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Improvement of Fast Initial Speed Estimation Using Fuzzy Logic Control Technique for Induction Motors in the Low Speed Range

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Abstract: The paper presents a fast initial speed estimation method resolved by using a Fuzzy logic controller. This is applied for sensorless induction motor drives under low speed operation based on the second order differential of the secondary flux. At restarting time of an induction motor, it produces unwanted disturbance torque. This disturbance can be reduced by fast estimation based on FLC. The performance of proposed method is tested by using MATLAB/Simulink and estimation time has been compared with conventional controller like PI. Simulation results shows that FLC is more efficient than PI control.

Keywords: Adaptive Flux Observer (AFO), Direct Current Injection (DCI), Fuzzy Logic Controller (FLC), Second Order Differential of the Secondary Flux (SOD-SF), Sensorless induction motors, Speed Estimator (SE).

I. INTRODUCTION

Induction machine drives without speed sensors have been embraced in industry applications inferable from their favorable circumstances. For example, simple preservation, high dependability, minimal effort and reduced size. By use of high frequency signal injected method and adaptive estimation technique, the performance and robustness are improved. Some of the applications are conveying devices, production devices and traction system. The induction motor with high inertia load rotates long time, when inverter is in off state. Due to inertia, the rotor run continuously then inverter should be restart, is common in certain application of traction system. Under restart method the interruption of power supply occurs due to insufficient power source. As to overcome this problem in restart operation the secondary flux be estimated with Voltage Controlled Current Regulated PWM (VCCR-PWM) inverter, was developed an option by Rowan and Kerkman to useful inverters, during conditions of ordinary working and over-burden. VCCR-PWM inverter is related to recurrence controller be solution for misstep activity on present and later of over-burden condition and on reconnection to a turning

engine under burden with interruption of power [3], proposes an estimation technique for rotational bearing and speed as per the normal for the air conditioner machine. This strategy [4] is conceivable to assume responsibility for the perfect machine by an inverter with an info and yield linearization technique is proposes to connect for restarting methods [5]. In it, the rotor with transition conditions of voltage are linearized with inverter recurrence info and the stator actuated voltage by rotor motion, with the stator flow supposition is consistent. Because of linear method, a straight forward d-pivot rotor motion actuated condition of voltage is acquired and remunerated with compensator correspondingly. In these techniques, the essential recurrence be controlled with the point as d-pivot instigated potential be zero. There is a base speed restriction nearly 175 rpm to the restarting activity [6], in fact that the speed estimator dependent on back emf weakens at low speed. The technique [7], difference between rotor frequency and evaluated frequency happens estimation of unsettling influence torque be not same as its real worth. This error makes the slip recurrence increment, which diminishes torque of engine and motion of rotor. To adapt to the issue, current error of torque is remunerated with controller of PI, repays an unsettling influence torque in motor test system. Likewise, considering the impact brought about inverter with PWM and an improved starting speed estimator was proposed to take out small oscillations. In this paper ripple free, speed stability and unwanted disturbance torque of drive results in simulation waveforms with AFO and SOD-SF.

II. SPEED ESTIMATION PRINCIPLE DURING DCI (DIRECT CURRENT INJECTION)

In it, the guideline of present estimation of speed technique with the SOD-SF be displayed. Firstly, the period of time to the Secondary Flux (SF) is determined as direct current flows in forced to acceptance motor. Later, issues of unwanted disturbance torque and estimation of basic speed in low range are determined.

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A. SECONDARY FLUX (SF) EQUATION

Firstly, with restart process by use of DCI is clarified. The reference voltages are obtained by current controller. In the estimation of basic speed, the necessary frequency ω_1 be zero and current reference of d axis i_d^* be steady value and current reference of q axis i_q^* be zero. Later, fulfillment with estimation of basic speed, an ordinary speed estimation allows to start. The estimation of proposed method takes DCI to inverter at initial step of restart operation. The SF obtained with relation of time. Let SF vector $\emptyset_{dqr} = [\emptyset_{dr}\ \ \emptyset_{qr}]^T$, the stator current vector $i_{dqs} = [i_d i_q]^T$, mutual inductance M, resistance of secondary R_r, inductance of secondary L_r, speed of rotor in electrically ω_{re}, and identity matrix I. The state condition of the SF is mentioned is,

$$\frac{d}{dt}\emptyset_{dqr} = A\emptyset_{dqr} + M\frac{R_r}{L_r}i_{dqs} \quad (1)$$

where, $A = -\frac{R_r}{L_r}I - (\omega_1 - \omega_{re})J$, $J = \begin{bmatrix} 0 & -1 \\ 1 & 0 \end{bmatrix}$.

assume $\emptyset_{dqr0}$ as $\emptyset_{dqr}$ at t = 0, calculation of (1) is,

$$\emptyset_{dqr} = e^{At}\emptyset_{dqr0} + \int_0^t e^{At} M \frac{R_r}{L_r} i_d dt$$
$$= e^{At}\emptyset_{dqr0} + A^{-1}(e^{At} - I)M\frac{R_r}{L_r}i_d \quad (2)$$

The flux with residual $\emptyset_{dqr0}$ be very low value, computation the product of matrix in second term of (2) and $\emptyset_{dqr}$ in obtained matrix format is,

$$\begin{bmatrix} \emptyset_{dr} \\ \emptyset_{qr} \end{bmatrix} = \frac{1}{\left(\frac{R_r}{L_r}\right)^2 + \omega_{re}^2} \times$$
$$\begin{bmatrix} e^{-\left(\frac{R_r}{L_r}\right)t}\left[\frac{R_r}{L_r}\cos(\omega_{re}t) + \omega_{re}\sin(\omega_{re}t)\right] + \frac{R_r}{L_r} \\ e^{-\left(\frac{R_r}{L_r}\right)t}\left[-\omega_{re}\cos(\omega_{re}t) - \frac{R_r}{L_r}\sin(\omega_{re}t)\right] + \omega_{re} \end{bmatrix} M\frac{R_r}{L_r}i_d \quad (3)$$

In the method of conventional, includes [3] SF with ripple frequency period. In any case SF is obtained indirectly. The currents of motor or reference voltages are detected instead of SF The high ripple period of low speed rotor is observed with non positive torque at restart operation. The SF are denoted as $\emptyset_{dr,}\ \emptyset_{qr}$.The non positive torque is obtain with multiplication of flux of q axis $\emptyset_{qr}$ and current of d axis. At some point speed of rotor in electrically ω_{re} is sufficiently large at $\frac{R_r}{L_r}$, from (3) flux of q axis $\emptyset_{qr}$ reduces as speed of rotor raises. Thus, method of conventional in low speed observes the ripple duration with an unwanted disturbance torque.

B. PROPOSED METHOD

If the method of conventional is completed in low duration, then unwanted disturbance torque is stifled. As to decrease the time of estimation, SOD-SF is shown in this paper. Calculated SOD-SF from (3) is,

$$\frac{d^2}{dt^2}\begin{bmatrix} \emptyset_{dr} \\ \emptyset_{qr} \end{bmatrix} =$$
$$e^{-\left(\frac{R_r}{L_r}\right)t}\begin{bmatrix} -\frac{R_r}{L_r}\cos(\omega_{re}t) - \omega_{re}\sin(\omega_{re}t) \\ \omega_{re}\cos(\omega_{re}t) - \frac{R_r}{L_r}\sin(\omega_{re}t) \end{bmatrix} M\frac{R_r}{L_r}$$

(4)

Let at t = 0, $\emptyset_{qr0}$ as $\emptyset_{qr}$ and $\frac{d^2}{dt^2}\emptyset_{qr0}$ are assumed to the second row of (4) is,

$$\frac{d^2}{dt^2}\emptyset_{qr0} = M\frac{R_r}{L_r}\omega_{re}i_d\ . \quad (5)$$

speed of rotor at starting solved as,

$$\omega_{re} = \frac{L_r}{MR_r i_d}\frac{d^2}{dt^2}\emptyset_{qr0} \quad (6)$$

This shows the differentiation of second order $\emptyset_{qr}$ at t=0 gives rotor speed initially ω_{re}. The estimation resulted in small time period. Hence, an unwanted torque be decreased at estimation of speed initially. In other case, the value of R_r is to be needed in present method. The speed of estimation controls the value of R_r in (6). Therefore, R_r measurable in motor by use of thermometer or estimators of resistance.

III. SYSTEM DESIGN

In this part the fundamental design of controller having speed without sensor is reported firstly. Later, the layout as inverter controller with PWM technique shown in proposed method of estimating speed. At last, simulation results be exhibited for suggested method.

A. FUNDAMENTAL SYSTEM DESIGN

The Fig.1 demonstrates speed sensor-less drive framework of paper. Estimated reference voltages v_d^* and v_q^* are determined with compensation of decoupling and controller of PI. References of current are allocated as per the referenced torque and operation mode.

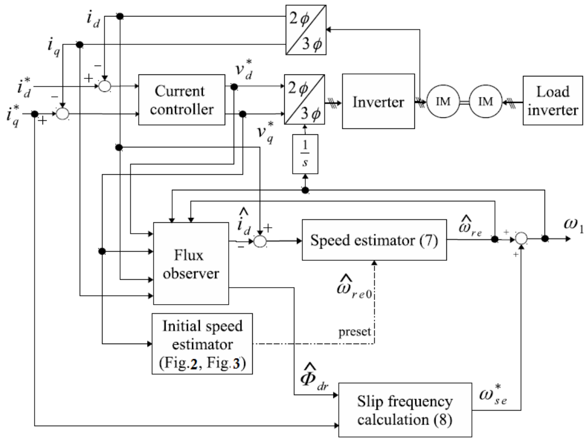


Fig.1. Fundamental system design diagram

Currents of phase are identified with sensors of current and changes as 3∅ to 2∅ with balanced terms. The usual speed of rotation is approximated with AFO, to obtain superior characteristics in the range of low speed. The SF is fixed, estimator of speed uses to estimate the current of d axis. The terms define as gain of proportional $K_{\omega P}$, gain of integral $K_{\omega I}$ and evaluated current of d axis $\hat{\imath}_d$. The condition of speed estimation is,

$$\widehat{\omega}_{re} = \int K_{\omega I}\,(i_d - \hat{\imath}_d)dt + K_{\omega P}(i_d - \hat{\imath}_d) \qquad (7)$$

The main frequency ω_1 is total of angular slip frequency referred as ω_{se}^* and the evaluated speed rotation as $\widehat{\omega}_{re}$. During steady operation condition, the angular slip frequency is taken from reference of current i_q^* and evaluated flux of d axis $\hat{\phi}_{dr}$ is appeared in (8).

$$\omega_{se}^* = \frac{MR_r i_q^*}{L_r \hat{\Phi}_{dr}} \qquad (8)$$

In further case, angular slip frequency and reference current of q axis are places with zero value.

B. ESTIMATOR OF IDEAL INITIAL SPEED

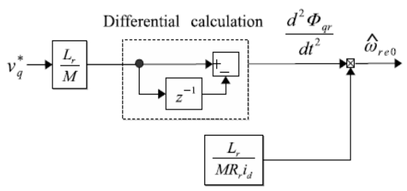


Fig.2. Estimator of ideal initial speed

This discuss about to acquire the axis of q with SOD-SF as reference voltage v_q^*. The primary frequency ω_1 be zero in estimation of speed at initially. The terms define as resistance of primary R_s, inductance of primary $L_s$and coefficient of leakage σ, respectively, then voltage of q axis derived as,

$$v_q = R_s i_q + \frac{d}{dt}\sigma L_s i_q + \frac{d}{dt}\frac{M}{L_r}\emptyset_{qr} \qquad (9)$$

Consider i_q^*= 0 (reference of q axis) in estimation mode of speed at initially. So after substituting i_q = 0 in (9), after differentiating (9). Thus, SOD with the flux of q axis is,

$$\frac{d^2}{dt^2}\emptyset_{qr} = \frac{L_r}{M}\frac{d}{dt}v_q$$

(10)

SOD-SF is shown in (10) with the differential computation of v_q. By substituting (10) in (6) to get rotor speed at initially. The Fig.2. is formed with (6), which shows the estimator of ideal initial speed. In Fig.2, voltage of q axis v_q is restored by reference voltage as v_q^*. The inverter with reference voltages v_d^* and v_q^*, currents of motor i_d and i_q, and calculated speed ω_{re0}^* in the estimation of speed at initial operation. The reference current of d axis i_d^* is consider at zero time of step function . At the same time, the d-axis voltage v_d^* quickly varies and i_d combines to i_d^* and reference voltage of q axis v_q^* be low value. By the (5) SOD-SF related linearly with current of d axis i_d. As to acquire the v_q^* value in the computation of speed, reference current of d axis i_d^* value is fixed. In the simulation, estimation of speed at initially ω_{re0}^* be zero. The estimation of speed at initial mode have some disturbance with the differentiation condition affected by voltage of inverter with PWM. Thus, the harmonics are eliminated nearly in 10 milli sec period. The estimation of speed in (6) at t = 0, otherwise the calculated speed diminishes 20 milli sec later.

C. ESTIMATOR OF IMPROVED INITIAL SPEED TO INVERTERS WITH PWM

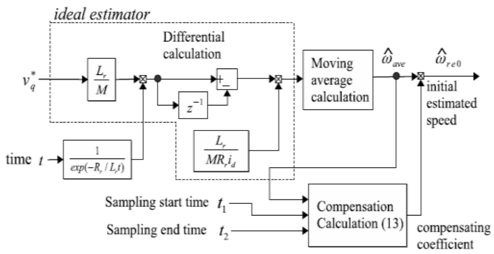


Fig.3. Estimator of improved initial speed

The Fig.3 demonstrates the estimator of improved initial speed. The estimator of ideal speed is in Fig.2. assumed value be neglected at t = 0. At (3) the term of exponential exp[-($\frac{R_r}{L_r}$)t] involved in flux of q axis, magnitude in SF diminishes with constant time of secondary. In this manner, flux of SOD diminishes likewise. As to neglect the term of exponential, the inverse of this exp[-($\frac{R_r}{L_r}$)t] as appeared in Fig.3. The voltage with PWM and average of moving are added to reduces component of larger frequency. The speed of average $\widehat{\omega}_{ave}$ is the average of moving.

The reference voltage v_q^* resulted in estimation of speed with particular time period, test begin with t_1 and end with t_2. The high value of t_2 takes place when the frequency of PWM be small. At t = 0, rotor initial speed calculation is complicated. Constant time t_2 - t_1 is mandatory in estimation of speed. Differentiation output with waveform of sine having ripple terms are given to the average of moving. The time period T_s be constantly used in calculation of differentiation with t_1 and t_2, an average of moving is,

$$\widehat{\omega}_{ave} = \frac{T_s}{t_2 - t_1} \times \sum_{k=0}^{(t_2-t_1)/T_s} \frac{\sin(\omega_{re}(k+1)T_s+t_1)-\sin(\omega_{re}(kT_s+t_1))}{T_s} \quad (11)$$

Assumed settling point of rotor at $\theta_1 = \omega_{re}\, t_1$ and $\theta_2 = \omega_{re}\, t_2$ in t = t_1 and t = t_2. When sampled period T_s is small, then (11) changes in integration form is,

$$\widehat{\omega}_{ave} = \frac{1}{\theta_2-\theta_1}\int_{\theta_1}^{\theta_2} \omega_{re} \cos\theta d\theta = \frac{\sin\theta_2-\sin\theta_1}{\theta_2-\theta_1}\omega_{re} \quad (12)$$

Where $\theta_1 = \widehat{\omega}_{ave} t_1$ and $\theta_2 = \widehat{\omega}_{ave} t_2$ are substituted in (12) .

$$\widehat{\omega}_{re0} = \frac{\sin\widehat{\omega}_{ave}t_2-\sin\widehat{\omega}_{ave}t_1}{\widehat{\omega}_{ave}t_2-\widehat{\omega}_{ave}t_1}\widehat{\omega}_{ave} \quad (13)$$

Speed of estimation at initially $\widehat{\omega}_{re0}$ is unintended speed for the estimator of speed with AFO showed in Fig.1.

D. ESTIMATION OF SPEED WITH AFO

The speed of rotor, estimated by use of AFO is obtained later an initial speed of rotor is observed. The suggested method in estimation of speed decreases unwanted large frequency with calculation of differentiation. The estimated initial speed included an error which is common to obtain the stability with AFO. In this part, about constant error of speed estimation and stable condition be discussed. Initially, induction motor (IM) state conditions are shown. State variable vector $\boldsymbol{x}_{dq} = [i_{dqs}\phi_{dqr}]^T$, input matrix B = $\left[\frac{1}{\sigma L_s}\frac{1}{\sigma L_s}\ 0\ 0\right]^T$,vector voltage $v_{dqs} = [i_{dqs}\phi_{dqr}]^T$,gain matrix of feedback G, output matrix C and resistance $R_n = R_s + \frac{M^2}{{L_r}^2 R_r}$, the state condition of IM is (14) and observer flux is (15).

$$\frac{d}{dt}\boldsymbol{x}_{dq} = A\boldsymbol{x}_{dq} + Bv_s \quad (14)$$

$$\frac{d}{dt} = \hat{A}\widehat{\boldsymbol{x}}_{dq} + GC(\boldsymbol{x}_{dq} - \widehat{\boldsymbol{x}}_{dq}) + Bv_s \quad (15)$$

where, A= $\begin{bmatrix}\boldsymbol{A}_{11} & \boldsymbol{A}_{21}\\ \boldsymbol{A}_{12} & \boldsymbol{A}_{22}\end{bmatrix}$

$$\boldsymbol{A}_{11} = R_n/(\sigma L_s)\boldsymbol{I} - \omega_1 J$$
$$\boldsymbol{A}_{21} = \frac{M}{\sigma L_s L_r}\{\frac{R_r}{L_r}\boldsymbol{I} - \omega_{re}J\}$$
$$\boldsymbol{A}_{12} = M\frac{R_r}{L_r}\boldsymbol{I}$$
$$\boldsymbol{A}_{22} = -\frac{R_r}{L_r}\boldsymbol{I} - \omega_{se}J$$
$$C = \begin{bmatrix}1 & 0 & 0 & 0\\ 0 & 1 & 0 & 0\end{bmatrix} \quad (16)$$

Parameter matrix of motor $\hat{A}$ is identical as A, excluding frequency of slip and speed rotation are stated to $\hat{A}$ with estimated values. The Laplace term 's' used to estimate angular slip frequency $\widehat{\omega}_{se}$, angular halt frequency from estimation of current observer ω_c and changeable term q . Gain matrix of feedback observer G is (15) is

$$G = \begin{bmatrix}g_{11} & g_{21} & MR_r/L_r & 0\\ \omega_1 & g_{22} & 0 & MR_r/L_r\end{bmatrix}^T$$

where, $g_{11} = g_{22} = \omega_c$,

$$g_{21} = -\omega_1 - \begin{bmatrix}\frac{\{s+\frac{R_s}{\sigma L_r}+\frac{M^2 R_r}{\sigma L_s {L_r}^2}+g_{11}\}}{s+\frac{\hat{R}_r}{L_r}} \times \\ \{\widehat{\omega}_{se} - q\,sgn(\omega_1)|\widehat{\omega}_{se}+1|\}\end{bmatrix} \quad (17)$$

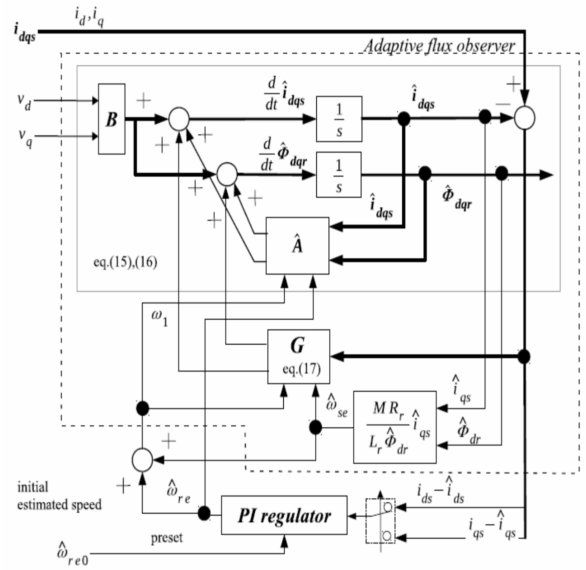


Fig.4. AFO Design Diagram

AFO consider by (15) and (17) are shown in Fig.5. The (15) and (17) are in Fig.5. shown by a line. AFO bounded by a dotted line. The error of consider input currents either $i_{qs} - \hat{\imath}_{qs}$ or $i_{ds} - \hat{\imath}_{ds}$ of estimation speed with controller of PI.

The state condition of error with dissimilarity of (14) and (15). Vector of state error $e_{dq} = [x_{dq} - \hat{x}_{dq}]$. The condition of state error is,

$$\frac{d}{dt}e_{dq} = (A - GC)e_{dq} + (A - \hat{A})\hat{x}_{dq} \qquad (18)$$

The estimation of speed error as $\Delta\omega_{re} = \omega_{re} - \widehat{\omega}_{re}$. Hence, result of (18) is,

$$e_{dq} = (sI - A + GC)^{-1} \times \left[-\frac{M}{\sigma L_s L_r}\hat{\phi}_{dr0}\hat{\phi}_{dr}\right]^T \Delta\omega_{re} \qquad (19)$$

The cofactors are $C_{21}, C_{22}, C_{41}, C_{42}$ for $[sI - A + GC]$ and an error with frequency of slip $\Delta\omega_{se} = \omega_{se} - \widehat{\omega}_{se}$.This paper involves, an error with frequency of slip $\Delta\omega_{se}$ and stable AFO are presented shown in Fig.1, with an approximated speed, currents and reference voltages are taken to AFO in the closed loop structure. The constant error used to make the system stable. Hence, suggested method takes an error for an estimation of d axis current till coincides with estimate speed. The current errors of d axis and q axis are in transfer function from estimation speed error are in (20) and (21) as,

$$i_d - \hat{\imath}_d = \frac{-\frac{M}{\sigma L_s L_r}C_{21} + C_{41}}{(s + \frac{R_n}{\sigma L_s} + g_{22})C_{22}}\hat{\phi}_{dr}\Delta\omega_{re}$$

$$= \frac{\frac{M}{\sigma L_s L_r}(\omega_{re}s + \frac{R_r}{L_r\omega_1})\widehat{\phi}_{dr}}{\left(s + \frac{R_r}{\sigma L_s} + g_{22}\right)(s^2 + 2\frac{R_r}{L_r}s + \left(\frac{R_r}{L_r}\right)^2 + \widehat{\omega}_{se}{}^2)}\Delta\omega_{re} \qquad (20)$$

$$i_q - \hat{\imath}_q = \frac{-\frac{M}{\sigma L_s L_r}C_{22} + C_{42}}{(s + \frac{R_n}{\sigma L_s} + g_{22})C_{22}}\hat{\phi}_{dr}\Delta\omega_{re}$$

$$= \frac{\frac{M}{\sigma L_s L_r}\widehat{\phi}_{dr}}{\left(s + \frac{R_r}{L_r}\right)\left(s + \frac{R_r}{\sigma L_s} + g_{22}\right)(s^2 + 2\frac{R_r}{L_r}s + \left(\frac{R_r}{L_r}\right)^2 + \widehat{\omega}_{se}{}^2)} \times$$

$$\left[s^3 + 2\frac{R_r}{L_r}s^2 + \left\{\left(\frac{R_r}{L_r}\right)^2 + \widehat{\omega}_{se}{}^2 + \omega_{re}\left(\omega_{se} + qsgn(\omega_1)\right)\right\}s + \frac{R_r}{L_r}(\omega_1\Delta\omega_{se} + q|\omega_1|)\right]\Delta\omega_{re} \qquad (21)$$

IV. ESTIMATOR OF IMPROVED INITIAL SPEED WITH FLC

In improved method, controller of current used in fundamental system design diagram of Fig.1. The controller of current is replaced with FLC to obtain better performance. The fundamental system design diagram replaces with FLC in Fig.5.

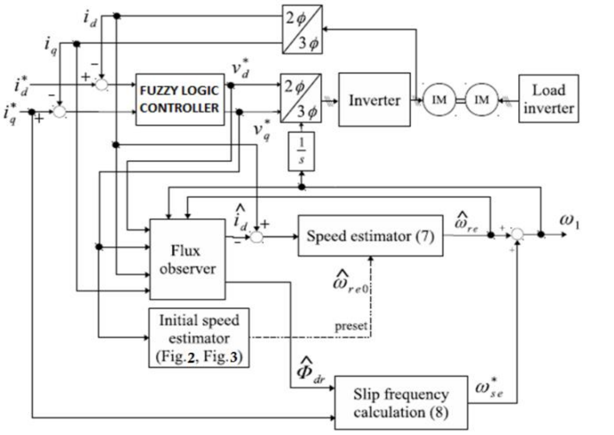


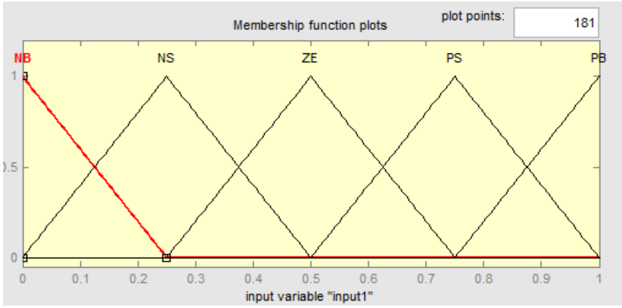
Fig.5. Estimator of improved initial speed with FLC

A. *Fuzzy control system*

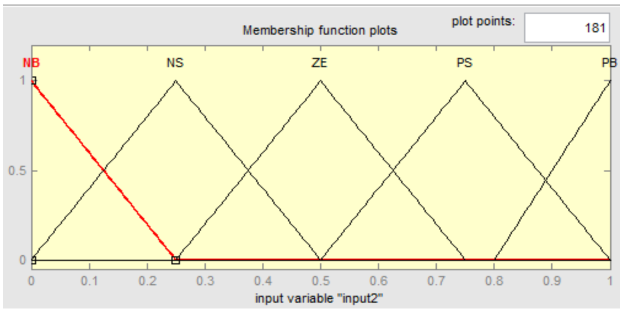
The control work is depends on logic of fuzzy is broadly utilized in machine control. It shows an uncomplicated term with constant attributes between 0 and 1. The enhanced logic works on discrete estimation of 0 or 1. The subject suggest the logic of fuzzy as false or true. For an instance, in logic of fuzzy with neural interface system and genetic algorithm are commonly used. Thus, it is easier with an effective performance.

B. *Fuzzy sets*

The representation of fuzzy control are to be mapped each other in all sets is called as fuzzy sets. The process of changing real scalar value into fuzzy value is known as fuzzification. The membership functions of inputs and outputs be as follows,



Input 1 Membership Function



Input 2 Membership Function

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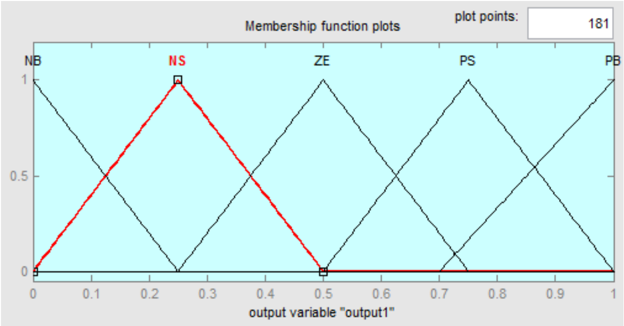

Output Membership Function

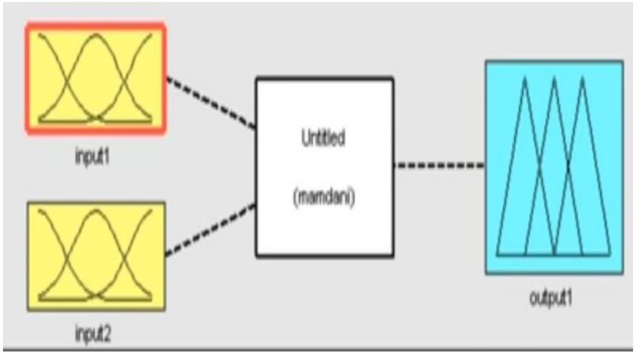

Fig.6. Input and output membership functions of FLC

TABLE - 1: FLC rule base for speed

E / ΔE	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NM	NM	NS	ZE	PS
NS	NB	NM	NS	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PS	PM	PB
PM	NS	ZE	PS	PM	PM	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

V. SIMULATION RESULTS

A. Simulation results of conventional control method at restart operation of 90 r.p.m (18.85 rad/sec).

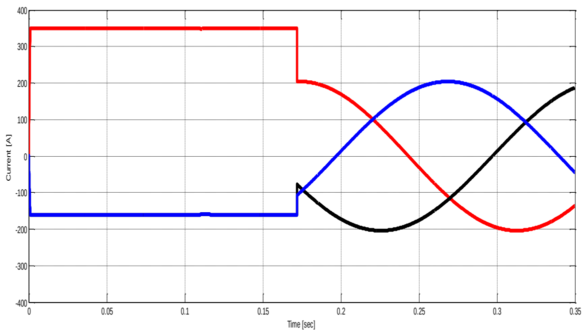

Fig.7. Stator currents of conventional method

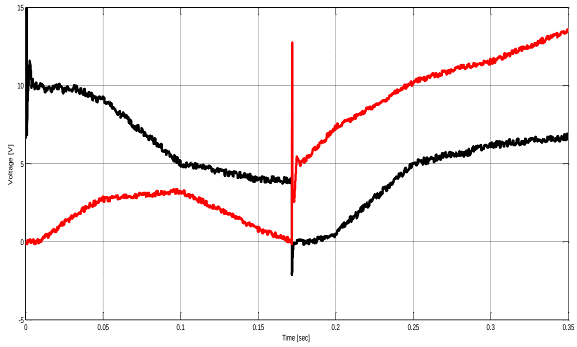

Fig.8. Voltages v_d^* and v_q^* of conventional method

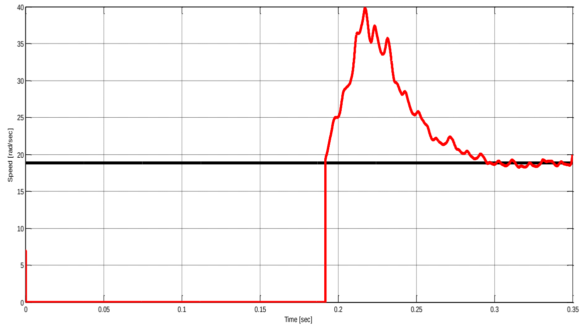

Fig.9. Speed (rad/sec) of conventional method

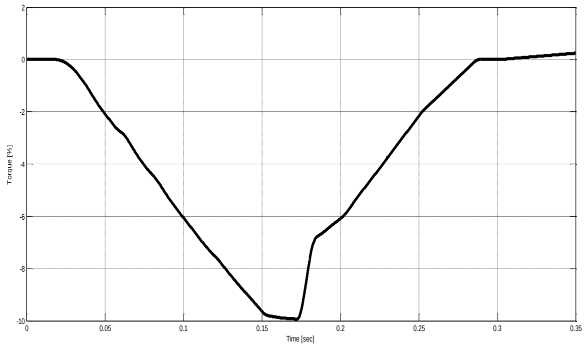

Fig.10. Torque (%) of conventional method

B. Simulation results of proposed fast initial speed estimator control method at restart operation of 90 r.p.m (18.85 rad/sec).

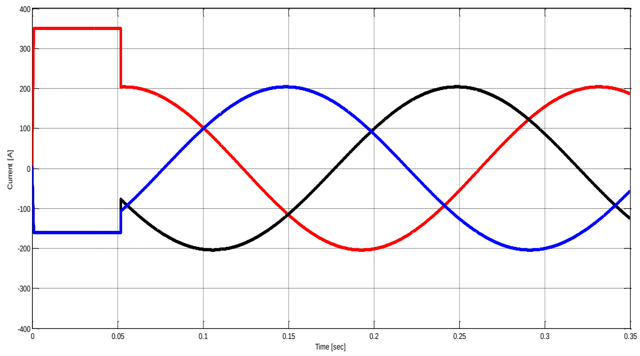

Fig.11. Stator currents of proposed method

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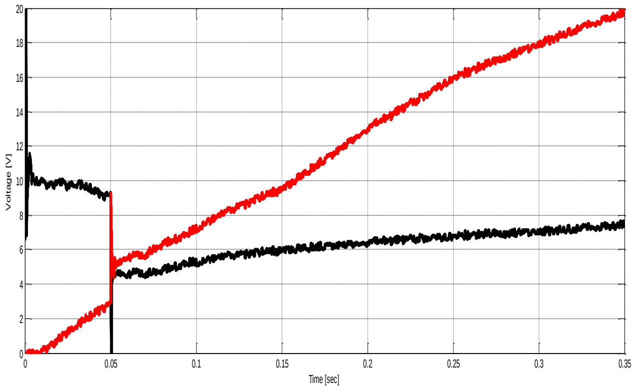

Fig.12. Voltages v_d^* and v_q^* of proposed method

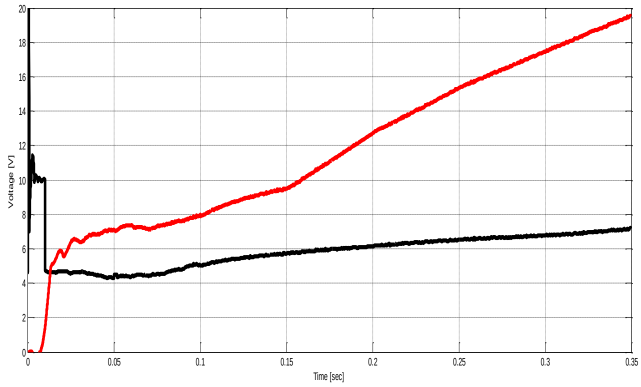

Fig.16. Voltages v_d^* and v_q^* of FLC method

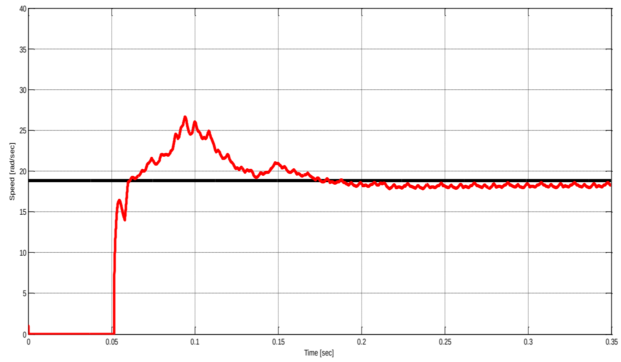

Fig.13. Speed (rad/sec) of proposed method

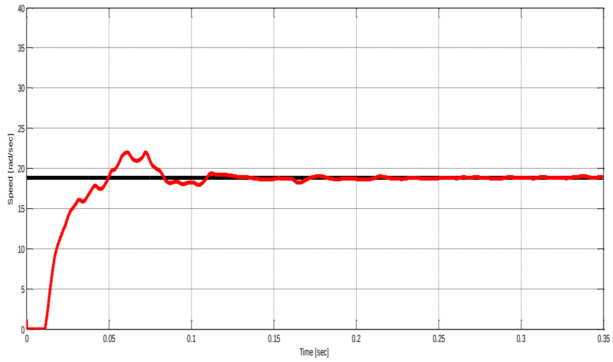

Fig.17. Speed (rad/sec) of FLC method

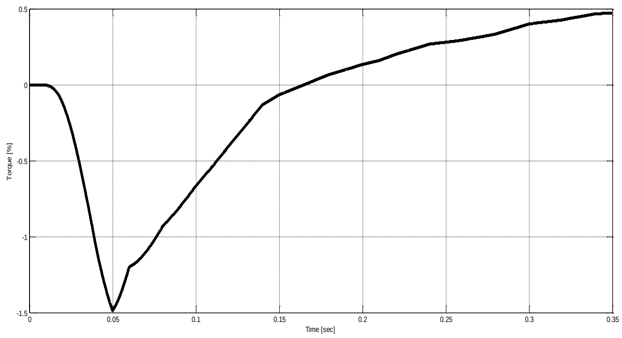

Fig.14. Torque (%) of proposed method

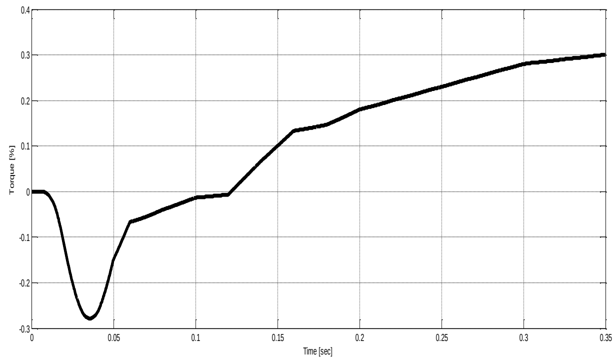

Fig.18. Torque (%) of FLC method

C. Simulation results of improved fast initial Speed estimator at restart operation of 90 r.p.m (18.85 rad/sec). using FLC.

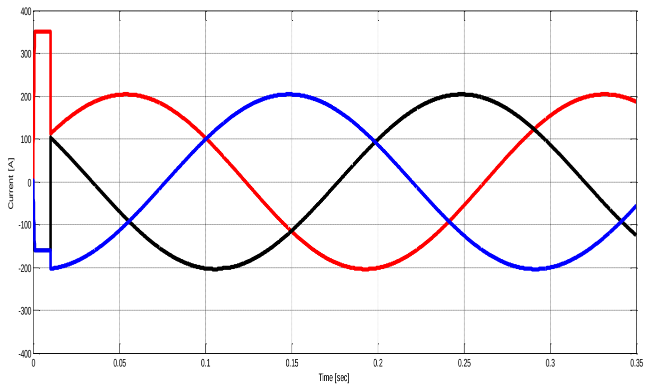

Fig.15. Stator currents of FLC method

TABLE- 2: Comparison of ideal, improved and FLC methods of speed estimation (SE)

PARAMETER	IDEAL SE	IMPROVED SE	SE BY FLC
Settling time (sec)	0.2	0.175	0.1
Estimated Speed (rad/sec)	40	27	22
Negative Torque (%)	10	1.5	0.28

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TABLE-3: Induction Motor (150 kw, 4 poles) Parameters

Rated voltage	750 V
Rated current	204 A
Primary resistance R_s	0.027Ω
Secondary resistance R_r	0.021Ω
Primary inductance L_s	8.569 mH
Secondary inductance L_r	8.632 mH
Mutual inductance M	8.227mH
Rated d axis current reference i_d^*	211 A
Maximum torque	1500 Nm

VI. CONCLUSION

This paper elaborates, the estimation of rotor speed at initially to IM with allowable period for low speed condition. Moreover, estimator of speed with an observer of secondary flux is enhanced than controller of fuzzy as to obtain high reliable and robustness. Therefore, simulation result represents an unwanted disturbance torque in restart operation is controlled less than 10% of at most torque and the speed estimation using Fuzzy logic controller is faster when compared to current controller used in the Initial speed estimator.

FUTURE WORK

The performance of proposed method gives better results in the low speed range of low rated induction motor but not for higher rated IM. The multiple high rated induction motors by direct current injection method or frequency signal injection method may employ to validate the system performance for further work.

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