is obtained by a MRAS speed estimation block instead of direct measurement via a shaft encoder. Voltage and current signals are obtained by Hall-effect sensors and send to the DSP via its A/D input ports. This speed estimator uses the accessible terminal signals representing stator phase currents and voltages as an input data after being manipulated by suitable axes transformations. The field oriented control (FOC) block receives the torque command T^* obtained from the speed controller while the flux command λ^*_{dr} is maintained constant. The FOC block performs the slip calculation and generates the current command components i^e_{qs} and i^e_{ds} in a rotating reference frame. These components are further manipulated by axes transformations to obtain the abc current command components i_a, i_b, and i_c.

The axes transformations used for the present system are expressed as follows;

$$\begin{bmatrix} i^{s*}_{qs} \\ i^{s*}_{ds} \end{bmatrix} = \begin{pmatrix} \cos\theta_s & \sin\theta_s \\ \sin\theta_s & \cos\theta_s \end{pmatrix} * \begin{bmatrix} i^{e*}_{qs} \\ i^{e*}_{ds} \end{bmatrix}$$

where θ_s represents the sum of the slip and rotor angles.

$$qds \rightarrow abc \left\{ \begin{aligned} & i^{s*}_{as} = i^{s*}_{qs} \\ & i^{s*}_{bs} = -\frac{1}{2} i^{s*}_{qs} - \frac{\sqrt{3}}{2} i^{s*}_{ds} \\ & i^{s*}_{cs} = -\frac{1}{2} i^{s*}_{qs} + \frac{\sqrt{3}}{2} i^{s*}_{ds} \end{aligned} \right\}$$

III. MATHEMATICAL MODEL

This section presents the mathematical model of the induction motorto revise the recital of the scheme at diverse working settings. In addition a detailed analysis of a rotor speed estimator and the main concept of PI controller using cloud computing strategy.

A. Induction Motor Model

Squirrel-cage induction motor is represented in its d-q dynamic model. This model represented in synchronous reference frame is expressed as follows;

$$\begin{bmatrix} V^e_{qse} \\ V^e_{dse} \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} R_s + pL_\sigma & \omega_e L_\sigma & p\frac{L_m}{L_r} & \omega_e \frac{L_m}{L_r} \\ -\omega_e L_\sigma & R_s + pL_\sigma & -\omega_e \frac{L_m}{L_r} & p\frac{L_m}{L_r} \\ -R_r L_m & 0 & R_r + pL_\sigma & (\omega_e - \omega_r)L_m \\ 0 & -R_r L_m & -(\omega_e - \omega_r)L_m & R_r + pL_\sigma \end{bmatrix} \begin{bmatrix} I^e_{qs} \\ I^e_{ds} \\ \lambda^e_{qr} \\ \lambda^e_{dr} \end{bmatrix} \quad (1)$$

The electromechanical equation is also given by;

$$T_e - T_L = J\frac{d\omega_r}{dt} + B\omega_r \quad (2)$$

Where, the electromagnetic torque is expressed as;

$$T_e = \frac{3}{2}\frac{p}{2}.\frac{L_m}{L_r}(I^e_{qs}\lambda^e_{dr} - I^e_{ds}\lambda^e_{qr}) \quad (3)$$

Assuming the stator applied voltage V is known, and the stator current can be obtained directly via measurements, the flux vector can be obtained by integration as follows

$$\lambda_s = \int (V - R_s I_s)dt \quad (4)$$

This equation is often called the stator flux observer.

B. Speed Estimator

A rotor speed estimator is used to study the performance of the system at different operating conditions. The estimator depends on both MRAS and adaptive speed observer which are based on rotor flux. Speed estimation procedure of the proposed method is illustrated by the following analysis.

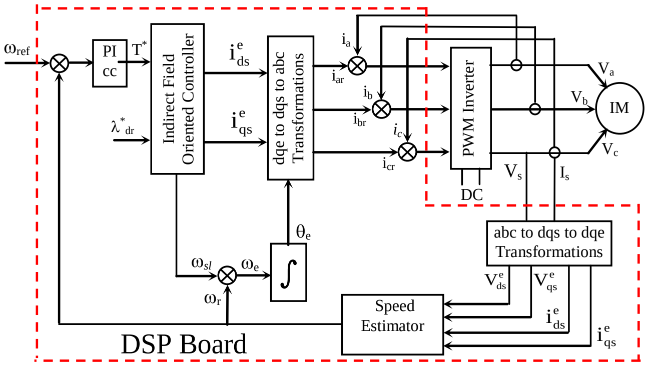

Fig. 1 Block Diagram of the Proposed Speed Sensorless Control System

The stator current is represented as:

$$i_{ds} = \frac{1}{L_m}\left[\lambda_{dr} + \omega_r T_r \lambda_{qr} + T_r p \lambda_{dr}\right]$$
$$i_{qs} = \frac{1}{L_m}\left[\lambda_{qr} - \omega_r T_r \lambda_{dr} + T_r p \lambda_{qr}\right] \qquad (5)$$

Using the above Eqns, the stator current is estimated as

$$\hat{i}_{ds} = \frac{1}{L_m}\left[\lambda_{dr} + \hat{\omega}_r T_r \lambda_{qr} + T_r p \lambda_{dr}\right]$$
$$\hat{i}_{qs} = \frac{1}{L_m}\left[\lambda_{qr} - \hat{\omega}_r T_r \lambda_{dr} + T_r p \lambda_{qr}\right] \qquad (6)$$

The difference in the stator current is obtained as

$$i_{ds} - \hat{i}_{ds} = \frac{T_r}{L_m}\lambda_{qr}\left[\omega_r - \hat{\omega}_r\right]$$
$$\hat{i}_{qs} - i_{qs} = \frac{T_r}{L_m}\lambda_{dr}\left[\omega_r - \hat{\omega}_r\right] \qquad (7)$$

Equation (7) may be rewritten as:

$$(i_{ds} - \hat{i}_{ds})\lambda_{qr} = \frac{T_r}{L_m}\lambda_{qr}^2\left[\omega_r - \hat{\omega}_r\right]$$
$$(\hat{i}_{qs} - i_{qs})\lambda_{dr} = \frac{T_r}{L_m}\lambda_{dr}^2\left[\omega_r - \hat{\omega}_r\right] \qquad (8)$$

Since the stator current error is represented as a function of estimated speed, an adaptive flux observer can be constructed from the machine model equation. The model outputs are the estimated values of the stator current vector $\hat{i}_S$ and the rotor flux linkage vector $\hat{\lambda}_r$.

From Eqn. (8),

$$(i_{ds} - \hat{i}_{ds})\lambda_{qr} + (\hat{i}_{qs} - i_{qs})\lambda_{dr} = \frac{T_r}{L_m}(\lambda_{qr}^2 + \lambda_{dr}^2)\left[\omega_r - \hat{\omega}_r\right] \qquad (9)$$

Hence, the error of the rotor speed is obtained as follows:

$$\omega_r - \hat{\omega}_r = [(i_{ds} - \hat{i}_{ds})\lambda_{qr} - (i_{qs} - \hat{i}_{qs})\lambda_{dr}]/K$$
$$\text{where} \quad K = \frac{T_r}{L_m}(\lambda_{qr}^2 + \lambda_{dr}^2) \qquad (10)$$

The right hand term seems as the term of speed calculation from adaptive observer, so the speed can be calculated from the following equation,

$$\hat{\omega}_r = \frac{1}{K}[(K_p(i_{ds} - \hat{i}_{ds})\lambda_{qr} - (i_{qs} - \hat{i}_{qs})\lambda_{dr}) + (K_I\int(i_{ds} - \hat{i}_{ds})\lambda_{qr} - (i_{qs} - \hat{i}_{qs})\lambda_{dr})dt] \qquad (11)$$

The speed estimation procedure represented by Eqns 5 to 11 is illustrated by the block diagram shown in Fig. 2.

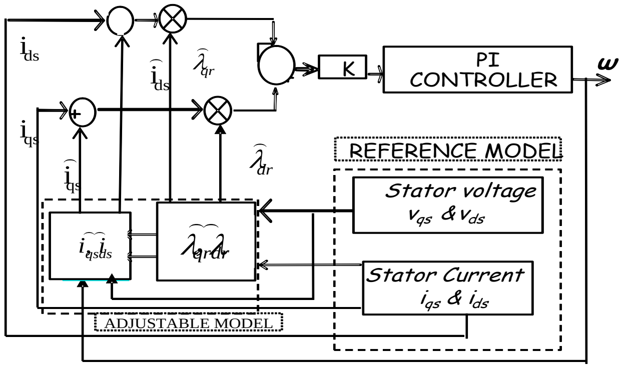

Fig. 2 Block Diagram for Speed Estimation Procedure

C. Cloud Computing Based PI Controller

Cloud computing is changing the whole manufacturing, lofty-concert subtracting and individual statistics allocation and organization. In cloud computing, computing power is abounding as a utility, comparable to electrical energy or irrigate. Overhaul supplier can centrally administer, preserve, and advance working out possessions, divesting the lumber on or after diminutive trade landlords or individuals who do not include the proficiency or funds to lever the speedy-varying subtracting transportation. By means of the cloud for elevated-recital computing can significantly diminish the entirety charge of tenure by eradicating the necessitate to preserve huge-balance equivalent machinery and their vigor-overriding rule and fresh structures. Starting a charge-efficacy perception, there are tradeoffs in requisites of reserve provisioning specified that a objective chore can be parallelized, a frequent holder for throughput-tilting calculation.

Fig 3 depicts the flowchart of proposed cloud computing algorithm. The baseline of the revise presumes that the whole occupation is executed on one a appliance consecutively on the fastest corporal knob. The greatest substantial lump can leave a work part each a subsequent. Since there are g self-regulating profession elements in the intact workload, the baseline pattern receives ga instants to terminate. This configuration munches through W × ga joules for carrying out the full workload, where W represents a corporeal node’s power. Thus, the EDP is EDPbase = (W × ga)(ga) = Wg2a2 [25].

An anticipation-based psychoanalysis is used to conclude a cloud model’s completing time and force expenditure. A novel allocation utility is worn to stand for the execution occasion of a practical appliance with more than one job element.

When sovereign models are supplementary from a consistent allocation, the outline's allotment purpose is liable to come near an ordinary allotment according to the central limit theorem.9, this theorem proves that when we add more autonomous modesl into the rundown, the précis's division will develop into extra approximating a standard supply. The mean and variance of the normal distribution representing the total execution time of a virtual machine responsible for m/p job units. First, we calculate the mean and variance for the original uniform distribution, U(a,(a + ((b – a)p)/n)):

$$mean = a + \frac{(b-a)p}{2n}$$

$$\mathrm{var}\,iance = \left(\frac{(b-a)p}{\sqrt{12n}}\right)^2$$

The innermost perimeter theorem depicts the rundown of m/p sovereign trials from this allocation will develop into a regular allotment with the subsequent mean and variance:

$$N\left(\frac{m}{p}\left(a + \frac{(b-a)p}{2n}\right) . \left(\sqrt{\frac{m}{p}} \times \frac{(b-a)p}{\sqrt{12n}}\right)^2\right) = N(\mu, \sigma^2)$$

For ease, μ and σ2 is used to signify the distribution's mean and variance. All in all, when using p effective machinery, apiece appliance's implementation time will follow the normal distribution, N(μ, σ2)[25].

IV. SIMULATION AND EXPERIMENTAL RESULTS

The proposed control system represented by Fig. 1 is designed and implemented for a simulation and experimental investigation.

Simulation is carried out using the general purpose simulation package Matlab/Simulink, while experimental study is implemented using a TMS320C31floating-point Digital Signal Processor (DSP) hosted on a personal computer. Simulation and experimental results are presented to show the effectiveness of the proposed drive system based cloud computing based controller instead of PI controller at different operating conditions.

For studying the performances of proposed system, a series of simulations and measurements have been carried out. In this respect, the dynamic response of the proposed speed estimation algorithm is studied under both step up and step down changes in the speed command as follow.

A. A-Speed step down change from (80 to 60 rad/sec.

To study the system response of the control system due to a step changes in the command of speed, the motor is subjected to step decrease in the speed command to evaluate its the performance.

At t=1.1 second the motor speed command is changed from 80 rad/sec to 60 rad/sec. Figure 4 shows the motor speed corresponding to this step down changes. It can be seen that the motor speed is decelerated smoothly to follow its reference value without over and under shoot and with nearly zero steady state error.

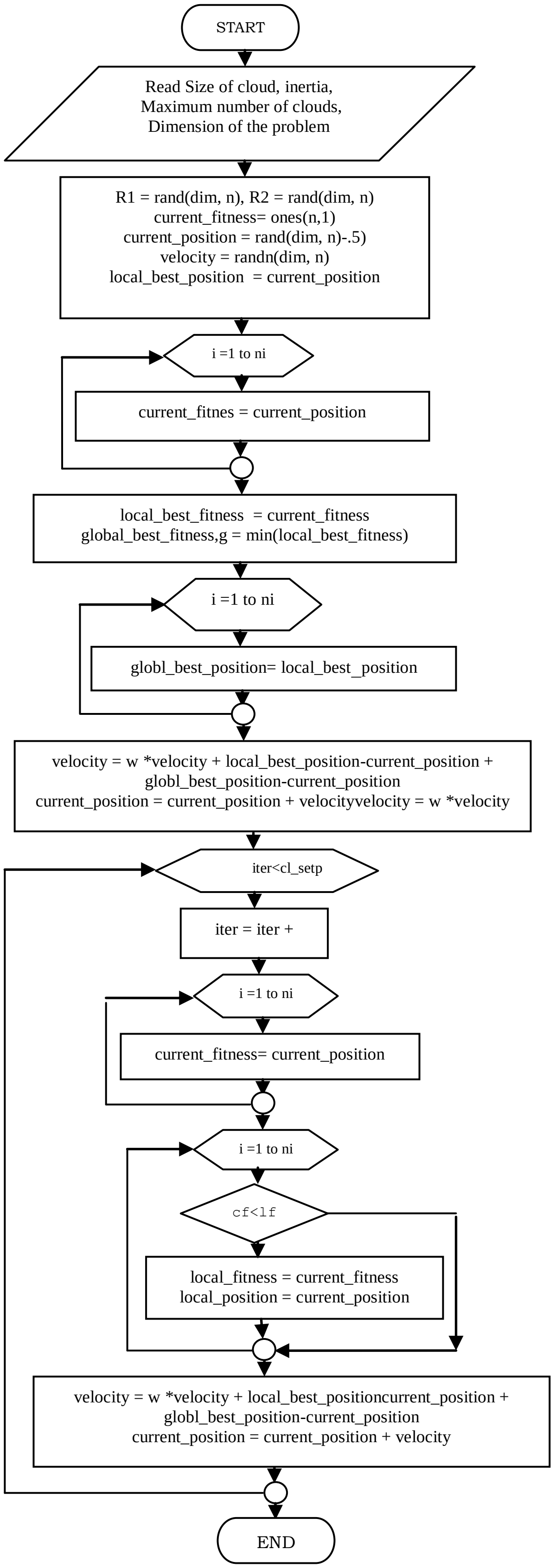

Fig. 3 Flowchart of proposed cloud computing algorithm

Figure 4.a shows the estimated speed signal and its corresponding signal obtained off line from simulation. Figure 4.b shows measured and estimated speed signals obtained in real time. These results show a good correlation between the estimated speed signal and its corresponding measured as well as simulated speed signals. Phase current correspondent to these step varying are depicted in Figs. 5, 6 in that order.

Figures 5a and 5b, symbolizes the phase current and its orientation domination, both from simulation and experimentally. There is a good association among all current signals, whereas figure 6a and 6b shows the three phase currents. These results make certain the efficacy of the projected controller and shows good actions of its self-motivated reaction.

B. B-Speed step up change from (40 to 60 rad/sec)

The second case of dynamic response is due to speed step up change. At t=1.1 second ,The motor is subjected to a command of speed up from 40 rad/sec to -60 rad/sec. Figure 7.a shows the estimated and simulated speed signals obtained off line for this condition. It can be seen that both speed signals have the same profile which are always almost correlated.

Figure 7.b shows the corresponding real time estimated and measured for this condition. Both signals show a good correlation during speed step up change. Phase current as well as its reference command corresponding to this case are shown respectively in Figs. 8, 9. Figure 10 shows that three phase motor currents and their changes during speed step up.

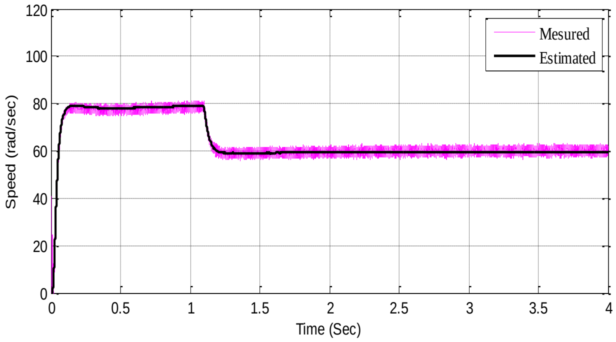

Fig 4.aEstimated and simulated motor speed signals obtained off line

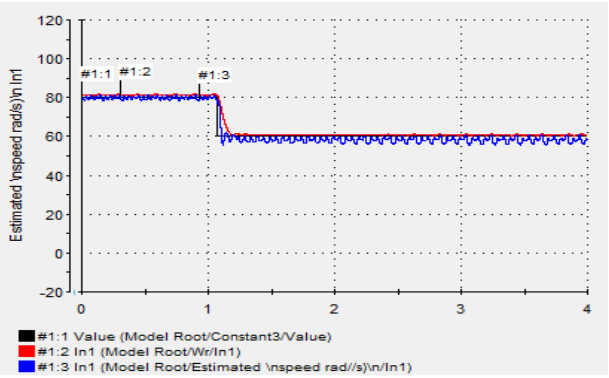

Fig 4.bEstimated and measured motor speed signals obtained in real time

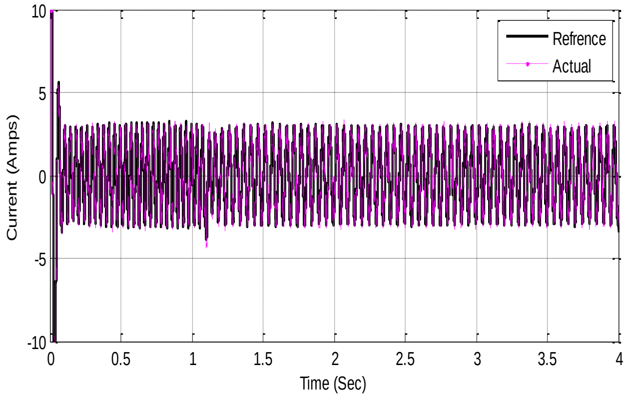

Fig. 5a (Simulation) Motor phase current and its reference command for step down of reference speed

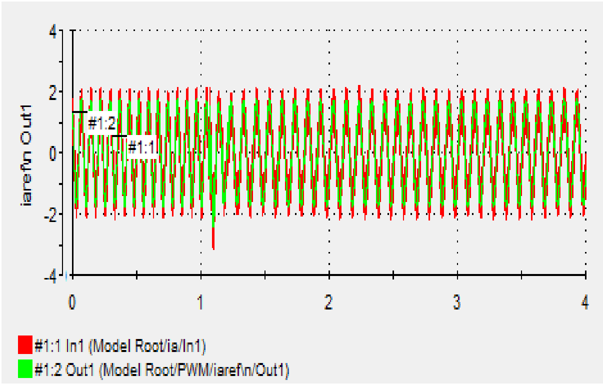

Fig. 6b (Experimental) Motor phase current and its reference command for step down of reference speed

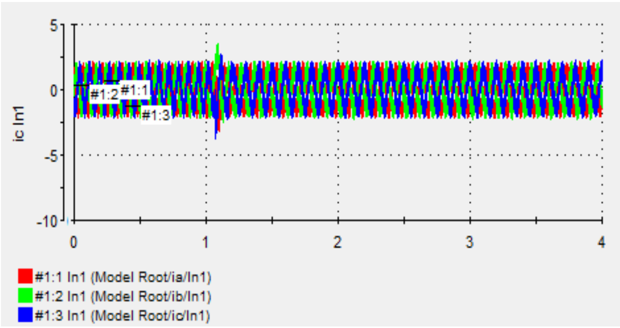

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Fig. 6.a (Experimental) Motor phase current and its reference command for step down of reference speed

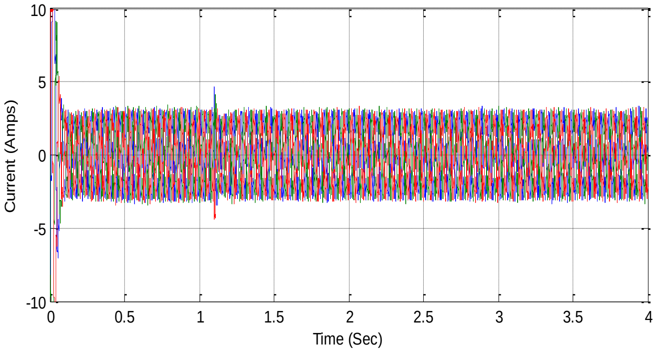

Fig. 6.b (Simulation) Motor three phase current for step down of reference speed

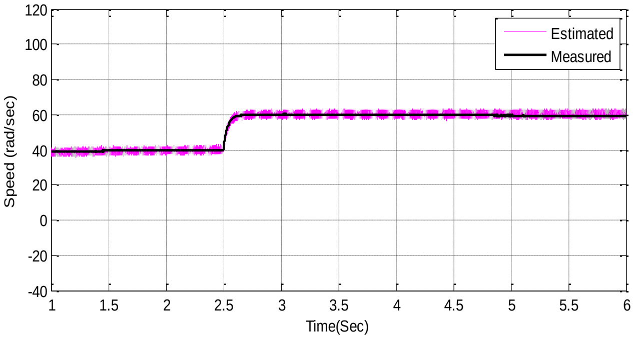

Fig 7.a Estimated and simulated motor speed signals obtained off line

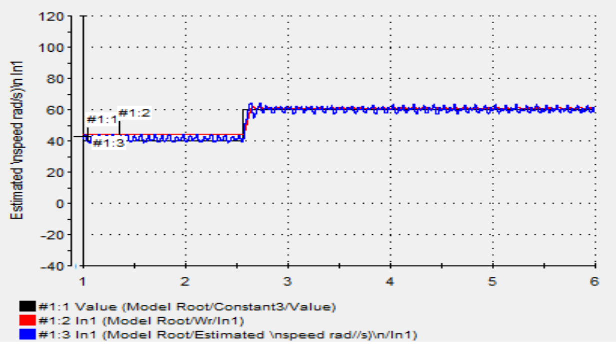

Fig 7.b Estimated and simulated motor speed signals obtained in real time

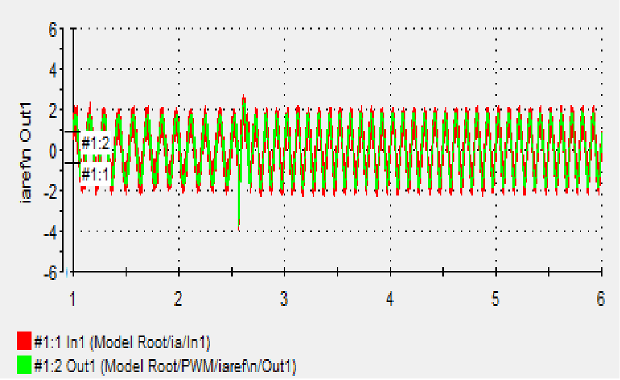

Fig 8.a (Experimental)Motor phase current and its reference command for step up of reference speed

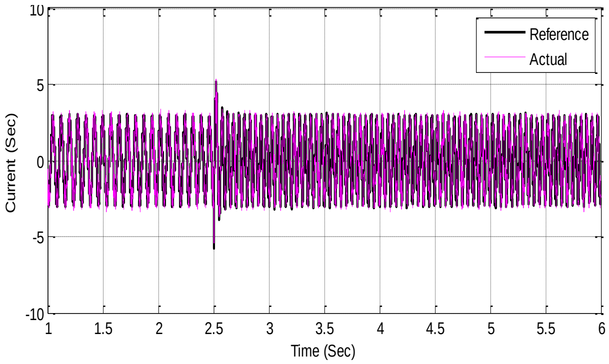

Fig. 8.b (Simulation) Motor phase current and its reference command for step up of reference speed

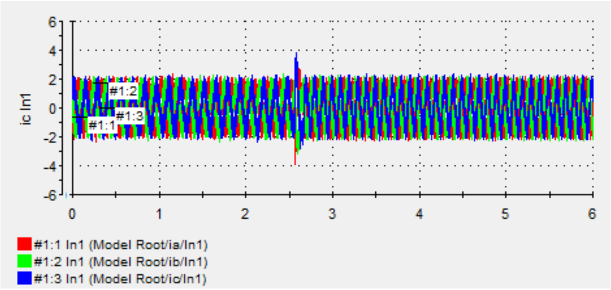

Fig. 9.a (Experimental) Motor three phase current step up of reference speed

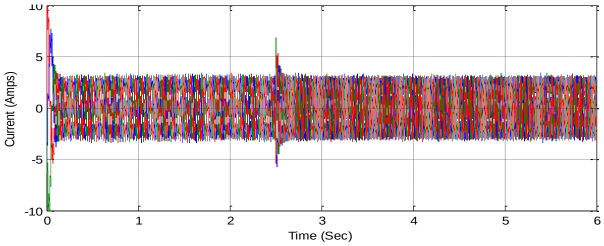

Fig. 9.b (Simulation) Motor three phase current for step up of reference speed

V. CONCLUSIONS

This paper presents the implementation of a speed sensorless induction motor drive system. PI Speed controller ofan indirect vector controlled induction motor drive system is based on cloud computing, whereas feedback speed signal is estimated using MRAS method. The drive system has been implemented based on MRAS speed estimation technique. The effectiveness of the proposed speed controller and speed estimation algorithm has been investigated under different operating conditions. A good correlation between simulated, estimated and measured speed signals has been obtained under different operating conditions. The results show the effectiveness and robustness of the proposed speed controller and speed estimation procedure.

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APPENDIX

A. Motor Data and Parameters:

A three-phase, 4-pole, 380V, 50 Hz induction motor of the following parameters:

$R_s = 7.4826\ \Omega$ $R'_r = 3.6840\ \Omega$

$L_s = 0.4335$ H $L'_r = 0.4335$ H

$L_m = 0.4114$ H $J = 0.0200\ \text{kg.m}^2$

B. List of Principle Symbols;

$$L_\sigma = L_s - \frac{L_m^2}{L_r},\quad T_r = \frac{L_r}{R_r},\quad k_1 = -\frac{R_s}{\sigma L_s} - \frac{L_m^2}{\sigma L_s L_r T_r} - \frac{1}{T_r}$$

$$k_2 = \frac{1}{\sigma L_s T_r},\quad k_3 = \frac{1}{\sigma L_s},\quad b_1 = \frac{1}{\sigma Ls},\quad \sigma = 1 - \frac{L_m^2}{L_s L_r}$$

V_{qse}, V_{dse}	qe-de –axis stator voltage
I_{qse} , I_{dse}	qe-de –axis stator current
λ_{qse} , λ_{dse}	qe-de –axis stator flux linkage
R_s , R_r	stator and rotor resistances
J, B	moment of inertia and viscous friction coefficients
L_s, L_r, L_m	stator, rotor and mutual inductances
T_e , T_L	electromagnetic and load torque

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