DTC - SVM scheme for a Three Phase Induction Motor Drive with Power Factor Correction

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***Abstract*— Three phase induction motors are widely used in industrial applications mainly because of its numerous advantages like better speed control,low cost and rugged construction.Several speed control techniques have been used for induction machines over the past decades.Vector control techniques are the modern speed control method now a days.Direct torque control,which is one of the vector control technique is considered as the most advanced and efficient speed control method used for controlling induction machines.The principle of the DTC method is based on selecting the voltage vector to maintain the torque and flux within two hysteresis bands. For a DTC scheme, only one voltage vector is applied during the whole sampling period.The major drawback of DTC is the presence of high torque ripple because of the presence of hysteresiscontrollers. An effective way to reduce high torque ripples is the use of space vector modulation in conventional direct torque control scheme. Also the power factor should be improved to reduce power quality problems associated with it.A zeta converter is implemented in the front side of the circuit for power factor correction. The simulations are done using MATLAB/SIMULINK software. The implementation of DTC-SVM with zeta converter results in good dynamic and steady state performance of the induction motor. Also the torque ripple and power quality problems , which are the major drawback of DTC is reduced.**

Keywords—Zeta converter, Induction motor, Direct torque control, Space vector modulation

I. INTRODUCTION

Induction Motors are the commonly used machines in high performance electric drives which have several applications in industrial and domestic areas.Low cost,rugged construction,wide speed range and have quick response in flux and torque are the major reasons for selecting induction motors widely.The speed control of induction machines can be classified into two:scalar control and vector control.Scalar Control or v/f control is the simple and economical control used in most of the industries. It is termed as scalar because the magnitude of stator voltage and frequency are the constraints to vary the speed. Since this control technique is open loop and if the speed and torque variations are concerned, it has less precise control. Vector control is a closed loop control where the stator voltages and currents are sensed continuously. It is the most advanced control method with accurate and precise control of speed and torque.

The most advanced vector control technique is the direct torque control method utilizing electromagnetic torque and stator flux of motor control. The advantages like lower parameter sensitivity and precise speed control makes DTCpopular. The major disadvantage of DTC is the presence of high torque ripple because of the presence of wide hysteresis bands. The torque ripples results in heavy vibrations and disturbances which causes errors in sensorless motor drives. In order to overcome this problem,a space vector modulation scheme is adopted in conventional DTC method.In DTC-SVM scheme, at every sampling period,an exact voltage vector is generated by a predictive method which will compensate the torque and flux errors accurately.

As the induction machines are widely used in industrial sectors,the power quality problems such as reduced power factor and high harmonic contents,associated with it should be compensated.A power factor correction rectifier at the front end of the control circuit improves the power quality of the system[1].A zeta converter is provided at the front end of the circuit which has properties similar to flyback converters.

II. DIRECT TORQUE CONTROL WITH SPACE VECTOR MODULATION

Direct torque control was introduced by Takahashi and Nagauchi[2] and it is further improved by Dopenbrock[3].This method of speed control results in independent control of torque and stator flux within the limits of hysteresis bands.Fig.1 shows the conventional direct torque control method which utilizes hysteresis bands for controlling stator flux and torque.The basic principle of DTC is by selecting optimum voltage vector from the switching table to minimize the torque and flux errors.

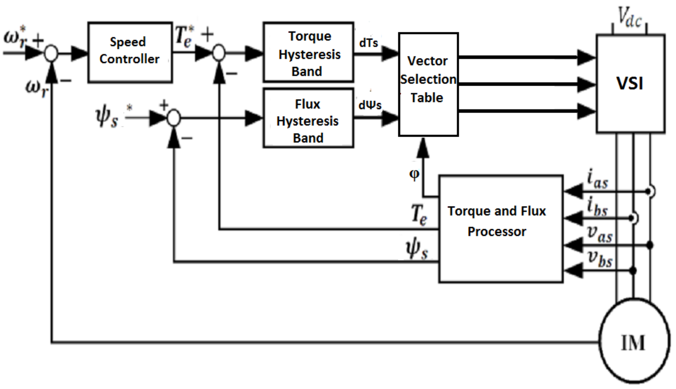

Fig 1:Block diagram for direct torque control

In a classic DTCsystem,the applied voltage vector is not on the basis of exact values of torque and flux linkages.It can only adjust the changes in torque and flux linkages through the hysteresis controllers.This will cause severe torque and flux ripples in the system[4].The implementation of space vector table instead of conventional switching table of DTC will reduce the torque ripples as the voltage vectors produced having both the changing trend of torque and flux and their exact value information is to be applied in each sampling period[5].The block diagram of the SVM-DTC method for four switch inverter fed induction motor drive system is illustrated in Fig.2, which utilizes a SVM based DTC algorithm.The two hysteresis controllers are replaced by flux and torque PI controllers and the switching table of classic DTC system is replaced by switching table of SVM

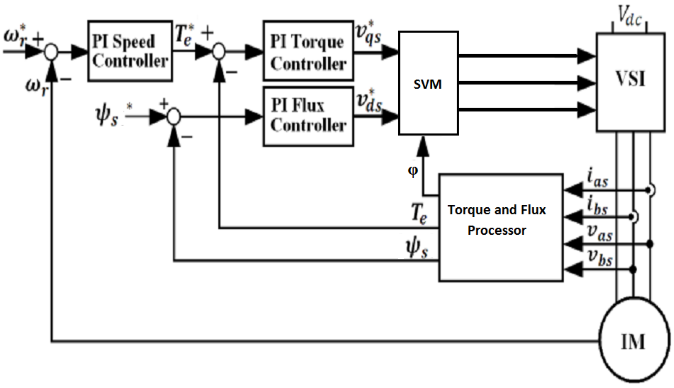

Fig 2:Block diagram for DTC-SVM

The stator voltages and currents are taken from the stator terminals and it is converted into stationary axis components.ie,d-q axis components by the equation,

$$v_{qs} = (\tfrac{2}{3})(v_a - \tfrac{1}{2}v_b - \tfrac{1}{2}v_c) \quad (1)$$

$$v_{ds} = (\tfrac{2}{3})(\tfrac{\sqrt{3}}{2})(v_b - v_c) \quad (2)$$

where Va,Vb and Vc are the three phase stator voltages.

From these measuredmotor terminal quantities, i.e. stator voltages and currents,actual torque and stator flux linkage are calculated.The actual electromagnetic torque can be calculated by the equation,

$$T_e = (\tfrac{3}{2})(\tfrac{P}{2})(\Psi_{ds} i_{qs} - \Psi_{qs} i_{ds}) \quad (3)$$

The d-q axis stator flux linkages can be calculated by the equation,

$$\Psi_{ds} = \int(v_{ds} - i_{ds} r_{ds}) \quad (4)$$

$$\Psi_{qs} = \int(v_{qs} - i_{qs} r_{qs}) \quad (5)$$

where, Ψ_{qs} and Ψ_{ds} are the d and q axis components of stator flux linkages.V_{ds} and $V_{qs}$are the d-q axis components of stator voltages,$i_{ds}$and i_{qs} are the d and q axis components of stator currents and P is the number of poles.The error signal is produced by comparing the actual and reference values of torque and flux, and is fed to PI comparators.The reference voltage vector generated in DTC-SVM scheme have the magnitude and angle of,

$$v_s = \sqrt{(v_{qs}^2 + v_{ds}^2)} \quad (6)$$

$$\varphi = \arctan(\frac{v_{qs}}{v_{ds}}) \quad (7)$$

Fig.3 shows the basic principle of SVM to generate Vs if the voltage vector is located in sector S_1

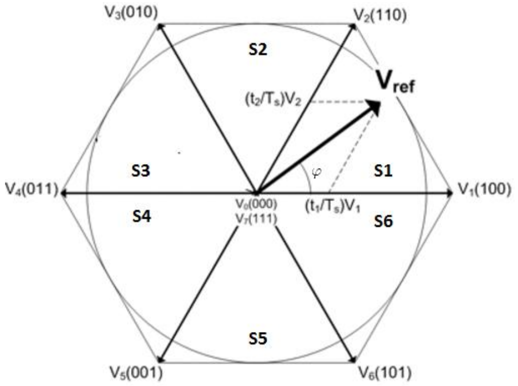

Fig 3: Voltage vector plane for DTC-SVM

In sector S_1, the desired voltage vector is synthesized from the adjacent two basic voltage vectors V_1 and V_2.The switching time of voltage vectors V_1 and V_2 are T_1 and T_2, respectively and the angle between V_1 and V_2 is φ.According to Fig.3, the following equations can be obtained:

$$T_s v_s = T_0 v_0 + T_1 v_1 + T_2 v_2 \quad (8)$$

$$T_s v_s \cos\varphi = \tfrac{2}{3} v_{dc} T_1 + \tfrac{1}{3} v_{dc} T_1 \quad (9)$$

$$T_s v_s \sin\varphi = \frac{1}{\sqrt{3} v_{dc} T_2} \quad (10)$$

Solving above equations,

$$T_1 = \tfrac{3}{2} n T_s (\tfrac{1}{\sqrt{3}} \cos\varphi - \tfrac{1}{3} \sin\varphi) \quad (11)$$

$$T_2 = n T_s sin\varphi \quad (12)$$

$$T_0 = T_s + T_1 - T_2, \text{ where } n = \frac{v_s\sqrt{3}}{v_{dc}}$$

III. Zeta Converter for Power Factor Correction

A zeta converter is designed to improve the power factor and there by reducing the power quality problems is placed in the front end of the circuit.The circuit diagram of a zeta converter is shown in Fig.4.

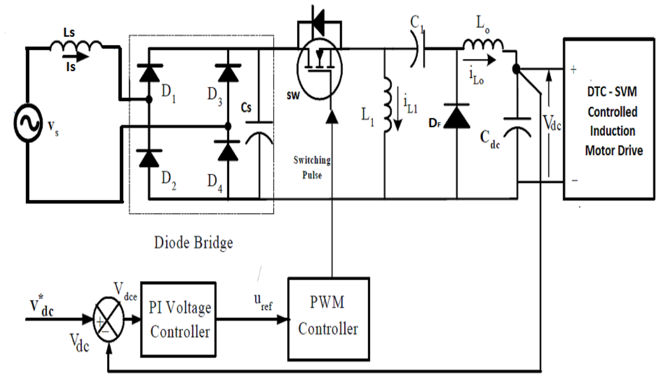

Fig 4:Zeta converter fed induction motor drive

Zeta converter topology provides the operation of a buck boost converter with non inverting output voltage. The converter is used as an output voltage regulator[6].The voltage across DC link capacitor is compared with the reference voltage and the error signal is fed to a PI controller and necessary compensation of output voltage is done by the switching of zeta converter. In order to follow Vin more closely by I in, and not have these high amplitude current pulses,C1 must charge over the entire cycle rather than just a small portion of it. The hold-up time for Cdc is designed to be greater than the frequency of Vin so that if there is a glitch in Vin and a few cycles are missed,C1will have enough energy stored to continue to power its load.This method is called power factor correction.

A.*Principle of Operation*

Fig.5 and Fig.6 shows the zeta converter operating in continous conduction mode when SW is ON and OFF respectively.

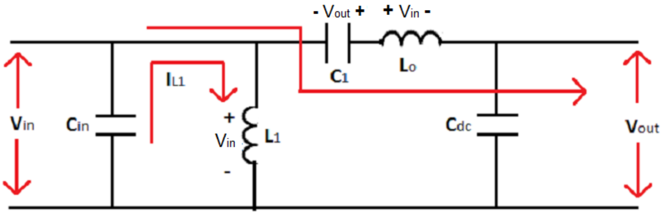

Fig 5:Operation when switch is ON

When SW is ON, energy from the input supply is being stored in L1,Lo and C1.Diode is reverse biased at that time. When Q1 turns OFF, L1 as current continues to flow from current provided byC1, and Lo again provides Iout.

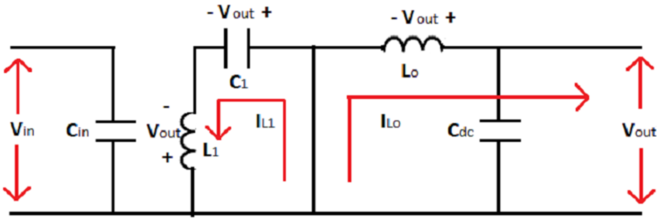

Fig 6: Operation when switch is OFF

When SW is OFF, the voltage across L1 must be Vout since it is in parallel with Cdc .Diode is forward biased then. Since Cdcis charged to Vout , the voltage across SW when SW is ON,the voltage is Vin +Vout ; therefore the voltage across L1 is Vo relative to the drain of SW. When SW is ON, capacitor C1 is charged to Vout, is connected in series with L1, so the voltage acrossLo is Vin and that across diode D1 is Vin +Vout.

B.*Design of Zeta Converter*

The converter is designed for the output voltage of 400 V in dc link capacitor Co.Supply voltageVs is set to 220 V with a supply frequency of 50Hz .Switching frequency of MOSFET is 50kHz,input current Is=4A,input inductor current ripple ΔIL1=0.82A,DC link current Idc=3.5A,peak to peak filter inductor ripple current ΔILo=3.5A,DC link voltage rippleΔVdc=8V,voltage ripple in capacitor C1,ΔVc1=220V.
Output voltage,

$$v_{out} = \frac{v_{in} D}{1-D} \quad (13)$$

$$v_{in} = \frac{2\sqrt{2}v_s}{\pi} \quad (14)$$

$$L_1 = \frac{v_{in} D}{f_s \Delta I_{L1}} = 3.2mH \quad (15)$$

$$C_1 = \frac{i_{out} D}{f_s \Delta v_{c1}} = 210nF \quad (16)$$

$$L_0 = \frac{v_{out}(1-D)}{f_s \Delta I_{L1}} = 0.77mH \quad (17)$$

$$C_0 = \frac{i_{L0}}{4\pi f \Delta v_0} = 696\mu F \quad (18)$$

IV. SIMULATION RESULTS

A three phase induction motor drive controlled by DTC - SVM method with zeta converter at the front end is simulated by MATLAB/Simulink software.Induction motor parameters used in simulations are as shown in Table I.

Motor type	Three phase squirrel cage induction motor
Nominal Power	3 HP
Frequency	50Hz
Line to line voltage	415 V
Stator resistance	0.425 Ω
Stator inductance	4e-3 H
Rotor resistance	0.816 Ω
Rotor inductance	2e-3 H
Mutual inductance	60.3e-3 H
Pole pairs	2

Table I:Induction motor parameters for simulation

The simulation block of the DTC-SVM control scheme for a three phase induction motor with zeta converter is shown in Fig.7.

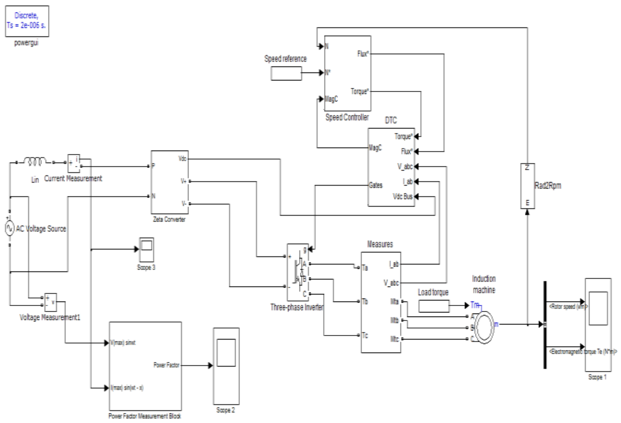

Fig 7:Simulink Model of induction motor with zeta converter

The system is composed of the squirrel cage induction motor , three phase voltage source inverter, torque and flux processors,speed controller,PI controllers and Zeta converter. The IGBT switches of inverter circuit are controlled using space vector modulation technique.The simulink model for zeta converter as per the design equation is shown in Fig.8.

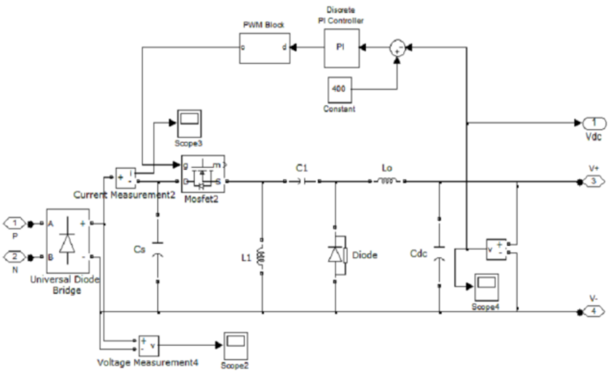

Fig 8:Simulink Model of zeta converter

The simulated waveforms of speed and torque at a reference speed of 1200 rpm is shown in Fig.9.

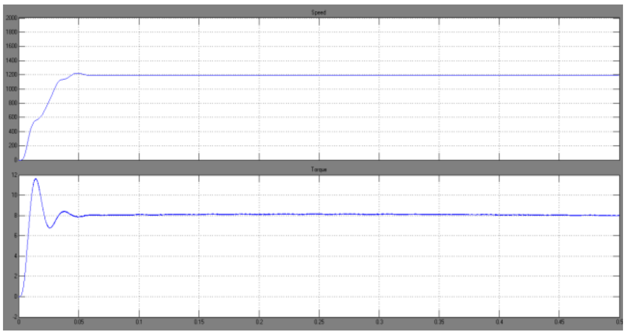

Fig 9:Simulated wave forms under 1200 rpm

From the wave forms shown in Fig.9,the speed reaches the reference speed of 1200 rpm in 0.05 seconds.From the waveforms,it is clear that the torque ripple content is very low as compared with conventional DTC scheme.
The DC link voltage is maintained at 400 V by zeta converter.The waveform is shown below.

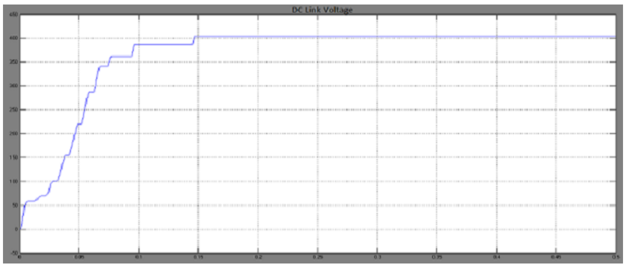

Fig 10:Constant DC link voltage

The power factor of DTC-SVM fed induction motor drive wthout zeta converter is shown in figure11.The waveform shows that the power factor is nearly 0.75 only.

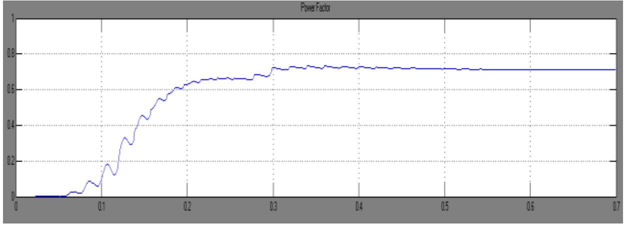

Fig 11:Power factor without Zeta converter

The power factor is improved to 0.998 as shown in Fig.12 when a zeta converter is added in the front end.

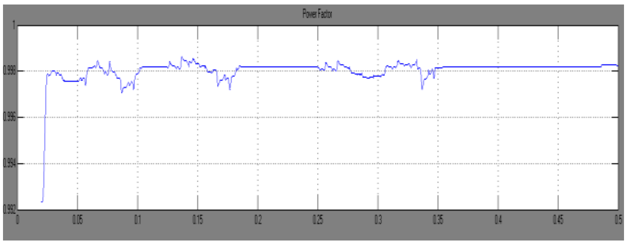

Fig 12:Power factor with Zeta Converter

Also the harmonic content is reduced.The total harmonic distortion is6.30% when the machine runs without zeta converter as shown in Fig.13.

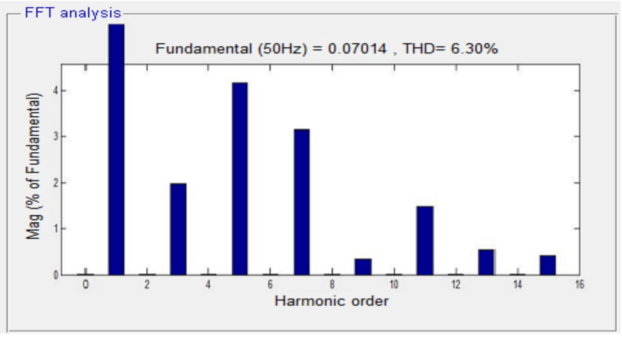

Fig 13:THD without Zeta Converter

Fig.14 shows the reduction in THD to 1.33 % when a front end zeta converter is used in the conventional system

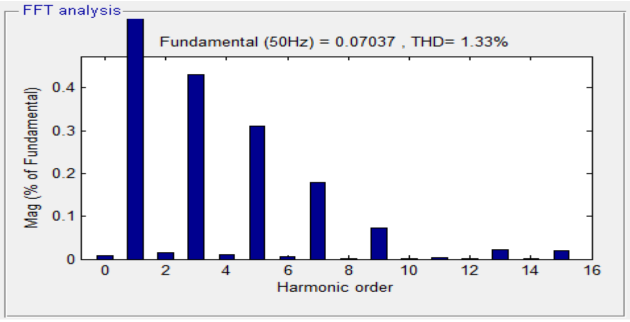

Fig 14.THD with Zeta Converter

V. ADVANTAGES AND DRAWBACKS

The implementation of space vector modulation in classic direct torque control method with a zeta converter results in following advantages and drawbacks.

A. ADVANTAGES

1.Less torque ripple.
2.Constant DC link voltage.
3.Almost unity Power factor.
4.Harmonics and THD reduces.
5.The overall efficiency can be improved.

B. DRAWBACKS

1.Overall circuit is complex
2.Difficulty to control torque and speed at very low speed.

VI. CONCLUTION

Inthis work, an active power factor correction (PFC) isattained by providing a Zeta converter at the front end ofinduction motor drive where theinput current follows the sinusoidal voltagewaveform. This method provides nearly unity powerfactor with low THD.Also the dc link voltage kept to aconstant value.The inverter switching is controlled by direct torque control space vector modulation scheme there by controlling the speed and torque with reduced torque ripple content.

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