Chapter 52
New Direct Torque Control Algorithm for High Performance Induction Motor

S. Srinivasan and A. Sabari Raja

Abstract This paper presents a new Direct Torque Control algorithm for high performance Induction motor with the information obtained from only one shunt resistor. The objective here is to develop low cost and high efficient induction motor drive using an algorithm in which the stator currents are remade to obtain the electromagnetic torque and motor flux using the DC link currents. A modified look up table is obtained by analyzing the theoretical background of the direct torque control. The current access table is designed for phase current reconstruction. Simulation results are shown for the proposed scheme of DTC using induction motor drive in order to validate the concept.

Keywords Direct torque control algorithm · Induction motor · Discrete space vector modulation (DSVM)

52.1 Introduction

The Direct Torque Control also known as direct self control was introduced in the mid 1980s particularly for voltage fed PWM inverter drives. This technique gives the same performance as given by the vector controlled drives and hence widely used in industrial applications due to its simple control structure. DTC uses wide area of application used in machines like PMSM, PMBLDC and also in reluctance motor. In this paper we propose low cost DTC algorithm for high performance induction motor. The stator flux vector and the electromagnetic torque are directly calculated from the voltage and current derived from single dc-link voltage sensor (voltage divider) and a single dc-link current sensor (shunt resistor). The phase

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currents are estimated by two dc-link current measurements processes. Stator currents and dc-link voltages are required for DTC scheme to estimate the values of stator flux and electromagnetic torque. The current feedback for the closed loop control is usually obtained by sensing phase current by current sensors. Typically at least two output of the power converter to provide current feedback signals. These Sensors though gives good results, suffers with the disadvantage of high cost, encumbrance with non-linearity. The latest development in this is to use Single current sensor to reconstruct phase current from the dc link current sensor [1].

Some methods adjusts the pulse width modulation (PWM) signals to ensure the two-phase Currents. DTC technique for induction motor and PMSM are dealt only in few papers in which the algorithm works in two steps. The stator currents are initially obtained from a model of the motor which is adjusted to get the corrected value later by sensing the dc-link current. This algorithm suffers with the following drawbacks 1. It requires additional computation to do and 2. The necessity of knowing the stator transient inductance. In the proposed method, a DTC scheme for Induction motor is proposed with a low cost single shunt current sensor which overcomes the above stated problems.

To summarise the rest of the paper, in Sect. 52.2, the basic DTC structure and its working is given. The control strategy and the control algorithm is given in Sects. 52.3 and 52.4 respectively. The simulation results are shown in Sect. 52.5. Finally conclusion is given in Sect. 52.6.

52.2 How DTC Works?

The advanced scalar control technique DTC directly control the stator torque and flux using the inverter voltage space vector selection through a look up table [2]. The instantaneous stator flux and output motor torque are calculated by measuring the current and voltage values. The flux and torque are brought to its rated value over a given period are possible with the help of control algorithm based on flux and torque hysteresis controllers. The fundamental functional blocks used to implement the DTC scheme are represented in Fig. 52.1.

Here the equation for stator flux vector and the torque of the motor, $T_{em,}$ can be calculated by the Eqs. (52.1) and (52.2) respectively. These necessities the applied voltage vector V_s and the measured stator current $\mathrm{I_S}$, measured stator resistance R_s and the number of Poles P

$$\varphi_{\mathrm{s}} = \int (V_s - R_s I_s)\ \mathrm{dt} \tag{52.1}$$

$$I_{em} = y_z\, with \underset{y}{\rightarrow} = \frac{3}{2} p(\varphi_s \times I_s) \tag{52.2}$$

The switching table is derived from applied voltage vectors using a hysteresis control. This is possible only when the magnitude of electromagnetic torque and

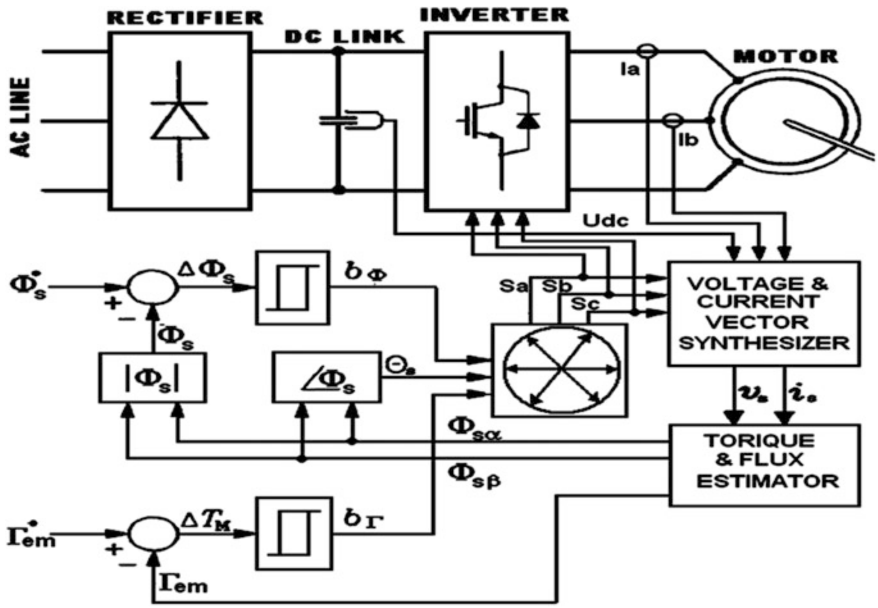

Fig. 52.1 Block diagram of DTC

stator flux are known. From the measured dc-link voltage U_{dc} Eqs. (52.3) and (52.4) can be obtained which gives the polar components of stator voltage on perpendicular reference frame where the switching states S_a, S_b *and* S_c are given by [2, 3].

$$V_{s\alpha} = \sqrt{\frac{2}{3}}U_{dc}\left(S_a - \frac{1}{2}(S_b + S_c)\right) \tag{52.3}$$

$$V_{s\beta} = \frac{1}{\sqrt{2}}U_{dc}(S_b - S_c) \tag{52.4}$$

And Stator current components are given by,

$$I_{s\alpha} = \sqrt{\frac{3}{2}}I_a \tag{52.5}$$

$$I_{s\beta} = \frac{1}{\sqrt{2}}(I_b - I_c) \tag{52.6}$$

The stator resistance R_s can be assumed constant. The voltage vector applied to the motor will be constant during a switching period. The EMF can be integrated to get the stator flux and is given by

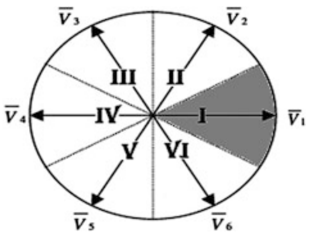

Fig. 52.2 DTC vectors and inverter voltage vectors

$$\varphi_{s\alpha} = \int(V_{s\alpha} - R_s I_{s\alpha})dt \tag{52.7}$$

$$\varphi_{s\beta} = \int\left(V_{s\beta} - R_s I_{s\beta}\right)dt \tag{52.8}$$

The switching period is constant during the switching period and Eqs. (52.7) and (52.8) can be written as

$$\varphi_{s\alpha} = \varphi_{s\alpha} + (V_{s\alpha} - R_s I_{s\alpha})T_s \tag{52.9}$$

$$\varphi_{s\beta} = \int\left(V_{s\beta} - R_s I_{s\beta}\right)dt \tag{52.10}$$

where T_s represents the control loop period.

The magnitude of the stator flux can be given by

$$\varphi_s = \sqrt{\left(\varphi_{s\alpha}^2 + \varphi_{s\beta}^2\right)} \tag{52.11}$$

and hence the electromagnetic torque

$$T_{em} = \frac{3}{2}p(\varphi_{s\alpha} - \varphi_{s\beta}I_{s\alpha}) \tag{52.12}$$

The switching combination is chosen for inverter operation such that it has six equally spaced vectors have same amplitude and two zero voltage vectors as shown in Fig. 52.2.

52.3 Control Strategy

The DTC method proposed in this paper requires only one shunt resistor for dc link current measurement as shown in Fig. 52.3 where as it is two in the basic DTC scheme.

By using Discrete Space Vector Modulation (DSVM) technique, it is possible to get new voltage vectors with respect to the basic scheme [4]. Out of the 12 new voltage vectors, only six are used in the proposed scheme as shown by red line in Fig. 52.4.

The new look up table for the new scheme is given for the modified DTC in Table 52.1.

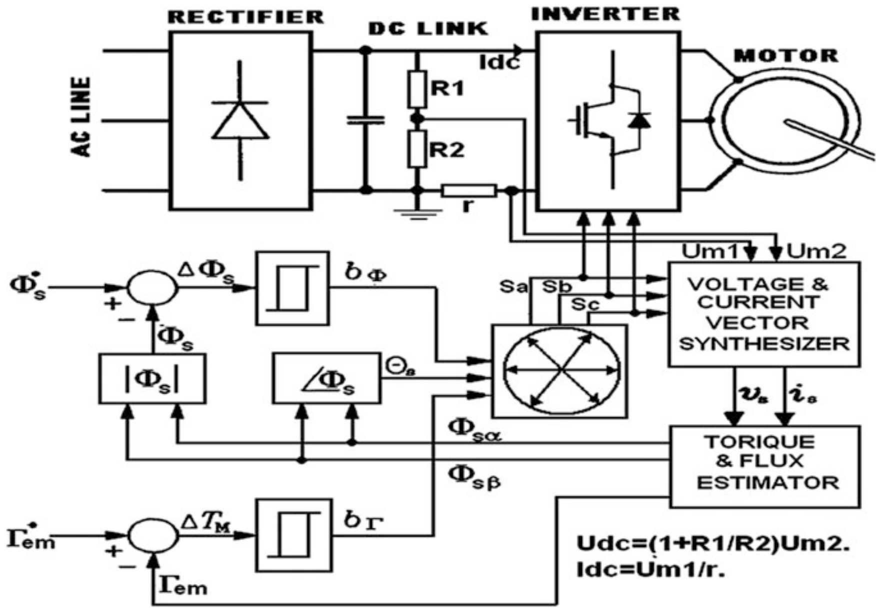

Fig. 52.3 Proposed DTC scheme

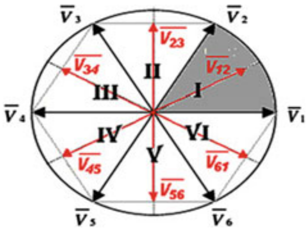

Fig. 52.4 Proposed DTC sectors and inverter voltage vectors

Table 52.1 Proposed DTC switching table for sensing dc-link current and stator current reconstruction

bΦ	b_r	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_{6I}	V_{12}

52.4 Control Algorithm

One of the most important purposes for single-shunt three phase reconstruction is to reduce the cost. This, in turn, simplifies the sampling circuit to one shunt resistor and some other electronic components. Moreover, the single-shunt algorithm allows the use of power modules that do not provide, for each phase, individual ground connection. Another single-shunt measurement advantage is that the same circuit is being used to sense all three phases. For all measurements, the gains and offset will be the same, which eliminate the software calibration of each phase measurement structure.

52.4.1 DC Current Measurement

Figure 52.5 explains how the dc current is sensed using only one shunt resistor in an voltage source Inverter. A measurement shunt resistor is placed between the lower side power switches emitter terminals and the negative dc bus rail that is connected to the ground. The voltage drop across the shunt resistor is amplified and level shifted. In the case of nonisolated grounds between control circuit and power circuit, the signal is sent directly to the analog-to-digital converter (ADC) inputs of a digital signal controller (DSC), where control algorithm for motor is implemented and executed in real time. For more protection, a linear photo isolator amplifier used to isolate the control circuit from power circuit.

52.4.2 Phase Current Reconstruction

In the basic DTC scheme, there is one current flowing in the dc link for every active voltage vector, where as it is measured in two intervals in the new scheme according to the switch states. The relationship between the dc-link current and the phase currents for the two schemes are shown in Tables 52.2 and 52.3.

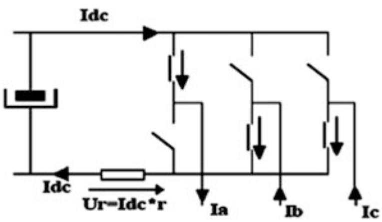

Fig. 52.5 DC current sensing in inverter

Table 52.2 Basic DTC voltage vector phase current measurement

Active voltage vector	DC-link Current
V_1	la
V_2	−Ic
V_3	lb
V_4	−la
V_5	Ic
V_6	−lb

Table 52.3 Proposed DTC voltage vector phase current measurement

Active voltage vector	1st interval DC-link current	2nd interval DC-link current
V_{12}	la	−Ic
V_{23}	−Ic	lb
V_{34}	lb	−la
V_{45}	−la	Ic
V_{56}	Ic	−lb
V_{61}	−lb	la

By using the two-interval discrete space vector modulation, for each one of the new six active vectors, we can reconstruct the three-phase motor currents. It is clear that by knowing the inverter switch position in two intervals of each period the actual currents for two phases can be obtained without further computing process. Assuming that, *I*dc1 is the dc-link current measured at the end of the first interval and *I*dc2 is the one measured at the second half interval, are summarized in Table 52.4, the three-phase motor currents *Ia*, *Ib*, and *Ic*are given in function of voltage vector and the dc-link current. A phase-current reconstruction time.

Table 52.4 Phase current reconstruction relationship for each voltage vector

Voltage vector	Ia	Ib	Ic
V_{12}	Idc_1	$Idc_2 - Idc_1$	$-Idc_2$
v_{23}	$Idc_1 - Idc_2$	Idc_2	$-Idc_1$
V_{34}	$-Idc_2$	Idc_1	$Idc_2 - Idc_1$
V_{45}	$-Idc_1$	$Idc_1 - Idc_2$	Idc_2
V_{56}	$Idc_2 - Idc_1$	$-Idc_2$	Idc_1
V_{61}	Idc_2	$-Idc_1$	$Idc_1 - Idc_2$

52.4.3 Motor Speed Range

In two-interval DSVM, the sampling period is divided into two equal time intervals and each of them is supplied with one VSI voltage vectors. In this way it is possible to generate 14 vectors. The proposed low-cost DTC algorithm uses only six voltage vectors out of them which can be used for phase-current reconstruction. The magnitude of the generated voltage vector V_1 using the basic DTC algorithm can be written as

$$|\mathrm{V}_1| = 2/3U_{dc} \tag{52.13}$$

The generated voltage vector $V12$ using the proposed DSVM. DTC algorithm is given by

$$|\mathrm{V}_{12}| = \frac{2}{3}U_{dc}\cos\frac{\pi}{6} = \frac{1}{\sqrt{3}}\,U_{dc} \tag{52.14}$$

The vector voltage magnitude ratio is given by

$$\mathrm{r} \;=\; |\mathrm{V}_{12}|/\,|\mathrm{V}_1| = \sqrt{3}/2 \tag{52.15}$$

Speed control is achieved by means of variable frequency. Apart from frequency, the applied voltage needs to be varied because the stator flux magnitude is kept constant by the DTC.

Neglecting the stator resistance drop, we can consider that the voltage magnitude, in steady state, is given by

$$V_{sn} = \varphi_{snw_s} \tag{52.16}$$

Reducing the voltage maximum magnitude will reduce the Rotational components of the back EMF, leading to a reduction in the maximum stator pulsation and hence to the speed range. The Maximum motor speed with the proposed algorithm is limited to 86 % compared to the original DTC control algorithm.

52.5 Simulation Results

The DTC scheme proposed for the high performance induction motor is simulated in the MATLAB environment (Figs. 52.6, 52.7, 52.8 and 52.9).

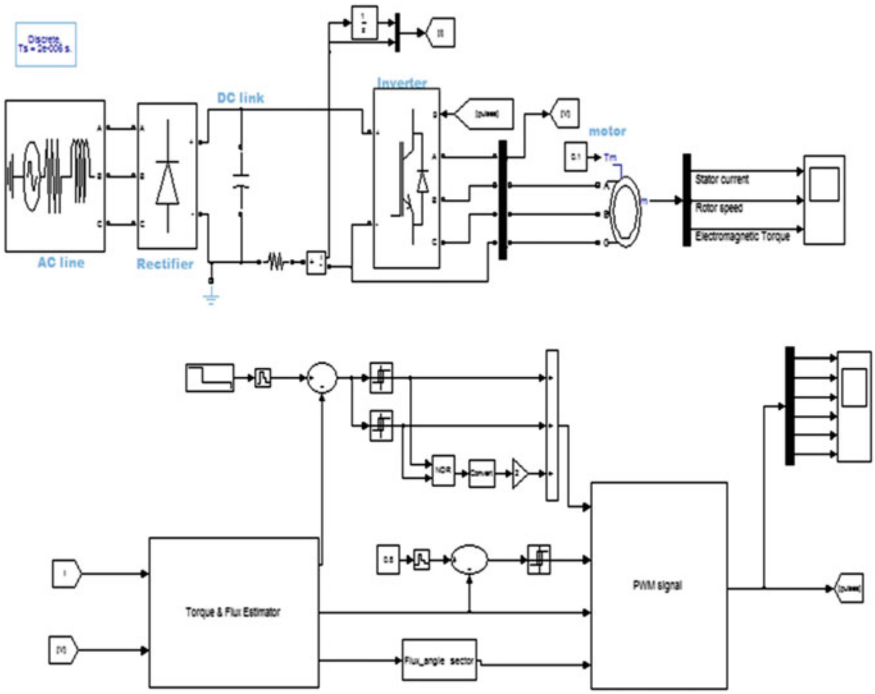

Fig. 52.6 Proposed DTC scheme simulation diagram

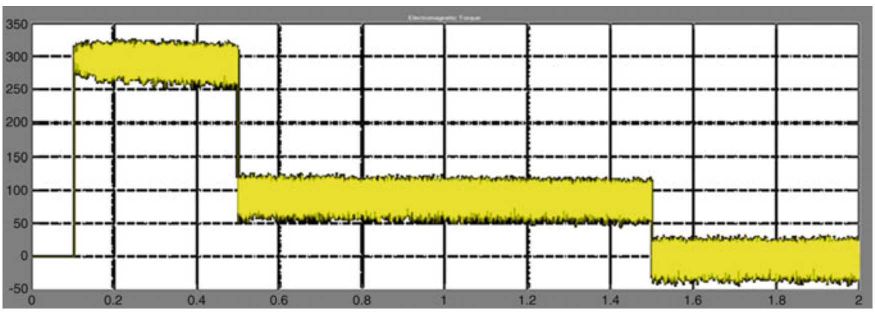

Fig. 52.7 Torque waveform

In the simulations, a sample frequency of 10 kHz is used. The dc-bus voltage V_{dc} equals 300 V and the desired grid rms voltage V_g equals 163 V with a fundamental frequency of 50 Hz was verified for a RL load with R = 10 ohms and L = 123 mH.

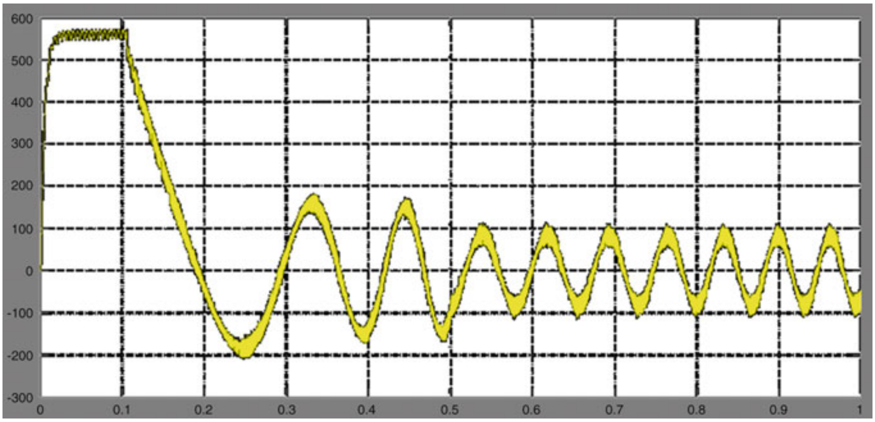

Fig. 52.8 Output current waveform

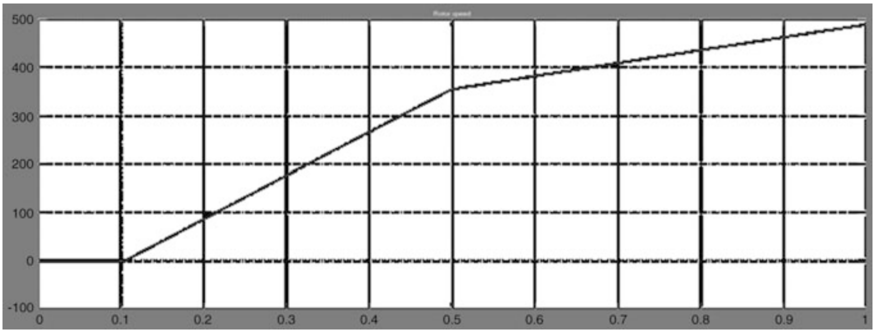

Fig. 52.9 Output speed waveform

52.6 Conclusion

In this paper, a new and low-cost direct torque control algorithm for IM drives has been presented where the phase-current reconstructed by having only one shunt resistor connected in the dc-link path. By using Discrete Space Vector Modulation (DSVM) technique with two equal time interval in the proposed method, there are twelve new voltage vectors are generated out of which only six are used for stator currents reconstruction to estimate the stator flux magnitude and the electromagnetic motor torque, by means of a simple modification in the basic DTC scheme; 30° zone shift strategy is applied. Hence the proposed scheme of DTC with single current sensor reduces the overall cost of the sampling circuit and other electronic devices compared to the existing method. Finally simulation results are shown to pave support to the proposed scheme.

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