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Improve the Performance Characteristics of Induction Motor through Bang Bang Controller

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***Abstract*— Improve the performance characteristics of the AC drive system is very important to get high dynamic performance so this paper choosing the PI controller to improve the bang bang controls. The bang bang controllers mean hysteresis current controller and ramp comparison current controller. Ramp comparison current controller and hysteresis current controller are used in many industrial applications because it has many advantages as fast, high dynamic performance, doesn't require any information about load parameters and less expensive. The drawback of the hysteresis current controller is varying switching frequency while the ramp comparison current controller has no limits current error. This paper presents adaptive hysteresis current controller and ramp comparison current controller to control the inverter. It is used to reduce the ripple, total harmonic distortion and improvement the switching frequency through design of PI current controller. The modified bang bang controllers are compared to conventional bang bang controllers under steady state and transient conditions with fixed load, sudden applied and sudden removal load to show the effectiveness of this modification. Induction motor is used due to has many advantages and spread in many industrial applications.**

***Keywords*— Hysteresis current controller, induction motor, ramp comparison current controller.**

I. INTRODUCTION

With development of the power electronics and control theories the induction motor is replaced the DC motor. The induction motor is spreading in the industrial applications from that time and still. This is because it has many advantages as simple, rugged construction, low maintenance, low cost, low weight and high long operating life. There are many methods of control invented to drive the induction motor from these methods, the field oriented control and direct torque control. In this paper, the field oriented control is applied. To apply this method, the machine parameters such as currents, voltages and fluxes are representing in the space i.e. these quantities changing from three phase quantities varying in time into two phase quantities non varying in time. To get high dynamic performance there are many methods of voltage or current controls can be applied inherent with field oriented control (FOC) [1-2].

The current control methods are preferable due to simplicity [3-4]. These methods of control depend upon the natural of the AC machine. This means that; some machine such as the induction motor needs sinusoidal supply where the other as the brush less DC motor need square wave. The current control methods can be divided into linear and nonlinear control. Linear control such as bang bang control while nonlinear current control such as PI current controller. In this paper, bang bang current controller is used i.e. the hysteresis current controller is used and ramp comparison current controller is used and to get the discuss the advantages and disadvantages of these controls. The improvement in term of high dynamic performance, low torque ripples, THD in the current. This paper is classified into I introduction, II mathematical model of induction motor, III field oriented control, IV hysteresis current controller, V ramp comparison current controller, VI simulation results, VII conclusion

II. MATHEMATICAL MODEL OF INDUCTION MOTOR

The mathematical model of induction motor can be written as

$$v_{qse} = r_s i_{qse} + \frac{d\psi_{qse}}{dt} + \omega_e \psi_{dse} \quad (1)$$

$$v_{dse} = r_s I_{dse} + \frac{d\psi_{dse}}{dt} - \omega_e \psi_{qse} \quad (2)$$

$$0 = r_r I_{qre} + \frac{d\psi_{qre}}{dt} + (\omega_e - \omega_r)\psi_{dre} \quad (3)$$

$$0 = r_r I_{dre} + \frac{d\psi_{dre}}{dt} - (\omega_e - \omega_r)\psi_{qre} \quad (4)$$

$$\psi_{qse} = L_s I_{qse} + L_m I_{qre} \quad (5)$$

$$\psi_{dse} = L_s I_{dse} + L_m I_{dre} \quad (6)$$

$$\psi_{qre} = L_r I_{qre} + L_m I_{qse} \quad (7)$$

$$\psi_{dre} = L_r I_{dre} + L_m I_{dse} \quad (8)$$

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$$T_e = 3\frac{P}{4}\frac{L_m}{L_r}(\psi_{dre} I_{qse} - \psi_{qre} I_{dse}) \quad (9)$$

$$J\frac{d\omega_r}{dt} = T_e - T_L - B\omega_r \quad (10)$$

Where V_{qse} and V_{dse} are the q and d axis stator voltage, I_{qse} and I_{dse} are the q and d axis stator current, I_{qre} and I_{dre} are the q and d axis rotor current, ψ_{qse} and ψ_{dse} are the q and d axis stator flux, ψ_{qre} and ψ_{dre} are the q and d axis rotor flux, r_s and r_r are the stator and rotor resistance, L_s, L_r and L_m are the stator, rotor and magnetizing inductances, P is the number of poles, T_e,T_L are the electromagnetic torque and load torque, $\frac{d}{dt}$ is a derivative, ω_r is a rotor speed, B is a friction viscous and J is a moment of inertia.

III. Field Oriented Control

The field oriented control introduced for the first time at the hands of Blashka in 1971 as an alternative to bring the induction motor instead of the DC motor in industrial applications that required high dynamic performance [5]. In FOC, the space phasor of the stator current is decoupled into two components torque current component and flux current component. The flux current control is aligned with the rotor flux as shown in Fig. 1. To implement that, the position and magnitude of the rotor flux are required and this can be done directly by using sensor to measure the rotor flux or indirectly by estimating the rotor flux. In this paper the rotor flux is estimated by indirect method [6-8]. This means that, the d-axis rotor flux is equal to the rotor flux and the q-axis rotor flux becomes zero so the rotor flux can be calculated as

$$\psi_r = \frac{L_m}{1+T_r\frac{d}{dt}} I_{dse} \quad (11)$$

In the estimated model, the reference rotor flux can be deduced from lookup table designed in MATLAB program depending upon the rotor speed. With aid of the above equation the estimating d-axis stator current can be calculated as

$$I_{dse}^* = (1+T_r\frac{d}{dt})\frac{\psi_r^*}{L_m} \quad (12)$$

The rotor flux angle can be calculated as the sum of rotor position and rotor field position referred to the rotor as the following equation

$$\theta_{rf} = \theta_r + \theta_s$$
$$\theta_s = \frac{L_m}{T_r\psi_r^*} I_{dse} \quad (13)$$

And the motor torque becomes

$$T_e = 3\frac{P}{4}\frac{L_m}{L_r}\psi_r I_{qse} \quad (14)$$

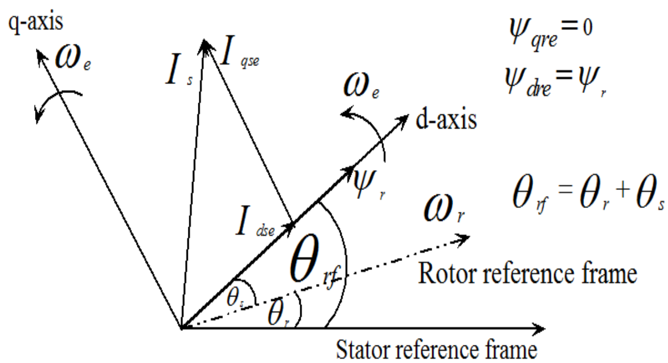

Fig. 1. Phasor diagram of field oriented control

This torque can be deduced from the PI torque current controller. With aid this torque, the estimated torque current component (I_{qse}) can be deduced from the above equation as

$$I_{qse}^* = \frac{1}{3}\frac{4}{P}\frac{L_r}{L_m\psi_r^*} T_e \quad (15)$$

With help of torque current component (I_{qse}^*), flux current component (I_{dse}^*) and position of rotor flux (θ_{rf}), the estimating three phase stator current can be calculated.

The three phase stator current estimated are compared to the actual three phase current which measured by sensor to switching frequency of inverter as shown in Fig. 2. This Figure shows the details of the indirect field oriented control for induction motor

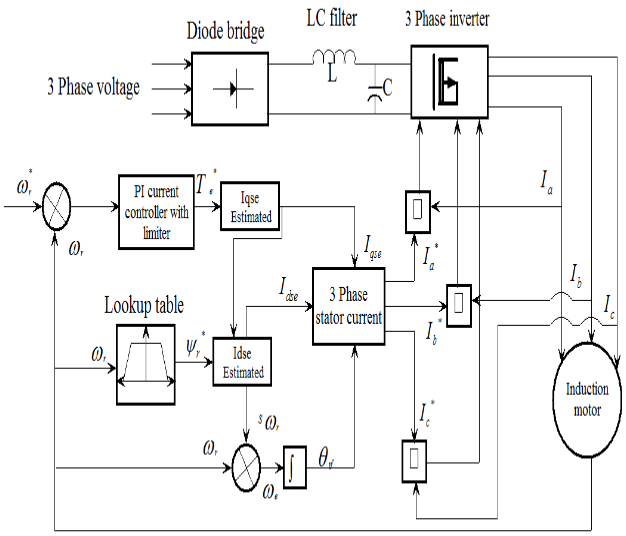

Fig. 2. Stigmatic diagram of the indirect field oriented control of induction motor

IV. Hysteresis Current Control Controller

The hysteresis current controller is used due to simplicity, fast dynamic response and insensitive to load parameters. Fig 3. represents the hysteresis current controller. In this method each phase consists of comparator and hysteresis band. The switching signals are generated due to error in the current [9]. The error comes from comparing between the reference current and actual current. The main task of this method of control is to force the input current to follow the reference current in each phase. The deviation of these currents (error current) represents the current distortion or ripples in the current which can be calculated as

$$\text{Ripples current} = \frac{100}{I_{rms}} \sqrt{\frac{1}{T} \int (I_{act} - I_{ref})^2 dt} \quad \% \qquad (16)$$

In this method of control, the deviation of the current between the upper and lower in the hysteresis band is limited. In any phase, if the actual current becomes more than the upper limit of hysteresis band (I_{ref}+HB) the upper switch of the inverter arm is turned off, the lower switch is turned on and the current starts to decay. In contrast if the actual current reaches lower limit or less than of hysteresis band (I_{ref}-HB) the lower switch of the inverter arm is turned off, the upper switch is turned on and the current comes back into the hysteresis band. The band width calculates the switching frequency and current ripple. The band width is directly to current ripple and inversely proportional to switching frequency so the selection of the band width means performance of inverter.

This is because the increasing in the band width will increase the current ripple in contrast; a decrease in the band width will increase the switching losses. PI current controller is proposed to overcome undesirable drawbacks of classical hysteresis current controller. This PI controller is used to adapt the hysteresis controller. The input of PI controller is the error in the current between the reference current and motor current for each phase as shown in Fig.4. Proportional gain is used to improve the rise time and integral gain is used to eliminate the steady state error. These parameters can be deduced by many methods such as: trial and error, Ziegler-Nichols method and internal model of control. The parameters of the PI controller are determined depending upon [10]. This PI current controller is used to improve the dis advantages of the hysteresis current controller such as the varying switching frequency.

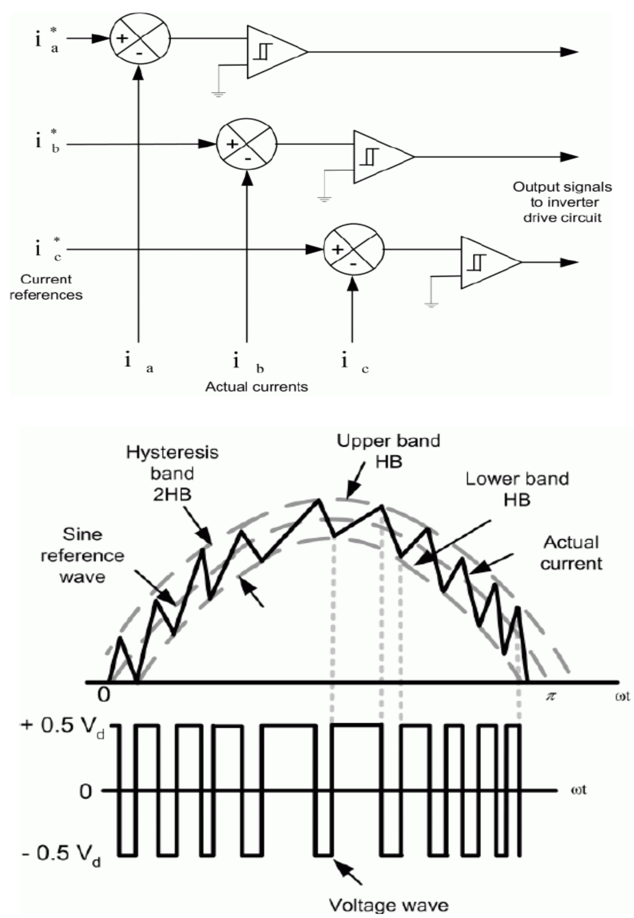

Fig. 3 Hysteresis current controller structure and basic concept

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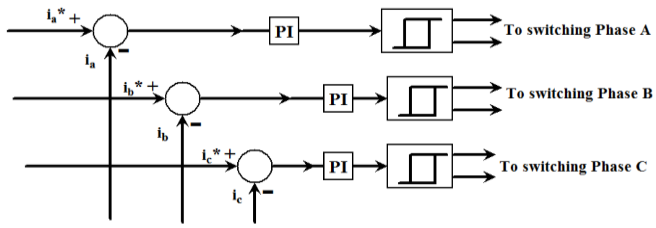

Fig. 4 Proposal hysteresis current controller

V. Ramp Comparison Current Control Controller

In this type of control, the switching frequency is constant which means that lower content of harmonics. In the classical ramp type current control, the motor current is compared to reference current and the errors signals is compared to fixed frequency triangular waveform. If this error is positive and larger than triangular wave positive voltage (Vdc) is applied to the motor and if the error is positive and smaller than triangular wave negative voltage (-Vdc) is applied to the motor [11]. Hysteresis band is added to avoid multiple crossing of error signal with triangular waveform. This technique suffers from errors in the magnitude and phase shift which means the motor disconnected several times. To repair this problem, triangular waveform is shifted by 120^0 between these phases to get the balance and get red from these errors. This can be done by phase shifter as shown in Fig. 5. With this modification the harmonics became less but the remaining harmonics still effect on performance drive so the PI current controller is proposed as shown in Fig. 6 to suppress the harmonics, noise, torque ripple and total harmonic distortion. The error of the current used as the input for PI current controller which minimize the error at steady state and increase the performance of the drives and inverter as will be seen when simulation studying.

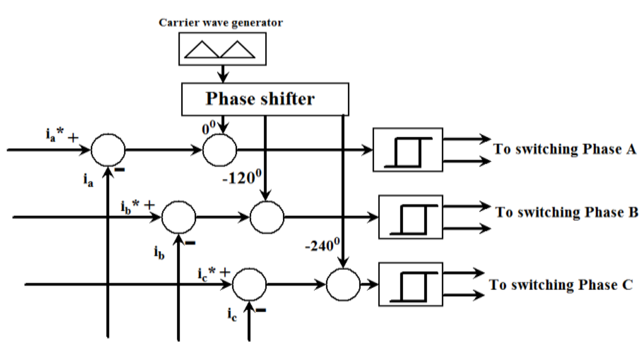

Fig.5 Modified ramp current controller

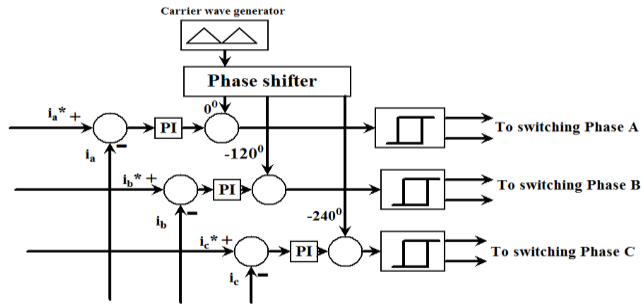

Fig.6 Proposed ramp current controller

VI. Simulation Rustles

Here the proposed models are compared to conventional models to show the effectiveness of proposed models. Tables 1&2 show the effectiveness the proposed models in suppressing the ripples, noise and THD if it is compared to classical models. Appendix I shows the motor parameters. During the simulations, the torque set at rated value. In all Figs the time axis is in seconds and the two cases are simulated which are

1- The operation of the motor at rated condition.
2- The operation of the motor at sudden applied and removal the load.

Where it is found that

A. Hysteresis Current Controller

The first case of study: The operation of the motor at rated condition.

Here the conventional method means hysteresis current controller and the proposed model; it is hysteresis current controller with adding PI controller.

The torque responses showing in Figs (7-8). Fig. 8 showed that, the torque ripple is reduced with proposed model if it is compared to the conventional model (Fig. 7). Fig. 9 shows little noise in the speed with conventional model if it is compared to the proposed model (Fig. 10). This is because the torque ripple reaches the improving value with proposed model due to improvement in q-axis current component. In Fig. 12, the stator currents become smoother with proposed model due to improvement in the switching frequency. In conventional model (Fig.11), the stator current is highly distorted due to noise and electromagnetic interference.

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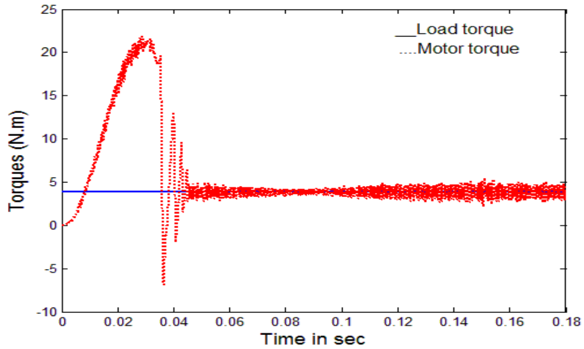

Fig. 7. Torque with conventional method

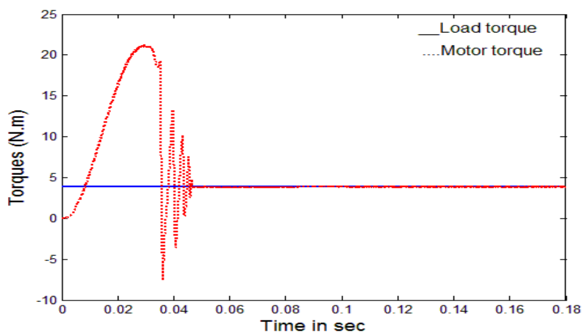

Fig. 8. Torque with proposal model

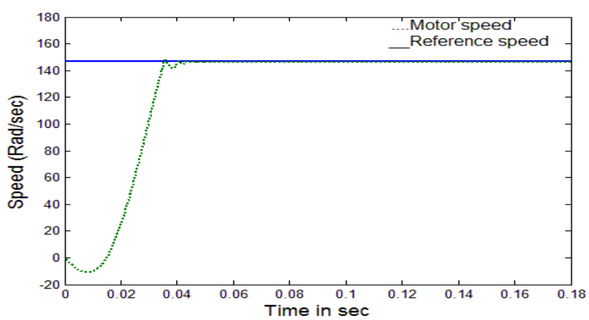

Fig. 9. Speed with conventional method

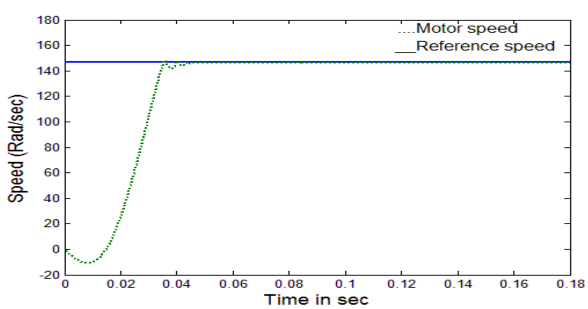

Fig. 10. Speed with proposal model

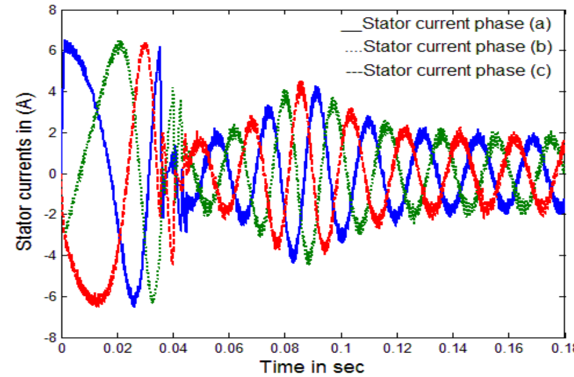

Fig. 11. Stator current with conventional method

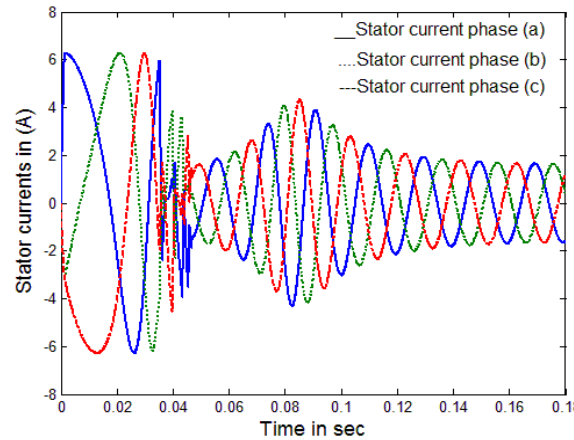

Fig. 12. Stator current with proposal model

The second case of study: sudden applied and removal the load

Here the motor starts without load, at 0.12 sec. sudden load is applied, at 0.28 sec the load is suddenly removed where it is found that, In Fig.14, the ripple torque is reduced with modified methods if it is compared to conventional method (Fig. 13) this occurs due to less in the electromagnet interface and improvement in q-axis current component with modified model.

Figure 15 shows some noise in the speed with conventional method if it is compared to the modified methods (Fig.16).

In Fig.18, the stator currents become smoother with modified method due to reduction of the noise in the stator flux and suppresses in electromagnetic interference if it is compared to conventional method (Fig.13).

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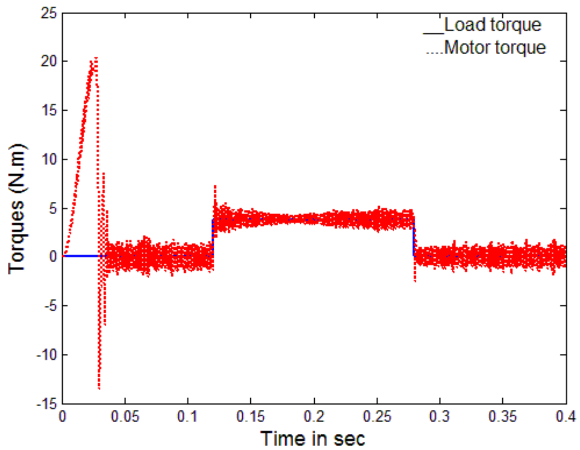

Fig. 13. Torque with conventional method

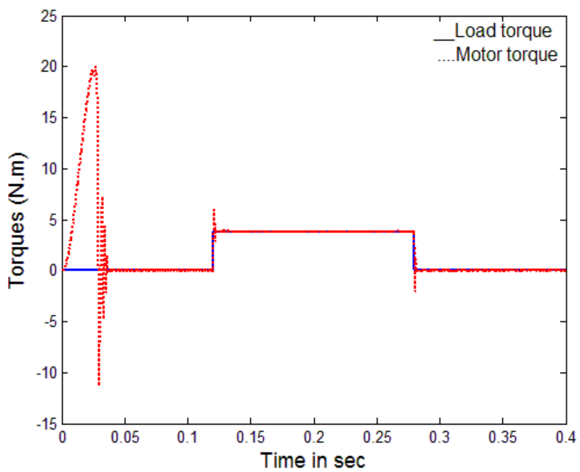

Fig. 14. Torque with proposal model

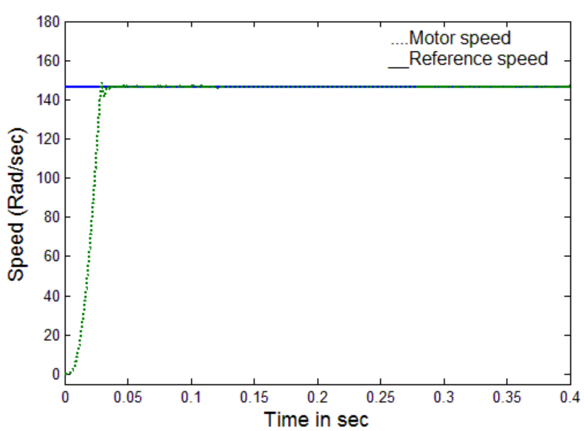

Fig. 15. Speed with conventional method

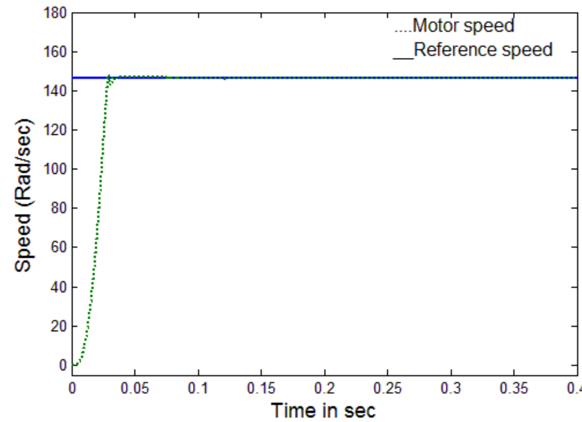

Fig. 16. Speed with proposal model

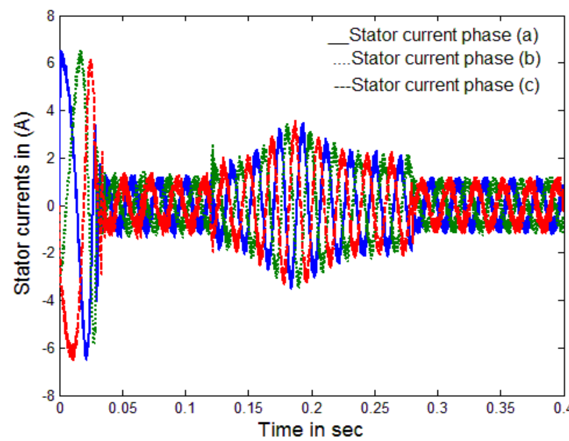

Fig. 17. Stator current with conventional method

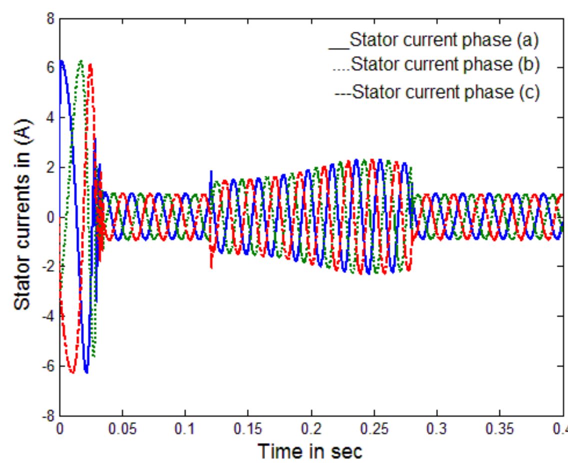

Fig. 18. Stator current with proposal model

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B. Ramp Comparison Current Controller

Here the conventional method means ramp modulation current controller and the proposed model means ramp modulation current controller with adding PI controller.

The first case of study: The operation of the motor at rated condition.

The torque responses showing in Figs (19-20). Fig. 20 showed that, the torque ripple is reduced with proposed model if it is compared to the conventional model (Fig. 19).

Fig. 21 shows some noise in the speed with conventional model if it is compared to modified method Fig. 22. Also the stator current is improvement with modified method if it is compared to classical method Figs (23-24).

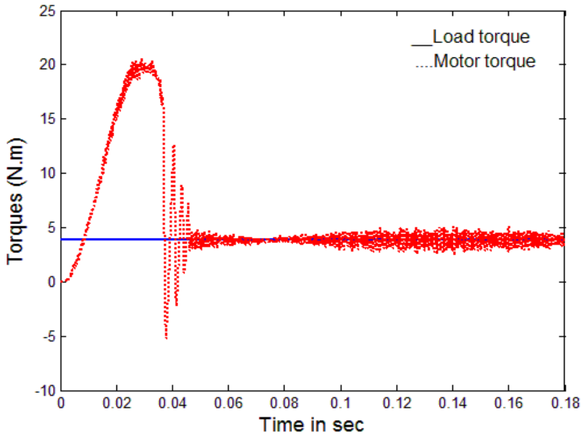

Fig. 19. Torque with conventional method

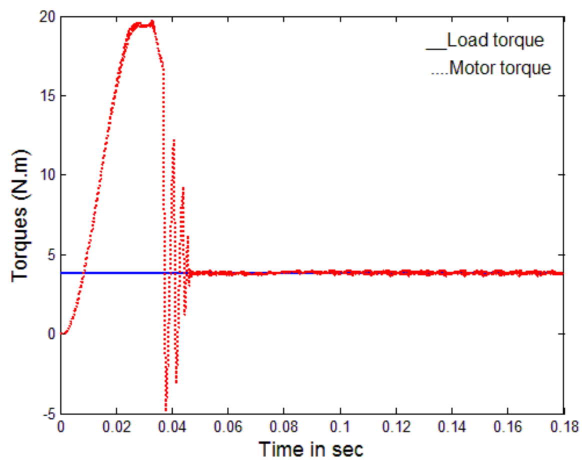

Fig. 20. Torque with proposal model

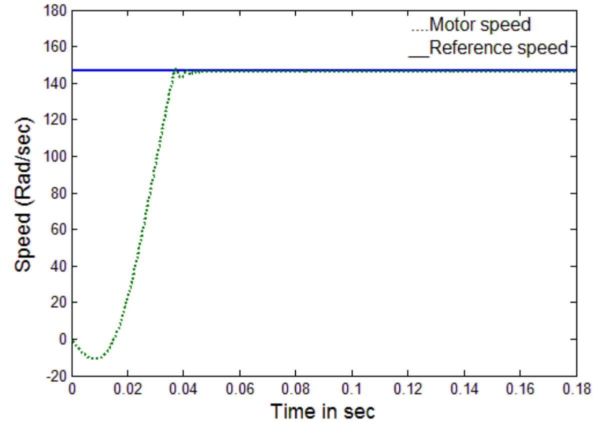

Fig. 21. Speed with conventional method

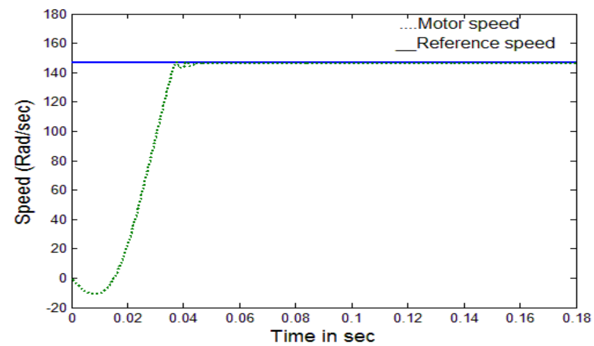

Fig. 22. Speed with proposal model

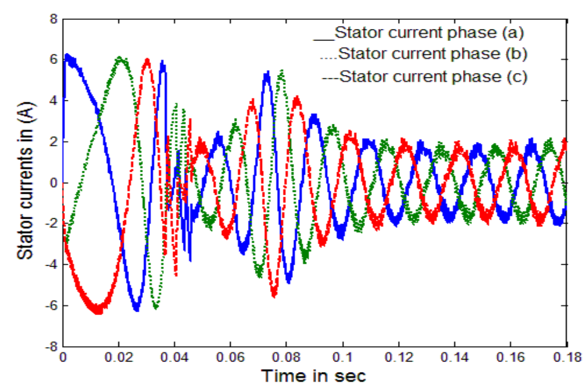

Fig. 23. Stator current with conventional method

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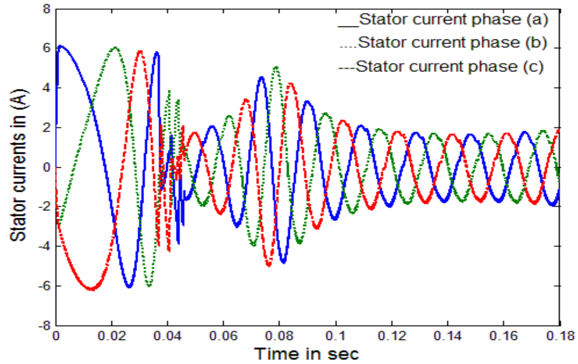

Fig. 24. Stator current with proposal model

The second case of study: sudden applied and removal the load

Here the motor starts without load, at 0.12 sec. sudden load is applied, at 0.28 sec the load is suddenly removed where it is found that, In Fig.26, the ripple torque is reduced with modified methods if it is compared to conventional method (Fig. 25) this occurs due to less in the electromagnet interface and improvement in q-axis current component with modified model.

Figure 27 shows some noise in the speed with conventional method if it is compared to the modified methods (Fig. 28).

With adding PI current controller (Fig.30), the stator currents become very small under no load but with conventional method these currents are high due to noise, harmonics and electromagnet interface (Fig.29). also the stator currents become smoother with adding PI current controllers

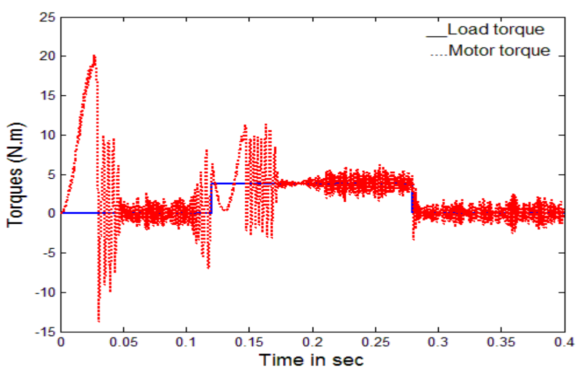

Fig. 25. Torque with conventional method

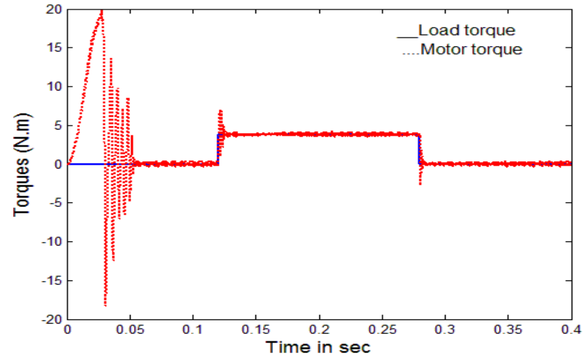

Fig. 26. Torque with proposal model

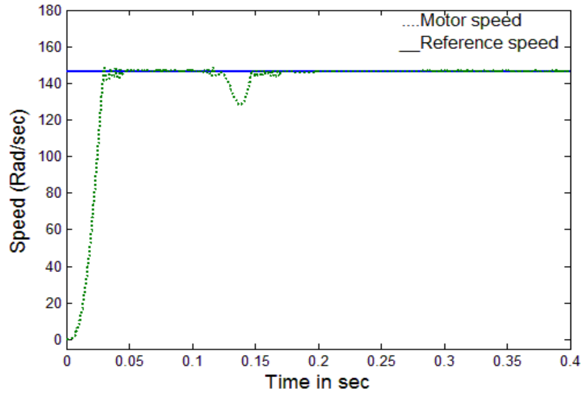

Fig. 27. Speed with conventional method

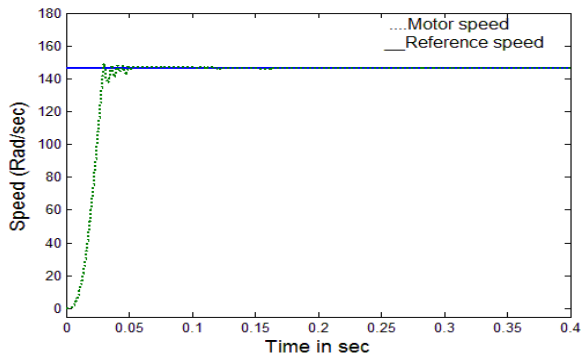

Fig. 28. Speed with proposal model

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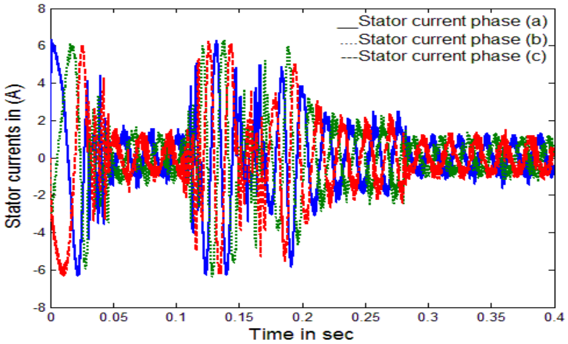

Fig. 29. Stator current with conventional method

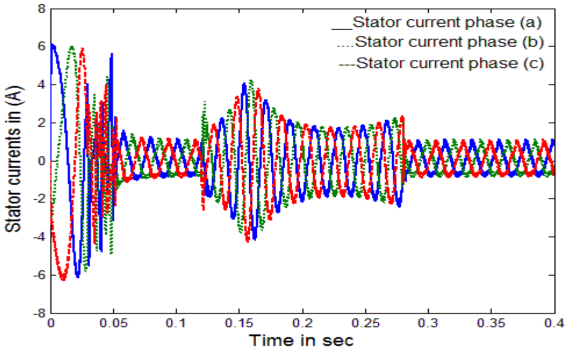

Fig. 30. Stator current with proposal model

VII. CONCLUSION

This paper is addressed the torque problem, noise and total harmonic distortion by adding PI controller to the conventional current control methods as, hysteresis current controller and ramp current controller. PI controller is introduced to suppress the harmonics, torque ripples, noise and electromagnetic interference in the previous methods of control. The PI current controller is affecting the inverter switching frequency to reduce the ripples in the torque and current. The stator current waveforms become smoother with modified methods. Also in proposed models, the dynamic response, the torque ripple and total harmonic distortion become excellent. The hysteresis current controller with PI current controller is very good if it is compared to the ramp comparison current controller with PI current controller.

Table "1'

Type of control	Torque ripples	
	Conventional control	Proposal control
Hysteresis current controller	13.59	0.93
Ramp current controller	10.37	1.67

Table "2'

Type of control	THD in current	
	Conventional control	Proposal control
Hysteresis current controller	14.84	1.54
Ramp current controller	14.34	6.54

APPENDIX I

MOTOR DATA

Line to line voltages	380V
Rotor speed (n_r)	1400 R.P.M
Pole pairs	2
Full load torque (T_f)	3.82 N.m
Power factor (pf)	0.8
Stator resistance	13 Ohm
Stator reactance	10.5 Ohm
Magnetizing reactance	231 Ohm
Rotor resistance	2.25S+12.35 Ohm
Rotor reactance	-3.694S+19.2643 Ohm
Output power	0.75 hp

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