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# Analysis of Resonance Complications on Z-Source Current Type Inverter Fed Induction Motor Drive

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***Abstract*— Current source inverter (CSI) has found applications in grid-interfaced inverter for superconducting magnetic energy storage (SMES) and other utility systems where its large dc inductive current filtering and implicit output short circuit protection are found to be desirable.[2] Despite these applications and the direct control of ac current, CSI suffers from oscillatory complications caused by its ac-side second-order LC filter and limited capability of only dc–ac current-buck conversion, which can be a serious limitation for renewable sources with wide-ranging output operating conditions[8]. The current source inverter is operated with the PWM switching pattern which is generated by the full digital control of computer software. The resonance current, caused by the LC low pass filter at the step change of the pattern, can be effectively suppressed by one pulse control of the pattern. Z-source current-type inverter[2] has been proposed as a possible buck-boost alternative for grid-interfacing with a unique X-shaped LC network connected between its dc power source and inverter topology. To improve its damping performance, fuzzy logic controller [9] is introduced before the inverter pulse-width modulator for damping triggered resonant oscillations and to wave-shaping the inverter boost factor and modulation ratio.***

***Keywords*—Current Source Inverter-Source Inverter, Fuzzy Logic Controller, Boost Factor, Modulation Ratio, Pulse Width Modulation, MATLAB-Simulink.**

## I. INTRODUCTION

The dc to ac power converters are known as inverters. In other words, an inverter is a circuit which converts a dc power into an ac power at desired output voltage and frequency. The ac output voltage could be fixed at a fixed or variable frequency. This conversion can be achieved either by controlled turn-on and turn-off devices (e.g., BJTs, MOSFETs, IGBTs, and GTOs) or by forced commutated thyristors, depending on applications. For low and medium power outputs, the above mentioned power devices are suitable but for high power outputs, thyristors should be used.

There exist two traditional Inverters

(i) Voltage -source Inverters or VSI

(ii) Current –source Inverters or CSI

Each inverter has six switches in the main circuit. These switches are power switches with anti-parallel diodes. The diodes will provide bidirectional current flow and reverse voltage blocking capability.

- Traditional inverters are having following limitations:
- It can operate as a boost or buck inverter and cannot be a buck-boost converter.
- These output voltage range is limited to either greater or smaller than the output voltage.
- Their main circuit cannot be interchanged. In other words the voltage source inverter main circuit cannot be used for the current source inverter and vice versa.
- They are vulnerable to EMI noise in terms of reliability.

The above limitations can be rectified in Z-source or impedance inverter. This concept can be applied in all AC to DC, AC to AC, DC to DC, DC to AC power conversion.

***A. BLOCK DIAGRAM***

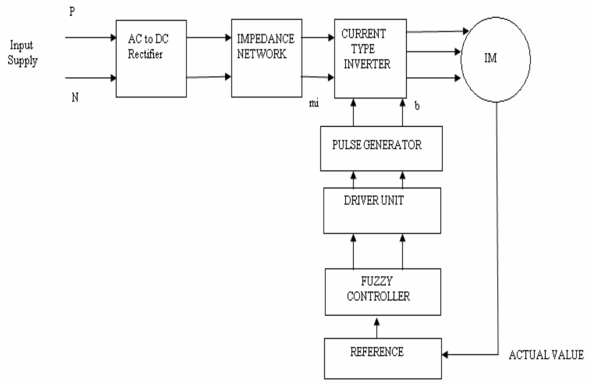


**Fig 1 Block Diagram of the Z-Source Current Type Inverter**

## II. IMPEDANCE SOURCE INVERTER [ZSI]

***A. Description***

To overcome the above limitations of the traditional voltage source and current source inverter, this project deals with an impedance-source inverter and its control method for implementing dc-to-ac power conversion. This project deals with how to overcome the limitations of voltage source inverter and current source inverter.

Fig.2 shows the general Z-source inverter structure proposed. It employs a unique impedance network (or circuit) to couple the converter main circuit to the power source, load, or another converter, for providing unique features that cannot be observed in the traditional voltage and current source inverters where a capacitor and inductor are used respectively. The Z-source inverter overcomes the above-mentioned conceptual and theoretical barriers and limitations of the traditional voltage source inverter and current source inverter and provides a novel power conversion concept. A two port network that consists of a

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split-inductor and capacitors connected in X shape is employed to provide an impedance source (Z-source) coupling the inverter to the dc source, load, or another converter. The dc source/or load can be either a voltage or a current source/or load. Therefore, the dc source can be battery, diode rectifier, thyristor converter, fuel cell, an inductor, a capacitor, or a combination of those. Switches used in the inverter can be a combination of switching devices and diodes such as the anti-parallel combination. The inductance can be provided through a split inductor or two separate inductors. The Z-source concept can be applied to all dc-ac, ac-dc, ac-ac and dc-dc power conversion.

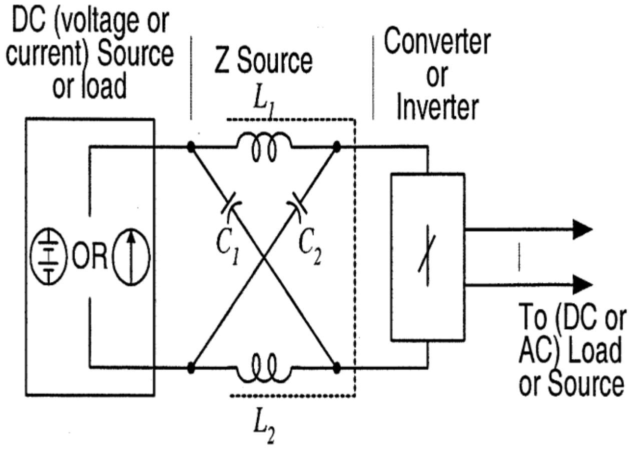


**Fig.2 Z source inverter**

### *B. THREE-PHASE BRIDGE ZSI USING IGBT*

The transistor family of devices is now very widely used in inverter circuits. Presently, the use of IGBT's in single phase inverters and three phase inverters is on the rise. The basic circuit configuration of inverter, however, remains unaltered as shown in figure 6. For a three-phase bridge ZSI using IGBTs in the place of thyristors. A large capacitor connected at the input terminals tends to make the input dc voltage constant. This capacitor also suppresses the harmonics fed back to the source.

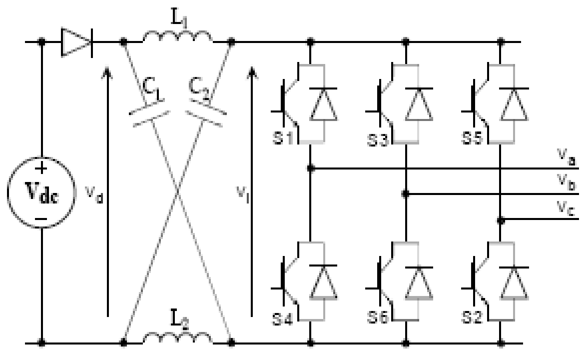


**Fig 3 Three Phase Bridge ZSI Using Igbts**

There are two possible patterns of gating the switching devices. In one pattern, each switching device conducts for $180^0$ and in the other each switching device conducts for $120^0$ but in both these patterns, gating signals are applied and removed at 600 intervals of the output voltage waveform. So both these modes require six step bridge converter.

### *C. COMPLICATIONS IN Z-SOURCE CURRENT TYPE INVERTER*

To date, current source inverter (CSI) has found applications in grid-interfaced inverter for superconducting magnetic energy storage (SMES) and other utility systems where its large dc inductive current filtering and implicit output short circuit protection are found to be desirable. Despite these applications and the direct control of ac current, CSI suffers from oscillatory complications caused by its ac-side second-order LC filter and limited capability of only dc–ac current- buck conversion, which can be a serious limitation for renewable sources with wide-ranging output operating conditions. For the second constraint of only current-buck power conversion, the traditional solution is to add a controlled front-end rectifier for stepping up the inverter dc link current, but unfortunately, adding a controlled rectifier would usually complicate the inverter control and synchronization, and might not function well under severely distorted supply conditions. Functionally, the Z-source current-type inverter is a robust single-stage buck-boost converter can easily be controlled by adding unconventional open-circuit states to the inverter pulse width modulated state sequence. Under steady-state conditions, the Z-source current-type inverter functions well, but during a dynamic step transition, it is expected to response sub-optimally due to the LC oscillatory complications introduced by its unique dc-side Z-source network, in addition to those caused by its ac-side second-order filter.

### *D. OPERATIONAL PRINCIPLES OF Z-SOURCE CURRENT-TYPE INVERTER*

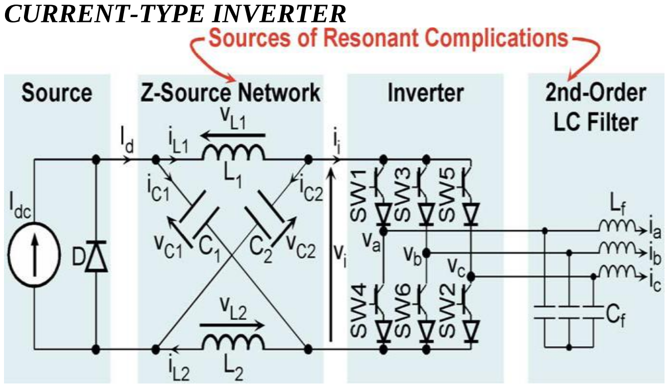


**Fig 4 The topology of a Z-source current-type inverter**

Fig. 4 shows the topology of a Z-source current-type inverter where the only topological difference identified, as compared to a conventional CSI, is the presence of a Z-source impedance network comprising of a split inductor {L1,L2}and two capacitors{C1,C2} . Using the Z-source network, the derived current-type inverter can step-up its output current by assuming open-circuit states with all power devices turned OFF, in addition to the six conventional CSI active states and three null states (open-circuit states are not allowed for conventional CSI since they give rise to large over-voltage due to the breaking of dc link current). Mathematical expressions for the peak

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inverter dc link current i1and ac output current ix(x=a, b or c), with open-circuit states inserted, are derived as

$$i_l = 2I_L - I_{dc} = \frac{1}{1 - \frac{2T_0}{T}} I_{dc} = B\, I_{dc}$$

$$I_x = MI i_l = B\,\{MI\, I_{dc}\} \qquad (2.1)$$

where $I_{dc}$ and $I_L$ are the input and Z-source inductor currents, To and T are the open-circuit duration and switching period, B and MI are the control boost factor and modulation ratio respectively, and the term in { } represents the ac output of a conventional CSI. Obviously, (2.1) shows that the ac output current of a Z-source current-type inverter can be stepped down below by decreasing MI and maintaining B=1 , and boosted above $I_{dc}$ by increasing above 1. Although having the Z-source network gives the inverter buck-boost capability, it also introduces new resonant complications caused by oscillatory charging/discharging of its inductors and capacitors, in addition to those caused by the ac filter placed at the inverter output for harmonic filtering (see Fig. 2.2 for the locations of the two sources of resonance). These oscillatory responses, usually triggered by the step transitions in command references, can over-stress power devices, passive components and other power equipment connected to the inverter, and should preferably be damped using software solution without using external resistors to minimize conduction losses.

## III. INTRODUCTION TO FUZZY LOGIC SYSTEM

A fuzzy control system is a control system based on fuzzy logic - a mathematical system that analyzes analog input values in terms of logical variables that take on continuous values between 0 and 1, in contrast to classical or digital logic, which operates on discrete values of either 0 and 1 (true and false).Fuzzy logic is widely used in machine control. The term itself inspires a certain skepticism, sounding equivalent to "half-baked logic" or "bogus logic", but the "fuzzy" part does not refer to a lack of rigour in the method, rather to the fact that the logic involved can deal with fuzzy concepts - concepts that cannot be expressed as "true" or "false" but rather as "partially true". Although genetic algorithms and neural networks can perform just as well as fuzzy logic in many cases (in fact, certain neural networks can be shown to be mathematically equivalent to certain fuzzy logic systems [1]), fuzzy logic has the advantage that the solution to the problem can be cast in terms that human operators can understand, so that their experience can be used in the design of the controller. This makes it easier to mechanize tasks that are already successfully performed by humans. Fuzzy logic was first proposed by Lotfi A. Zadeh of the University of California at Berkeley in a 1965 paper. He elaborated on his ideas in a 1973 paper that introduced the concept of "linguistic variables", which in this article equates to a variable defined as a fuzzy set. Other research followed, with the first industrial application, a cement kiln built in Denmark, coming on line in 1975.The input variables in a fuzzy control system are in general mapped into by sets of membership functions similar to this, known as "fuzzy sets". The process of converting a crisp input value to a fuzzy value is called "fuzzification". Fuzzy controllers are very simple conceptually. They consist of an input stage, a processing stage, and an output stage. The input stage maps sensor or other inputs, such as switches, thumbwheels, and so on, to the appropriate membership functions and truth values. The processing stage invokes each appropriate rule and generates a result for each, then combines the results of the rules. Finally, the output stage converts the combined result back into a specific control output value. The most common shape of membership functions is triangular, although trapezoidal and bell curves are also used, but the shape is generally less important than the number of curves and their placement. From three to seven curves are generally appropriate to cover the required range of an input value, or the "universe of discourse" in fuzzy jargon.

### *A. DESIGN OF THE FUZZY LOGIC CONTROL SCHEME*

A fuzzy set A of a universe of discourse X is represented by a collection of ordered pairs of generic element x ∈ X and its membership function μ : X→ [ 0 1], which associates a number μA(x): X→ [ 0 1] , to each element x of X. A fuzzy logic controller is based on a set of control rules called as the fuzzy rules among the linguistic variables. These rules are expressed in the form of conditional statements. Our basic structure of the fuzzy logic controller to control the output of the z-source current type inverter fed induction motor drive consists of 4 important parts, viz., fuzzification, knowledge base, decision making logic and defuzzification. The internal structure of the controller is shown in below figure

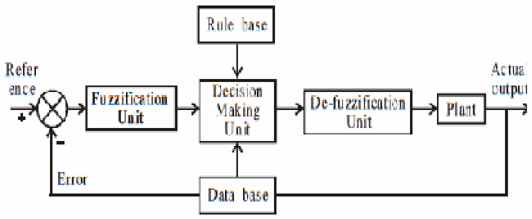


**Fig 5 Internal Structure Of The Fuzzy Logic Controller.[9]**

$$e(k) = \omega_{ref} - \omega_r$$

$$\Delta e(k) = e(k) - e(k-1) \qquad (3.1)$$

Where $\omega_{ref}$ is the reference speed and ωr is the actual rotor speed, e(k) is the error and Δe(k) is the change in error. The output of the decision making unit is given as input to the de-fuzzification unit and the linguistic format of the signal is converter back into the numeric form of the data in crisp form. The decision making unit uses the conditional rules of ‘ IF-THEN-ELSE’. In the first stage, the crisp

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variables e(k) and Δe(k) are converted fuzzy variables. The fuzzification maps the error, and the error changes to linguistic labels of the fuzzy sets. The proposed controller uses following linguistic variables (NB Negative Big), (NM NegativeMedium),(NS Negative Small),(ZE Zero),( PS Positive Small),(PM Positive Medium),(PB Positive Big).Each fuzzy label has an associated membership function.

### *B. MEMBERSHIP FUNCTION*

The membership function of a fuzzy set is a generalization of the indicator function in classical sets. In fuzzy logic, it represents the degree of truth as an extension of valuation. Degrees of truth are often confused with probabilities, although they are conceptually distinct, because fuzzy truth represents membership in vaguely defined sets, not likelihood of some event or condition. Membership functions were introduced by Zadeh in the first paper on fuzzy sets (1965).The membership function of triangular type is shown in below figure

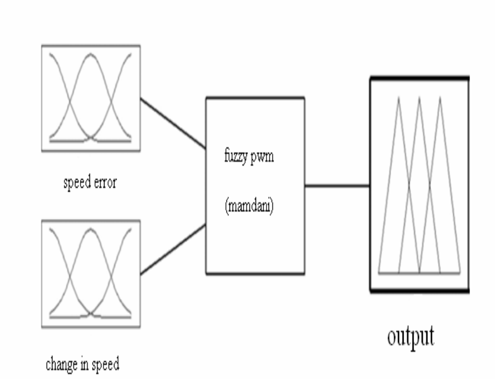


**Fig 6 FIS Editor with Two Inputs and One Output Developed In Simulink Model. [9]**

### *C. RULE BASE*

**Rule Based Systems**

The most common way to represent human knowledge is to form it into natural language expressions of the type. If premise (antecedent) then conclusion (consequent). The rules comprising a rule based system might derive from sources other than human experts. The design parameters involved in the construction of the rule base includes

(i) Choice of process state and control output variables.
(ii) Choice of the rule antecedent and rule consequent.
(iii) Choice of term sets for the process state and control output variables.
(iv) Derivation of the set of rules.

**1 Fuzzy If-Then Statement**

A fuzzy conditional or fuzzy if-then rule is symbolically expressed as if (fuzzy proposition) then (fuzzy proposition) is either an atomic or compound fuzzy proposition. An if then production rule describes the relationship between process state and control output variable. In approximate reasoning two inference rules are of major importance viz.the compositional rule of inference and the generalized modus pones. The first rule uses a fuzzy relation to represent explicitly the connection between two fuzzy propositions, the second uses and if-then rule that implicitly represents a fuzzy relation.

**2 Rule Base For The Decision Making Unit**

| ΔE \ E | NB | NM | NS | ZE | PS | PM | PB |
|---|---|---|---|---|---|---|---|
| NB | NB | NB | NB | NB | NM | NS | ZE |
| NM | NB | NB | NM | NM | NS | ZE | PS |
| NS | NB | NM | NS | NS | ZE | PS | PM |
| ZE | NB | NM | NS | ZE | PS | PM | PB |
| PS | NM | NS | ZE | PS | PS | PM | PB |
| PM | NS | ZE | PS | PM | PM | PB | PB |
| PB | ZE | PS | PM | PB | PB | PB | PB |

**Fig 7 Rule base for the decision making unit**

## IV. DESIGN PARAMETERS FOR SIMULATION USING MATLAB-SIMULINK

### *A.DESIGN OF Z-SOURCE INVERTER*:

L1=160mH
L2=160mH
C1=1000µF
C2=1000µF

### *B. INPUT PARAMETERS:*

Modulation index for buck operation MI=0-0.5
Modulation index for boost operation MI=0.5-1.0
Boost Factor B>1 for boost operation.
Boost Factor B<1 for buck operation.
Switching frequency=50HZ
Shoot Through Duty Cycle To/T=0.3-0.5

### *C. SIMULATION DIAGRAM*

**1 Triggering pulses for switching devices using Sinusoidal pulse width modulation.**

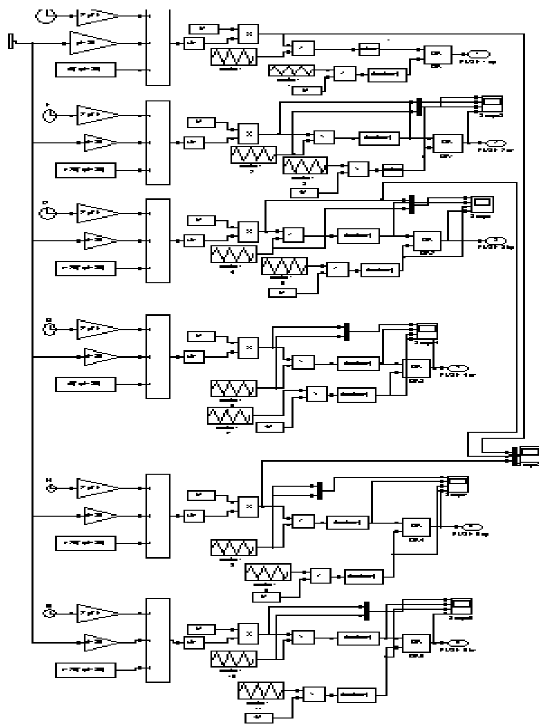

**Fig 8 . Triggering Pulses Generated With Sinusoidal Pulse Width Modulation Using MATLAB-SIMULINK**

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2 Triggering Pulses for All Switching Devices

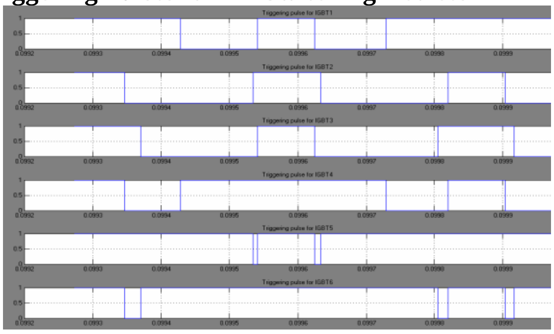

Fig 9 Triggering pulses for all switching devices.

3 Simulation diagram for z-source type inverter fed Induction motor without fuzzy controller

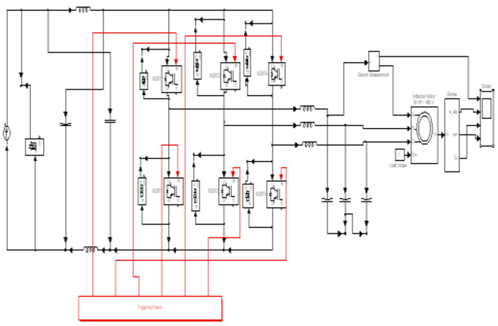

Fig 10 Simulation Diagram Of Z-Source Current Type Inverter Using MATLAB-SIMULINK.

4 Simulation results:

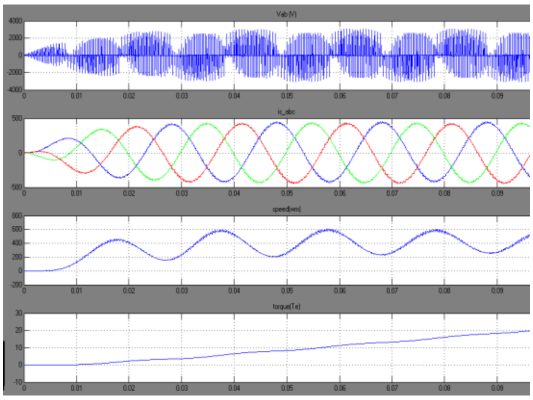

Fig 11 Buck Outputs Of Z-Source Current Type Inverter Fed Induction Motor Drive For MI=0.3

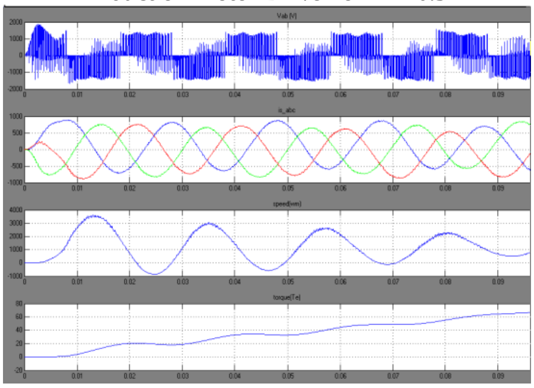

Fig 12. Boosted Outputs of Z-Source Current Type Inverter Fed Induction Motor Drive for MI=0.7.

*D SIMULATION DIAGRAM FOR FUZZY LOGIC CONTROL OF Z-SOURCE CURRENT TYPE INVERTER FED INDUCTION MOTOR DRIVE*

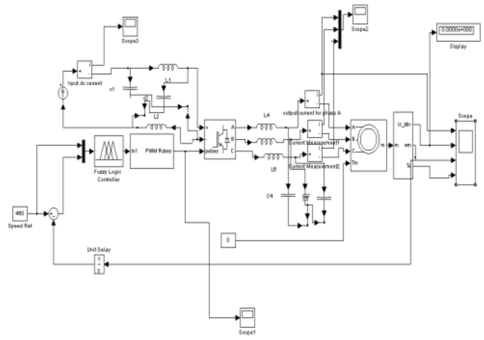

Fig 13 Simulation Diagram For Z-Source Current Type Inverter Fed Induction motor Drive Using Fuzzy Controller with Reference Value=150.

1 Simulation results for z-source current type inverter Fed induction motor using fuzzy controller

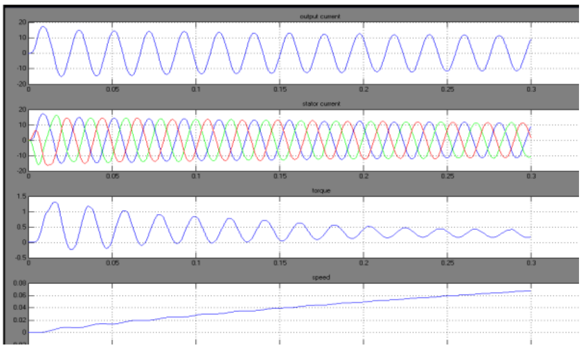

Fig 14 Simulation Results for Z-Source Current Type inverter fed induction motor drive with fuzzy controller.

*E. HARDWARD IMPLEMENTATION FOR Z-SOURCE CURRENT TYPE INVERTER FED INDUCTION MOTOR DRIVE*

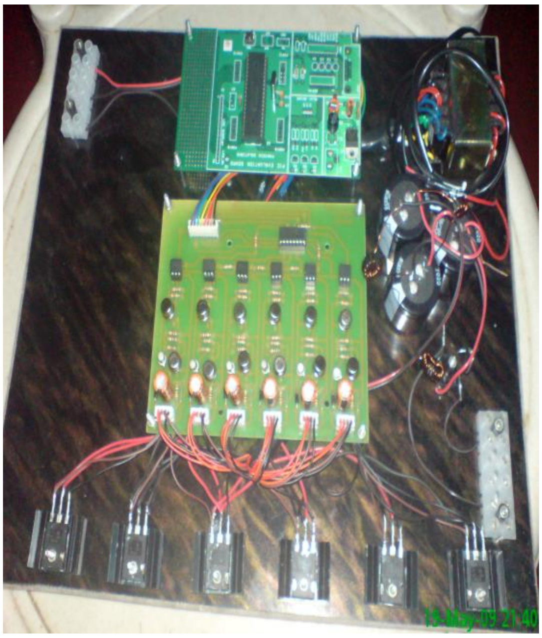

Fig 15 Hardware Prototype for Z-Source Current type Inverter fed induction motor drive

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## V. CONCLUSION

A new type of inverter has been presented. The impedance source inverter is specially suited for fuel cell applications and AC electrical drives. Unique features like single stage power conversion, improved reliability, strong EMI immunity and low EMI.The impedance source technology can be applied to the entire spectrum of power conversion. The Z-source concept can be easily applied to adjustable-speed drive (ASD) systems. The Z-source current type inverter can produce an output current greater than ac input current by controlling the boost factor and modulation index which is responsible for the conventional ASD systems. The resonance complications in Z-source current type inverter can be avoided by adjusting boost factor and modulation index with providing a fuzzy controller in the feed back loop. Better results are obtained in providing fuzzy controller and resonance complications are reduced.

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