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Speed Control of A Doubly Fed Induction Motor using Integral Plus Proportional Controller

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Abstract

Conventionally, the speed control manipulate of Doubly-Fed Induction Motor (DFIM) has been developed primarily which is based on traditional Proportional-Plus-Integral (PI) controller due to its simple construction and implementation. The steady-state error minimization, overshoot removal and disturbance rejection are not possible in which the benefits of PI controller are chosen through trial and errors approach. The steady-state error and disturbance rejection may be viable, if the benefits of Proportional-Plus-Integral controller are chosen through right on the poles. But the overshoot elimination is not possible where the Proportional-Plus-Integral based controller is designed. In this paper, Integral-Plus-Proportional (IP) controller is proposed to design for speed control of the Doubly-Fed Induction Motor. The Integral-Plus-Proportional controller is well suited to minimize the overshoot problem that is arisen in Proportional-Plus-Integral controller. The performance of proposed Integral-Plus-Proportional controller for speed control of Doubly-Fed Induction Motor system has been analyzed and investigated through the simulation works. The outcomes of simulation works are illustrated to show the effectiveness of recommend Integral-Plus-Proportional controller in comparison with traditional Proportional-Plus-Integral controller. The proposed Integral-Plus-Proportional controller shows the much better performance over Proportional-Plus-Integral controller in phrases of minimization of overshoot.

Keywords: *DFIM, vector control, PI controller, IP controller*

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INTRODUCTION

Known seeing that 1899 [1], the doubly fed induction motor (DFIM) is a wound rotor asynchronous machine provided through the stator and the rotor from two external supply voltages. This machine is very desirable for variable speed functions such as the electric automobile and the production of electrical energy [2–4]. Consequently, it covers all energy ranges. Obviously, the requested variable speed area and the preferred performances rely on the utility sorts [5–7]. The use of DFIM affords the chance to modulate energy drift into and out of the rotor winding in order to have, at the same time, a variable velocity in the characterized super–synchronous or sub–synchronous modes in motor or in generator regimes. Two modes can be related to slip energy recovery: sub–synchronous motoring and super–synchronous generating operations. In general, while the rotor is fed through a cycloconverter, the energy range can obtain the MW order which provides the dimension of energy frequently reserved to the synchronous machine [7–10]. The DFIM has some awesome benefits in contrast to the traditional squirrel-cage machine. The DFIM can be controlled from the stator or rotor via more than a few viable combinations. The drawback of two used converters for stator and rotor offering can be compensated through the quality control performances of the powered systems. Indeed, the enter instructions are carried out with the aid of skill of four particular stages of manipulate freedom relative to the squirrel cage induction machine where it's manipulate appears quite simple. The flux orientation strategy can transform the non-linear and coupled DFIM-mathematical mannequin into a linear model leading to one captivating solution for producing or motoring operations

[10–14]. It is known that the motor driven systems account for about 65% of the electricity fed on in the world. Implementing excessive efficiency motor driven systems, or enhancing current ones, ought to save over 200 billion kWh of electrical energy per year. This trouble has emerged as very important, specifically following the economic crisis due to the amplify in oil prices as such, innovative energy saving technologies are appearing and creating swiftly in this century [15–18]. In this framework, the DFIM continues to be of extremely good pastime owing to the beginning of the thinking of double flux orientation [19, 20].

Several techniques of control are used to control the induction motor amongst which the vector control or area orientation manipulate that permits a decoupling between the torque and the flux, in order to achieve an impartial control of torque and the flux like DC motors. Therefore, decoupling the control scheme is required via compensation of the coupling effect between d-axis and q-axis current dynamics. With the field orientation control (FOC) method, induction machine drives are turning into a major candidate in high-performance movement manipulate applications, where servo quality operation is required. Fast transient response is made viable with the aid of decoupled torque and flux control. The most broadly used control technique is possibly the proportional integral control (PI). It is effortless to design and implement, however it has problem in dealing with parameter variations, and load disturbances.

In order to improve the overall performance of PI controller of extraordinary electrical motors IP has been designed in [22–25]. In this paper, the speed control of DFIM based on IP control scheme is proposed considering it can effortlessly design and implement. The proposed IP controller is capable to overcome the steady state error and overshoot issues and to reject the disturbance. The overall performance of speed control based on the proposed IP controller is investigated by using simulation results, which had been carried out through Matlab/Simulink software. From the simulation works, it is observed that the IP controller gives higher performance through ability of overshoot and steady-state error.

DYNAMIC MODELING OF DOUBLY FED INDUCTION MOTOR

Figure 1 shows the typical configuration of overall control system of DFIM. Two inverters are used to transmit current from dc source to the stator winding and the rotor windings. The switching action of inverters is performed based on the injecting the controllable voltage in to the stator and the rotor to obtain the desired voltage with desired frequency of both stator and rotor for variable speed operation.

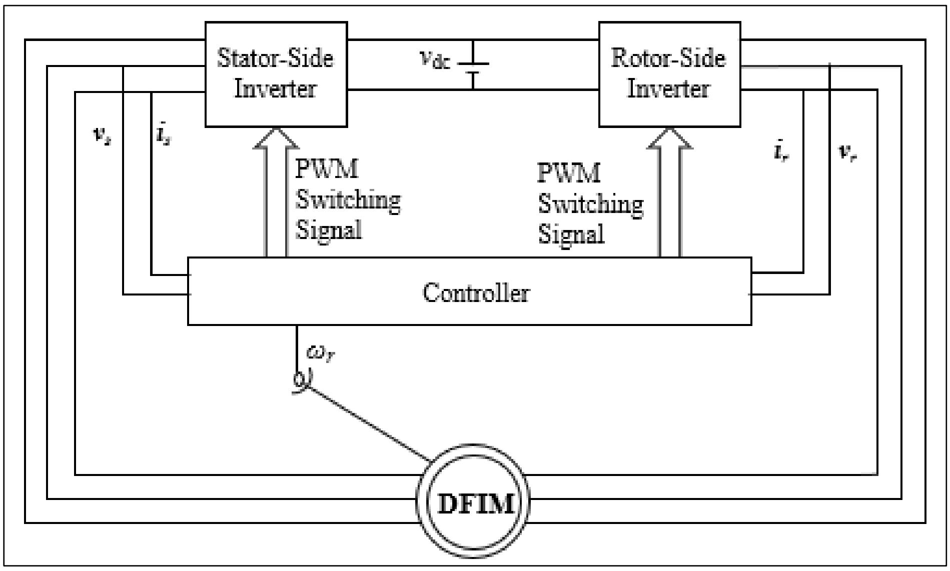

Fig. 1: *Overall Block Diagram of DFIM Drive System.*

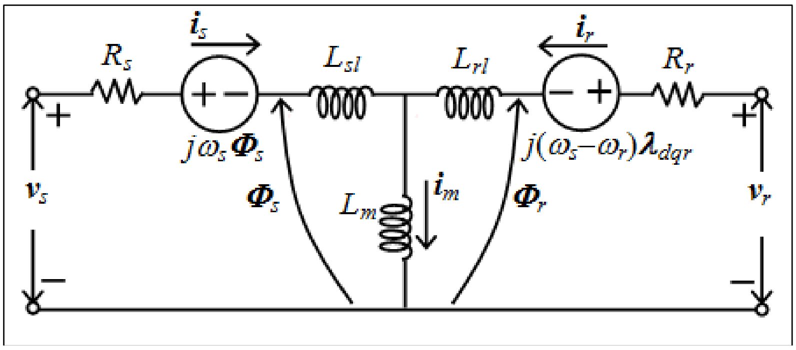

Fig. 2: *Complex Synchronously Rotating dq-Axes Reference Frame Equivalent Circuit of DFIM.*

Though the two inverters share the same dc bus, they can be operated separately, meaning that both stator and rotor windings can be controlled independently.

Figure 2 shows the equivalent circuit diagram of a DFIM in complex vector form in a synchronously rotating dq-axes reference frame.

In this Figure 2 subscripts "*s*" and "*r*" refer to the stator and rotor windings variable, respectively. $\boldsymbol{v}_s = v_{sd}+jv_{sq}$ and $\boldsymbol{v}_r = v_{rd}+jv_{rq}$ are the stator and rotor voltage vectors; $\boldsymbol{i}_s = i_{sd}+ji_{sq}$ and $\boldsymbol{i}_r = i_{rd}+ji_{rq}$ denotes stator and rotor current vectors; R_s and R_r are the stator and rotor resistance; L_m, L_{sl}, L_{rl} are the magnetizing, stator leakage and rotor leakage inductances, respectively; $\boldsymbol{\Phi}_s = \Phi_{sd}+j\Phi_{sq}$ and $\boldsymbol{\Phi}_r = \Phi_{rd}+j\Phi_{rq}$ are the stator and rotor flux vectors; ω_s is the stator winding electrical angular velocity and ω_r is the rotor winding electrical angular velocity.

Using the fundamental laws of ohm's law and faraday's law, the expressions of stator and rotor voltages with the currents and fluxes in synchronously rotating frame can be given as follows [21]:

$$v_{sd} = R_s i_{sd} + p\Phi_{sd} - \omega_s \Phi_{sq} \quad (1)$$

$$v_{sq} = R_s i_{sq} + p\Phi_{sq} + \omega_s \Phi_{sd} \quad (2)$$

$$v_{rd} = R_r i_{rd} + p\Phi_{rd} - \omega_r \Phi_{rq} \quad (3)$$

$$v_{rq} = R_r i_{rq} + p\Phi_{rq} + \omega_r \Phi_{rd} \quad (4)$$

$$\Phi_{sd} = L_s i_{sd} + L_m i_{rd} \quad (5)$$

$$\Phi_{sq} = L_s i_{sq} + L_m i_{rq} \quad (6)$$

$$\Phi_{rd} = L_r i_{rd} + L_m i_{sd} \quad (7)$$

$$\Phi_{rq} = L_r i_{rq} + L_m i_{sq} \quad (8)$$

In the above equations subscripts *d* and *q* are represented for *d*-axis quantities and *q*-axis quantities, respectively, and *p* is represented *d/dt*.

The electromagnetic torque and the mechanical dynamics can be given by:

$$T_e = K_t\left[i_{sq}\Phi_{rd} - i_{sd}\Phi_{rq}\right] \quad (9)$$

$$T_e = \frac{J_m}{P_n} p\omega_m + \frac{B_m}{P_n}\omega_m + T_m \quad (10)$$

where, $K_t = \frac{P_n L_m}{L_m}$, J_m is inertia, B_m is friction coefficient and P_n is the number of pole pair.

Using the above equations (1) to (10), the state-space equations of a DFIM can be written as follows:

$$pi_{sd} = -K_2 i_{sd} + K_4 \Phi_{rd} + \omega_s i_{sq} + K_3 \omega_m \Phi_{rq} + K_1 v_{sd} - K_3 v_{rd} \quad (11)$$

$$pi_{sq} = -K_2 i_{sq} + K_4 \Phi_{rq} - \omega_s i_{sd} - K_3 \omega_m \Phi_{rd} + K_1 v_{sq} - K_3 v_{rq} \quad (12)$$

$$p\Phi_{rd} = K_6 i_{sd} - K_5 \Phi_{rd} + \omega_r \Phi_{rq} + v_{rd} \quad (13)$$

$$p\Phi_{rq} = K_6 i_{sq} - K_5 \Phi_{rq} - \omega_r \Phi_{rd} + v_{rq} \quad (14)$$

$$p\omega_m = -K_7 \omega_m + K_9 i_{sq} \Phi_{rd} - K_9 i_{sd} \Phi_{rq} - K_8 T_L \quad (15)$$

where, $K_1 = \frac{1}{\sigma L_s}$, $K_2 = \frac{R_s L_r^2 + R_r L_m^2}{\sigma L_s L_r^2}$, $K_3 = \frac{K_1 L_m}{L_r}$, $K_4 = \frac{K_3 R_r}{L_r}$, $K_5 = \frac{R_r}{L_r}$, $K_6 = K_5 L_m$,

$$K_7 = \frac{B_m}{J_m} \cdot\ K_8 = \frac{P_n}{J_m},\ K_9 = K_8 K_t$$

VECTOR CONTROL OF DFIM

A vector controlled doubly fed induction machine is a captivating solution for excessive limited speed range electric powered force and era application, it consists in guiding an electromagnetic flux of the DFIM along the axis *d* or *q* [5]. In this paper, we select the direction of reference (*d*, *q*) in accordance to the direct stator flux vector Φ_{sd}, so the model of steady-state DFIM will be simplified as follows:

$$V_{sd} = R_s I_{sd} - \omega_s \Phi_{sq} \tag{16}$$

$$V_{sq} = R_s I_{sq} + \omega_s \Phi_{sd} \tag{17}$$

$$V_{rd} = R_r I_{rd} - \omega_r \Phi_{rq} \tag{18}$$

$$V_{rq} = R_r I_{rq} + \omega_r \Phi_{rd} \tag{19}$$

where, $\omega_r = \omega_s - \omega$

The magnetization of machine is certain by way of the rotor direct current, so the stator current in the *d* axis is taken to zero ($i_{sd} = 0$). The current and voltage in the stator are then in phase: $V_{sq} = V_s$ and $I_{sq} = I_s$. In this case we acquire a unity power factor at the stator, so the stator reactive electricity is zero i.e. $Q_s = 0$. Vector control consists in orienting the stator flux. Thus, it results the constraints given below in (20). The stator flux is oriented on the *q* axis.

$$\left.\begin{array}{l} \Phi_{sd} = \Phi_s \\ \Phi_{sq} = 0 \end{array}\right\} \tag{20}$$

Using the constraints of vector control of Eq. (15), the developed torque of Eq. (9) can simply be written as follows:

$$T_e = P_n \Phi_s I_{sq} \tag{21}$$

According to the previous mathematical derivations, the reference for stator currents and rotor currents can be obtained. Based on the vector control strategy these references are summarized in Table 1.

Table 1: *Control Strategy to the DFIM Model.*

Objectives	**References**
$\Phi_{sd} = \Phi_s = \Phi_{sn}$	$i_{rd}^{ref} = \Phi_{sn} / L_m$
$\Phi_{sq} = 0$	$i_{rq}^{ref} = -(L_s / L_m) i_{sq-ref}$
$Q_s = 0, (\cos\varphi = 1)$	$i_{sd}^{ref} = 0$
$T_e = T_e^{ref}$	$i_{sq}^{ref} = T_e^{ref} / K_{Tem}$

DESIGN OF CONTROLLER SYSTEM

In order to design the current controllers, we have the following expressions by rearranging the Eqs. (1) to (4):

$$\sigma L_s p i_{sd} + R_s i_{sd} = u_{sd} - C_{sd} = v_{csd} \tag{22}$$

$$\sigma L_s p i_{sq} + R_s i_{sq} = u_{sq} - C_{sq} = v_{csq} \tag{23}$$

$$\sigma L_r p i_{rd} + R_r i_{rd} = u_{rd} - C_{rd} = v_{crd} \tag{24}$$

$$\sigma L_r p i_{rq} + R_r i_{rq} = u_{rq} - C_{rq} = v_{crq} \tag{25}$$

The decoupling compensation terms C_{sd}, C_{sq}, C_{rd}, and C_{rq}, and the intermediate voltages u_{sd}, u_{sq}, u_{rd}, and u_{rq}, in Eq. (17–20) are given as follows:

$$C_{sd} = -\frac{R_r L_m}{L_r} i_{rd} - \omega_s \Phi_{sq} + \frac{L_m}{L_r} \omega_r \Phi_{rq} \tag{27}$$

$$C_{sq} = -\frac{R_r L_m}{L_r} i_{rq} + \omega_s \Phi_{sd} - \frac{L_m}{L_r} \omega_r \Phi_{rd} \tag{28}$$

$$C_{rd} = -\frac{R_s L_m}{L_s} i_{sd} + \frac{L_m}{L_s} \omega_s \Phi_{sq} - \omega_r \Phi_{rq} \tag{29}$$

$$C_{rq} = -\frac{R_s L_m}{L_s} i_{sq} - \frac{L_m}{L_s} \omega_s \Phi_{sd} + \omega_r \Phi_{rd} \tag{30}$$

$$u_{sd} = v_{sd} - \frac{L_m}{L_r} v_{rd} \tag{31}$$

$$u_{sq} = v_{sq} - \frac{L_m}{L_r} v_{rq} \tag{32}$$

$$u_{rd} = v_{rd} - \frac{L_m}{L_s} v_{sd} \tag{33}$$

$$u_{rq} = v_{rq} - \frac{L_m}{L_s} v_{sq} \tag{34}$$

With the constraints of vector control of Eq. (15), the mechanical dynamics of Eq. (10) with Eq. (16) can be written as follows:

$$p\omega_m + \frac{B_m}{J_m}\omega_m = \frac{P_n}{J_m}T_e - \frac{P_n}{J_m}T_m \tag{35}$$

It is evident from Eq. (29) that the speed of a DFIM can be control by controlling the electromagnetic torque of DFIM. Then the reference for stator *q*-axis current can be generated from the reference of electromagnetic torque which is the output of speed controller. Using Eqs. (17–20) and *s*-domain of Laplace transformation, the open-loop transfer function for four different current controllers can be given as follows:

$$T_{sd} = T_{sq} = \frac{B_s}{s + A_s} \tag{36}$$

$$T_{rd} = T_{rq} = \frac{B_r}{s + A_r} \tag{37}$$

Considering the load torque T_m as a step function the open-loop transfer function for speed controller from Eq. (29) is obtained as follows:

$$T_\omega = \frac{B_\omega}{s + A_\omega} \tag{38}$$

In Eqs. (30) to (32) $T_{sd} = \frac{I_{sd}(s)}{V_{csd}(s)}$, $T_{sq} = \frac{I_{sq}(s)}{V_{csq}(s)}$, $T_\omega = \frac{\omega_m(s)}{T_e(s)}$, $A_s = \frac{1}{\sigma T_s}$, $B_s = \frac{1}{\sigma T_s R_s}$, $T_{rd} = \frac{I_{rd}(s)}{V_{crd}(s)}$, $T_{rq} = \frac{I_{rq}(s)}{V_{crq}(s)}$, s, $B_r = \frac{1}{\sigma T_r R_r}$, $A_\omega = \frac{B_m}{J_m}$, $B_\omega = \frac{P_n}{J_m}$, $T_s = \frac{L_s}{R_s}$, $T_r = \frac{L_r}{R_r}$.

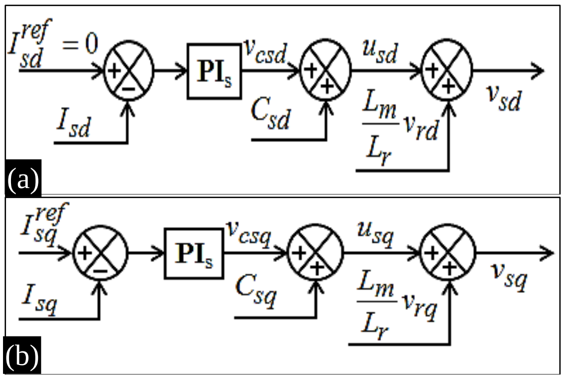

Fig. 3: *Block Diagram of Stator Current Controller. (a) d-axis current controller, (b) q-axis current controller*

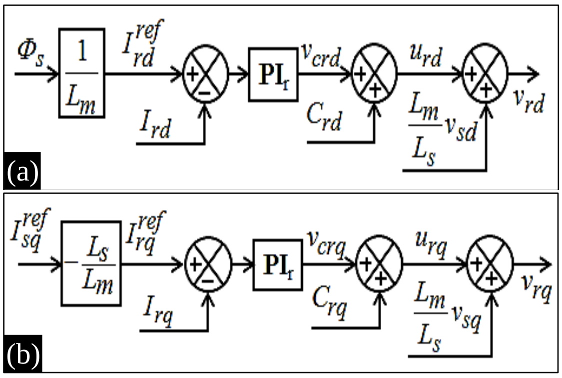

Fig. 4: *Block Diagram of Rotor Current Controller. (a) d-axis Current Controller, (b) q-axis Current Controller*

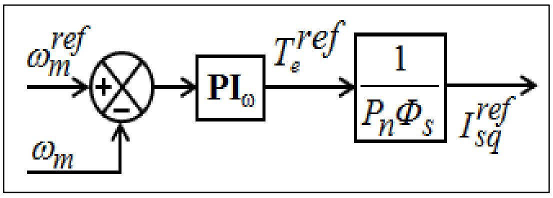

Fig. 5: *Block Diagram of Speed Controller of a DFIM.*

To obtain the *d*-axis and *q*-axis stator and rotor voltage with the implementation of vector control and based on the Eqs. (17) to (28), the block diagrams of stator and rotor current controllers are shown in Figures 3 and 4. Similarly, the speed controller based on PI and the calculation procedure of reference stator *q*-axis current is shown in Figure 5.

The generic form of open-loop transfer function Eqs. (30–32) for speed and currents controllers can be written as follows:

$$G_o = \frac{B}{s + A} \tag{39}$$

The transfer function of PI controller and IP controller are given as follows:

$$G_{PI}(s) = \left(K_P + \frac{K_I}{s}\right)e(s) \tag{40}$$

$$G_{IP}(s) = \frac{K_I}{s}e(s) - K_p a(s) \tag{41}$$

where, $e(s) = r(s) - a(s)$, $a(s)$ is actual value, $r(s)$ is reference value, K_P is proportional gain and K_I is the integral gain.

Combining the open-loop transfer function and controller transfer function the closed-loop transfer function can be written as follows:

$$G_{cPI}(s) = \frac{K_P Bs + K_I B}{s^2 + (A + BK_P)s + BK_I} \qquad (42)$$

$$G_{cIP}(s) = \frac{BK_I}{s^2 + (A + BK_P)s + BK_I} \qquad (43)$$

Considering two poles α_1 and α_2 (and they are chosen as $\alpha_1 = \alpha_2$) in the left-half of complex plane the gain of PI and IP controller can be calculated as follows:

$$\left.\begin{aligned} K_P &= \frac{2\alpha_1 - A}{B} \\ K_I &= \frac{\alpha_1^2}{B} \end{aligned}\right\} \qquad (44)$$

It has been seen from these closed-loop transfer function of Eq. (36) for PI controller that a zero is placed in the left-half plane. The overshoot problem of PI controller is raised due to the zero and the overshoot is increased as the proportional gain increased. On the other hand, the zero of PI controller can be eliminated by changing the structure which becomes as IP controller. The overshoot problem can be minimized by using IP controller instead of PI controller.

SIMULATION AND RESULT

At first the modeling of DFIM is done by using Eqs. (11–15) have been developed in Matlab/Simulink software. The used DFIM rating and parameters are given in Appendix. The controller of DFIM with vector control strategy based on PI controller as shown in Figures 3–5 and IP controller has been performed for step change of speed to perform simulation works for IP controller, just the PI controller of Figures 3–5 replaced by IP controller. In the simulation works, the gains are chosen same values for both PI controller and IP controller. The pole for speed controller is chosen 50 and for the four current controllers the value of pole is chosen of 500. Since the poles of closed-loop system are placed in the left-half plane, the controller performance is stable under the variation of load torque.

Figures 6 and 7 show the transient performance of speed control system of a DFIM based on the designed PI controller and IP controller. In simulation work, the variation of reference speed has been considered as follows: (**i**) the speed step-up from 0 rpm to 600 rpm at starting condition i.e. *t*=0 s, the speed step-up from 600 rpm to 1200 rpm at *t* =2 s, the speed step-down from 1200 rpm to 600 rpm at *t* =4 s, the speed step-down from 600 rpm to 0 rpm at *t* =2 s, the speed step-down from 600 rpm to 0 rpm at *t* =6 s.

Figure 6(a) and Figure 7(a) shows the performance of speed for PI controller and IP controller. The performance of both controllers is almost similar at steady-state conditions. But it is clear from these figures that the overshoot problem is totally vanished in the performance of IP controller. Figure 6(b) and Figure 7(b) evident that the stator *d*-axis current remaining zero at steady state condition and very small change in transient condition. From these Figures, it has been seen that the variations of stator current based on IP controller at transient condition is better as compared with that of PI controller. Figure 6(c) and Figure 7(c) shows that the stator *d*-axis flux is remaining constant which is the requirement of vector control strategy. Figure 6(d) and Figure 7(d) shows the performance of electromagnetic torque with applied load torque. Since the overshoot is occurred in PI controller the change of electromagnetic torque is larger as compared with the same performance in case of IP controller.

CONCLUSION

This paper presents the design of an IP controller for speed control of a DFIM. The simulation outcomes got on a DFIM the usage of the IP controller are presented in this paper. The overall performance of IP controllers used to be compared with that of traditional PI controlled system. From the comparative simulation outcomes of each IP and PI controllers, it can be concluded that the two controller's performances under steady-state condition are almost same. The most necessary advantage to reduce the overshoot can be obtained by the use of the proposed IP controller. The two controllers against system parameters variant are also verified. It is evident from the simulation outcomes that the performance of each IP and PI is almost similar when the parameters are varied.

Constructionally, there is little difference between PI and IP controllers and each implementation will be easy and simpler for that reason the use of IP controller can be more preferable than PI controller for practical application.

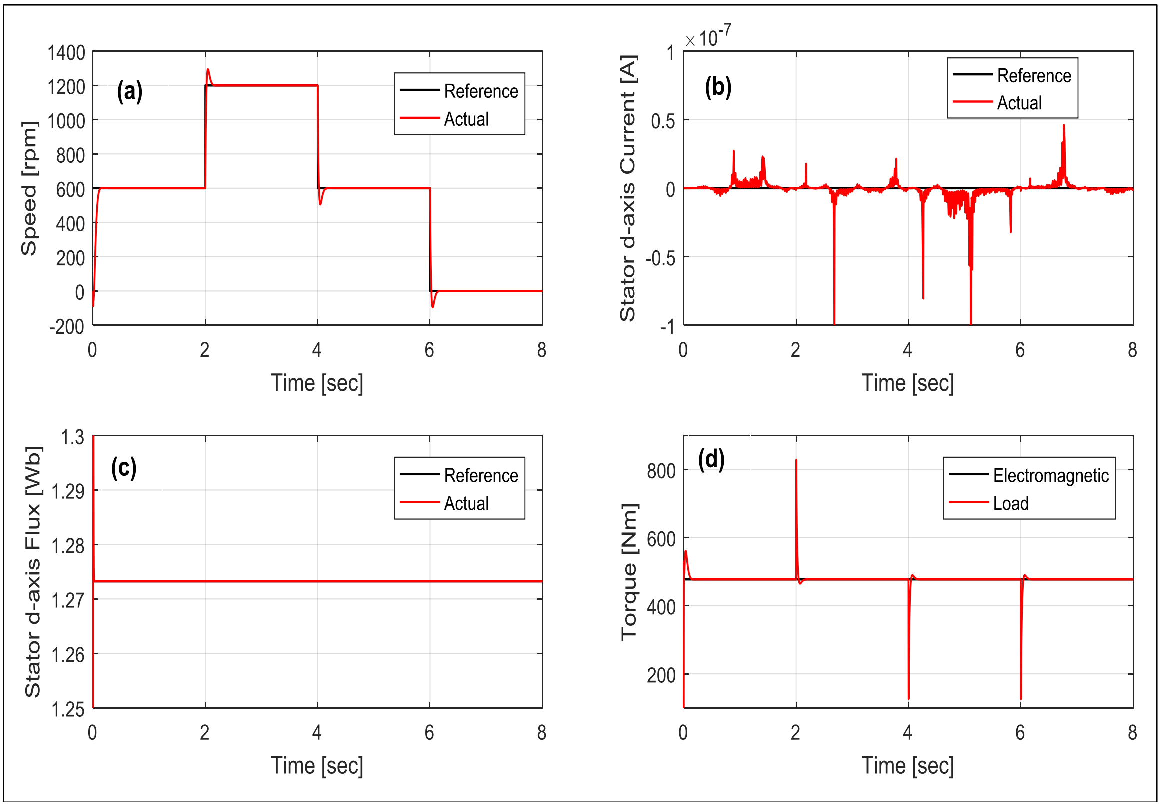

Fig. 6: *Transient Performance of Speed Controller Based on PI.*

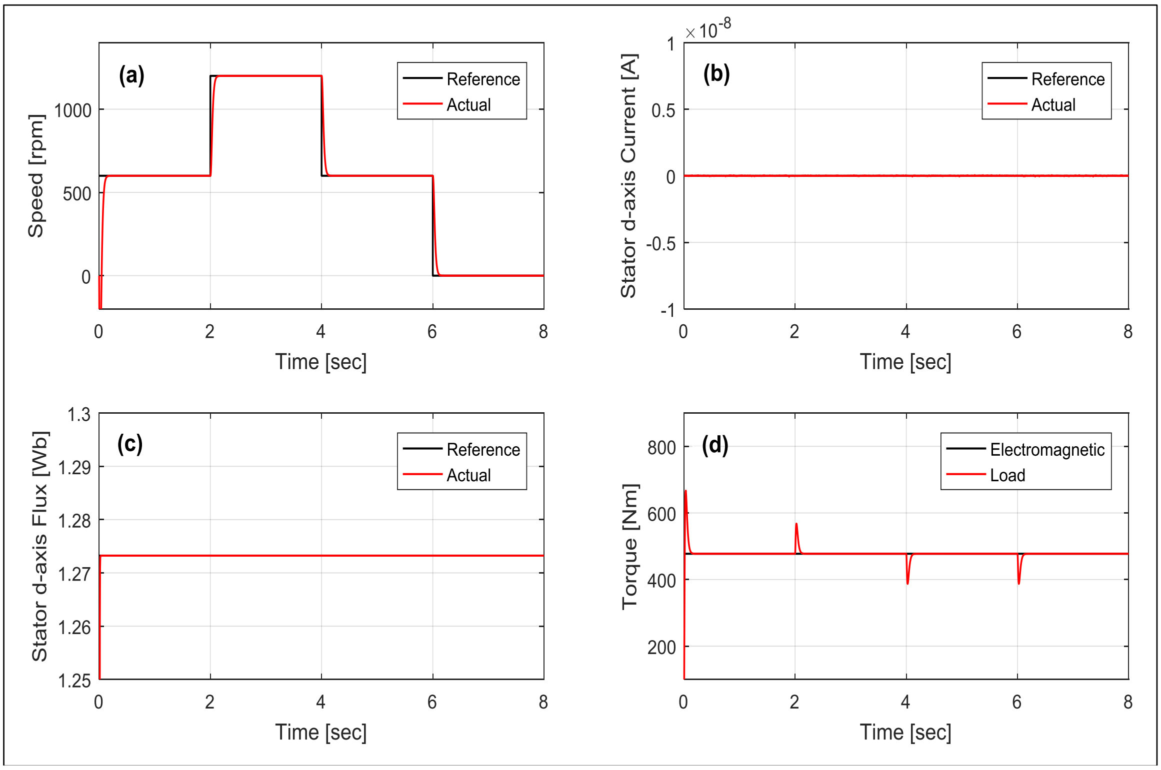

Fig. 7: *Transient Performance of Speed Controller Based on IP.*

APPENDIX

The DFIM ratings and parameters are given as follows:

Ratings	75 kW, 2 pole, 1500 rpm
Parameters	R_s =35.52 mΩ, R_r = 20.92 mΩ, L_s = 15.45 mH, L_r = 15.45 mH, L_m = 15.1 mH, J_m = 0.001 Kg-m^2, B_m = 0.07 N/(rad/s)

REFERENCES

1. Michael S, Vicatos, John A, Tegopoulos. A Doubly-Fed Induction Machine Differential Drive Model for Automobiles. *IEEE Trans. on Energy Conversion.*2003; 18(2): 225–30p.
2. Akagi H, Sato H. Control and Performance of a Flywheel Energy Storage System Based on a Doubly-Fed Induction Generator-Motor. *IEEE Power Electronics Specialists Conference.*1999; 27: 32–39p.
3. Panda D, Benedict EL, Venkataramana G, Thomas A. Lipo A Novel Control Strategy of the Rotor Side Control of a Doubly-Fed Induction Machine. *IEEE.* 2001; 1695–1702p.
4. Leonhard W. *Control Electrical Drives.* Germany, Springier verlag Berlin Heidelberg;1997.
5. Wang S, Ding Y. Stability Analysis of Field Oriented Doubly Fed induction Machine Drive Based on Computed Simulation. *Taylor & Francis Electrical Machines and Power Systems.*1993.
6. Morel L, Godfroid H, Mirzaian A, Kauffmann JM. Double-fed induction machine: converter optimisation and field oriented control without position sensor. *IEEE Proc. Electr. Power Appl.* 1998; 145(4): 360–368p.
7. Hopfensperger B, Atkinson DJ, Lakin RA. Stator flux oriented control of a cascaded doubly fed induction machine. *IEEE Proc. Electr. Power Appl.* 1999; 146(6).
8. Hopfensperger B, Atkinson DJ, Lakin RA. Stator flux oriented control of a cascaded doubly fed induction machine with and without position encoder, *IEE Proc. Electr. Power Appl.* 1999; 147(4): 241–250p.
9. Metwally HMB. et al. Optimum performance characteristics of doubly fed induction motors using field oriented control. *Elsevier Science Energy Conversion and Management*. 2002; 43: 3–13p.
10. Akagi H, Sato H. Control and Performance of a Doubly fed Induction Machine Intended for a Flywheel Energy Storage System. *IEEE Trans. on Power Electronics*. 2002; 17(1).
11. Djurovic M et al. Double Fed Induction Generator with Two Pair of Poles. *IEMDC Conferences of Electrical Machines and Drives IEEE.* 1995; 412:11–13p.
12. Leonhard W. Adjustable-Speed AC Drives Invited Paper. *Proceedings of the IEEE.* 1988; 76(4): 455–471p.
13. Longya Xu, Wei Cheng Torque,Reactive Power control of a Doubly Fed Induction Machine by Position Position Sensorless Scheme. *IEEE Transactions on Industry Applications.*1995; 31(3): 636–642p.
14. Peresada S, Tilli A, Tonielli A. Indirect Stator Flux-Oriented Output Feedback Control of a Doubly Fed Induction Machine. *IEEE Trans. On control Systems Technology*. 2003; 11875–888p.
15. Wang DH, Cheng KWE. General Discussion on Energy Saving Power Electronics Systems and Applications. *Proceedings 2004 First International Conference*. 2004; 298–303p.
16. Li Zang, Hasan K H. Neural Network Aided Energy Efficiency Control for a Field Orientation Induction Machine Drive. Proceeding of Ninth International Conference on Electrical Machine and Drives. *IEEE Conference Publication*. 1999; 468.
17. David E. Rice. A Suggested Energy-Savings Evaluation Method for AC Adjustable-Speed Drive Applications. *IEEE Trans. on Industry Applications.*1988; 24(6): 1107–1117p.
18. Jaime Rodriguez et al. Optimal Vector Control of Pumping and Ventilation Induction Motor Drives. *IEEE Trans. on Electronics Industry.* 2002; 49(4): 889–895p.
19. Drid S, Nait-Said MS, Tadjine M. Double flux oriented control for the doubly fed induction motor *Electric Power Components and Systems Journal.* 2005: 33(10).
20. Drid, Said, Makouf, Abdesslam, Nait-Said, Mohamed-Said,Tadjine, Mohamed. Highly Efficient Control of the Doubly Fed Induction Motor. *Journal of Electrical Engineering and Technology.* 2007; 478–484p.

21. Peter Vas.Vector Control of AC Machines. Clarendon Press; New York: Oxford University Press 1990.
22. Liaw CM, Lin FJ, Kung YS. Design and Implementation of Highperformance Induction Motor Servo Drive. *IEEE Proc.*-B.1993; 140: 241–248p.
23. Mannan MA, Murata T, Tamura J. Energy Model Based Direct TorqueControl of Induction Motor Using IP Controllers. *Journal of International Conference on Electrical Machines and Systems.* 2012; 1: 9–15p.
24. Mannan MA. Integral Plus Proportional Controller Based Speed Control of Direct Torque Controlled IPMSM. *American Academic and Scholarly Research Journal*. 2013; 5: 80–90p.
25. Riadh RR, Imran MA, Shobial AM, Shahjalal M, Mannan MA. SpeedControl of An Inverter Fed Three-Phase Induction Motor Using IP Controller Considering Core Loss and Stray Load Loss. *Trends in Electrical Engineering.* 2015; 5: 28–35p.

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