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Research on AC Variable Frequency Speed Regulation System

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Abstract: In view of shortcomings existing in shear speed control system, shearer AC speed regulating system is designed and studied. The mathematical model of three-phase asynchronous motor in rotating coordinate system is established, and PWM technology of space vector is discussed. Software and hardware of the asynchronous motor vector control variable frequency speed regulating system are designed. The simulation of system based on Matlab is made and the correctness and feasibility of the system is verified. Results show that, good dynamic performance of the system can be obtained when start motor, adjust rotational speed and load and shutdown.

Key words: Shear, speed control system, SVPWM, vector control, rotating coordinate system

INTRODUCTION

The development with power of comprehensive mechanized coal mining technology and high production and efficient mine construction, it become a trend for shearer hauled by motor. Motor hauled system of shearer has four kinds according to speed control methods, DC motor speed control, induction motor frequency control, electromagnetic speed control and switched reluctance motor speed control (Wang *et al*., 2012; Zhang *et al*., 2012a; Wei *et al*., 2006). The explosion-proof DC motor with large volume and complex structure has poor reliability. Switch reluctance motor needs to install position sensor on rotor and this could be reduce the operation reliability (You *et al*., 2012; Vafakhah *et al*., 2010). The efficiency of electromagnetic speed control system is low, even at low speed. Before vector control appearing, AC speed control system use constant ratio control method V/F also called scalar control, at low speed and dynamic situations, as acceleration or deceleration and modified load, the system shows apparent defect (Reddy *et al*., 2011). Vector control can eliminate the scalar control defects and greatly improve the control performance of the system. It has great significance for solve the problem of shearer speed control system by improve the dynamic performance of induction motor system and use vector control technique (Wang *et al*., 2010; Hongliang *et al*., 2012; Zhang *et al*., 2012b; Xiao and Zhu, 2012). In this study, shearer AC speed regulating system is designed and studied to solve shortcomings existing in shear speed control system.

SPACE VECTOR PULSE WIDTH MODULATION (ABBREVIATED AS SVPWM)

Some basic space vectors and sector distribution is shown in Fig. 1. the tow-phase stationary coordinate αβ can be get from rotation coordinates dq through coordinate transformation. Specific transformation formula is as follows:

$$\begin{bmatrix} u_\alpha \\ u_\beta \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\vartheta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} u_d \\ u_q \end{bmatrix} \quad (1)$$

Set $U_{\alpha r}$ and $U_{\beta r}$ as projection on the α axis and β axis of reference voltage vector U_r, then:

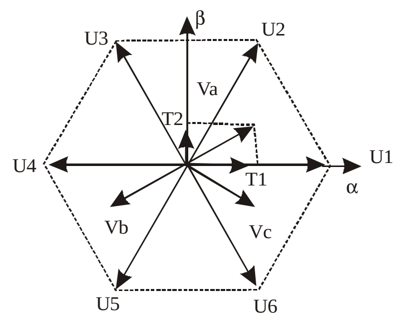

Fig. 1: Voltage space vector

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Table 1: Sector judge table of reference voltage vector

N	1	2	3	4	5	6
Sector	2	5	1	4	3	6
x	1	0	1	0	1	0
y	0	1	1	0	0	1
z	0	0	0	1	1	1

Table 2: Assignment table of T_1 and T_2

Sector	1	2	3	4	5	6
T_1	Y	-Y	X	-X	-Z	Z
T_2	X	Z	-Z	-Y	Y	-X

$$U_r = |U_r|(\cos\theta + j\sin\theta) = U_\alpha + jU_\beta \tag{2}$$

Defy three variables U_x, U_y and U_z satisfy the following relations:

$$\begin{cases} U_x = U_{\beta r} \\ U_y = \dfrac{\sqrt{3}U_{\alpha r} - U_{\beta r}}{2} \\ U_z = -\dfrac{\sqrt{3}U_{\alpha r} + U_{\beta r}}{2} \end{cases} \tag{3}$$

Defy variables x, y and z, if $U_x>0$, then, x = 1, else x = 0. If U_y, then. y = 1, else y = 0. If $U_x>0$, then, z = 1, else z = 0. Set N = x+2y+4z, the relationship between N and U is shown in Table 1.

Take the first sector as an example to calculate the synthetic reference space vector and space voltage vector synthesis function time:

$$\begin{cases} T_1 = \dfrac{\sqrt{3}T_c U_r}{V_{dc}}\sin(\dfrac{k\pi}{3} - \theta) \\ T_2 = \dfrac{\sqrt{3}T_c U_r}{V_{dc}}\sin(\theta - \dfrac{(k-1)\pi}{3}) \\ T_0 = T_c - T_1 - T_2 \end{cases} \tag{4}$$

In which, k = 1,2,3,4,5,6. When the effect time is saturate, $T_c<T_1+T$

$$T_1 = \frac{T_1}{T_1 + T_2}\cdot T_c \tag{5}$$

$$T_2 = \frac{T_2}{T_1 + T_2}\cdot T_c \tag{6}$$

Make the value of X, Y and Z as:

$$\begin{cases} X = \dfrac{\sqrt{3}T_c V_{\beta r}}{V_{dc}} \\ Y = \dfrac{\sqrt{3}T_c}{V_{dc}}\left[\dfrac{\sqrt{3}}{2}V_{\alpha r} - \dfrac{1}{2}V_{\beta r}\right] \\ Z = \dfrac{\sqrt{3}T_c}{V_{dc}}\left[\dfrac{\sqrt{3}}{2}V_{\alpha r} + \dfrac{1}{2}V_{\beta r}\right] \end{cases} \tag{7}$$

For different sectors, two adjacent space vector time T_1 and T_2 can obtain according to Table 2.

MATHEMATICAL MODEL OF INDUCTION MOTOR VECTOR CONTROL SYSTEM

Induction motor is a high order, nonlinear and strong coupling of multi variable system. In a study of induction motor variable mathematical model, often make the following assumptions (Chen *et al*., 2012):

- Ignores space harmonics, a three-phase winding symmetry, magnetic along the air gap circumferentially according to sine distribution
- Ignore the magnetic saturation, the winding inductance and mutual inductance is constant
- Ignore iron loss
- Ignore the effect of temperature and frequency changes to the motor winding resistance

In these conditions, after coordinate transformation the system equation in A, B, C coordinates convert to M-T coordinate mathematical model. In M-T coordinate, coordinate axis M and T rotate at synchronous speed ω_1, the M axis along the direction of rotor flux vector ψ_2 and T axis is perpendicular to vector ψ_2. $\psi_2 = \psi_{m2}, \psi_{t2} = 0$. Short circuit of rotor winding and $u_{m2} = 0$. The mathematical model of induction motor in M-T coordinate is followed:

- Voltage equation:

$$\begin{bmatrix} u_{m1} \\ u_{t1} \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} R_1 + L_s p & -\omega L_s & L_m p & -\omega L_m \\ -\omega_1 L_s & R_1 + L_s p & \omega_1 L_m & L_m p \\ L_m p & 0 & R_2 + L_r p & 0 \\ \omega_s L_m & 0 & \omega_s L_r & R_2 \end{bmatrix} \begin{bmatrix} i_{m1} \\ i_{t1} \\ i_{m2} \\ i_{t2} \end{bmatrix} \tag{8}$$

- Flux equation:

$$\begin{bmatrix} \psi_{m1} \\ \psi_{t1} \\ \psi_{m2} \\ \psi_{t2} \end{bmatrix} = \begin{bmatrix} L_s & & L_m & \\ & L_s & & L_m \\ L_m & & L_r & \\ & L_m & & L_r \end{bmatrix} \begin{bmatrix} i_{m1} \\ i_{t1} \\ i_{m2} \\ i_{t2} \end{bmatrix} \tag{9}$$

- Torque equation:

$$T = p_m \frac{L_m}{L_r} i_{t1} \psi_2 \tag{10}$$

- The relationship between slip frequency ω_5 and torque:

$$\omega_s = p_m \frac{R_2}{\psi_2^2} T_e \tag{11}$$

where, R_1, R_2 are equivalent resistance of stator and rotor. p is differential operator. p_m is motor number of pole-pairs. u_{m1}, u_{t1} are voltage component in M-T axis of stator and rotor. i_{m1}, i_{t1}, i_{m2}, i_{t2} are current component in M-T axis of stator and rotor. T_e is electromagnetic torque.

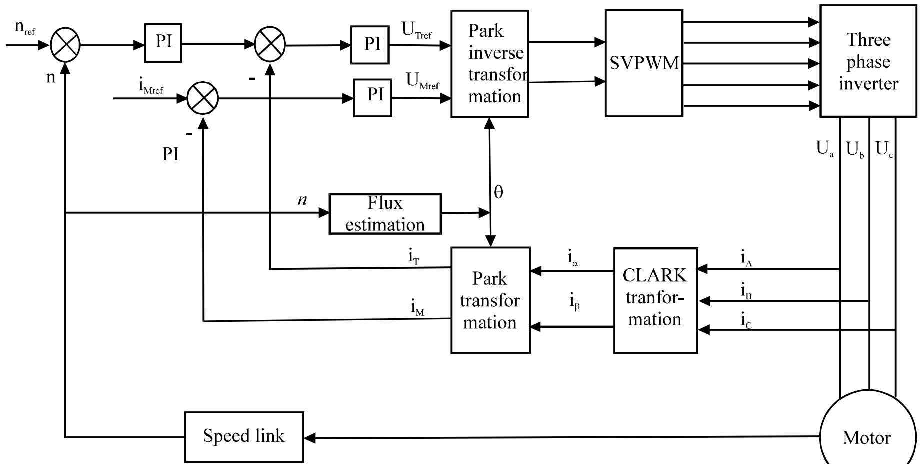

Fig. 2: Overall diagram of SVPWM variable speed system based on DSP induction motor

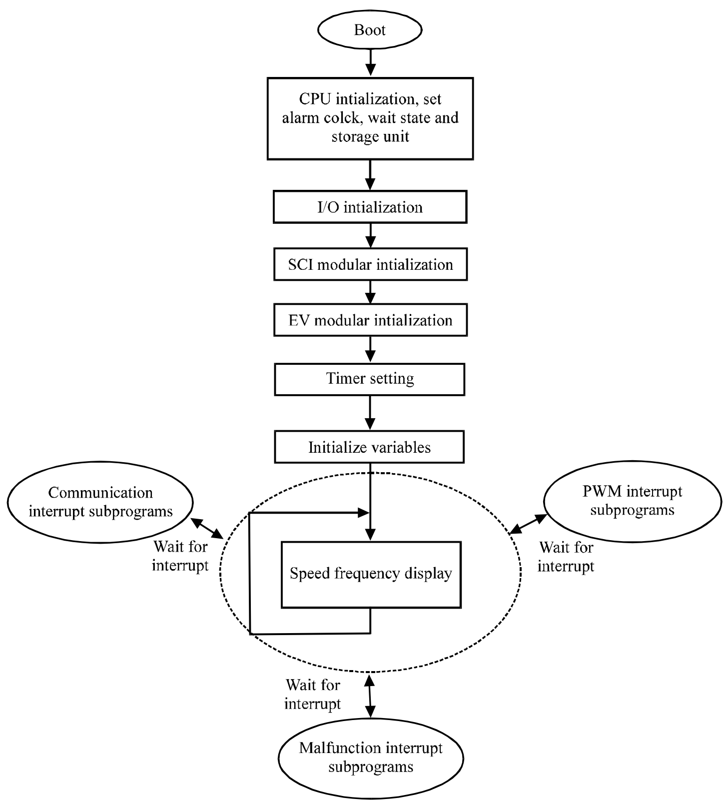

Fig. 3: Main program flowchart of control system

According to the mathematical model above and SVPWM, vector control for variable speed system is designed as Fig. 2.

Simulation analysis of control system

System software design: The software of the system has two parts, one is control display program of host computer, the other is control program of lower computer. The effect of the host computer is setting motor parameter, include rotational speed and current velocity information transfer from the lower computer. Meanwhile the effect of the lower computer is current sampling, velocity sampling, vector transformation, SVPWM output, serial communication, speed display and fault output. The main program flowchart of control system is shown as Fig. 3.

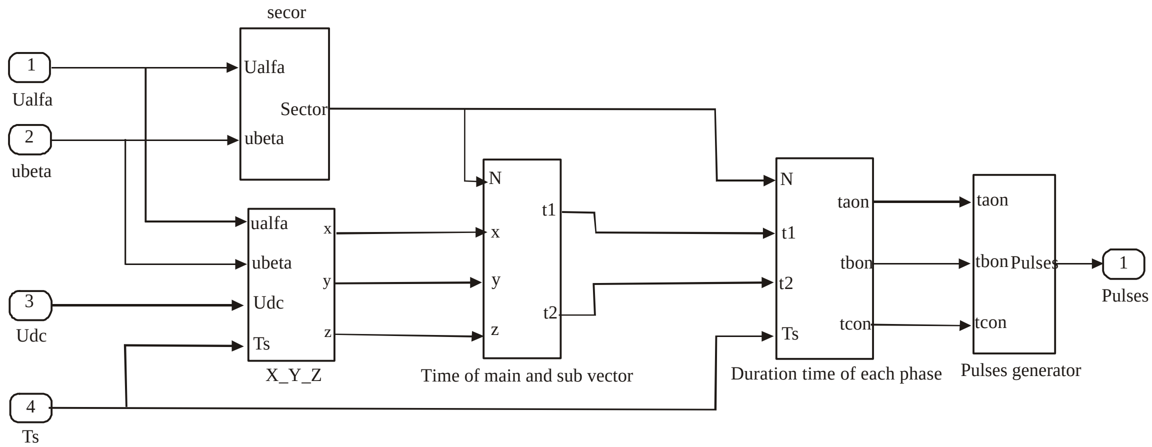

Fig. 4: SVPWM simulation module

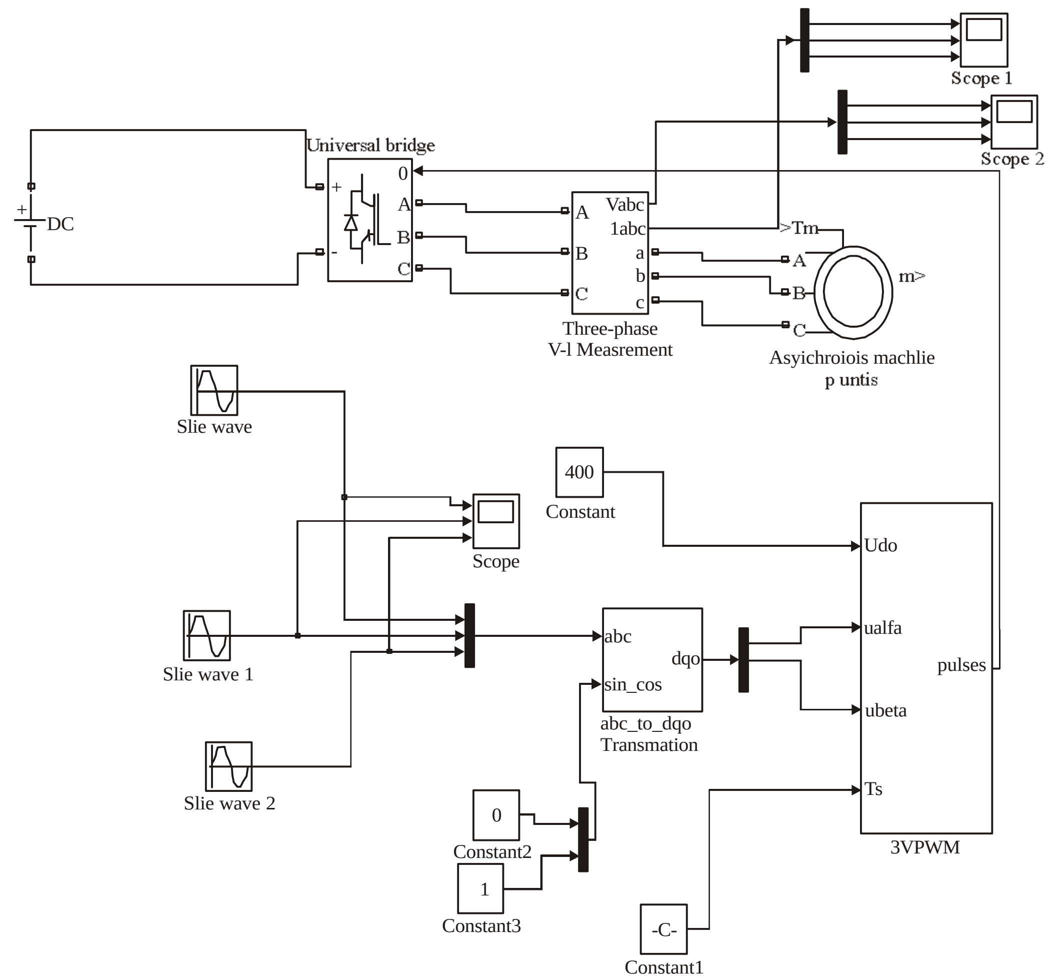

Fig. 5: SVPWM algorithm simulation model

Algorithm simulation of SVPWM: The simulation module of SVPWM is as follows Fig. 4.

Using voltage type inverter circuit simulation, the switching frequency is 0.00002 sec and input ideal three-phase voltage 50 Hz, 300 V. When DC input voltage is 400 V, algorithm simulation model of SVPWM is shown in the Fig. 5 as follows.

Simulation waveforms are shown in Fig. 6.

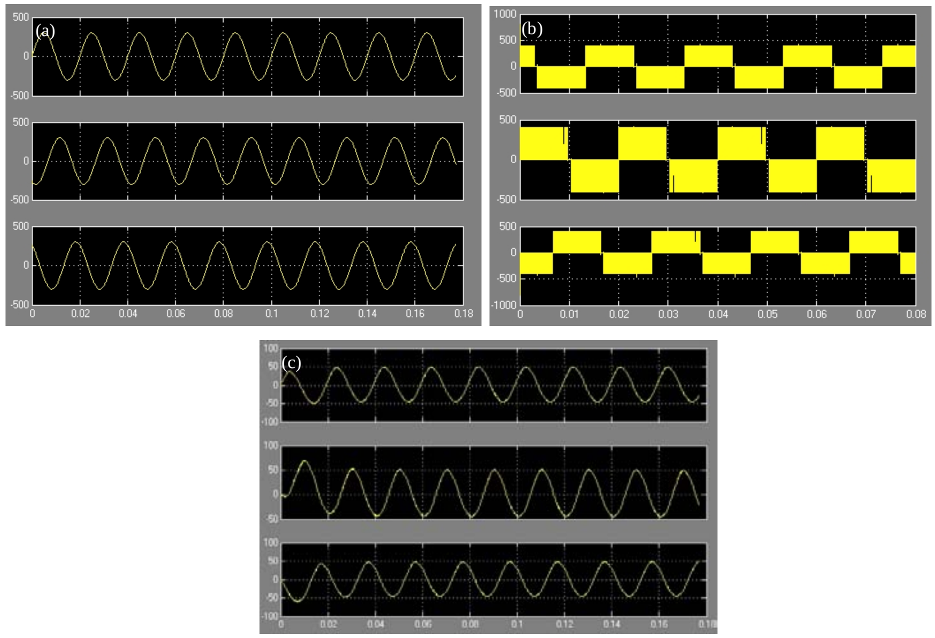

Fig. 6(a-c): Simulation waveforms, (a) Given sine wave, (b) Output line voltage, (c) Output three-phase current

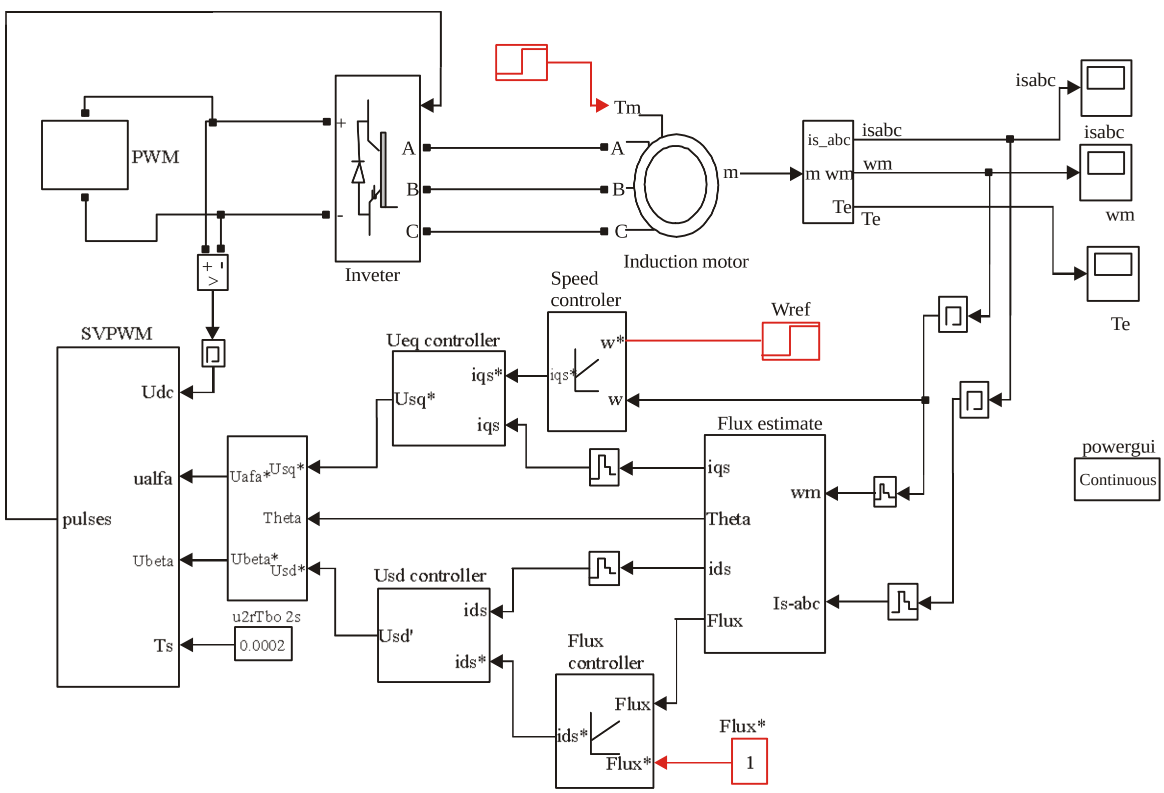

Fig. 7: Main Circuit of control system based on SVPWM

Simulation model of induction motor variable frequency speed control system using vector control based on voltage space vector technique are shown in Fig. 7, 8 and 9. The figures represent main circuit of

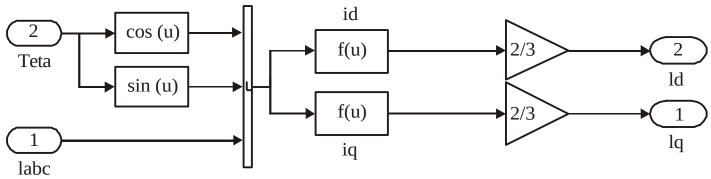

Fig. 8: Three-phase stationary to rotating two-phase model

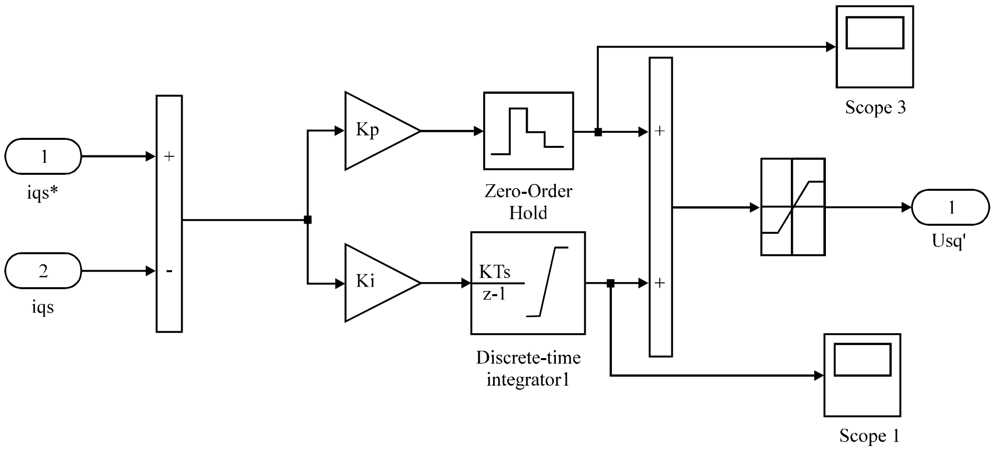

Fig. 9: Proportional integral controller model

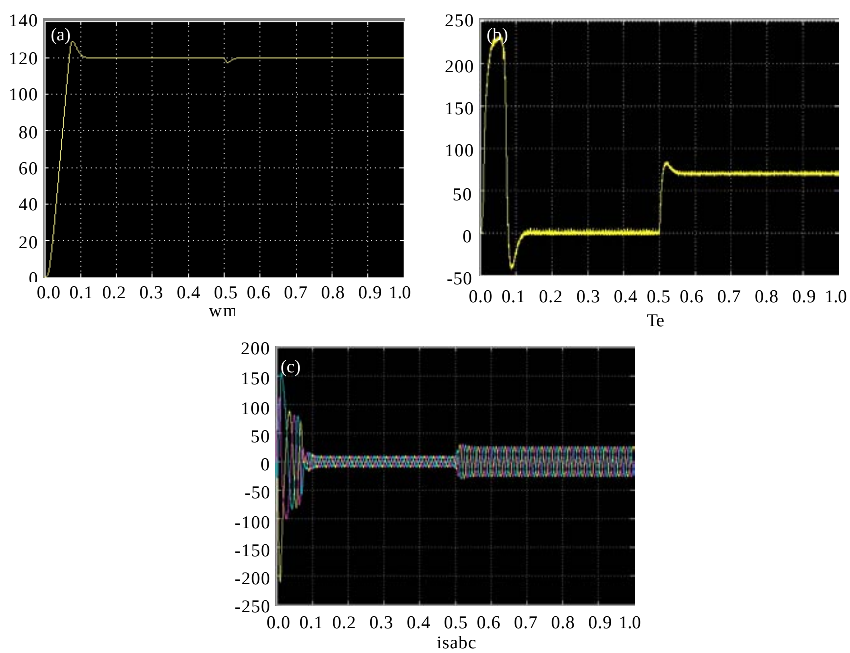

Fig. 10(a-c): Simulation results of sudden load, (a) Sudden load speed waveform, (b) Sudden load toque waveform, (c) Sudden load three-phase stator current waveforms

control system, three-phase stationary to rotating two-phase model and proportional integral controller model. It also uses SVPWM for control in rectifier side.

Rated power and speed of induction motor are 22 kw and 1750 r min^{-1} and rated voltage and frequency are 380 V and 50 Hz. Other parameters of the motor are that, R_S = 0.5257Ω, Rr = 0.3017Ω, Ls = 4.9 mH, Lr = 4.9 mH, Lm = 116.6 mH, J = 0, 102 kg m^{-2}. When rotational speed is 120 rad s^{-1} and a sudden load increase to 70 Nm^{-1} in 0.5 s, the wavefor of speed, torque and current are shown in Fig. 10. If the speed increases from 100-120 rad sec^{-1} after 0.5 sec and set the torque is 70 N m^{-1}, the waveform

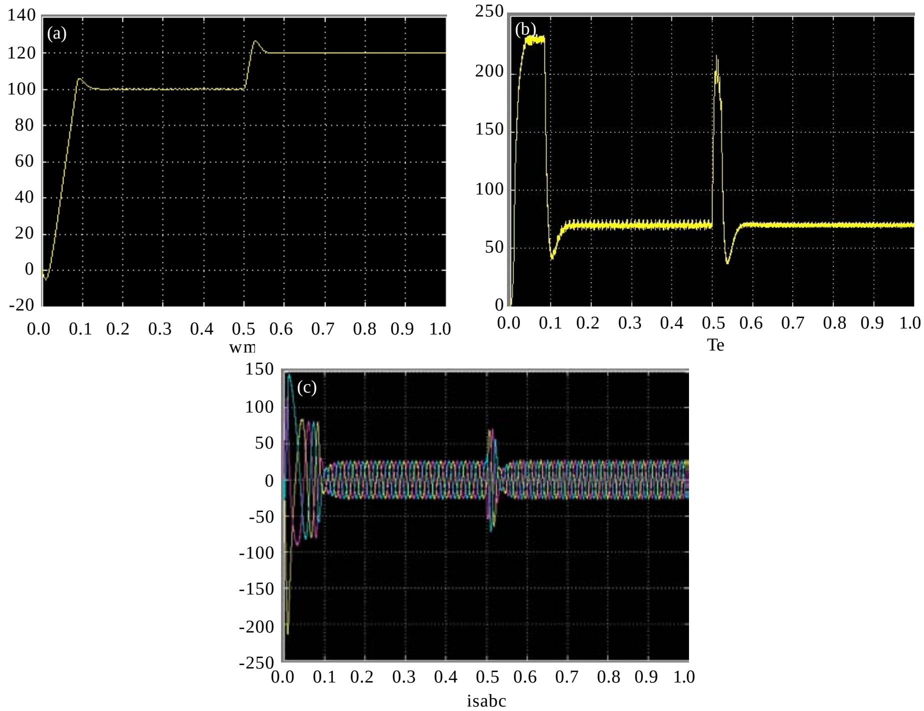

Fig. 11(a-c): Simulation results after the adjustment speed in 0.5 sec, (a) Speed at 0.5 sec rose after the wave speed, (b) After the adjustment speed in 0.5 sec torque waveform, (c) After the adjustment speed in 0.5 sec three-phase stator current waveforms

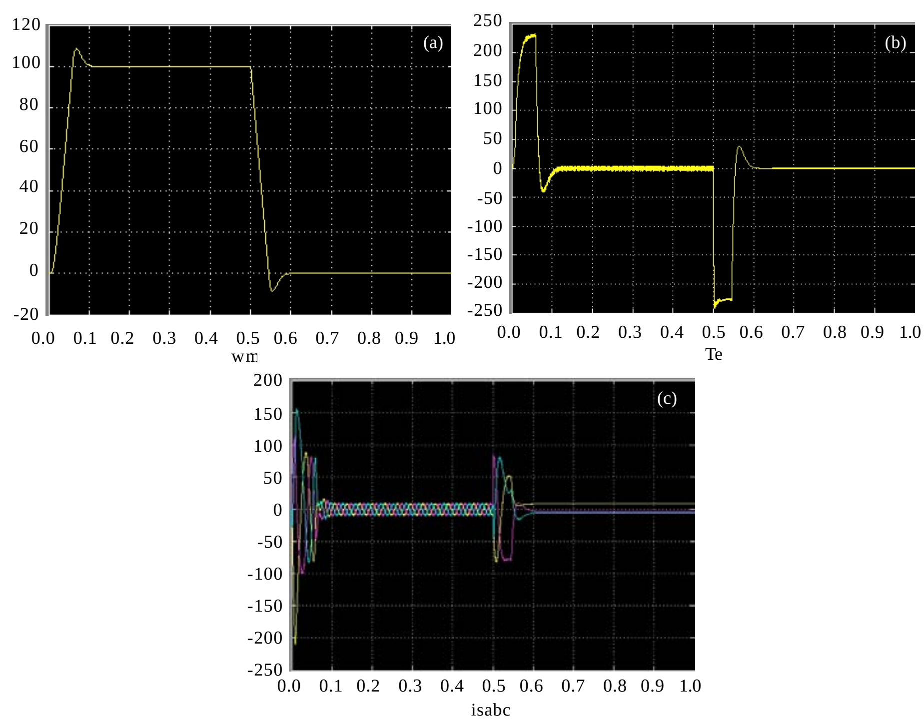

Fig. 12(a-c): Simulation results in 0.5 sec braking, (a) In 0.5 sec braking wave speed, (b) In 0.5 sec braking torque waveforms, (c) In 0.5 sec braking three-phase stator current waveforms of speed, torque and current are shown in Fig. 11. In 0.5 sec when the motor brake, the results show in Fig. 12.

CONCLUSION

It can conclude that from the simulation results, the system can obtain good dynamic performance when start motor, adjust rotational speed and load and shutdown. Speed control system can well track the given speed and verify the correctness and feasibility of the design. But for the proportion and integral of PI regulation, the parameters still need engineering test according to the actual site. Only in ideal PI regulation parameters action, it can achieve the desired effect.

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