Speed Control of Induction Motor Drive Based on DC Link Measurement

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Abstract

Induction motors are the most frequently used machines in different electrical drives. About 80% of all industrial loads utilize induction motors for various applications which require speed control for its implementation. Speed control of an induction motor requires position feedback information from an encoder, or a hall sensor to a controller unit. These feedback signals, which often pickup noise due to electromagnetic interference, can change the performance of the motor control system. In this project the feedback signals like current and speed are not taken directly from the motor side, instead it is estimated from the current and voltage measured from the dc link. The phase voltages and line currents are reconstructed from the measured dc link current and voltage. An algorithm is used to reconstruct the voltage and current. Speed is estimated, where the inputs to the estimators are reconstructed stator voltage and current. It reduces the number of sensors used for measuring the current and voltage which avoids the noise. It also reduces the use of mechanical sensor as the rotor speed is not measured directly. As the values are estimated from dc link it is less dependent on machine parameters. The proposed speed control scheme is simulated using Matlab/Simulink software.

1. Introduction

A three-phase motor is the best type to use for variable speed control. The three-phase motor can give good torque performance at all operating speeds. Single- phase motors are also used, but they have limited performance in the low-speed range. Depending on the motor, there may be significant torque pulsations when a single-phase induction motor is run at low speeds.

Three-phase voltage source inverters with closed-loop current regulator are widely used in various applications. Isolated current sensors are used in two or three of the inverter lines to provide the current feedback signals. Accurate measurements of these currents in the presence of high di/dt and dv/dt switching transients are difficult. It is also very complex to get the current sensors with equal gain over a wide range of frequencies, voltages and currents. With more than one current sensor, the related signal conditioning circuits increases the complexity, cost and size of the motor drive. An alternative to direct measurement of the two phase currents is the reconstruction of phase currents by using the measured dc link current and the switching vector information of the inverter. Meanwhile only one current sensor is used in the dc link, basically all the three phase currents are measured with the same gain and no dc-offset occurs due to the transducer. A current sensor is normally present in the dc link of most drives that is employed for the over-current protection.

Variable speed control of an IM is very simple. The frequency and amplitude of the drive voltage must be varied to change the motor speed. The control technique used which is similar to that of field oriented control. But here there is no need of Clarke and park transformation. The line current and phase voltages are derived using the switching vectors of inverter. The stationery d-q values of stator current and stator flux are found using FOC technique. The electromagnetic torque is required as it need to find the reference value of the rotor speed. It is estimated using the stator flux. To estimate the speed, the synchronous speed and slip speed of motor is required. From the flux angle the synchronous speed is calculated. The slip speed is calculated using the electromagnetic torque and constant slip value. By subtracting the slip speed from the synchronous speed, the rotor speed is estimated.

The line current is taken as reference and the inverter switching signals are generated, and the speed of motor is controlled.

2. Proposed scheme

Figure 1 shows the block diagram of the proposed scheme. It consists of speed loop, estimation block and current regulator. The DC current and voltage are measured from the dc link. The reconstruction algorithm is used to estimate three phase current and voltages. The dc link voltage and current is given as input to the algorithm. Estimator is used to calculate speed from the reconstructed 3-phase voltage and current. The calculated speed is compared with the reference speed. Speed controller and current regulator were used and pulse is generated and given to the inverter. With that inverter pulse the speed of the induction motor is controlled.

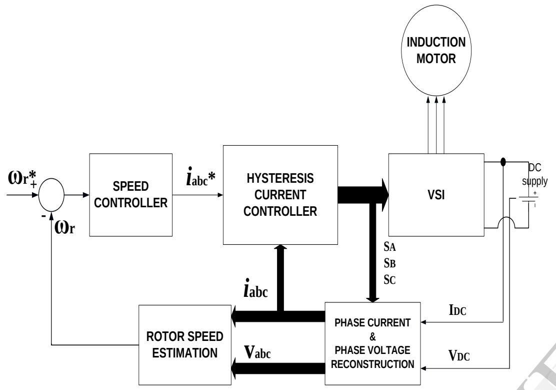

Figure 1. Block Diagram of Speed Control Technique

3. Stator voltages and current reconstruction from dc link

Speed can be derived from the stator voltages and currents expressed in d-q reference frame with the help of torque estimated. Generally, IGBTs are used because feedback diodes are used as switch in inverters. Due to the reverse recovery effect of diode, when a switch is being turned-on and the conducting diode at the same leg is being blocked off by this turn-on. This leg is in fact shorted and at this moment such that a positive current spike will appear at the dc link side.

3.1. Switching states

In the normal state, there are eight switching states of inverter which can be expressed as space voltage vector (SA,SB,SC) such as (0,0,0), (0,0,1), (0,1,0), (0,1,1), (1,0,1), (1,0,0), (1,1,0) and (1,1,1). SA =1 means upper switch of leg A is on while the lower one is off, and vice versa. The same switching logic is applicable to SB and SC also. Among the above eight voltage vectors, (0, 0, 0) and (1, 1, 1) are termed as zero vectors while the other six as active vectors. The switching vectors describe the inverter output voltages.

3.2. Phase voltage & line current reconstruction

For different voltage vectors, the phase voltage that will appear across stator winding can be determined by circuit observation. It is assumed that the stator winding is star connected. The expressions for the reconstruction of three phase voltages are as follows.

$$\tilde{v}_a = \frac{V_{dc}}{3}(2S_A - S_B - S_C) \quad (1)$$

$$\tilde{v}_b = \frac{V_{dc}}{3}(2S_A - S_B - S_C) \quad (2)$$

$$\tilde{v}_c = \frac{V_{dc}}{3}(2S_A - S_B - S_C) \quad (3)$$

The stator voltages are expressed in stationary d-q frame as:

$$\tilde{v}_{qs} = \tilde{v}_a = \frac{V_{dc}}{3}(2S_A - S_B - S_C) \quad (4)$$

$$\tilde{v}_{ds} = \frac{1}{\sqrt{3}}(v_b - v_c) = \frac{V_{dc}}{3}(S_B - S_C) \quad (5)$$

The relationship between the applied active vectors and the phase currents measured from the dc link. It is clear that at-most, one phase current can be related to the dc.-link current at every instant. The reconstruction of phase currents from the dc-link current can be realized easily only if two active vectors are present for at least enough time to be sampled. If the PWM frequency is high, the phase current does not change much over one PWM period. Hence, a reconstructed current calculated from the dc link current gives a reasonable approximation of the actual current. In terms of switching vectors and I_{dc}, the three ac line currents can be derived as follows.

$$\tilde{i}_a = I_{dc}(S_A - \frac{S_B}{2} - \frac{S_C}{2}) \quad (6)$$

$$\tilde{i}_b = I_{dc}(-\frac{S_A}{2} + S_B - \frac{S_C}{2}) \quad (7)$$

$$\tilde{i}_c = I_{dc}(-\frac{S_A}{2} - \frac{S_B}{2} + S_C) \quad (8)$$

The stator currents are expressed in stationary d-q frame as:

$$i_{qs}{}^{s} = i_a;\ i_{ds}{}^{s} = \frac{1}{\sqrt{3}}(2i_b + i_a) \quad (9)$$

$$i_{qs}{}^{s} = i_a;\ i_{ds}{}^{s} = \frac{-1}{\sqrt{3}}(2i_c + i_a) \quad (10)$$

$$\tilde{i}_{qs}{}^{s} = -(i_b - i_c);\ i_{ds}{}^{s} = \frac{1}{\sqrt{3}}(i_b + i_c) \quad (11)$$

4. Feedback signal estimation

By using the Matlab simulation tool, the improved performance of the system is simulated. The feedback signals required to simulate the proposed scheme i.e., flux, torque and rotor speed are estimated as:

4.1. Estimation of Flux and torque

The stator flux in stationary d-q frame and thus can be obtained on integration of the phase voltage minus voltage drop in the stator resistance Rs

$$\widetilde{\Psi}_{ds} = \int (\tilde{v}_{ds} - R_s \tilde{i}_{ds})dt \qquad (12)$$

$$\widetilde{\Psi}_{qs} = \int (\tilde{v}_{qs} - R_s \tilde{i}_{qs})dt \qquad (13)$$

$$|\widetilde{\Psi}_s| = \sqrt{\widetilde{\Psi}_{ds}{}^2 + \widetilde{\Psi}_{qs}{}^2} \qquad (14)$$

$$\cos\theta_e = \frac{\widetilde{\Psi}_{ds}}{|\widetilde{\Psi}_s|};\ \sin\theta_e = \frac{\widetilde{\Psi}_{qs}}{|\widetilde{\Psi}_s|} \qquad (15)$$

Where θ_e is the stator flux angle with respect to the q-axis of the stationary d-q frame.

The electromagnetic torque(Te), which can be expressed in terms of stator currents and stator flux as follows:

$$T_e = \frac{3P}{4}(\widetilde{\Psi}_{ds}\widehat{\iota_{qs}}^s - \widetilde{\Psi}_{qs}\widehat{\iota_{ds}}^s) \qquad (16)$$

4.2. Estimation of Rotor Speed

To estimate the rotor speed, the synchronous speed should be known. It can be calculated from the expression of the angle of stator flux as:

$$\theta_e = \tan^{-1}\frac{\widetilde{\Psi}_{ds}}{\widetilde{\Psi}_{qs}} \qquad (17)$$

$$\widehat{\omega}_e = \frac{d\theta_e}{dt} \qquad (18)$$

The slip speed is also required for estimating rotor speed, which its compensation can be derived using the steady-state torque speed curve

$$\widehat{\omega}_{sl} = K_s \tilde{T}e \qquad (19)$$

Where Ks- rated slip frequency/rated torque and it can be derived from the name plate of the machine.

The rotor speed is than given by subtracting the synchronous speed from slip speed

$$\widehat{\omega}_r = \widehat{\omega}_e - \widehat{\omega}_{sl} \qquad (20)$$

5. Simulation and hardware results

The switching signals for inverter are generated by comparing the command ac currents with reconstructed ac currents.

The Figure.2 shows the overall simulation block of the speed control system.

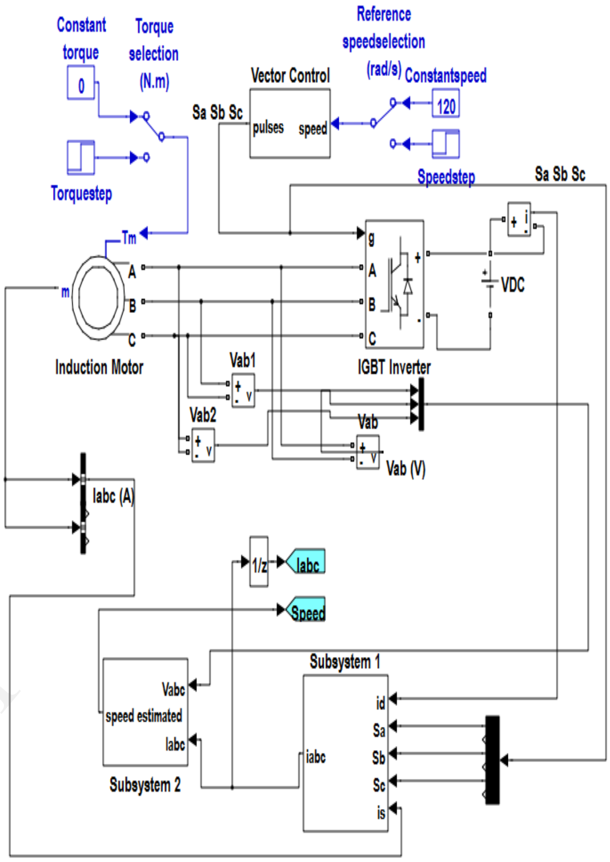

Figure 2. Simulation block of overall system

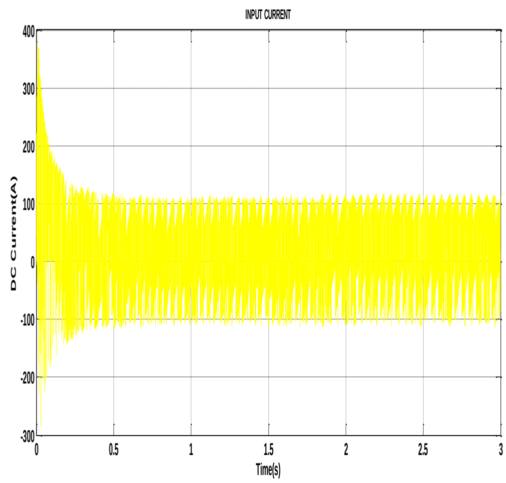

Figure 3. Input DC current

The input dc current is shown in Figure.3 which has some ripples due to rectification.

Figure.4 DC offset current values of both calibrated and measured. It is helpful for reconstruction which is used to reduce dc offset in the inverter side. The calibrated value is minus from the measured value.

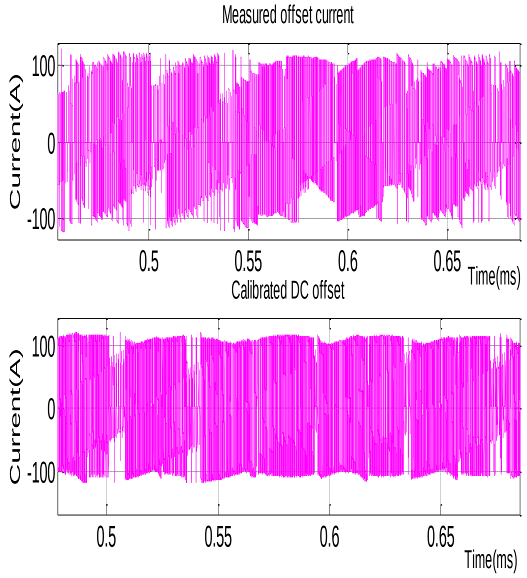

Figure 4. DC Offset Current

The Figure 5 shows the reconstructed three phases current. The algorithm is used to reconstruct the stator currents. The algorithm required the dc offset values that are shown in the above Figure.2.

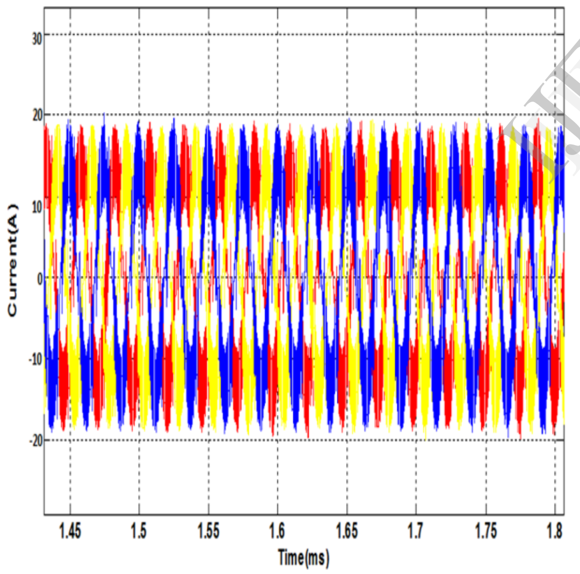

Figure 5. Estimated Three Phase Current

The Figure.6 shows estimated rotor speed for 120rps by using the three phase currents. Thus the rotor speed is compared with reference speed. Based on that switching signals are generated and given to the inverter.

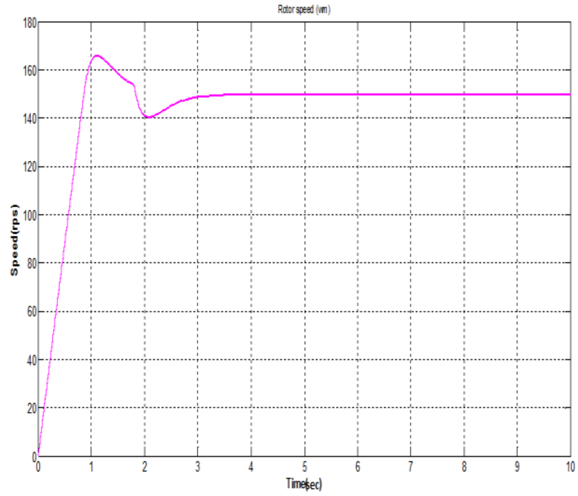

Figure 6. Estimated rotor speed

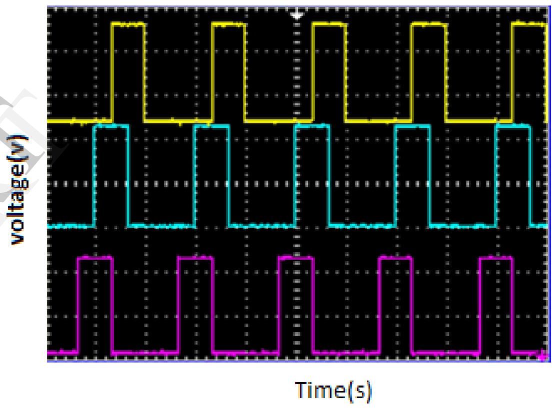

Figure 7. Hardware output of Inverter

The Figure 7 shows three phase inverter output. It can be seen that each switch conducts 120 degree and turning on the adjacent switch staggered by 60 degrees. The Figure.8 shows the gate pulse given to the inverter.

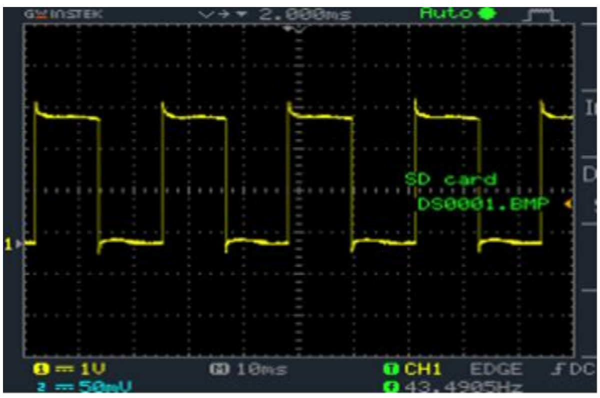

Figure 8. Gate pulse for Inverter

6. Conclusion

The proposed technique uses only dc link voltage and dc link current measurements to generate the estimates of line currents, phase voltages, flux and rotor speed. If the dc link voltage is assumed as constant, one current sensor in the dc link is sufficient to give the estimates of all required feedback variables. It reduces the use of sensors in the stator side and also it does not require any mechanical sensors for measuring the motor speed. Simulation and Hardware results confirm the effectiveness of the proposed scheme.

7. References

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