Speed Control of a ZSI FED Induction Motor by IFOC

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ABSTRACT
This paper presentsa speed control method for a ZSI fed Induction motor. By employing ZSI,the DC-link voltage can be boosted to any value thus providing compensation against any voltage sags resulting in increased reliability.For controlling the speed, Indirect Field Oriented Control (IFOC) along with Double Space Vector Pulse Width Modulation(DSVPWM)techniques isused.The performance of the proposed control strategy is verified with simulation and hardware results.dsPIC6010A is used for the implementation of the proposed scheme.

Keywords
Impedance source Inverter (ZSI),Indirect-Field oriented control(IFOC),Shoot-through(ST),Double Space Vector Pulse Width Modulation (DSVPWM).

1. INTRODUCTION
Automobile Industry has taken a transformation from conventional fossil fuel technology to battery driven technology.This transformation can be attributed to various factors like increase in carbon emission,energy conservation etc. In this aspect controlling the non-linear speed of EVs plays a major role in design.Among all the motors adapted for EVs, Induction motors are the most suitable.[10]

This paper mainly focusses on the effective role of ZSI in controlling the speed of the induction motor.The DSVPWM technique generates the gating signals for the switching devices of the ZSI with the required amount of shoot-through and the speed control is done by implementing IFOC.

The paper is organized as follows: Section 2 describes ZSI and designing of L and C components. Section 3 describes the voltage boosting by DSVPWM technique. Section 4 describes the control of DC-link voltage. Section 5 describes the speed control of induction motor. Section 6 describes the hardware implementation and Section 7 includes simulation and hardware results followed by conclusion and references.

2. ZSI
A ZSI overcomesall the operational problems faced by the traditional inverters and at the same time is less expensive and provides a single-stage power conversion for the drives.[1]

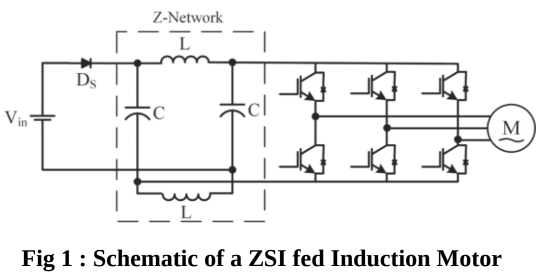


Fig 1 : Schematic of a ZSI fed Induction Motor

A ZSI in its most simple form can be represented by 2 split inductors and capacitors (L_1&L_2,C_1& C_2 resp.) connected as shown in the fig 1.

Based on the switching states, the working of a ZSI can be categorized into three modes [8]:

i. Traditional Active State:

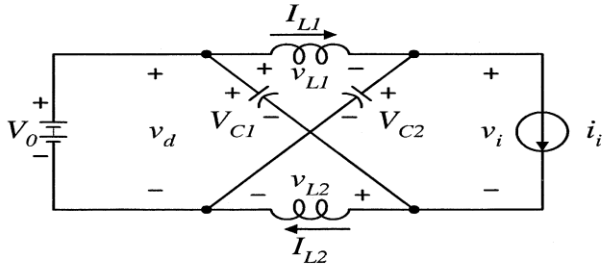


Fig2: Eq. Circuit of ZSI - Non-Shoot Through State

In this state,the inverter acts as a basic inverter with the inverter bridge acting as an equivalent current source as shown in the fig 2.From the above fig

$V_L = V_O - V_C$ $\quad$ $V_D = V_O$ $\quad$ $V_i = V_C - V_L = 2V_C - V_O$ $\quad$ (1)

Where, Vo: input DC voltage $\quad$ Vi: peak DC-link voltage

T_1: time period during non- shoot –through state.

ii. Shoot-Through State:

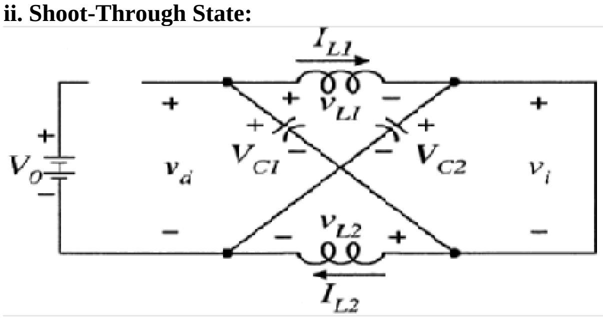


Fig3: Eq. Circuit of ZSI - Shoot Through State

During this mode energy is transferred from capacitors to inductors and capacitor voltage drops and inductor current increases to its maximum value.

$V_L = V_C$ $\quad$ $V_D = 2V_C$ $\quad$ $V_i = 0$ $\quad$ - (2)

iii.**Traditional Zero State:**
This state is similar to the zero-state of the traditional inverter (ie. either all upper or all lower devices are shorted) and creates a zero output voltage at the output terminals of the inverter as in the case of traditional inverter.

2.1 Designing of L and C
During non-shoot-through condition, inductor voltage is different from capacitor voltage and inductor current decreases linearly.[8]

During shoot-through theCapacitor and inductor voltage become equal and inductor current increases linearly.

So the average current through inductor can be written as

$$\bar{I}_L = \frac{P}{V_{in}} \quad (3)$$

Where, P is the converter power rating and V_{in} is the input DC source voltage.

When the shoot-through period is maximum,the current ripple through the inductors becomes maximum. For the design of inductor, inductor current ripple is considered as

30% of the inductor current:

Max. Inductor current $=\hat{I}_L = \bar{I}_L + 30\% I_L$

Min. Inductor current $=\check{I}_L = \bar{I}_L - 30\% I_L$

In ZSI,

$$V_{dp} = BV_{in} \quad (4)$$

$$V_{dp} = 2V_C - V_{in} \quad (5)$$

$$D_{sh} = \frac{T_{sh}}{T} = \frac{B-1}{B} \quad (6)$$

$T=1/f_s T_{sh}$ is the shoot through period per switching cycle.

B=Boost factorDsh/Do=Tsh(To)/T shoot-thru. duty ratio

From (4),(5) and (6) capacitor voltage V_C can be expressed as

$$V_C = \frac{(B+1)}{2} V_{in} \quad (7)$$

$$\text{Or,} V_C = \frac{1-\left(\frac{Tsh}{T}\right)}{1-\left(\frac{2Tsh}{T}\right)} V_{in} \quad (8)$$

During shoot- through, $V_L=V_C=V$

Inductor value is

$$L = \frac{V * T_{sh}}{\Delta I} \quad (9)$$

Where, $\Delta I = \hat{I}_L - \check{I}_L$

Restricting the capacitor voltage ripple (ΔV_C) to less than 1%, the capacitor value can be calculated as

$$C = \frac{\bar{I}_L * T_{sh}}{\Delta V_C} \quad (10)$$

3. DSVPWM

1. This technique makes use of two sets of 3-Ø sinusoidal signals as ref. and for carrier, a triangular wave is employed.[7]

2. For generating 1st set of reference waveforms, SVPWM is implemented ,which results in generation of 1st set of reference wave with the required modulation index "m" of the input voltage and then the 2nd set of signals is generated by adding a finite negative DC-offset (Voffset) to the 1st set. (let the reference signals be V_{a1},V_{b1} ,V_{c1}, represent 1st set and V_{a2}, V_{b2}, V_{c2} represent 2nd set).

The reference signal V_{a1} generates the pulses for the top switch and the bottom switch pulses are generated by V_{a2} of leg "a," resp, as shown in fig4

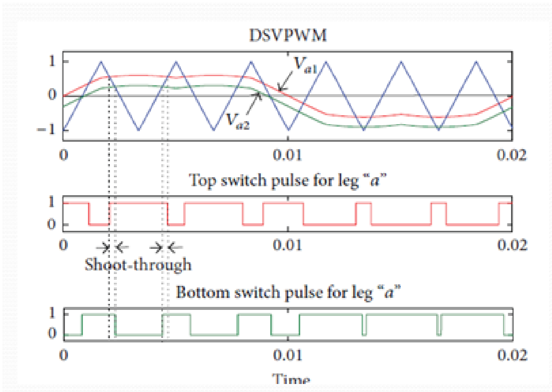


Fig 4: DSVPWM Pulses for phase a

3.Relation between Vdc-offset and Dsh :

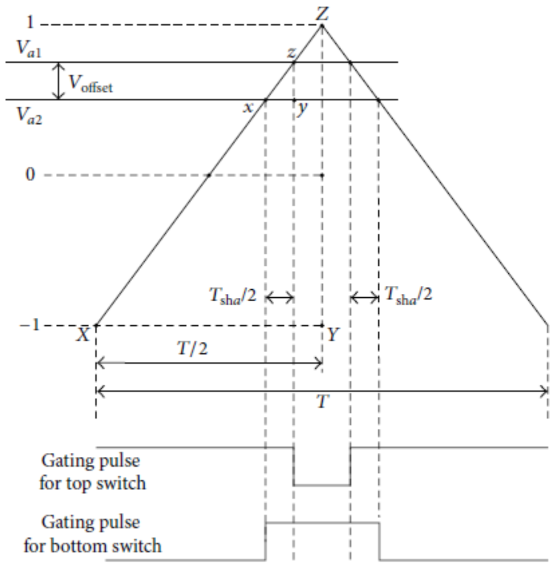


Fig 5: Shoot-through for phase a

As can be seen from the fig.5 V_{offset} is responsible for creating shoot-through.From fig.5,using property of similar triangles for triangles XYZ and xyz

$$xy = \left(\frac{yz}{YZ}\right) XY \quad (11)$$

$$\frac{T_{sha}}{2} = \left(\frac{V_{offset}}{1-(-1)}\right) * \left(\frac{T}{2}\right) \quad (12)$$

Therefore shoot-through time for leg a is given by

$$T_{sha} = (V_{offset}) * \left(\frac{T}{2}\right) \quad (13)$$

The shoot through time in all three legs of the inverter remains same only the instants at which they take place vary. So, the shoot through time in leg b and c is

$$T_{sha} = T_{shb} = T_{shc} = (V_{offset}) * \left(\frac{T}{2}\right) \quad (14)$$

Therefore the total shoot-through time is given by

$$T_{sh} = 3 * T_{sha} = 3 * (V_{offset}) * \left(\frac{T}{2}\right) \quad (15)$$

Therefore the shoot-through duty ratio(Dsh/Do)

$$D_{sh} = \frac{\text{shoot through time } (T_{sh})}{\text{total switching time } (T)} = 3 * \frac{V_{offset}}{2} \quad (16)$$

4. DC-LINK VOLTAGE CONTROL

ZSI employs the shoot-through states to boost the DC-link voltage by varying the shoot-through duty ratio. The DC-link voltage is affected by any change in speed or load,hence making it a pulsating quantity.So the DC-link voltage is controlled in an indirect manner by controlling the capacitor voltage.

The ref-capacitor voltage,V_{Cref} is determined from the ref. DC-link voltage (V_{dpref}) and the input volatge using the relation V_{dpref} =2V_{Cref}-V_{in}.Then the error thusobtained by compairingthe Vc and Vcref is fed to a PI controller ,which generates the required value of the DC -Off-set voltage. This DC-offset voltage is then used to determine the second set of reference waveforms as required for the DSVPWM technique and hence the gating pulses resulting from the DSVPWM technique has both desired value of MI,m and the Dsh.

Table 1:Parameters of Induction Motor

S.NO	PARAMETERS	VALUE
1	Output Power	0.5HP
2	Line Voltage	400V
3	Frequency	50Hz
4	No. of poles	4
5	Speed	1440rpm
6	Stator Resistance, R_s	2.015ohms
7	Rotor Resistance, R_r	1.95ohms
8	Stator Inductance, L_s	1.78mH
9	Rotor Inductance, L_r	1.79mH
10	Mutual Inductance, L_m	5.3mH
11	Inertia	0.0034Kgm^2

5. SPEED CONTROL

Field-Oriented Control: The main advantage of employing vector control for induction motor is that it allows independent control of torque and flux like separately-excited DC-motor.It can be broadly divided into direct and indirect vector control methods.

The basics of both schemes are the same except for the way in which the unit vectors are determined .In indirect scheme the unit vectors are indirectly computed using the rotor speed and the slip frequency.

$\theta_e = \int \omega_e . dt = \int (\omega_r + \omega_{sl}). dt$(17)

The rotor circuit equations are given as

$$\frac{d}{dt}\varphi_{dr} + \frac{R_r}{L_r}\varphi_{dr} - \frac{L_m}{L_r}R_r i_{ds} - \omega_{sl}\varphi_{qr} = 0 \quad (18)$$

$$\frac{d}{dt}\varphi_{qr} + \frac{R_r}{L_r}\varphi_{qr} - \frac{L_m}{L_r}R_r i_{qs} + \omega_{sl}\varphi_{dr} = 0 \quad (19)$$

Where, ,$\omega_{sl} = \omega_e - \omega_r$ and for obtaining decoupling $\varphi_{qr} = 0$ ie. $\frac{d}{dt}\varphi_{qr} = 0$

Therefore from equ (17) and (18)

$\widehat{\varphi_r} = L_m . i_{ds}$ and $\frac{L_m}{L_r}\frac{R_r}{\varphi_r} i_{qs} = \omega_{sl}$(20) and the electromagnetic torque is given as

$$Te=\frac{3}{2}\left(\frac{P}{2}\right)\frac{L_m}{R_r}(\varphi_r . i_{qs}) \quad (21)$$

6. HARDWARE IMPLEMENTATION

This section describes the hardware implementation of speed control of a ZSI by implementing IFOC algorithm along with DSVPWM techniques.dsPIc6010A is programmed with IFOC algorithm with the shoot through technique of DSVPWM.The controller accepts the input variables like the line current to the motor, capacitor voltage and the motor speed and generates the gating pulses for the switches o the inverter with required modulation index and shoot-through ie with the required amount of boost.

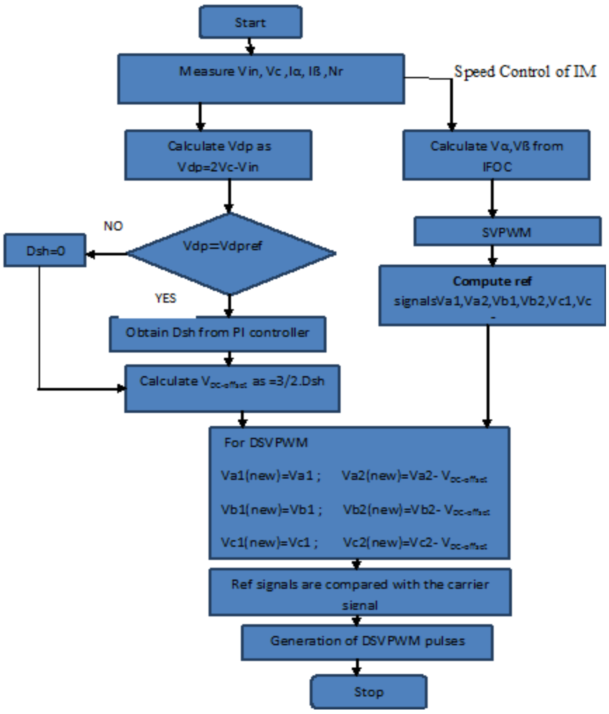


Fig. 6:Flowchart DSVPWM-IFOC

7. RESULT

Simulation and hardware results for the proposed scheme are presented in this section. The scheme is tested for two cases (i) Variable loading conditions

(ii) Variable reference speed condition.

The details are discussed in the following subsections.

7.1 Hardware Results:

Table2: Response of Induction Motor with changes in the Reference Speed

S.no.	Input DC Voltage (Vin)	DC-Link Voltage (Vdc)	Set speed (rpm)	Actual Speed (rpm)
1	140V	164-167 V	750	700-800
2	140V	167-173V	850	800-900
3	140V	174 V	950	900-1000

1. The reference speed to the induction motor is changed from 750rpm to 950 rpm.

2. The Induction motor drive with the proposed technique I seen to follow the reference speed.

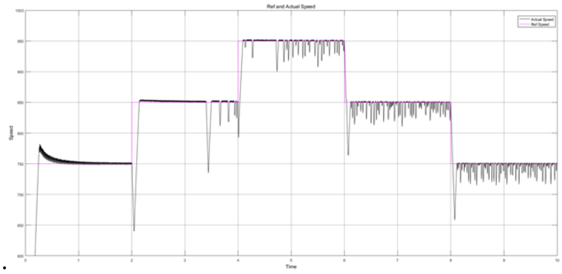
Table 3: Response of Induction Motor with load change Set speed=850rpm

S.no.	Input DC Voltage(Vin)	DC-Link Voltage(Vdc)	Load (gm)	Actual Speed(rpm)
1	145V	170	100	820
2	145V	173	200	870
3	145V	178	300	810

1. The ZSI fed Induction motor under varying load and set rpm speed of 850 rpm, with the proposed technique maintains the speed (to around 850 ±50 rpm) and also tries to maintain the DC-link voltage .(maintains it around 170 V±10 V).

7.2 Simulation Results:

Case i. ZSI-fed Induction Motor Speed with -changes in reference speed



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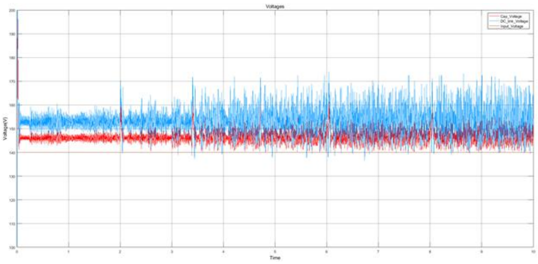
Y-axis :-Motor speed (rpm)   X- axis :-Time (seconds).

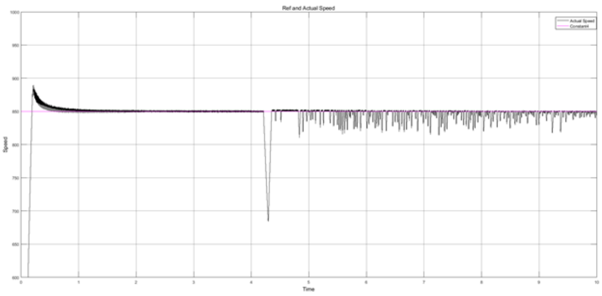
Fig 7: Induction Motor Rotor Speed



Y-axis :-Voltage (Volts)   X-axis :-Time(seconds)

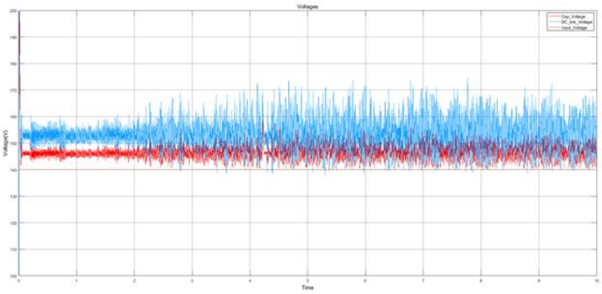
Fig 8:DC-Link voltage with change in Reference speed

Case ii. ZSI-fed Induction Motor Speed with -changes in Load



Y-axis :-Motor speed (rpm)   X- axis :-Time (seconds).

Fig 9: Induction Motor Rotor Speed



Y-axis :-Voltage (Volts)   X-axis :-Time(seconds)

Fig 10: Changes in DC-Link voltage with changes in load

8. CONCLUSION

In this paper, the speed control of Induction motor is achieved by employing a Z-Source Inverter. A 0.5 HP ZSI fed Induction motor with IFOC and DSVPWM technique is modeled and implemented with a DSP controller dsPIC30F6010A. The DSVPWM signals are generated by creating 1st set of reference wave by SVPWM technique ,with the required modulation index and then creating a 2nd set of reference wave by giving required DC-offset value (for the required duty ratio) and then comparing them with the triangular carrier wave with the help of relational operators. These signals are then applied to the gates of the IGBTs for the required duration as computed by the microcontroller to get the required AC output voltage. At the same time the stator currents and rotor speed are also sensed and given to microcontroller for implementation of IFOC for controlling the speed of the induction motor. The following observations regarding performance of the ZSI fed drive are made:

In case 1, the ZSI fed induction motor is run with changing reference speeds .With the proposed strategy, the Induction motor catches the reference speed while maintaining the DC-link voltage stably.

In case 2, the ZSI fed induction motor is run with constant reference speed, with varying load. For the load changes, the drive with the proposed strategy not only follows the reference speed but tries to maintain constant DC-link voltage. The further research on this topic can be done by considering a different topology for the ZSI like quasi-ZSI along with a different control strategy for controlling the shoot-through states in ZSI resulting in increased boost factor with minimum stress across the switching devices.

9. ACKNOWLEDEMENTS

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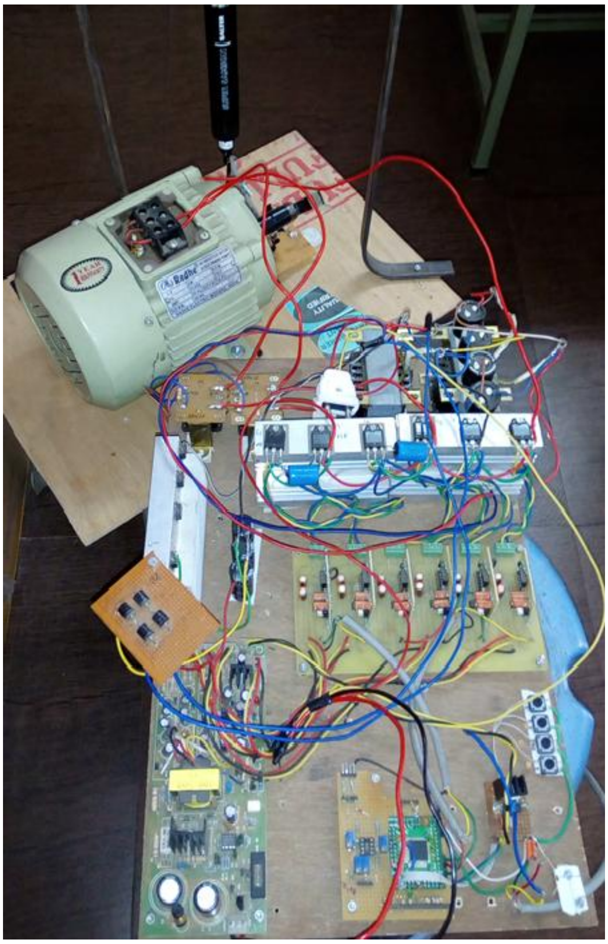
HARDWARE SET-UP



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