Low Cost Single Shunt Current Sensor Induction Motor DTC

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Abstract

A Sensorless three phase induction motor under direct torque control is proposed in this paper. The proposed method is very simple because it uses the information obtained from one shunt resistor .That is in order to evaluate the torque use the dc current to reconstruct the stator current. So from the above details our aim is to develop a low cost high performance induction motor drive. The shortcomings are also presented. The effectiveness of proposed scheme is confirmed by simulation in MATLAB software.

Keywords: Direct torque control (DTC), induction motor (IM), single current sensor, sensor count reduction

1. Introduction

DTC of induction motors has very simple control structure so it can be used in many industrial applications [1]. The other merits are fast torque response and robustness against motor parameter variation. So without using current loop sensor, DTC scheme achieves the closed loop control of the motor stator flux and electromagnetic torque

In order to evaluate the values of stator flux and electromagnetic torque DTC scheme need the information about the stator current and dc–link voltage. The current feedback for the closed loop can be obtained by sensing instantaneous phase currents by current sensors. In this paper single current sensor operation has been proposed to reconstruct the phase currents from the dc- link current sensor. [6]

The procedure used in this paper operates in two stages. First stage is that, it predicts the stator current from the model of the motor. In second stage it adjusts the prediction by the use of sensed dc link current. So by calculating the voltage and the current derived from a single dc-link voltage sensor and dc-link current sensor, the stator flux vector and electromagnetic torque can be calculated .Single dc-link voltage sensor means the voltage divider and dc-link current sensor means the shunt resistor. And also this procedure doesn't need another motor parameters or additional computation

2. DTC Operation

The basic DTC scheme is shown in fig 1.Inorder to attain a desired output torque DTC uses a simple switching table shown in fig 2 to find out the inverter state [1]. By measuring the voltage and current, instantaneous stator flux and output motor torque can compute .The flux and torque hysterisis controllers will find out the voltage required to drive the flux and torque to the preferred value within a fixed time period.

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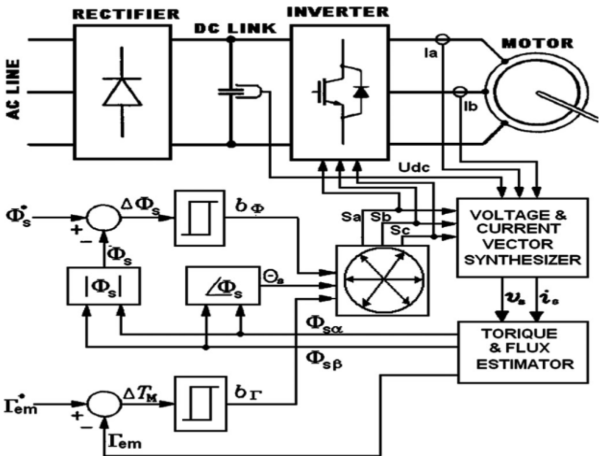

Fig.2.1. Basic DTC

Here the flux plane is divided into 6 sectors. In order to control the flux and torque we need four non-zero vectors and two zero vectors in each sector. Each vector has different response on the torque and flux linkage. For example, if the flux linkage vector is in first sector, voltage vector V3 (011) is used to increase both the torque and the flux linkage. Voltage vector V4 (100) is used to decrease the torque and flux linkage. V2 (010) is used to increase torque and decrease the flux linkage. V5 (101) is used to reduce both torque and flux linkage. If we neglect the voltage drop on the stator resistance it can be assumed that the flux linkage is always following the direction of the voltage vector. And there are two components for each vector, first one is for controlling torque and the second one is for flux linkage. It can be seen that the torque and the flux component should be different at different position.

So if the electromagnetic torque and stator flux magnitudes are evaluated, a hysteresis control is complete. The voltage vectors to be applied can be found from the switching table. During switching period, voltage vector applied to the motor is constant. So stator flux can be found out by integrating the back electromotive force

3. DTC sectors and inverter voltage vectors

The DTC sectors and inverter voltage vectors are shown in fig 1.The stator voltage space vector Vs, may have six different non zero states and two zero states as shown in Figure 3.2 The change of the magnitude of stator flux space vector and the change of the torque with varying angle of the stator flux space vector are shown in Figure 3.3. From the fig it can be seen that the change of stator flux and torque is sinusoidally distributed over the stator flux angle for the non zero voltage vectors V1 to V6 and is constant for the zero vectors V0, and V7. The dc offset of all sinusoids coincides with the line for voltage vectors V0 and V7.

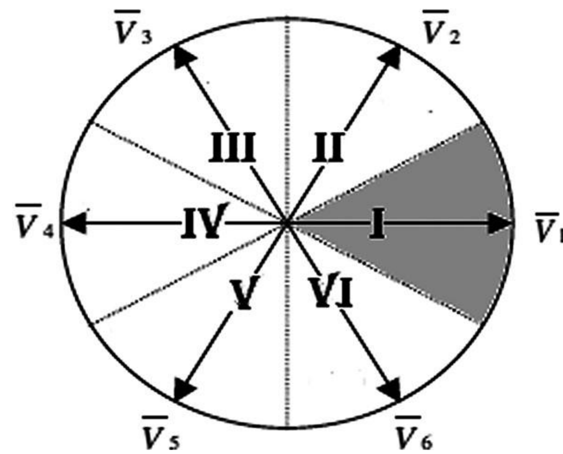

Fig3.1. DTC Sectors and Inverter Voltage Vectors

From the fig3.2 when the motor speed is increased zero change line tends to move upwards .So less positive torque change may be obtained and maximum motor speed is limited. Similarly, when the motor speed is decreased, the zero change line moves towards the negative peaks in Figure3.2, thus positive torque changes are easily obtained. Since the sequence of the stator flux and torque changes for the voltage vectors V0 to V7 remains unchanged, a selection table as shown in Table 3.1 may be obtained in order to control the stator flux and torque of an induction motor. The sectors of the stator flux space vector are denoted as S1 to S6.Let Φ denotes the magnitude error of the stator flux space vector. If Φ = 1 then the stator flux level remains too low which will cause a positive flux change, and therefore the voltage vectors V2 or V6 are selected, as can be seen from Figure 3.3.

As from fig3.1 six equally spaced voltage vectors will have the same amplitude. So two zero-voltage vectors are the only switching combinations, which can be chosen for an inverter operation. The selection of a voltage vector is made to preserve the torque and the stator flux inside the hysteresis bands limits.

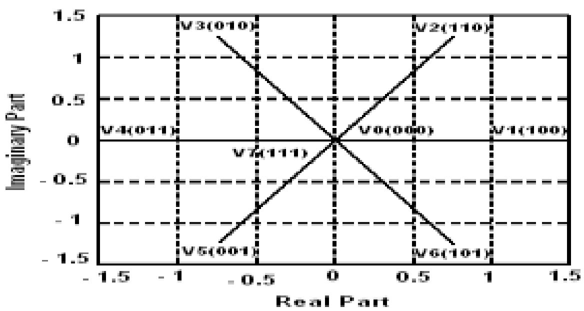

Fig3.2. Voltage Vectors of 3-Phase Inverter

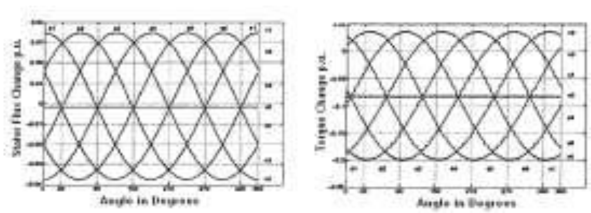

Fig3.3. Change in Flux and Torque

Table3.1. DTC Switching Table

bΦ	b_Γ	Sector I	Sect II	SectI II	Sect IV	Sect V	Sect VI
1	1	V_5	V_6	V_1	V_2	V_3	V_4
	0	V_3	V_4	V_5	V_6	V_1	V_2
0	1	V_6	V_1	V_2	V_3	V_4	V_5
	0	V_2	V_3	V_4	V_5	V_6	V_1

4. Shunt Current Sensor DTC

For basic DTC scheme at least we need two current sensors .But the proposed DTC scheme requires only one shunt resistor for dc-link current measurement as shown in Fig. 4. For this purpose, we modify the basic DTC scheme using zone shift strategy to renovate the phase currents and voltages .So two modifications are used for evaluating the three-phase currents from a single dc link current sensor [3]. On the first modification, the control system should be able to generate more voltage vectors. This goal can be realized approximately by applying, at each cycle period, different voltage vectors for prefixed time intervals, leading to a discrete SVM technique. . By using this strategy, new voltage vectors can be combined with respect to those used in the basic DTC. So with two equal time intervals, 12 new voltage vectors can be produced by using the discrete SVM technique .But here we use only six active voltage vectors .The proposed DTC scheme is shown in Fig 4.1. The red vectors will represent the synthesized voltage vectors

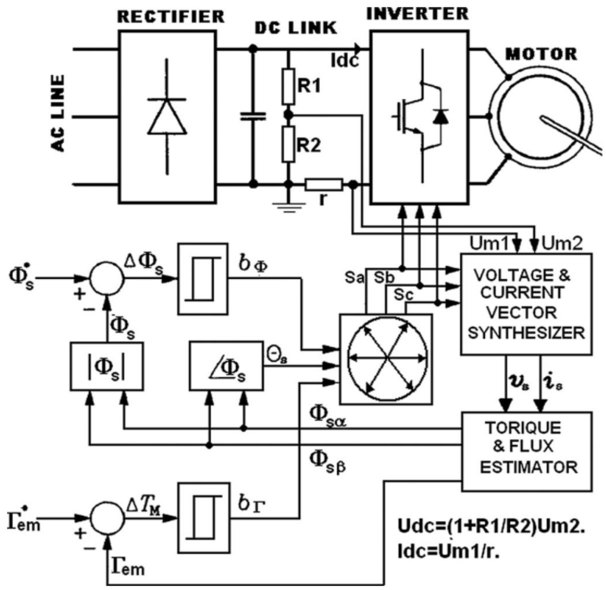

Fig4.1. Proposed DTC Scheme

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By using the zone shift strategy, the modification results in improving the DTC by using a new lookup table. The new look up table is formed by adjusting the six stator flux sectors of the basic DTC. In basic DTC first sector is taken from−30◦ to 30◦. But in proposed one first sector is taken from 0◦ to 60◦. The new operation table of the modified DTC is presented in Table 4.2

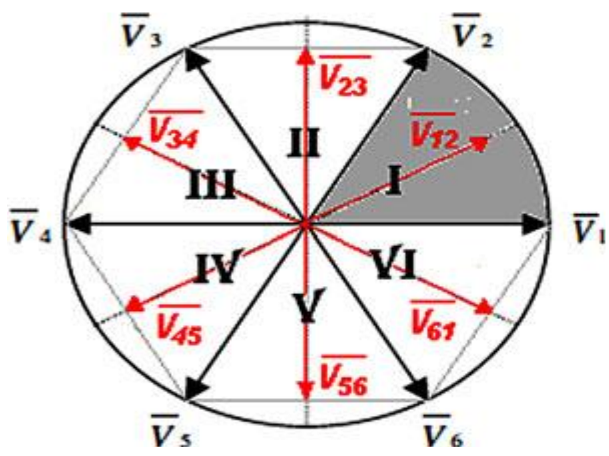

Fig4.2. Proposed DTC Sectors and Inverter Voltage Vectors

Table 4.2. Proposed DTC Switching Table

b_Φ	b_Γ	Sect I	Sect II	Sect III	Sect IV	Sect V	Sect VI
1	1	V_{56}	V_{61}	V_{12}	V_{23}	V_{34}	V_{45}
	0	V_{34}	V_{45}	V_{56}	V_{61}	V_{12}	V_{23}
0	1	V_{61}	V_{12}	V_{23}	V_{34}	V_{45}	V_{56}
	0	V_{23}	V_{34}	V_{45}	V_{56}	V_{61}	V_{12}

5. DC-link Current Sampling Stator Current Reconstruction.

For the application of the three-phase-current reconstruction both dc-link current sampling instants must be chosen. From Fig.5.1 the optimal sampling instants can be calculated with respect to the active vector transition instants.

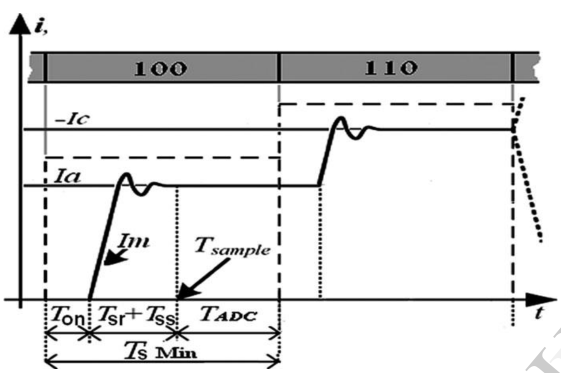

Fig5.1.Sampling Time

For a consistent dc-link current value, the signal sampling must take place after an additional delay

$$T\text{sample} \geq T\text{on} + T\text{sr} + T\text{ss}$$

Where,
*T*on means the total switching device turn-on delay time
*T*sr means thadc-link current signal rise time and *T*ss means the signal settling time.

However once the sampling process is started, it require an extra sample-and-hold time delay (*T*ADC). But if compared to the DTC control period these delays can be neglected. The smallest DTC control period is given by

$$Ts \geq 2\,(T\text{on} + T\text{sr} + T\text{ss} + T\text{ADC})$$

Actually, the sum of all these time delays is about a few microseconds.

6. Simulation & Results

Simulation is done in MATLAB and the results obtained are shown. The simulink model of the DTC is shown below in figure 6.1. Figure 6.2 shows the variation of motor speed in the proposed DTC. Figure 6.3 shows the variation of torque in the proposed DTC. Figure 6.4 presents the simulation results of phase current.

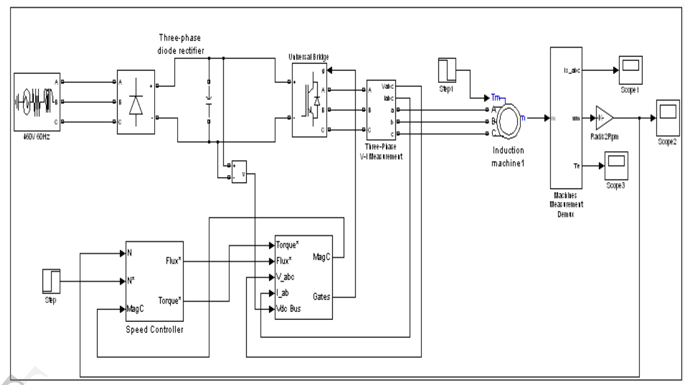

Fig6.1. Simulation Diagram

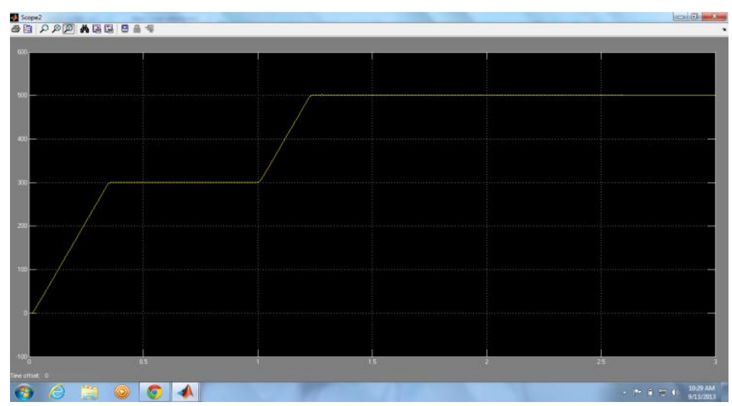

Fig6.2. Speed Waveform of Modified DTC

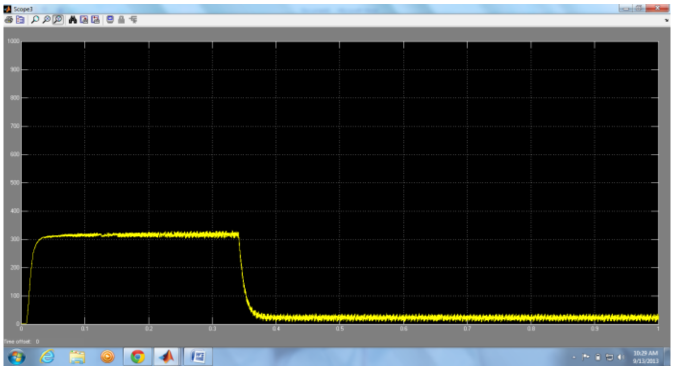

Fig6.3. Torque Waveform of Modified DTC

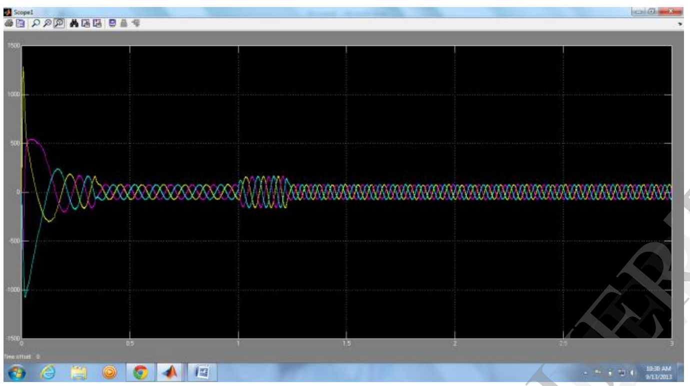

Fig6.4. Current Waveform of Modified DTC

7. Conclusion

In this paper a low cost single shunt current sensor induction motor DTC has been analysed, modelled and simulated in matlab. One of the most important purposes for single shut three phase reconstruction is to reduce cost. The proposed method reconstructs the stator currents needed to estimate the stator flux magnitude and electromagnetic torque by means of single modification in the basic DTC. For basic DTC a single voltage vector is applied during one sampling time. But for the proposed DTC sequence of six vectors is applied during the sampling time. It can be stated that, using the proposed topology, the overall system performance is increased

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