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Simulation Based Performance Comparison of Different Control Methods of ZSI Feeding Industrial Drives

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Abstract**—**Industrial drives are source of serious power quality problems. In this, two typical industrial drives have been dealt with, namely, FOC induction motor drives and DTC induction motor drive. The Z-source inverter is an emerging topology of power electronic converters which is capable of buck boost characteristics. The performances of different control methods based Z-source inverters feeding these industrial drives have been investigated, in this work. The test systems have been modeled and simulated in MATLAB/SIMULINK. The results obtained after carrying out these simulations have been used to draw the conclusions.

Keywords**—**Z-Source Inverter, total harmonic distortion, direct torque control, field orientation control.

I. Introduction

POWER electronics based devices such as industrial drives [1]-[3] being non-linear in nature lead to serious power quality problems. The presence of these drives in a distribution network also deteriorates the performances of other equipment's connected to the same distribution network. These loads are not only the major source but also the major victims of power quality problems. With the new technological developments in the field of power electronics a variable induction motor drives have evolved as a new technology in the last decades. These drives in which dc to ac inverters have used to drive induction motors as variable frequency three- phase voltage or current source has been used in wide industrial applications.

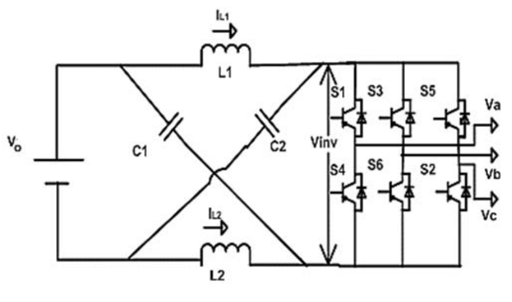

Fig. 1 Three-phase Z-source inverter

In this paper, power distribution network with industrial drives, namely, Direct Torque Control (DTC) drive or Field Orientation Control (FOC) drive have been considered. To overcome the problems introduced in the power distribution network due to the presence of these drives, custom power devices [4] are very useful. The heart of these custom power devices is a power electronic converter which produces an ac output waveform from a dc supply. In this work, a Z-source converter has been used to overcome the limitations imposed voltage source converter or current source converter.

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II. Z-Source Inverter

Fig. 1 depicts the general structure of Z-source converter. It consists of a two-port network with a split inductor L1 and L2 and capacitors C1 and C2 connected in X shape. The dc source /or load can be either a voltage or a current source /or load.

In this work, it is assumed that $L_1 = L_2$, and $C_1 = C_2$. The AC output voltage equation of PWM based ZSI is given by:

$$\widehat{v_{ac}} = M.B.\frac{V_0}{2} \tag{1}$$

where $\widehat{v_{ac}}$ is maximum sinusoidal inverter output voltage, B is boost factor, M is modulation index and V_o is dc input voltage. The product (B.M) is known as inverter gain and is denoted by G. So, (1) can be rewritten as:

$$\widehat{v_{ac}} = G.V_o/2 \tag{2}$$

Boost factor is determined from the following relation:

$$B = \frac{T}{T_1 - T_0} == \frac{1}{1-2\frac{T_0}{T}} \tag{3}$$

where T_0 is the shoot-through time interval over a switching cycle T. So, in the 3-phase Z-source inverter there are 9 permissible switching states – 6 active states, 2 zero states and one additional zero state (when the both devices of any one phase leg are gated on) known as shoot through state.

The control methods based on sinusoidal PWM techniques to control Z-source inverter reported in literature are: simple boost control (SBC) [5]-[6], maximum boost control (MBC) [7], constant maximum boost control (CBC) [8] and third harmonics injected constant maximum boost control (HBC) [8], [9]. In this paper, the performances of these control methods based Z-source inverters feeding industrial drives have been compared.

III. Industrial Drives

Of the various industrial drives being used in modern hitech industry, in this work, only two drives, namely, DTC drive and FOC drive have been considered. Their modeling has been presented in the following sub-sections.

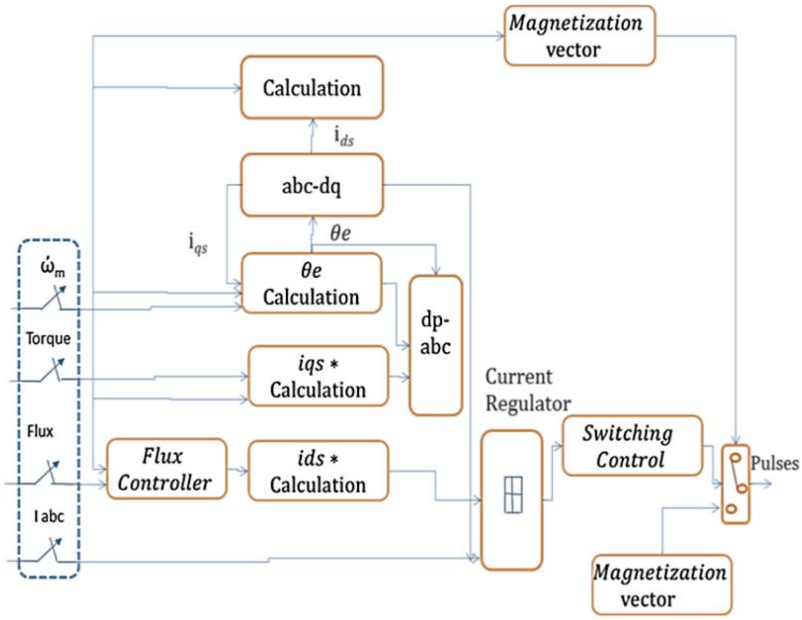

Fig. 2 Block diagram of FOC scheme

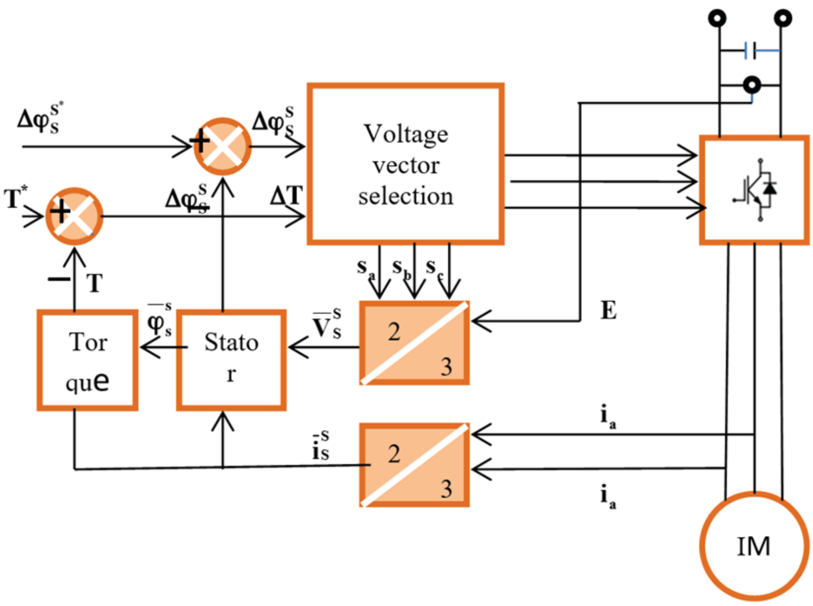

Fig. 3 Block diagram of DTC scheme

A. FOC Drive

The block diagram of field oriented control (FOC) induction motor drive is shown in Fig. 2. The concept of field oriented control was proposed by Blaschke in 1972. This technique has allowed independent control of the torque and flux of the dynamic machine. This could be done by direct or indirect flux orientation. In the direct field oriented control (DFOC), both the instantaneous magnitude and position of the rotor flux are supposed to be directly measured. The condition for flux orientation is $\varphi_{qr} = 0$. So, the FOC performance equations become:

$$\varphi_r = \varphi_{dr} \tag{4}$$

$$T = p\frac{M}{L_r}\varphi_r i_{qs} \tag{5}$$

$$\varphi_r = \frac{M}{1+sT_r}\, i_{ds} \quad (6)$$

$$\omega_r = \omega_{s-}\,\omega = \frac{M}{T_r}\frac{i_{qs}}{\varphi_r} \quad (7)$$

$$V_{ds}{}^{*} = \sigma L_{S}\frac{di_{ds}}{dt} + R_s i_{ds} - \sigma L_S \omega_s i_{qs} + \frac{M}{L_r}\frac{d\varphi_r}{dt} \quad (8)$$

$$V_{qs}{}^{*} = \sigma L_{S}\frac{di_{qs}}{dt} + R_s i_{qs} - \sigma L_S \omega_s i_{ds} + \frac{M}{L_r}\omega_s \varphi_r \quad (9)$$

where

$$T_r = \frac{L_r}{R_r} \text{ and } \sigma = 1 - \frac{M^2}{L_r L_s} \quad (10)$$

B. DTC Drive

The block diagram of Direct Torque Control drive [2], [3] is shown in Fig. 3. The main feature of DTC is that position of inverter switches are determined directly thus refrained from using any modulation techniques like pulse width modulation (PWM), space vector modulation (SVM). The control objective is to keep motor's torque and stator flux within pre specified limits. The inverter is triggered by hysteresis controllers to switch whenever these bounds are violated. The choice of the new switch has made using a pre designed look up table that has been designed using a geometric insight in the problem and additional heuristics.

The direct torque control (DTC) has the advantage of fast dynamic torque response and has good robustness to the changes of rotor parameters etc. But the torque ripple is an inadequacy of the system. The pulsation becomes more apparent especially in the low-speed operating conditions.

TABLE I
SWITCHING TABLE [1]

Output of hysteresis comparator		Sector 1	2	3	4	5	6
C_φ = -1	C_T =-1	V_2	V_3	V_4	V_5	V_6	V_1
	C_T =0	V_7	V_0	V_7	V_0	V_7	V_0
	C_T =+1	V_6	V_1	V_2	V_3	V_4	V_5
C_φ = + 1	C_T =-1	V_3	V_4	V_5	V_6	V_1	V_2
	C_T =0	V_0	V_7	V_0	V_7	V_0	V_7
	C_T =+1	V_5	V_6	V_1	V_2	V_3	V_4

The basic idea of DTC for induction motor is to control the voltage space vectors properly, which is based on the relationship between the slip frequency and torque by using a α-β stationary stator reference frame, the stator flux linkage φ_s and electromagnetic torque T are calculated by using:

$$\varphi = \sqrt{(\varphi_{\alpha s})^2 + (\varphi_{\beta s})^2} \quad (11)$$

where

$$\varphi_{\alpha s} = \int_0^t (V_{\alpha s} - R_S i_{\alpha s})\, \mathrm{dt} \quad (12)$$

$$\varphi_{\beta s} = \int_0^t (V_{\beta s} - R_S i_{\beta s})\, \mathrm{dt} \quad (13)$$

$$\text{The angle } \theta_s = artg\frac{\varphi_{\beta s}}{\varphi_{\alpha s}} \quad (14)$$

$$\mathrm{T} = \mathrm{p}\,[\varphi_{\alpha s} i_{\beta s} - \varphi_{\beta s} i_{\alpha \epsilon s}] \quad (15)$$

The error between the estimated torque T and the reference torque T* is the input of a three level hysteresis comparator, whereas the error between the estimated stator flux magnitude $\varphi_s$and the reference stator flux magnitude φ_s*is the input of a two level hysteresis comparator [1]. The selection of the appropriate voltage vector is based on the switching table given in Table I. The input quantities are the flux sector and the outputs of the two hysteresis comparators.

IV. SIMULATION RESULTS

Simulations were conducted for the various Z-source inverter configurations feeding industrial drives with the following system parameters:

A. ZSI Parameters

ZSI parameters are as follows: $L_1 = L_2$ = 1 mH; $C_1 = C_2$ = 1300 μF; Input voltage = 230V; Switching frequency = 10 kHz; Output-filter cutoff frequency = 1 kHz.

B. DTC Drive Parameters

DTC parameters are as follows: 230V, 50Hz; Stator Resistance R_S = 0.435Ohm; Leakage Reactance X_S = 2mH; Rotor Resistance R_r = 0.816Ohm; Leakage Reactance X_r = 2mH; Mutual Inductance = 69.31mH.

C. FOC Drive Parameters

FOC parameters are as follows: 230V, 50Hz; Stator Resistance R_S = 0.435Ohm; Leakage Reactance X_S = 2mH; Rotor Resistance R_r = 0.816Ohm; Leakage Reactance X_r = 2mH; Mutual Inductance = 69.31mH.

For all the configurations, the modulation index (m) is varied from 0.4 to 1.2 in the step size of 0.2. The variation of Fundamental Output Voltage (V_1) and its THD Level versus Modulation Index for different types of Z-Source Inverters feeding DTC Drive is shown in Table II. Whereas, the variation of Fundamental Output Voltage and its THD Level versus Modulation Index for different types of Z-Source Inverters feeding FOC Drive is shown in Table III.

TABLE II
VARIATION OF FUNDAMENTAL OUTPUT VOLTAGE AND ITS THD LEVEL VERSUS MODULATION INDEX FOR DIFFERENT TYPES OF Z-SOURCE INVERTERS FEEDING DTC DRIVE

m	Simple Boost Control		Maximum Boost Control		Constant Maximum Boost Control		Third Harmonic Injected Constant Maximum Boost Control	
	V_1 (V)	THD (%)	V1 (V)	THD (%)	V_1 (V)	THD (%)	V_1 (V)	THD (%)
0.4	126	165.5	298.2	167.58	193	165.3	4.489	164.6
0.6	185	121.2	279.7	120.05	292.4	121.2	126.8	121.2
0.8	253	92.22	274.3	93.02	389.1	92.04	172.7	91.92
1	291	79.06	266.3	70.13	407.7	87.07	214	69.56
1.2	308	74.24	255.4	61.15	415.9	84.09	244.6	53.89

TABLE III
VARIATION OF FUNDAMENTAL OUTPUT VOLTAGE AND ITS THD LEVEL VERSUS MODULATION INDEX FOR DIFFERENT TYPES OF Z-SOURCE INVERTERS FEEDING FOC DRIVE

m	Simple Boost Control		Maximum Boost Control		Constant Maximum Boost Control		Third Harmonic Injected Constant Maximum Boost Control	
	V_1 (V)	THD (%)	V1 (V)	THD (%)	V_1 (V)	THD (%)	V_1 (V)	THD (%)
0.4	117	165.3	298.5	167.6	186.7	165.3	17.98	164.3
0.6	177	121.1	271.6	119.9	281.8	121.2	128	121.1
0.8	236	92.06	260.4	93.04	376.1	92.06	169.3	91.9
1.0	270	78.92	266.9	70.29	395.3	87.09	211.2	69.18
1.2	284	74.15	263.3	61.22	402.9	84.11	242.1	53.3

V. CONCLUSIONS

In this work, simulations of Z-Source inverter configuration schemes have been done in MATLAB/SIMULINK. For each of the configuration, input voltage, inductor current, voltage stress and output voltage have been studied. The following conclusions are drawn from these waveforms:

- In simple boost control method, inductor current does not contain any low frequency ripples. So, the components of smaller size are required.
- The voltage gain observed for maximum boost control is higher as compared to that for simple boost control. The voltage stress has been reduced while it contains large inductor current ripples.
- The THD level of output voltage in case of maximum boost control method is higher as compared to any other method for modulation index equal to 0.4.
- The THD level of output voltage in case of constant maximum boost control method is higher as compared to any other method for modulation index between 0.4 and 0.8.
- The THD level of output voltage in case of third harmonic injected constant maximum boost control method is higher as compared to any other method for modulation index greater than 0.8.
- Voltage gain in case of third harmonics injection constant boost control is lower than the simple boost control and constant maximum boost control methods.

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