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# Simulation, Transient State Analysis for Speed Control of Induction Motor with Rotor Resistance Adaptation Based on Sensorless Field Oriented Method Using PID controller

Vivek Kushwaha, Anand Goswami, Dr. L. S. Titare,

*Electrical Engineering Dept.,*
*Jabalpur Engineering College, Jabalpur*

**Abstract – In this paper a simulation model for speed control of Induction Motor with rotor resistance adaptation based on Sensorless field oriented method using PID controller has been developed. A developed model is capable of speed control of motor without sensor. Obtained simulation results are comparable with the nature of high performance motor drive system. Results obtained using developed model with PID controller shows better precision and stability in speed and torque control of 3Φ induction motor. These results demonstrate a comparison between PI and PID based field oriented control.**

**Key Words:-** Induction Motor, Sensorless field oriented method, PID Controller, Rotor Resistance Adaptation

## I. INTRODUCTION

The field oriented control method is widely used for induction motor drives. In these applications, a rotational transducer such as a shaft encoder is used. However, a rotational transducer cannot be mounted in some cases, such as motor drives in a hostile environment, high-speed motor drives, etc. Several field-oriented induction motor drive methods without rotational transducers have been proposed. These methods have a disadvantage that the rotor resistance variation causes an estimation error of the motor speed. Therefore, simultaneous estimation of the motor speed and the rotor resistance is required.

This paper presents a method of identifying simultaneously the motor speed and the rotor resistance using the adaptive flux observer. Simulated results are analyzed using PI & PID controllers and study carried out for the transient stability analysis and for the speed control adaptation for the speed estimation. In this paper notching up period of induction motor has been reduced using Field Oriented Control sensorless based PID controller. Section II presents flux observer based field oriented induction motor drives. Section III presents, adaptive scheme for stator and rotor resistance identification. Section IV gives, the adaptive scheme for speed estimation. Section V presents, Results & Discussions and section VI describes conclusion.

## II. FLUX OBSERVER-BASED FIELD-ORIENTED INDUCTION MOTOR DRIVES

A. Description of Induction Motor

An induction motor can be described by the following state equations in the stationary reference frame:

$$\frac{d}{dt}\begin{bmatrix} \boldsymbol{i}_s \\ \phi_r \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix}\begin{bmatrix} \boldsymbol{i}_s \\ \phi_r \end{bmatrix} + \begin{bmatrix} \boldsymbol{B}_1 \\ 0 \end{bmatrix}\boldsymbol{v}_s$$

$$= \boldsymbol{Ax} + \boldsymbol{Bv}_s, \quad (1)$$

$$\boldsymbol{i}_s = \boldsymbol{Cx}, \quad (2)$$

Where,

$$\boldsymbol{i}_s = [i_{ds} \quad i_{qs}]^{\mathrm{T}}\text{: Stator current.}$$

$$\phi_r = [\phi_{dr} \quad \phi_{qr}]^{\mathrm{T}}\text{: Rotor flux.}$$

$$\boldsymbol{v}_s = [v_{ds} \quad v_{qs}]^{\mathrm{T}}\text{: Stator voltage.}$$

$$\boldsymbol{A}_{11} = -\{R_s/(\sigma L_s) + (1-\sigma)/(\sigma\tau_r)\}\boldsymbol{I} = a_{r11}\boldsymbol{I}.$$

$$\boldsymbol{A}_{12} = M/(\sigma L_s L_r)\{(1/\tau_r)\boldsymbol{I} - \omega_r \boldsymbol{J}\} = a_{r12}\boldsymbol{I} + a_{i12}\boldsymbol{J}.$$

$$\boldsymbol{A}_{21} = (M/\tau_r)\boldsymbol{I} = a_{r21}\boldsymbol{I}.$$

$$\boldsymbol{A}_{22} = -(1/\tau_r)\boldsymbol{I} + \omega_r\boldsymbol{J} = a_{r22}\boldsymbol{I} + a_{i22}\boldsymbol{J}.$$

$$\boldsymbol{B}_1 = 1/(\sigma L_s)\boldsymbol{I} = b_1\boldsymbol{I}.$$

$$\boldsymbol{C} = [\boldsymbol{I} \quad \boldsymbol{0}].$$

$$\boldsymbol{I} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}, \qquad \boldsymbol{J} = \begin{bmatrix} 0 & -1 \\ 1 & 0 \end{bmatrix}.$$

$R_s, R_r$: Stator and rotor resistance.
$L_s, L_r$: Stator and rotor self-inductance.
$M$: Mutual inductance.
$\sigma$: Leakage coefficient, $\sigma = 1 - M^2/(L_s L_r)$.
$\tau_r$: Rotor time constant, $\tau_r = L_r/R_r$.
$\omega_r$: Motor angular velocity.

B. Direct Field-Oriented Induction Motor Drive System

Fig. 1 shows a block diagram of a direct field-oriented induction motor drive system. The stator current command is calculated with rotor fluxes as follows:

$$i_{ds}^* = i_m^* \cos\hat{\theta} - i_t^* \sin\hat{\theta}, \qquad (3)$$

$$i_{qs}^* = i_m^* \sin\hat{\theta} + i_t^* \cos\hat{\theta}, \qquad (4)$$

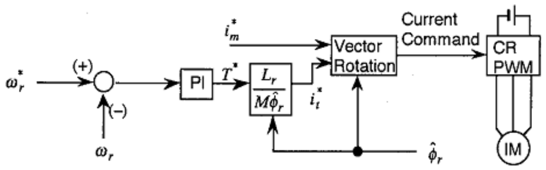


Fig. 1. Block diagram of direct field-oriented induction motor control system.

Where,

$\cos\hat{\theta} = \hat{\phi}_{dr} / \hat{\phi}_r$

$\sin\hat{\theta} = \hat{\phi}_{qr} / \hat{\phi}_r$

$\hat{\phi}_r = \sqrt{\hat{\phi}_{dr}^2 - \hat{\phi}_{qr}^2}$

$i_m^*$ = Field Current Command

$i_t^*$ = Torque Current Command

The rotor flux is estimated by a rotor flux observer in practice.

C. Rotor Flux Observer of Induction Motor

The full-order state observer which estimates the stator current and the rotor flux together is written by the following equation:

$$\frac{d}{dt}\hat{x} = \hat{A}\hat{x} + Bv_s + G(\hat{i}_s - i_s) \qquad .....(5)$$

$$G = \begin{bmatrix} g_1 & g_2 & \cdots\ g_3 & g_4 \\ \vdots & & \ddots & \vdots \\ -g_2 & g_1 & \cdots - g_4 & g_3 \end{bmatrix}^T \qquad .....(6)$$

$$g_1 = (k-1)(a_{r11} + a_{r22}) \qquad .....(7)$$

$$g_2 = (k-1)\, a_{i22} \qquad .....(8)$$

$$g_3 = (k^2-1)(ca_{r11} + a_{r21}) - c(k-1)(a_{r11} + a_{r22}) \qquad ....(9)$$

$$g_4 = -c(k-1)a_{i22} \qquad .....(10)$$

Where, $c = (\sigma L_s L_r) / M$

### III. Adapative Scheme For Stator And Rotor Resistance Identification

The stator resistance and rotor time constant, which vary with the motor temperature, are identified by the following adaptive schemes. See Fig. 2. These adaptive schemes were derived by using the Lyapunov's stability theorem.

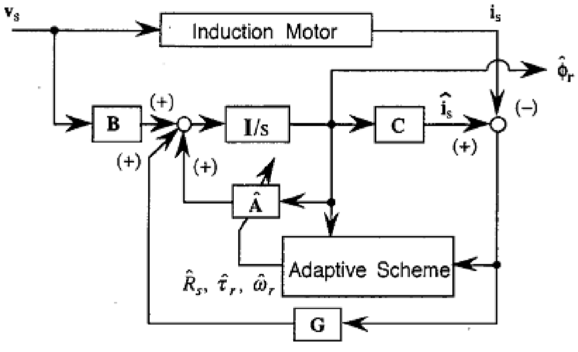


Fig. 2. Block diagram of adaptive flux observer.

$$\frac{d}{dt}\hat{R}_s = -\lambda_1(e_{i_{ds}}\hat{i}_{ds} + e_{i_{qs}}\hat{i}_{qs}) \qquad .....(11)$$

$$\frac{d}{dt}\left(1/\hat{\tau}_r\right) = {}^{\lambda_2}/_{L_r}\left\{e_{i_{ds}}(\hat{\phi}_{dr} - M\hat{i}_{ds}) + e_{i_{qs}}(\hat{\phi}_{qr} - M\hat{i}_{qs})\right\} \qquad .....(12)$$

$e_{i_{ds}} = i_{ds} - \hat{i}_{ds}$ , $e_{i_{qs}} = i_{qs} - \hat{i}_{qs}$ ,

$\lambda_1, \lambda_2$: arbitrary positive gain.

### IV. Adaptive Scheme For Speed Estimation

In order to eliminate rotational transducers, the motor speed is estimated by the following adaptive scheme.

$$\hat{\omega}_r = K_p\left(e_{i_{ds}}\hat{\phi}_{qr} - e_{i_{qs}}\hat{\phi}_{dr}\right) + K_I\int\left(e_{i_{ds}}\hat{\phi}_{qr} - e_{i_{qs}}\hat{\phi}_{dr}\right)dt \qquad .....(13)$$

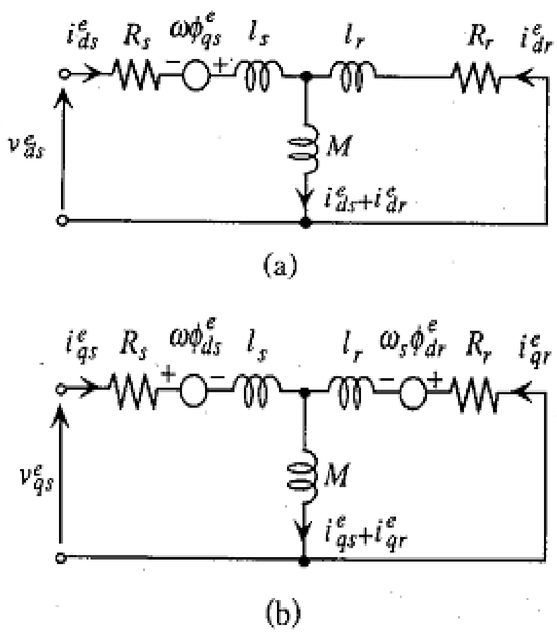


Fig. 3. Equivalent circuit of induction motor in synchronous reference frame. (a) d- axis (Rotor flu axis). (b) q- axis (torque axis).

## V. RESULTS AND DISCUSSION

The results validate the control structure proposed in this paper. This model uses a modified version of the sim power system library of the MATLAB. We have the results of simulation in the form of the waveforms for speed, torque and stator current, for PI and PID controllers.

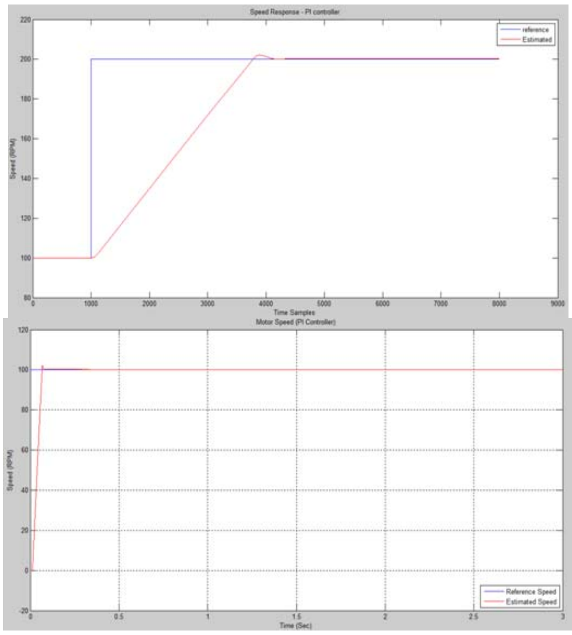

Fig. 4. Speed Time Characteristic of Induction Motor using PI Controller

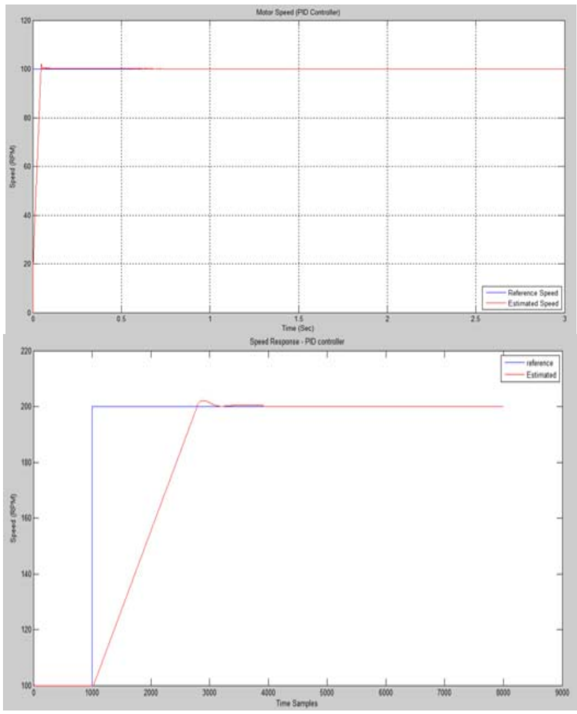

Fig.5. Speed Time Characteristic of Induction Motor using PID Controller

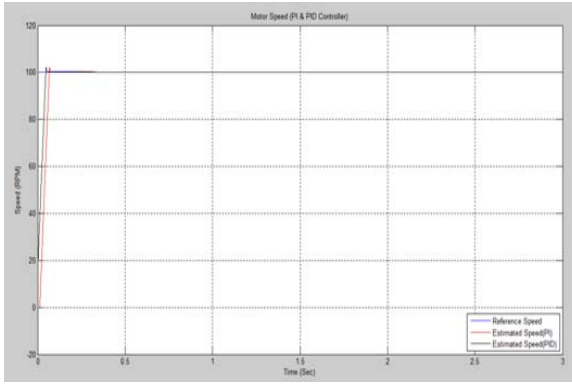

Fig. 6. Compared Characteristics of Speed Using PI & PID Controller

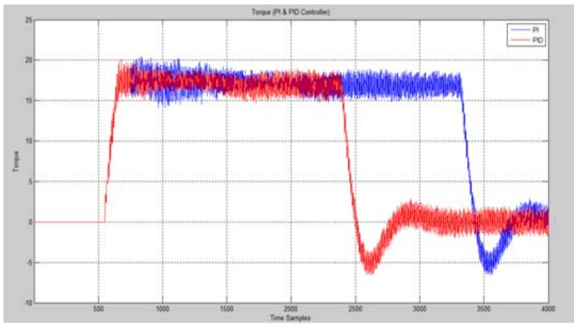

Fig. 7. Compared Characteristics of Torque Using PI & PID Controller

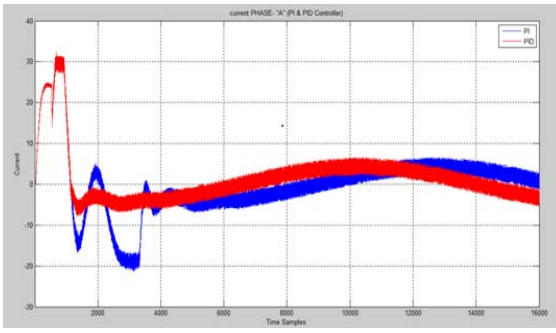

Fig. 8. Compared Characteristics of Current Using PI & PID Controller

The figure 6 shows, the speed – time characteristic of Induction Motor with Rotor Resistance Adaptation Based on Sensorless Field Oriented Method Using PI Controller is compared with PID Controller. It is observed from the results, that the transient settling time is found earlier in PID controller than the PI controller scheme. Observing the waveforms keenly, it is seen that the early response of the PID as compared to the PI for reaching required speed i.e. 100 rpm. That means the PID controller is superior than the PI controller. It is also seen that the waveform in case of PID is getting its maximum value approximately 20 ms prior to PI controller . There is 50 cycles in a second in AC, thus in 20 ms there is one cycle, this means that we get desirable speed of motor in case of PID one cycle ahead that of PI. The effect of PID controller in industries can be seen up to greater extent of control of induction drives .

The figure 7 shows the torque in the Induction Motor with Rotor Resistance Adaptation Based on Sensorless Field Oriented Method. The graph shown in the blue colour is motor torque when PI Controller is used. The graph in red colour is torque of motor when PID Controller is used. It is observed from the graphs in the transient condition, the steady state torque reached in higher time in case of PI controller scheme. In PID controller, scheme the transient torque appears for less time rather than PI controller. This significance induction motor reach earlier in its steady state condition in proposed PID controller scheme.

The figure 8 shows the current in the Induction Motor with Rotor Resistance Adaptation Based on Sensorless Field Oriented Method. The graph shown in the blue colour is current when PI Controller is used. The graph in red colour is current when PID Controller is used. Per phase stator transient current response to get reference speed is for minimum time in case of PID controller & much more in case of PI controller scheme.

## VI. CONCLUSION

In this paper, the simulation model of speed Sensorless Field Oriented control of Induction motor using PID controller has been developed. Various essential aspects of an Induction motor and Field Oriented control were explored such as principles of its operation, the electrical properties and the torque/speed relationships. The motor speed and the rotor resistance have been simultaneously estimating using developed model of an induction motor has been proposed. In addition, a new rotor resistance adaptive scheme has been proposed in order to decouple the rotor resistance adaption with the motor speed variation. The validity of the proposed method has been verified by the simulation in MATLAB. Obtained results using developed simulation model are presented in the form of the waveforms for speed, torque and stator current, using PI and PID Controllers.

The motor speed is estimated from terminal voltages and currents based on the MRAS (Model Referencing Adaptive System) technique. Consequently, the speed sensor is no more required. The induction motor is fed by a PWM voltage source inverter, which is built using a Universal Bridge Block. The speed control loop uses a PI controller to produce the flux and torque references for the Field Oriented Control (FOC). The FOC computes the three reference motor line currents corresponding to the flux and torque references and then feeds the motor with these currents using a three-phase current regulator.

In the case when PID controller is used, the desired level of speed is acheived prior to that acheived in case of PI controller. Time difference between these two are approximately 20ms which affects control system of industry or plant.

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