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Quasi-Z-Source Inverter based Induction Motor Drive with Voltage sags/swells Mitigation

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***Abstract*--** **This paper presents a quasi-Z-Source inverter based induction motor drive system. The speed of the induction motor is controlled by using V/f control method. Also the proposed system has an ability to compensate the voltage sags and swells. The advantage of the proposed system is that no energy storage component is required to compensate the voltage sag/swell. The operating principal of the proposed quasi-Z-source inverter based system is described and Matlab/Simuliink simulation is presented to verify the proposed concept and theoretical analysis.**

***Index Terms*—Induction Motor Drive, Quasi-Z-Source inverter (q-ZSI), Simple Boost Control (SBC), V/f Control.**

I. Introduction

The power quality was not an important issue before some decades because it had no effect on most of the loads connected with the electrical power supply. In recent years power quality issues have been received most attention with the increased use of high efficiency adjustable speed drives and power electronic controllers [1]. Among these, voltage sags and swells are the two most important power quality problems.

The voltage sags is defined as the sudden reduction in the supply voltage followed by a recovery after a short interval. The voltage swell is defined as the sudden increment of the supply voltage from the nominal value.

To increase the reliability of the power system many techniques have been proposed in literature based upon inverter system and power switches. Some of them are also based upon dynamic voltage restorer (DVR) and uninterrupted power supply (UPS) .These techniques are able to compensate the power quality problem like voltage sags and swells [2]. But some of these techniques are based upon use of large energy storage components like capacitors and batteries bank, as the power level increases the size of these energy storage devices also increases which increase the cost of the system and also the system become bulky [3].

In this paper a feedback control technique is presented which has a capability to compensate the voltage sags and swells. The impedance source inverters i.e. Z-Source inverter, quasi-Z-Source inverter were proposed as an alternate power Conversion concept and they have capability to both voltage buck and boost [4]. Among these two the quasi-Z-Source inverter has an advantage of continuous input current.

During voltage sags and swells the control system regulates the load voltage and maintained a constant rated voltage at motor terminals so as the motor operation is not interrupted.

II. Proposed System

The proposed system is shown in fig. 1. The whole system consists of mainly eight blocks- the three phase ac supply, rectifier, quasi-Z-Source impedance network, traditional three phase inverter, 3-phase induction motor, RPM to Hz gain constant, V/Hz gain constant and control block.

The purpose of the control system is to vary the speed of the induction motor by varying the frequency of the stator voltage while keeping the V/f ratio constant. Besides this it also keeps the stator voltage at reference value during voltage sags or swells in the three phase supply voltage.

The base speed of the induction motor is directly proportional to the supply frequency and indirectly proportional to the number of poles (1).

$$N = \frac{120 * f}{P} \quad (1)$$

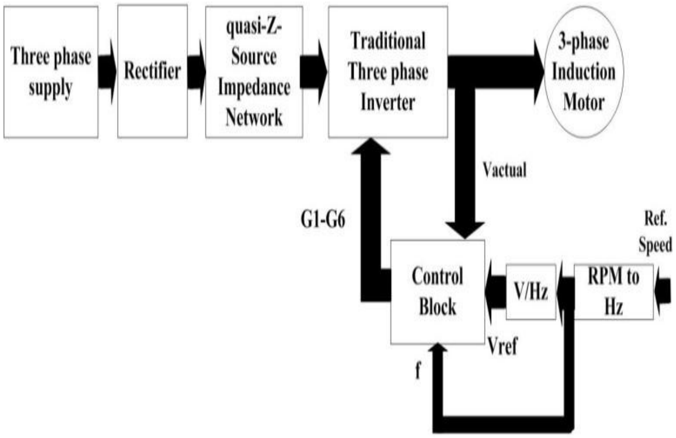

Fig. 1 The scheme of the proposed system

Now the number of poles for an induction motor is fixed by design, so we can vary the speed of the induction motor by controlling the supply frequency.

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The voltage applied to the stator is directly proportional to the product of the stator flux and angular velocity (2) and the torque developed by the motor is directly proportional to the magnetic field produced by the stator. This makes the flux produced by the stator proportional to the ratio of applied voltage and frequency of supply (3).

By varying the frequency, the speed of the motor can be varied. Therefore, by varying the voltage and frequency by the same ratio, flux and hence the torque can be kept constant throughout the speed range. This makes constant V/F the most common speed control of the induction motor.

$$\mathrm{V} = \varphi * 2\pi \mathrm{f} \qquad (2)$$

$$\varphi \propto \frac{\mathrm{V}}{\mathrm{f}} \qquad (3)$$

The flow chart of the control block is shown in fig. 2. The basic function of the controller in the proposed system is to detect voltage sag/swell in the system, computation of correcting voltage and generation of trigger pulses for the three phase quasi-Z-Source DC-AC inverter [5][6]. The dq0 transformation or Park's transformation (4), (5) & (6) has been used in the system [7]. First it converts the actual stator voltage from abc-frame to dq0-frame.For the sake of simplicity the zero sequence component is made zero. The error signal is generated by comparing this transformed actual voltage with the reference value of stator voltage. Further this error is minimized using PI controller the output signal from the PI controller is converted into abc-frame by using inverse Park's transform (7), (8) & (9) [7]. This signal is used as a reference signal to generate the gate pulses for the inverter. Before applying these pulses to the inverter the shoot through pulses are inserted using OR logic. The PLL circuit is used to generate the unit sinusoidal signal of frequency equal to frequency calculated from the V/Hz gain constant block.

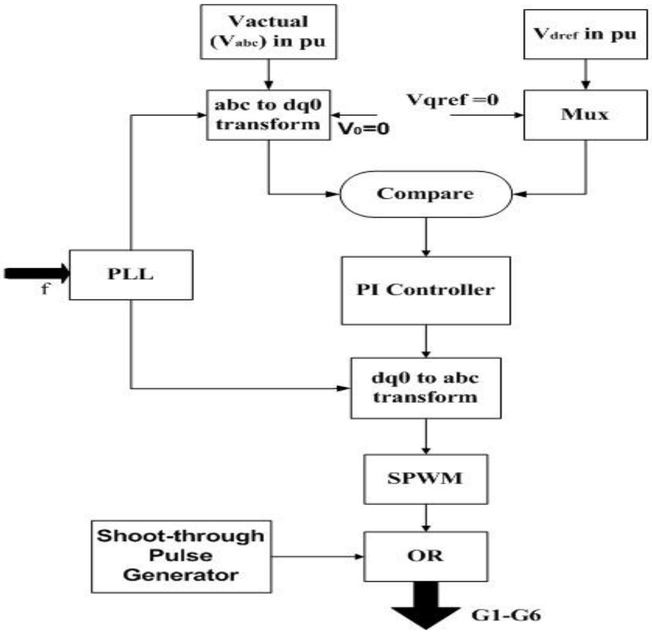


Fig. 2 Flow chart of feedback control technique based upon dq0 transform

The Park's transform is given as:

$$V_d = \frac{2}{3}[V_a \sin\omega t + V_b \sin\left(\omega t - \frac{2\pi}{3}\right) + V_c \sin\left(\omega t + \frac{2\pi}{3}\right)] \qquad (4)$$

$$V_q = \frac{2}{3}[V_a \cos\omega t + V_b \cos\left(\omega t - \frac{2\pi}{3}\right) + V_c \cos\left(\omega t + \frac{2\pi}{3}\right) \qquad (5)$$

$$V_0 = \frac{1}{3}[V_a + V_b + V_c] \qquad (6)$$

The inverse Park's transform is given as:

$$V_a = V_d \sin\omega t + V_q \cos\omega t + V_0 \qquad (7)$$

$$V_b = V_d \sin\ (\omega t - \frac{2\pi}{3}) + V_q \cos\left(\omega t - \frac{2\pi}{3}\right) + V_0 \qquad (8)$$

$$V_c = V_d \sin\ (\omega t + \frac{2\pi}{3}) + V_q \cos\left(\omega t + \frac{2\pi}{3}\right) + V_0 \qquad (9)$$

III. Quasi-Z-Source Inverter

Fig. 3 shows the circuit diagram of q-ZSI. It has two working stages- Shoot- through stage in which the load terminals are short circuited through at least one of the phase leg which is forbidden into traditional voltage source inverter and second is non shoot through stage, same as in traditional voltage source inverters. The q-ZSI has following advantages:

- Buck –Boost operation can be performed using single power stage.
- It gives continuous input current that means the input current never reaches to zero. Due to this the voltage Stress at input dc power supply become very less which is very advantageous in case of fuel cell or solar cell supply systems.

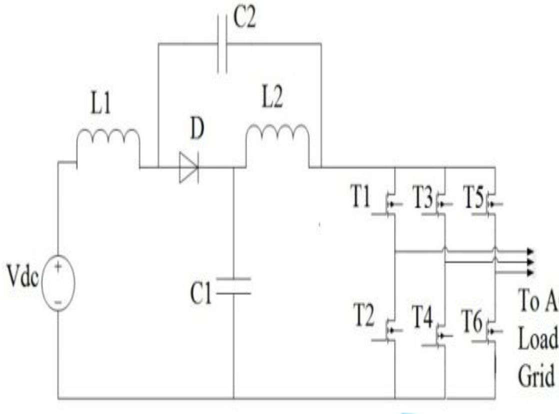


Fig. 3 Three phase Voltage fed q-ZSI

A. *Operating Principle of the Voltage fed q-ZSI*

In CCM the q-ZSI consists of two states- Shoot- through state (t_S) & Active state (t_A)

$$T = t_A + t_S \tag{10}$$

Equation (10) can be represented as:

$$\frac{t_A}{T} + \frac{t_S}{T} = D_A + D_S = 1 \tag{11}$$

Where D_A is the Active (non-shoot-through) state duty cycle and D_S is the shoot-through state duty cycle.

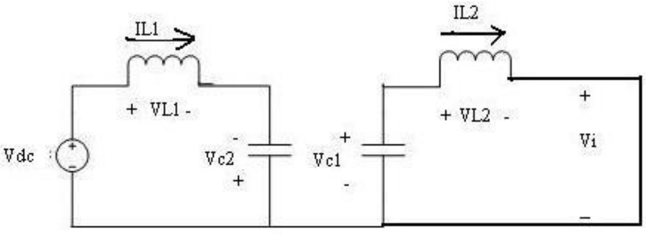


Fig. 3(a) Equivalent circuit of q-ZSI during Shoot-through

From the equivalent circuit of q-ZSI during Shoot state i.e. fig. 3(a), the voltage across inductor L_1 is given as:

$$V_{L_1} = V_{dc} + V_{C_1} \tag{12}$$

and the Voltage across L_2 is given as:

$$V_{L_2} = V_{C_2} \tag{13}$$

:

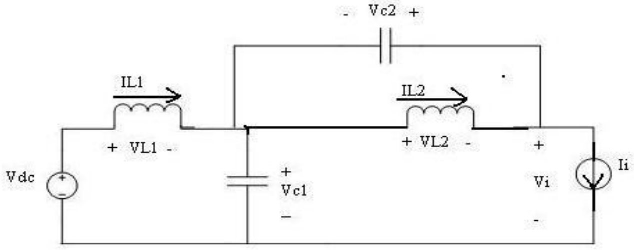


Fig. 3(b) Equivalent circuit of q-ZSI during non- Shoot through

From the equivalent circuit of q-ZSI during non-Shoot-through state i.e. fig. 3(b), the voltage across inductor L_1 is given as:

$$V_{L_1} = V_{dc} - V_{C_2} \tag{14}$$

and the Voltage across L_2 is given as:

$$V_{L_2} = -V_{C_2} \tag{15}$$

In steady- state the average voltage across inductors must be zero. So from (12) & (14)

$$< V_{L_1} > = \frac{(V_{dc} + V_{C_1}) D_S T + (V_{dc} - V_{C_2})(1 - D_S)\, T}{T} = 0$$

Or, $(V_{dc} + V_{C_1}) D_S T + (V_{dc} - V_{C_2})(1 - D_S) T = 0$

Or, $$V_{dc} + V_{C_1} D_S + V_{C_2}(1 - D_S) = 0 \tag{16}$$

and from (13) & (15)

$$-V_{C_2} D_S T + V_{C_1}(1 - D_S) T = 0$$

Or, $$V_{C_2} = \frac{V_{C_1}(1-D_S)}{D_S} \tag{17}$$

From (16) & (17) we have

$$V_{C_1} = \frac{D_S}{(1-2D_S)} V_{dc} \tag{18}$$

And from (17) & (18)

$$V_{C_2} = \frac{(1-D_S)}{(1-2D_S)} V_{dc} \tag{19}$$

The peak dc link Voltage is given as:

$$\hat{V}_i = V_{C_1} + V_{C_2}$$

$$\hat{V}_i = \frac{D_S}{(1-2D_S)} V_{dc} + \frac{(1-D_S)}{(1-2D_S)} V_{dc}$$

$$\hat{V}_i = \frac{1}{(1-2D_S)} V_{dc} = B\, V_{dc} \tag{20}$$

Where B (Boost factor) $= \frac{\hat{V}_i}{V_{dc}} = \frac{1}{(1-2D_S)} = \frac{1}{1-2\frac{t_S}{T}} = \frac{T}{t_A - t_S} \geq 1$ (21)

The output peak phase voltage from the inverter can be expressed as:

$$\hat{V}_{ac} = M \frac{\hat{V}_i}{2} \tag{22}$$

Where M is the modulation Index. Using (20), (22) can be further expressed as:

$$\hat{V}_{ac} = M\, B \frac{V_{dc}}{2} \tag{23}$$

For a traditional PWM-VSI inverter we have a well known relationship as: $\hat{V}_{ac} = M \frac{V_{dc}}{2}$. Equation (23) shows that the output voltage of q-ZSI can be stepped up or stepped down by selecting appropriate value of buck-boost factor (B_B).

$$B_B = M.B = (0 \sim \infty) \qquad (24)$$

The buck-boost factor (B_B) can be determined by modulation index (M) and the boost factor (B). From (21) the boost factor can be controlled by controlling the shoot-through interval over non-shoot-through interval.

B. *Switching Strategy*

The shoot-through states are introduced in quasi-Z-Source inverter to boost up the dc-link voltage. During shoot-through state the upper and lower switches of the same phase leg conduct simultaneously to give the desired output ac voltage level which is greater than available dc-link voltage.

There are several methods have been proposed in literature to insert the shoot-through states within traditional PWM pulses like-Simple Boost Control (SBC)[8], Maximum Boost Control (MBC)[9] and Maximum Constant Boost Control [10].

In Simple Boost Control the shoot-through pulses are inserted by using two straight lines as reference. The value of upper reference (positive reference) is equal to or greater than the amplitude of the three phase modulating signal and the lower reference (negative reference) has same value as positive reference with negative sign. In Quasi-Z-Source inverter the six active states remains unchanged. In Simple Boost Control the maximum shoot-through duty ratio (D_s) that can be obtained is limited to (1-M). So as the modulation index (M) increases the shoot-through duty ratio (D_s) decreases. Fig.3(c) shows the simple boost control waveforms [9].

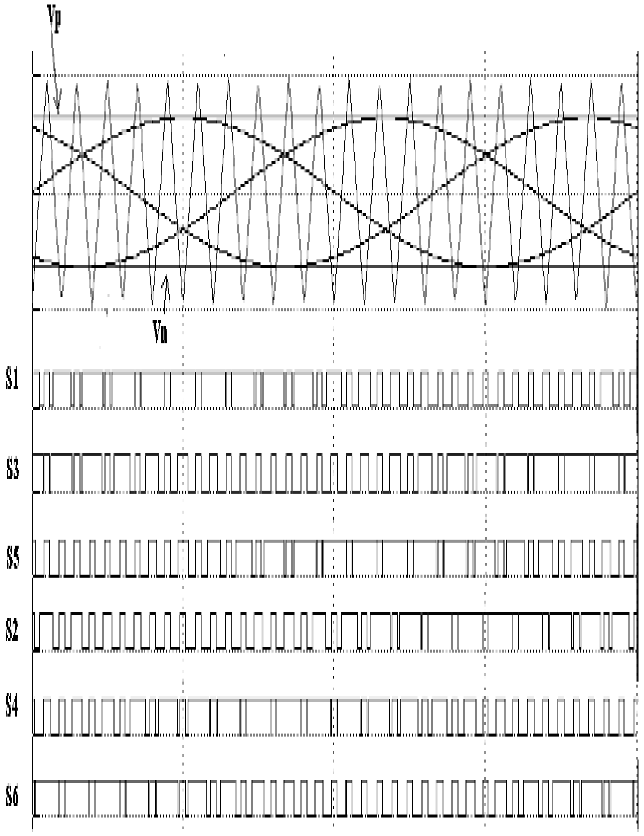


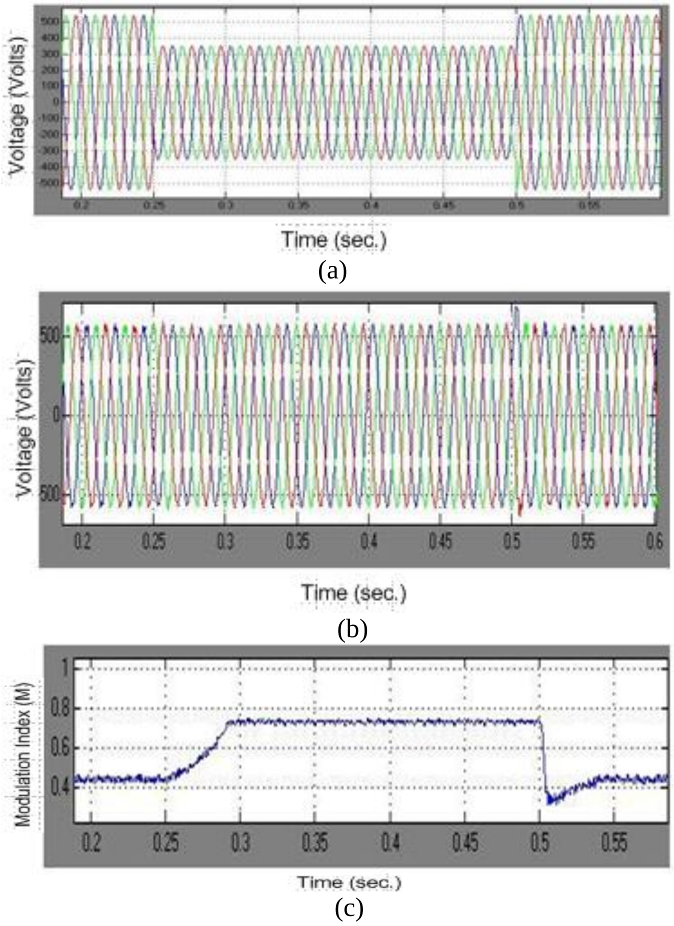
Fig. 3(c) Simple Boost Control Waveforms

IV. Simulation Results & Discussion

The simulation has been performed in Matlab/Simulink environment and simulation results are presented to verify the validity of the proposed system. The simulation parameters are as follows:

I. Three phase Supply = 220 Volts, 50 Hz
II. Quasi-Z-Source Network: $L_1 = L_2 = 160\ \mu H$, $C_1 = C_2 = 1000\ \mu F$
III. Load = Three phase 5.4 HP (4KW), 400 V, 50Hz, 1430 rpm Induction Motor
IV. Switching frequency = 10KHz

Fig. 4(a) to 4(c) shows the simulation result of voltage sag compensation. The voltage sag occurs between 0.25 sec to 0.5 sec and it can be observed that the proposed system responds instantaneously and maintain the load voltage at constant reference value.



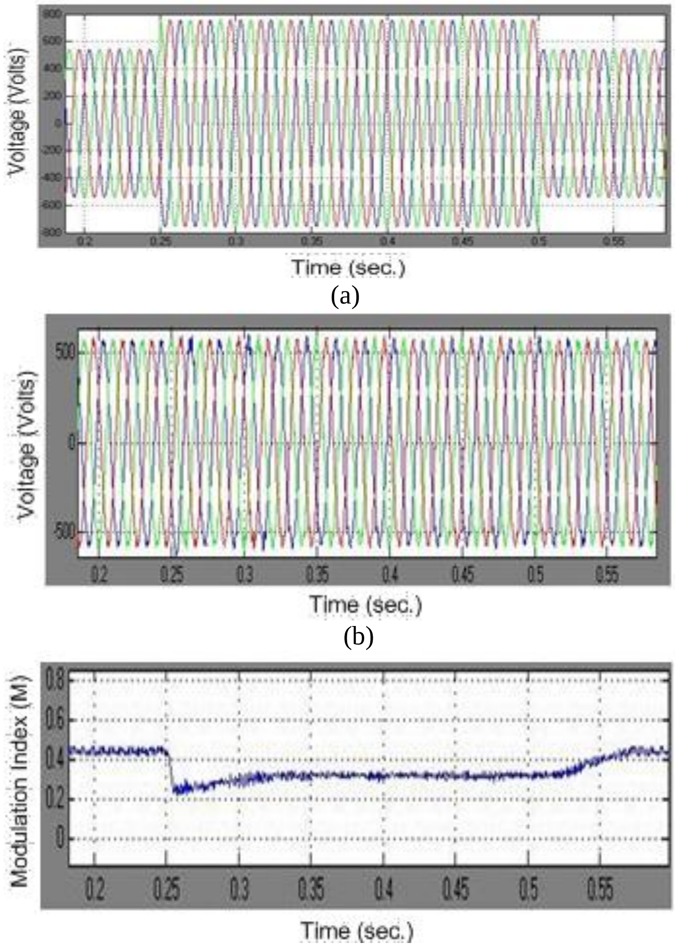
(a)

(b)

(c)

Fig. 4 Simulation result of Voltage sag compensation (a) Input Voltage (b) Load Voltage (c) Modulation Index (M)

Fig. 5(a) to 5(c) shows the simulation result of voltage swell compensation. The voltage sag occurs between 0.25 sec to 0.5 sec and it can be observed that the proposed system responds instantaneously and maintain the load voltage at constant reference value.



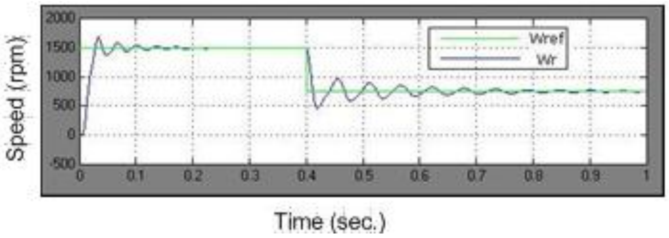
(a)

(b)

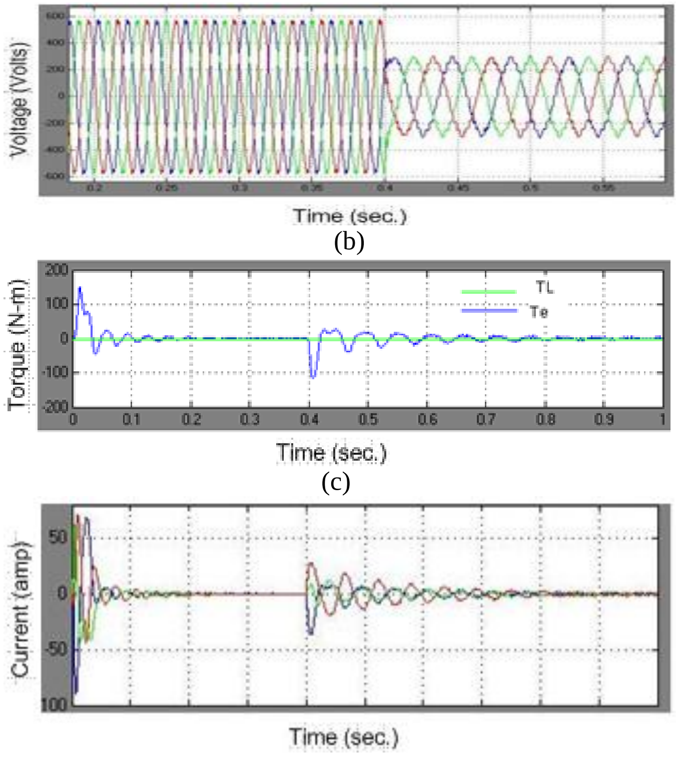
(c)

Fig. 5 Simulation result of Voltage swell compensation (a)Input Voltage (b) Load Voltage (c) Modulation Index (M)

Fig. 6(a) to 6(d) showing the simulation result of V/f control. Initially the reference speed is set to 1500 rpm and after 0.4 sec the reference speed is set to 750 rpm. It can be seen from fig 6(a) that rotor speed follows the reference speed. Fig 6(b) shows the stator voltage of motor, Initially, when the reference speed is set to 1500 rpm the ratio V/f = 400/50=8 and at 0.4 sec when speed is set to 750 rpm the phase to phase stator voltage ($V_{rms)}$ is changed to 200 volts and frequency become 25Hz to maintain the constant V/f ratio = 200/25=8. Fig.6(c) the electromagnetic torque generated by the motor. As the load torque is set to zero (motor is operating at no load), the motor toque reaches to steady state value within 0.25 sec.fig 6(d) is showing the rotor current at no load condition.



(a)



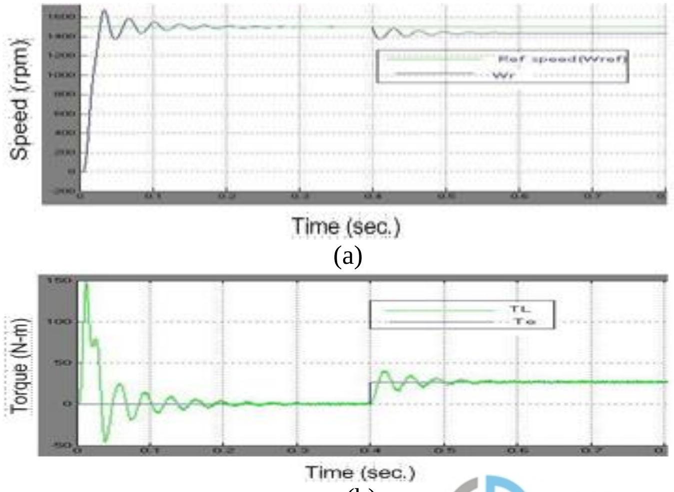
(b)

(c)

(d)

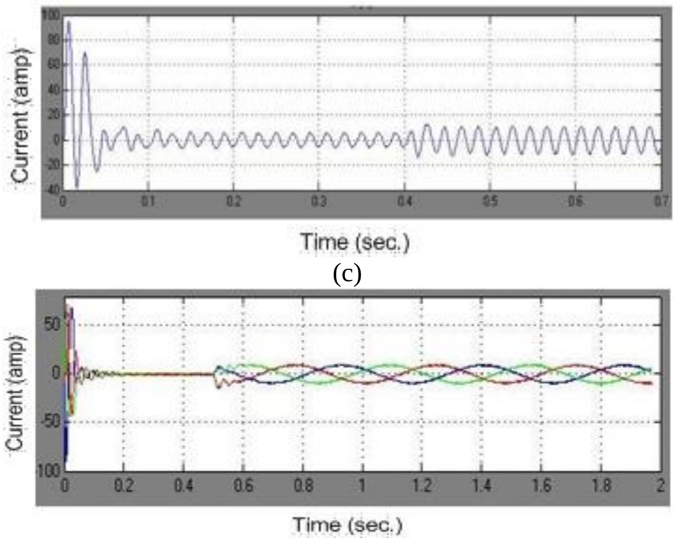
Fig. 6 V/f Control of Induction Motor (a) Rotor Speed (b) Stator Voltage (V_{rms}) ph-ph (c) Electromagnetic Torque (d) Rotor Current

Fig 7 shows the simulation results of response of induction motor during load disturbance. Initially the load torque (T_L) is set to zero and at 0.4 it is being set to 26 N-m. Fig 7(a) is showing the slip change of motor which is approximate 4.8%. Fig 7(b) is showing the electromagnetic torque of motor which reaches its steady state value 0.3 sec. Fig 7(c) showing the change in the stator current during load disturbance. The stator current become is increased to meet load requirement. Fig 7(d) is showing the rotor current. Initially when the motor is operating at no load the rotor current is zero and when the load changes it amplitude increases and at the same time the rotor current frequency changes to $f_r = s * f_s = .048 * 50 = 2.4$ Hz, where f_s is supply frequency.



(a)

(b)



(c)

(d)

Fig. 7 System response during load disturbance with V/f control (a) Rotor Speed (b) Electromagnetic Torque (c) Stator Current (d) Rotor Current

V. Conclusion

A quasi-Z-Source inverter based induction motor drive system is presented in this paper. The proposed system has an ability to compensate the voltage sags and swells. The advantage of the proposed system is that no energy storage component is required to compensate the voltage sag/swell. The operating principal of the proposed quasi-Z-source inverter based system is described and Matlab/Simuliink model based simulation results are presented to verify the proposed concept and theoretical analysis.

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