International Journal of Applied Engineering Research
ISSN 0973-4562 Volume 10, Number 10 (2015) pp. 26321-26338
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http://www.ripublication.com

Implementation of New Algorithm for EV fed through an Impedance Source Inverter

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Abstract

An electric vehicle (EV) drive must feature fast torque response, high efficiency over wide speed and torque ranges, and reasonable cost. This paper proposes an efficient and robust control scheme for EV fed through an impedance source inverter. The main control strategy is a hybrid, field oriented control (FOC) and Double Space Vector PWM which combines the advantages of both FOC and DSVPWM and simultaneously eliminates certain implementation difficulties. DSVPWM with impedance source inverter has high boosting factor and minimum voltage stress across the switches. The control method is analyzed with experimental results and the control method is implemented using DSP (TMS320F28335).

Key Words — Z-Source Inverter, FOC, Double Space Vector PWM (DSVPWM), Hybrid Electric Vehicle (HEV). Modulation Index (M), Boosting Factor (B).

I. INTRODUCTION

The Induction motor (IM) has many more advantages compared to DC motor, synchronous motor and switched reluctance motor in many aspects, such as reliability, controllability, technological and cost as indicated by a recent comparative study for vehicles (EV) [1]. Therefore, induction motor is one of the right electric motor for automotive and variable speed applications.

The electric vehicles commonly makes use of a boosted inverter, comprising of a DC-DC boost converter followed by a VSI to drive the motor. However, this formation has some problems, such as the high cost and complexity associated with the two-stage power conversion. Therefore, there has been a lot of effort to develop new DC/DC converters and inverters suitable for EV applications; one of the most promising topology is the impedance or Z source inverter (ZSI) [2]. The ZSI is an emerging topology for power-electronics converters with very interesting properties such as buck-boost characteristics and single stage conversion. A special Z-network composed of two capacitors and two inductors connected to well known three phase bridge, allows working in buck or boost mode using the shoot-through state [3][4].

At present, the induction motor control is sophisticated. The control methods of high performance induction motor are conventional field-oriented vector control and direct torque control. The Indirect field-oriented control (IFOC) and direct torque control (DTC) are generally engaged to act as torque transducers. IFOC, initiated in the 1970s, requires no flux estimation. The DTC [4], [5], developed in the mid-1980s, requires flux estimation to happen. These methods have many common aspects, such as torque and flux commands, fast torque response, and sensitivity to certain motor parameters. The flux command in conventional IFOC is the direct-axis rotor flux in the synchronous frame, while that of DTC is the stator flux in the synchronous frame. Available comparisons target field oriented control (FOC) and DTC without specifically considering IFOC. IFOC avoids the need for a flux estimator. The field-oriented control method relies on motor parameters closely. It does not adapt to the motor control of an electric vehicle. Given choices of switching (hysteresis current control or SVPWM) schemes that differ between IFOC and DTC, when the drive controls are decoupled from the switching scheme, differences are more subtle, and indeed IFOC appears to have advantages in terms of dynamic performance and immunity against parameter variations [6].

This paper presents a closed loop speed control of an indirect field-oriented control space vector modulated induction motor fed by a ZSI with the new control algorithm.

II. Z-SOURCE INVERTER

Z source or impedance source network is a new kind of inverter. This Z source converter overcomes the difficulties in traditional converters. A diode D_s and an Impedance network are the only difference between a traditional inverter and a Z source Inverter. This impedance source inverter employs a solitary impedance network connected in between the inverter main circuit and the power source. In Fig.1, a two-port network that consists of a split-inductor L_1 and L_2 and capacitors $C_1$and C_2 connected in X shape is employed to provide an impedance source (Z-source) coupling the converter (or inverter) to the DC source. The DC source can be either a voltage or a current source. Therefore, the ***DC source can be*** a ***battery, solar cell, fuel-cell stack, diode rectifier.***

One interesting point about Z source inverter is that a dead band need not be afforded as we did in the voltage source inverters. In fact, a shoot through is deliberately created to boost the input voltage. Among all the available topologies, the Z source inverter appears to be gaining popularity over the others. The aspect of the

Z-source inverter is that the output AC voltage can be any value between zero and infinity (theoretically) unconcern of the input voltage. That is, the Z source inverter is a buck–boost inverter that has a wide range of obtainable voltage. The traditional V- and I-source inverters cannot provide such feature.

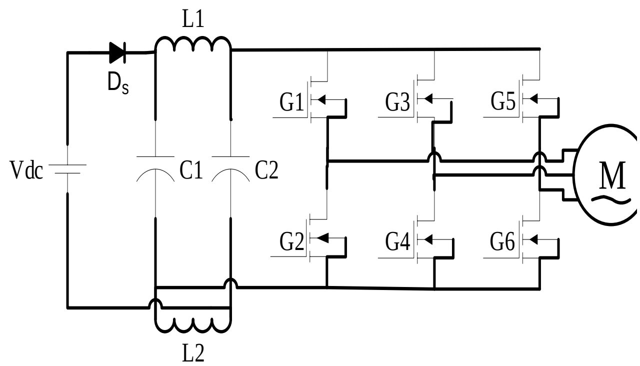

Figure 1. Schematic of a Z-source Inverter Fed Induction Motor

The impedance network allows the VSI to operate in a new state called shoot through state in which the switching devices in the same leg are simultaneously turned on. During this state, energy is transferred from the capacitors to the inductors hence giving rise to voltage boost capability. As the capacitors may be charged more than the input DC voltage, a diode D_s is connected so as to avoid the discharge of the capacitor through the source. When compared to a conventional VSI, we have two switching states in Z source Inverter [7]. They are

1) Active State; 2) Shoot through State

In the active state, the z source inverter operates as a normal voltage source inverter and the capacitor charges more or less equal to the input source.

In the shoot through state, the voltage across the inverter is 0V because both the switches are short circuited. At this instant the capacitors are in series and the voltage across the capacitors is more than the input voltage, hence the diode Ds is automatically sickened. Each capacitor starts discharging through the inductor, hence transferring its energy. The capacitor voltage drops from its initial value and simultaneously, the inductor current increases towards its peak value with increasing time. A three-phase Z-source inverter has nine permissible switching states (vectors) unlike the traditional single-phase V-source inverter that has eight. The traditional three-phase V-source inverter has six active vectors when the DC voltage is impressed across the load and two zero vectors when the load terminals are shorted through either the top or bottom three devices, respectively. However, the three-phase Z-source inverter has one extra null state when the load terminals are shorted through both the top and bottom devices of any one phase leg (i.e., both devices are gated on), any two phase legs, or all three phase legs. This shoot-through null state is forbidden in the traditional V-source inverter, because it would cause a shoot-through [8]. We call this third zero state the shoot-through null state, which can be generated by seven different ways: shoot-through via any one phase leg, combinations of any two phase legs, and all three phase legs. The Z-source network makes the shoot-through null state possible. This shoot-through null state provides the lone buck-boost feature to the inverter [9].

Generally the currents and voltages behave in the Z-Source Converter, according to the Kirchhoff's mesh and node laws. The circuit is designed so that the two capacitors, the same capacity, and the inductors have the same inductance. For this reason, the components have the same voltage.

$$V_{c1} = V_{c2} = V_c \quad (1)$$

$$V_{L1} = V_{L2} = V_L \quad (2)$$

During the shoot-through condition, the duration T_0, the choke is charged by the capacitor, the inductor voltage is therefore equal to the capacitor voltage. The voltage at the output of the Z-source is the DC during the shoot-through state to zero.

$$V_c = V_L \quad (3)$$

$$V_d = 2V_C \quad (4)$$

$$V_{OUT} = 0 \quad (5)$$

The remainder of the period T is the circuit in the non-shoot-through state, T_1 duration. During this period, thus discharging the reactors and feed the intermediate circuit, the inductor voltage is negative. The output voltage decreases during this time and the Z_{out} voltage is the difference between the capacitor voltage and inductor voltage [10].

$$V_L = V_{dc} - V_c \quad (6)$$

$$V_d = V_{dc} \quad (7)$$

$$V_{OUT} = V_C - V_L \quad (8)$$

Where V_{dc} is the DC source voltage and $T = T_0 + T_1$

The average voltage of the inductors over one switching period (T) should be zero in steady state, from (3) to (8), thus, we have

$$V_L = \frac{(T_0 * V_C + T_1(V_{dc} - V_C))}{T} = 0 \quad (9)$$

Or

$$\frac{V_C}{V_{dc}} = \frac{T_1}{T_1 - T_0} \tag{10}$$

Similarly, the average DC-link voltage across the inverter bridge can be found as follows:

$$V_{OUT} = \frac{(T_0 * 0 + T_1(2V_C - V_{dc}))}{T} = \frac{T_1}{T_1 - T_0} * V_{dc} = V_C \tag{11}$$

The peak DC-link voltage across the inverter is expressed in (6) to (8) and that can be rewritten as

$$V_{OUT} = V_C - V_L = 2V_C - V_0 = \frac{T}{T_1 - T_0} * V_{dc} = B * V_{dc} \tag{12}$$

Where

$$\text{(Boosting Factor)} \ B = \frac{T_1}{T_1 - T_0} = \frac{1}{1 - 2\frac{T_0}{T}} \tag{13}$$

A ripple in the capacitor voltage appears as a ripple in the DC-link voltage applied to the inverter. A large ripple in the DC-link voltage degrades the waveform of the AC voltage by giving rise to unexpected harmonics in addition to increasing the voltage rating of the inverter.

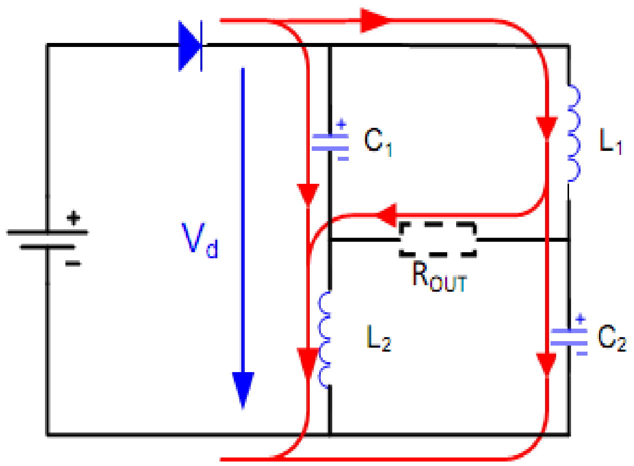

Figure 2. Non Shoot Through State

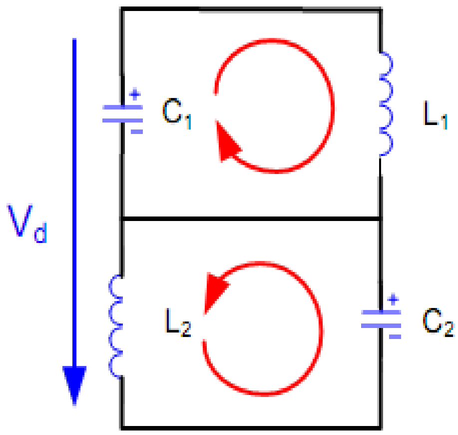

Figure 3. Shoot Through State

The capacitor voltage and inductor current is an instantaneous Position. As the capacitors may be charged to higher voltages than the input source voltage, a diode Ds is necessary to prevent discharge of them through the input source. The impedance network parameters can be calculated as follows.

$$C = \frac{I_0 T_S (2V_M - V_{dc})}{2KV_{dc}(4V_M - V_{dc})} \tag{14}$$

$$L = \frac{V_{dc} T_S (2V_M - V_{dc})}{2KI_0 (4V_M - V_{dc})} \tag{15}$$

Where I_0 = Load current; V_m = Output voltage desired; V_{dc} = Input dc voltage; K = Ripple factor; Ts = Switching time

III. DOUBLE SVPWM

This method employs three phase six sinusoidal reference signals, V_{a1}, V_{a2}, V_{b1}, V_{b2} and V_{c1}, V_{c2} and one triangular waves of high frequency as carrier signals. Among this V_{a1}, V_{b1}, V_{c1} are used with DC offset equals to zero and V_{a2}, V_{b2}, V_{c2} are varied according to shoot through duty ratio (Do) such that Modulation Index(M) varies in between 0 to 1 and dc offset should not be greater than 0.5.[11][12]

We now see the relationship of voltage boost and DC offset voltage.

The voltage gain of ZSI can be shown as,

$$\frac{V_{ac}}{V_s/2} = MB \tag{16}$$

B is determined by,

$$B = \frac{1}{1 - 2\frac{T_0}{T}} \tag{17}$$

$T_0/T = D_{Sh}$, is the shoot through duty ratio.

In this control method, the variation of the shoot through duty ratio is done by varying the DC offset voltage, and is derived in the following way,

$$D_{Sh} = 3 * \frac{V_{DC_{offset}}}{2} \tag{18}$$

Contrary to other traditional control methods, in this control technique, DC offset voltage is the only factor that affects the duty ratio; modulation index is out of scenario when it comes to affecting the duty ratio here. To get finite voltage gain, D_{sh} should be below 0.5.

These traditional control methods are difficult to implement with real time controllers. So for simplicity, we can easily have control with two sets of three phase sine waves.

The salient features of DSVPWM control method over other traditional control methods:

- Switching losses are reduced as only one of the phase legs is gated during the shoot through state.
- Number of shoot through states per cycle is increased.
- Ripple content in inductor current is reduced due to alternative active and shoot through states and no zero states.
- Total harmonic distortion is decreased.
- Keeping the modulation index high the voltage stress across the switches can be reduced

In Fig. 4, there are two sine waves, V_a and $V_{a1,}$ the V_a sine wave is not having the any DC offset value and it will generate the pulses for top switch and V_{a1} is given a finite DC offset and it will generate the pulses for of bottom switch. In the Fig. 4, the top and bottom switch pulse having overlap or the shoot through. The DC offset increase the shoot through also increase.

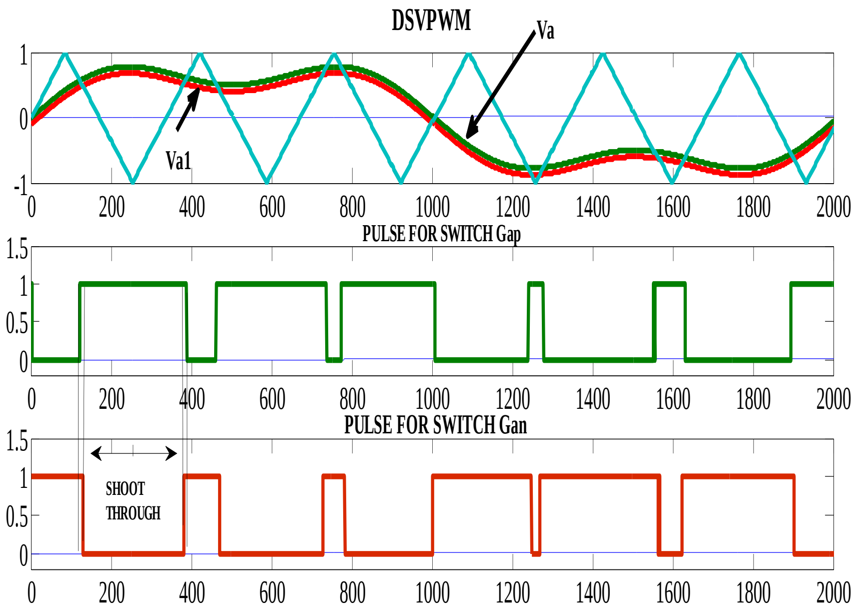

Figure 4. DSVPWM Pulses

IV. VECTOR CONTROL of INDUCTION MACHINE

Induction machine has been widely used in many industrial applications due to advantages of low cost, ruggedness, and good efficiency. There are a number of various mathematical models of induction machine to analyze. However, the model used in vector control algorithm should come from the space vector theory. The Field Oriented Control (FOC) algorithm is based on controlling the components of the motor stator currents in a rotating reference frame 'd', 'q' aligned with the rotor flux space vector. The vector control requires the dynamic model equations of the induction motor and returns the instantaneous current and voltage values in order to implement the control system. The dynamic equations of induction machine in the two-axis (d-q model) in a synchronously rotating reference frame can be expressed by the following equations:

$$v_{qs}^e = R_s i_{qs}^e + \frac{d}{dt}\lambda_{qs}^e + \omega_e \lambda_{ds}^e \tag{19}$$

$$v_{ds}^e = R_s i_{ds}^e + \frac{d}{dt}\lambda_{ds}^e - \omega_e \lambda_{qs}^e \tag{20}$$

$$v_{qr}^e = R_r i_{qr}^e + \frac{d}{dt}\lambda_{qr}^e + (\omega_e - \omega_r)\lambda_{dr}^e \tag{21}$$

$$v_{dr}^{e} = R_r i_{dr}^{e} + \frac{d}{dt}\lambda_{dr}^{e} - (\omega_e - \omega_r)\lambda_{qr}^{e} \tag{22}$$

$$\lambda_{qs}^{e} = L_s i_{qs}^{e} + L_m i_{qr}^{e} \tag{23}$$

$$\lambda_{ds}^{e} = L_s i_{ds}^{e} + L_m i_{dr}^{e} \tag{24}$$

$$\lambda_{qr}^{e} = L_r i_{qr}^{e} + L_m i_{qs}^{e} \tag{25}$$

$$\lambda_{dr}^{e} = L_r i_{dr}^{e} + L_m i_{ds}^{e} \tag{26}$$

$$T_e = \frac{3}{2}\frac{p}{2}(\lambda_{ds}^{e} i_{qs}^{e} - \lambda_{qs}^{e} i_{ds}^{e}) \tag{27}$$

$$L_s = L_m + L_{ls} \text{ and } L_r = L_m + L_{lr}$$

The main purpose of vector control is to make the induction machine emulate like the separated excited DC motor or the PM brushless DC motor. It can be seen that DC motor is the easiest electrical machine to control torque and flux independently due to the fact that the field flux linkage space vector λ_f is stationary and along the d-axis of the motor while the armature current space vector $\vec{i}_a$ is always along with q-axis of the motor. It is clear that the orthogonality between the field and armature current ensures the best condition of torque production for DC motor. To induction machine controls, via vector control, we can also obtain higher performance in terms of separate torque and flux control like DC motor control. Also, vector control in induction machines enables the machine to produce step changes in torque with instantaneous transition from one steady state to another steady state, which helps dynamic performance of the control system dramatically improve.

Field Oriented Control (FOC) is a complex control method that utilizes the position of rotor measured from encoders combined with 3-phase stator currents caught from sensors to generate instantaneous means of controlling torque and flux. Not like scalar control method, Field Oriented control requires both magnitude and phase of AC quantities, therefore, it is called “vector controller”. The control implementation is always performed in d-q rotating reference frame, which is attached to rotor flux space vector. This is the reason why vector control demands an accurate rotor flux angle for calculations. In addition to this, the stator currents of induction machine are separated into two parts, which are known as d-axis component that produces flux and q-axis component that produces torque.

There are several ways to implement vector control in induction machine. Both stator and rotor are applied to the common reference axis in accordance with control algorithm of users. However, the simplest way is to use rotor flux oriented reference frame in which the direct d-axis is always aligned with the rotor flux λ_r while the q-axis is always 90^0 ahead of the d-axis. As a result, q-axis rotor flux $\lambda_{qr} = 0$ and the torque is given

$$T_{em} = \frac{3}{2}\frac{P}{2}\frac{L_m}{L_r}\lambda_{dr} i_{qs} \tag{28}$$

From this equation, it is relatively easy to determine the q-axis stator current 'i_{qs}'. The d-axis rotor flux in steady state is given as $\lambda_{dr} = L_m i_{ds}$, hence, the stator current along the direct axis is determined. These analyses give an excellent response of vector control approach in induction machine.

A. The typical scheme of torque control with IFOC

As we know, the vector control is one of the most effective methods for AC motor control in terms of torque and flux control to be controlled independently. According to this, the frequency, amplitude, and phase of the motor drive voltage are considered as key elements of the control method. The key to vector control is to generate the three-phase voltage to control three-phase stator current as a phaser that controls the rotor flux vector and then rotor current, which cannot be measured directly from the motor. What is needed for the indirect vector control approach? There are two main parameters such as stator currents and rotor mechanical velocity measured by sensors and encoders in a closed-loop control strategy.

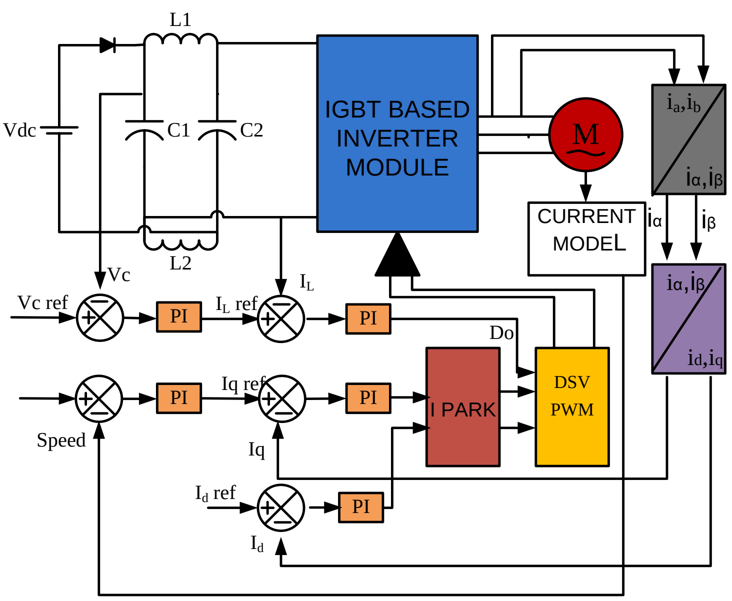

Figure. 5 Indirect Field Oriented with DSVPWM for induction machine fed Z-Source Inverter

It can be concluded that the indirect vector control method consists of the following steps:

- The 3-phase stator currents i_{as}, i_{bs}, i_{cs} and motor speed ω_r are measured by current sensors and encoders.
- The 3-phase currents are converted into 2-axis time variant system α, β . This stage gives the currents $i_{\alpha s}, i_{\beta s}$ from 3-phase current i_{as}, i_{bs}, i_{cs} via Clark transformation.
- The 2-axis time variant coordinate system is converted into 2-axis time invariant system with respect to d-q rotating reference frame aligned with rotor flux. This conversion provides the variables i_{qs}, i_{ds} from $i_{\alpha s}, i_{\beta s}$ with the help of an accurate rotor flux angle θ_{rf} .
- Error signals are computed from current values i_{qs}, i_{ds} and the reference values i_{qs}^*, i_{qs}^*. The d-axis component is used to control the flux while q-axis component control the torque of the motor. The errors are applied to PI controller that generates the reference voltages V_{ds}^*, V_{qs}^* that are voltage vector to be applied to motor.
- Calculation of rotor flux angle from rotor speed measured by encoder, i_{qs} , and i_{ds} that is called rotor flux estimator or current controller.
- The values V_{ds}^*, V_{qs}^* in rotating reference frame are converted back to the stator reference frame using the rotor flux angle previously calculated. This conversion is done via the inverse Park transformation, and the output is $V_{\alpha s}^*$ and $V_{\beta s}^*$.
- The values $V_{\alpha s}^*$ and $V_{\beta s}^*$ are used to determine the 3-phase values V_{ref1}, V_{ref2} and V_{ref3}. Using space vector modulation, PWM duty cycle is calculated from these reference voltages.

V. HARDWARE ANALYSIS AND IMPLEMENTATION

This section describes the hardware implementation for impedance source-inverter with IFOC for Induction motor.

B. DSP (TMS320F28335):

Nowadays, many of applications in industrial drives need to be met with high speed of computation process. Therefore, the most important thing is to find a suitable solution of chip selection used in a controller so that the price is the most minimum expense, but its reliability is improved. To cope with these requirements, a lot of chip production companies are attempting to develop on how to achieve expected problems regarding to either prices or efficiency.

In this project, impedance source-inverter with IFOC system will be designed with a single DSP controller using the TMS320F28335, a new kind of DSP chip of Texas Instrument (TI). The reason to use this one is that the integrated and flexible features in the device meet the requirements we need for control systems.

The implementation is focused on formulating a software design that practically takes full advantage of DSP controller to control both induction motors in decoupled manner. The software design is an important point of the whole implementation process. Accuracy and performance of the control system in fact much depends upon optimal characteristics of software design. In this section, therefore, all theories and analysis presented in previous sections come to together to form an appropriate software design. All programs are coded in C program that is helpful in later use for the user in terms of correction and maintainability.

The figure 6 shows the software flowchart of IFOC control for induction machine. This flowchart is more complicated than a standard flow chart to be used in microprocessor. However, DSP controller is a leading-edge platform, which brings to control fields many advantages. This helps so much to solve the complex control algorithm such as vector control that naturally requires many calculations.

The outline of the whole program contains many software blocks, which are programmed and described separately. The initialization section is where all variables and constants used in the program are initialized. The software structure consists of a lot of functions defined for analog to digital conversion (ADC), serial communication interface (SCI), PWM interrupt service routine (ISR), and Quadrature Encoder Pulse (QEP). In these methods, all relevant registers with respect to the program are appropriately written to.

All calculations of the control program for Field Oriented control are given in interrupt service routine of CPU timer0 that is provided with DSP TMS320F28335. It is this CPU timer that the sampling time of the program can be easily generated.

For DSVPWM with IFOC control method is implemented in DSP (TMS320F28335). The carrier frequency is 10kHz so the TBPRD register is set to 7500.

Z source converter and Induction motor parameters:

Inductance in Z network (L_1, L_2)	100µH
Capacitance in Z network (C_1, C_2)	1000µF
Stator resistance (R_s)	11.05 ohm
Rotor resistance (R_r)	3mH
Stator inductance (L_s)	0.316423 H
Rotor inductance (L_r)	0.316423 H
Magnetizing inductance (L_m)	0.29393 H
Number of poles (p)	4
Switching frequency (f_s)	10kHz
Induction Motor Power Rating	¼ hp

The speed control of induction motor depends up on voltage and frequency of supply. Here, the speed reference is 1080, then frequency (f=np/120) is 36Hz, as per

V/F control the voltage required is 126V (at rated torque). The input voltage is100 V, so the required DC link voltage is 222 V then the VcRef is 161V. The Z network is boosting and maintains the DC voltage constant even though input DC voltage changes.

The real time shoot through pulses are shown in Fig 7 and Fig 8. In Fig 9, the input voltage of Z source network is 100V and output of Z-source network is 126V due to modulation index being 0.8 and the boosting factor 2.22. In Fig 10, Z-Source inverter output phase voltage and current are shown. The Z-Source inverter load is three phase induction motor. In Fig 11, the induction motor line currents are I_a and I_b. In Fig 12, Z source network input and output DC voltages are shown where the input voltage is changing (60V to 120V) but output (126V) of z network is regulated so that the three phase inverter getting constant DC voltage. The speed reference is set ~~by~~ to 1080 (0.3*3600) rpm. The speed of induction motor speed shown in ccs graph window (fig. 13).

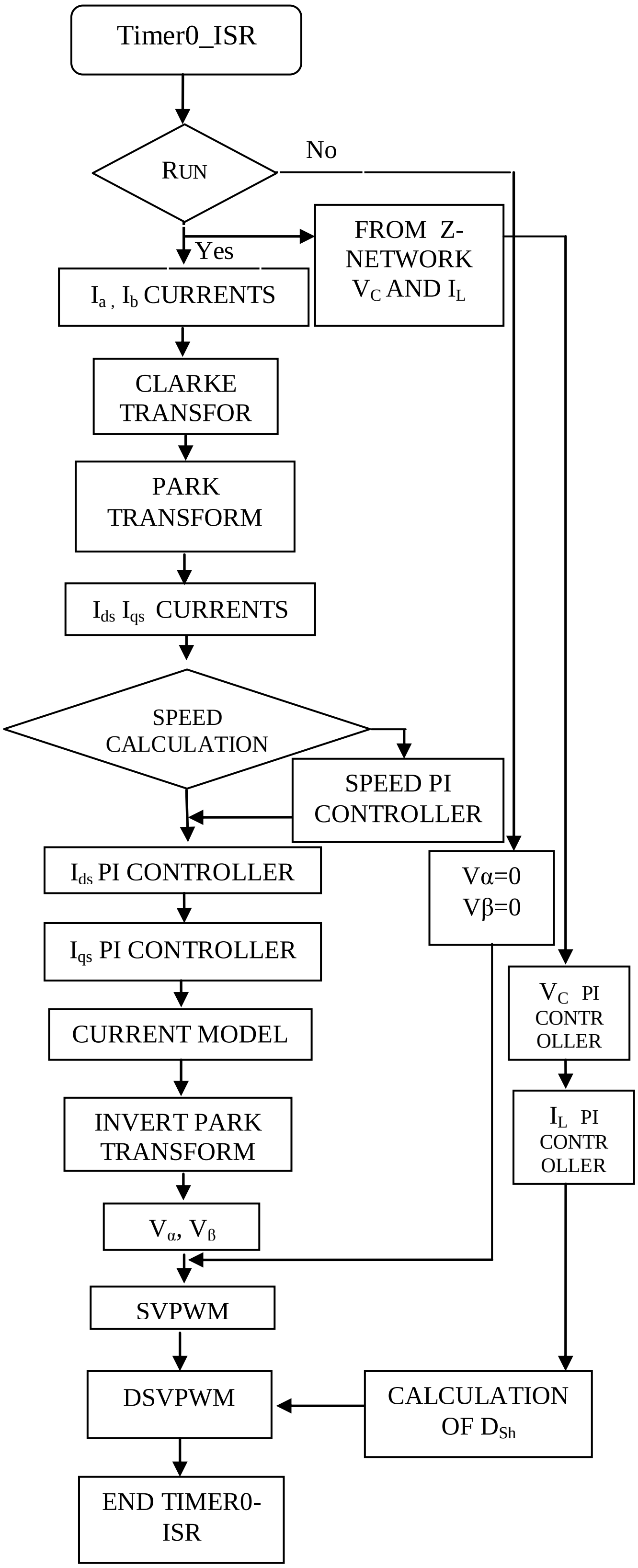

Figure. 6 Flowchart of Field Oriented control of induction motor

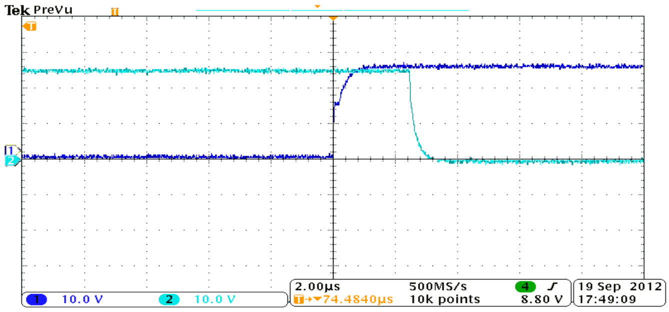

Figure 7. Shoot through Pulse

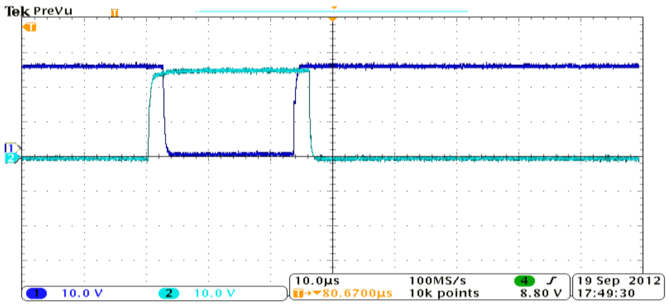

Figure 8. Shoot through Pulse

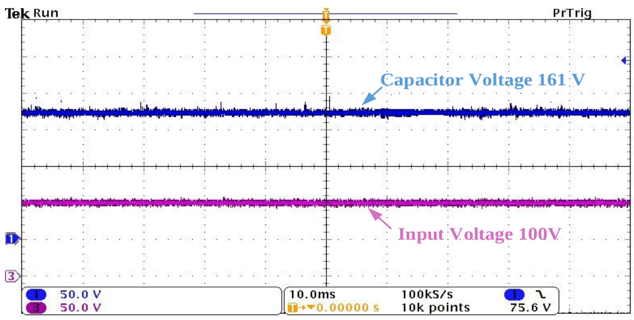

Figure 9. Z source Network Input and Output DC Voltages

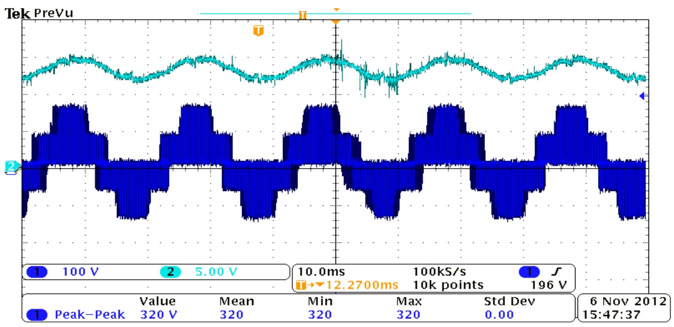

Figure 10. Z-Source Inverter Phase Voltage and current waveforms

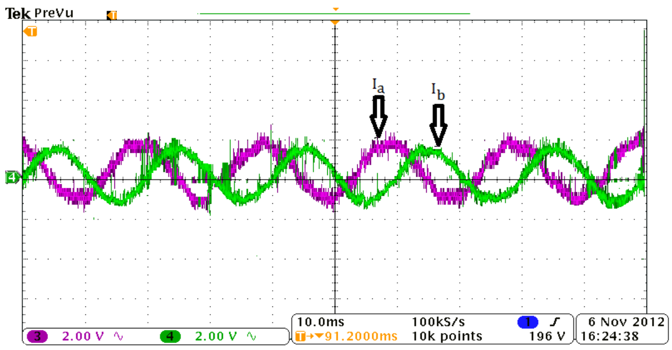

Figure 11. Induction Motor Stator Currents I_a and I_b

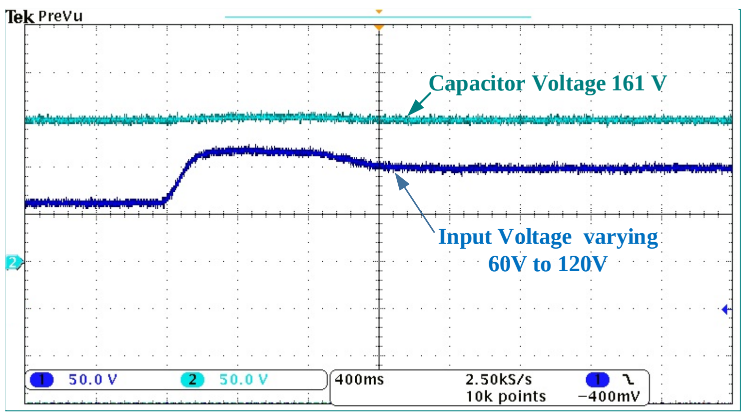

Figure 12. Z source Network Input and Output DC Voltages

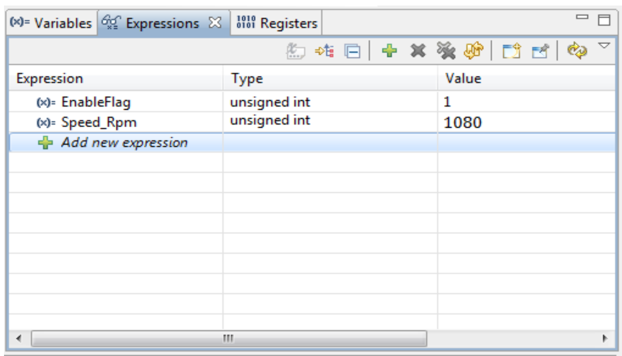

Figure 13. Induction Motor Speed in RPM at CCS Graph Window

Figure 14. Full hardware setup of z source inverter with induction motor

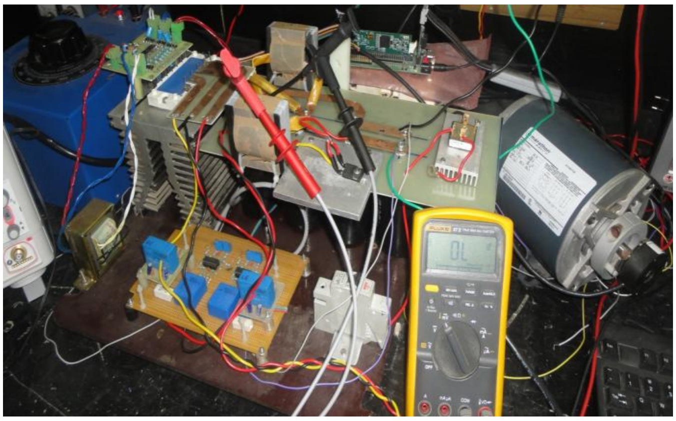

Figure 15. Z-Source inverter with induction motor

VI. CONCLUSION

In this paper, a new algorithm for closed loop speed control of an induction motor fed by a high performance Z-source inverter based on V/F control and hybrid indirect field-oriented control induction motor drive for electric vehicles has been presented. The DSVPWM with IFOC scheme is controlling the output voltage of the three phase Z source inverter with high voltage gain for the given boost factor. The speed control of induction motor is controlled even input DC source voltage changes. The new control algorithm is implemented in DSP (TMS320F28335). Hardware results are shown for electric vehicles.

REFERENCES

[1] Zeraoulia, M.; Benbouzid, M.E.H.; Diallo, D.;, "Electric Motor Drive Selection Issues for HEV Propulsion Systems: A Comparative Study," *Vehicular Technology, IEEE Transactions on*, vol.55, no.6, pp.1756-1764, Nov. 2006

[2] Miaosen Shen; Fang Zheng Peng;, "Converter systems for hybrid electric vehicles," *Electrical Machines and Systems, 2007. ICEMS. International Conference on*, vol., no., pp.2004-2010, 8-11 Oct. 2007
[3] Fang Zheng Peng;, "Z-source inverter," *Industry Applications, IEEE Transactions on*, vol.39, no.2, pp. 504-510, Mar/Apr 2003
[4] Ellabban, O.; Van Mierlo, Joeri; Lataire, Philippe, "Direct torque controlled space vector modulated induction motor fed by a Z-source inverter for electric vehicles," *Power Engineering, Energy and Electrical Drives (POWERENG), 2011 International Conference on*, vol., no., pp.1,7, 11-13 May 2011
[5] Takahashi, Isao; Noguchi, Toshihiko;, "A New Quick-Response and High-Efficiency Control Strategy of an Induction Motor," *Industry Applications, IEEE Transactions on*, vol.IA-22, no.5, pp.820-827, Sept. 1986
[6] Bazzi, A.M.; Friedl, A.P.; Choi, S.; Krein, P.T.;, "Comparison of induction motor drives for electric vehicle applications: Dynamic performance and parameter sensitivity analyses," *Electric Machines and Drives Conference, 2009. IEMDC '09. IEEE International*, vol., no., pp.639-646, 3-6 May 2009
[7] Shen, M.; Jin Wang; Joseph, A.; Peng, F.Z.; Tolbert, L.M.; Adams, D.J.;, "Maximum constant boost control of the Z-source inverter," *Industry Applications Conference, 2004. 39th IAS Annual Meeting. Conference Record of the 2004 IEEE*, vol.1, no., pp. 4 vol.(lvi+2822), 3-7 Oct. 2004
[8] Fang Zheng Peng; Miaosen Shen; Zhaoming Qian;, "Maximum boost control of the Z-source inverter," *Power Electronics, IEEE Transactions on*, vol.20, no.4, pp. 833-838, July. 2005
[9] Gitizadeh, M.; Nayeripour, M.; Akrami, A.;, "Maximum constant boost control for QZSI in a fuel cell system," *Renewable Energy and Distributed Generation (ICREDG), 2012 Second Iranian Conference on*, vol., no., pp.7-11, 6-8 March 2012
[10] Loh, P.C.; Gao, F.; Blaabjerg, F.;, "Topological and Modulation Design of Three-Level Z-Source Inverters," *Power Electronics and Motion Control Conference, 2006. IPEMC 2006. CES/IEEE 5th International*, vol.2, no., pp.1-5, 14-16 Aug. 2006
[11] Kumar, A.A.; Singh, D., "DSP based IFO control of HEV fed through impedance source inverter," *India Conference (INDICON),2013 Annual IEEE*, vol., no., pp.1,6, 13-15 Dec. 2013.
[12] Akkarapaka, A.K.; Singh, D., "The IFOC based speed control of induction motor fed by a high performance Z-source inverter," *Renewable Energy Research and Application (ICRERA), 2014 International Conference on*, vol., no., pp.539,543, 19-22 Oct. 2014