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Fuzzy logic controller based Current-Fed Quasi-Z-Source Inverter with Bidirectional Power Flow

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Abstract – This paper proposes a new controller design and realization of a high power current fed quasi Z source inverter with bidirectional power flow. A bidirectional active switch in the quasi Z source network improves the performance of the inverter under small inductance and low power factor. To maintain constant output fuzzy logic control technique is used in the closed loop. And also overall efficiency of the inverter is increased. The circuit analysis shows that with a bidirectional switch in the current fed quasi Z source inverter network, the performance of the inverter under small inductance and low power factor can be improved. Based on the circuit analysis, a small signal model of the current fed BQ-ZSI is derived, which indicates that the circuit is prone to oscillate when there is disturbance on the dc input voltage.

Index Terms – Adjustable speed drive (ASD) system, bidirectionalpower flow, buck-boost, current-fed quasi-Z-source inverter(qZSI).

1. INTRODUCTION

The ever increasing application of automation in industrial motion control requires efficient operation, low maintenance, and high reliability of the ac motor drives and their power converters. Today's power converters for such applications consist of voltage source inverters (VSI's), current source inverters (CSI's) and Z-source inverters (ZSI's). As we know, traditional voltage source inverter and current source inverter have intrinsic drawbacks, such as they are buck or boost converter,and could not provide buck-boost function, the shoot through or open-circuit due to the electromagnetic interference(EMI) often cause the damage of the power semiconductor devices or the power supply.

2. CURRENT-FED QUASI-Z-SOURCE INVERTER-BASEDADJUSTABLE SPEED SYSTEM

Fig. 1 shows three current-fed quasi-Z-source inverter-basedASDs, wherein Fig. 1(a) shows a diode front-end type topology,the three phase voltage source powers the diode front-end through inductors, the quasi-Z-source network is used to provide buck-boost and filter function, this topology only permits unidirectional power flow due to the characteristics of the diodefront-end.

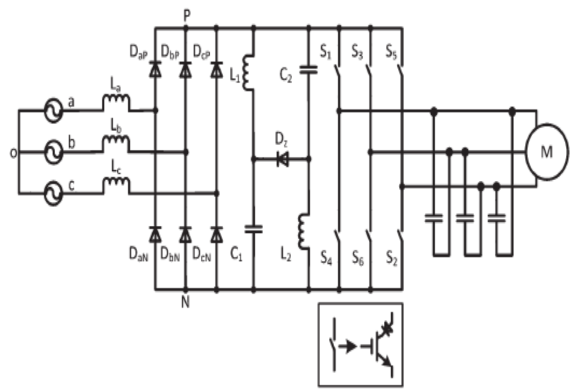

Fig. 1. Current-fed quasi-Z-source inverter-based ASDs: (a) Diode frontend type topology

Fig. 1(b) shows a thyristor front-end type topology, the three phase voltage source powers the thyristor front end through inductors and the quasi-Z-source network is also used to provide buck-boost and filter function. Because of the controllability of thyristor, this topology permits bidirectional power flow by operating the thyristor front-end both in the rectifier and active inverter state. To increase the input side power factor, when the thyristor front-end operates in rectifier mode,the control angle of thyristors is kept in zero, and they actually equal to diodes. And when the thyristor front-end operates inactive inverter mode, the control angle of thyristors is close to π;in these two modes the subsequent current-fed quasi-Z-source inverter provides buck-boost function. And Fig. 1(c) shows a full-controllable type topology, the rectifier and the inverter are all comprised by full-controllable power devices, i.e. Insulatedgate bipolar transistor (IGBT), Power MOSFET, Gate-turn-off thyristor (GTO), etc. Generally, the full-controllable rectifier and the inverter bridge could use the reverse-blocked IGBT (RB-IGBT) to simplify the circuit structure. This topology is symmetrical and can provide input unity power factor. These three types of adjustable speed drive systems have different application area. The topology shown in Fig. 1(a) suits to be applied in the area which only need to transmit power unidirectional, the topology shown in Fig.1(b) used in area needing to transmit bidirectional power flow and has low requirements to input side power factor with a high power load. And the topology shown in Fig. 1(c) suits to be applied in the area needing to transmit bidirectional power flow and requires high input side power factor.

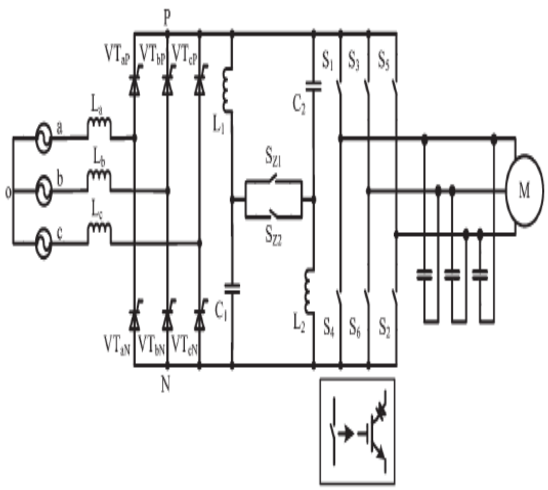

Fig. 1. Current-fed quasi-Z-source inverter-based ASDs: (b) Thyristor front-end type topology

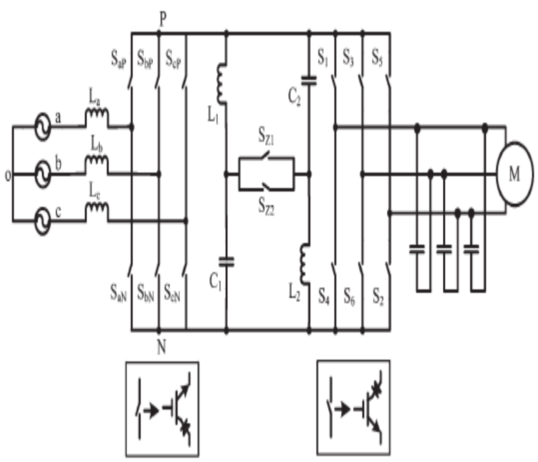

Fig. 1. Current-fed quasi-Z-source inverter-based ASDs (c) Full-controllable device front-end type topology.

To transmit bidirectional power flow, the quasi-Z-network of Fig. 1(b) or (c) exists two anti paralleled unidirectional controllable power switches SZ1 andSZ2, these two power switches play a part in the two directional power transmission process, respectively. And their structures are same to that of inverter bridge power switches; this will also improve the universality of the power switches and make the circuit realized more easily. In this paper the topology shown in Fig. 1(b) will be analyzed detailed. As mentioned above, when the power flows from ac power supply to the ac load, the power switch SZ1 on duty, and when the power flows from ac load to ac power supply, the power switch SZ2 on duty.

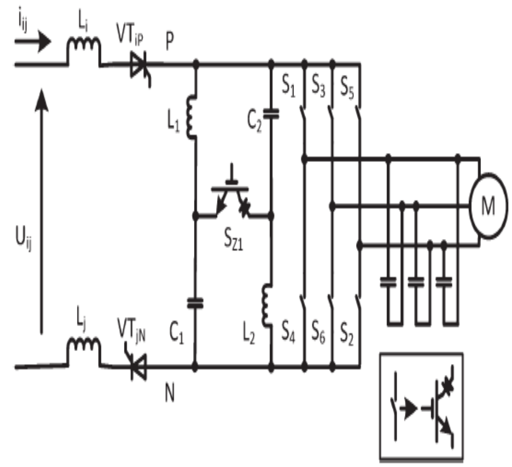

Fig. 2. Equivalent circuit of the whole system during 1/6 input voltage cyclewhen ac power supply powers ac load.

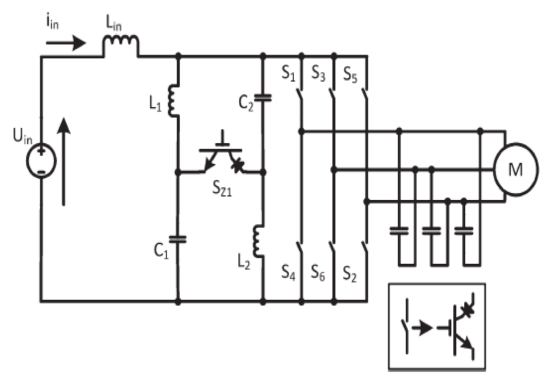

Fig. 3.Equivalent circuit of the system during a switching period when acpower supply powers ac load.

Since the switching frequency ofthe inverter bridge is much higher than that of the input powersupply, during a switching cycle the output current of the thyristor rectifier bridge could be looked as a constant value. Thus we can obtain an equivalent circuit of the whole system in the case of the ac load is powered, as shown in Fig. 2. In any time there are two thyristors are turned on simultaneously, one belongs to the upper common cathode three thyristors, and the other belongs to lower common anode three thyristors, these two thyristors belong to different phases, and the input voltageof the equivalent circuit is line-to-line voltage uij, it is a six pulse waveform, and then the input current iij will also be six pulse waveform with less harmonics, i, j = a, b, c and i _= j, Pis the common cathode node, and N is the common anode node.

Same to other Z-source or quasi-Z-source inverter/converter topologies, here the quasi-Z-network is also symmetrical, L1 =L2, and C1 = C2. Then an equivalent circuit during a switching period could be further obtained, as shown in Fig. 3. Uin denotes the instantaneous value of Uij in a switching period and could be looked as a constant value, and iin denotes the corresponding value of iij in a switching period,

$$Lin = Li + Lj$$

In this case, the control angle of the thyristors is controlled to be zero to improve the input side power factor, and the buck-boost function is provided by the backward current-fed quasi-Z-source inverter. The circuit structure of Fig. 3 is same to the current-fed quasi-Z-source inverter, so we can have similar conclusions by the similar analysis. As we know, the current fed quasi-Z-source inverter has ten switching states or vectors, that is, six active states and three zero states that same to the traditional current source inverter and current-fed Z-source inverter, and there is a unique open-circuit zero state that same to the current-fed Z-source inverter.

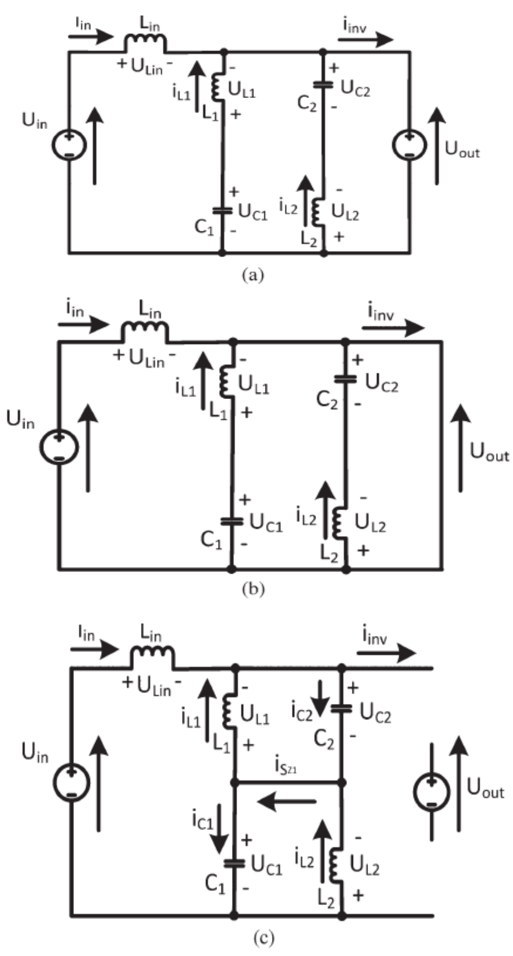

Fig. 4.Equivalent circuits of the system. (a) Active states. (b) Traditional zero states. (c) Open-circuit zero-state.

So similarly, we can have three equivalent circuits, as shown in Fig. 4.In equivalent circuit (a), the inverter operates in the activestate; two switches belonging to different phase legs are turned on simultaneously, the power flows to the load. The current of the input side inductor could be looked as a constant value, the inductors of the quasi-Z-network were charged, and the capacitors of the quasi-Z-network were discharged, the quasi-Z-network switch SZ1 was turned off. In this duration,in equivalent circuit (b), the inverter operates in the traditionalzero state, two switches belonging to same phase leg are turned on simultaneously, and the power could not flow to the load but to the quasi-Z-network. Similarly, the current of the input side inductor could be looked as a constant value,the inductors of the quasi-Z-network were charged, and the capacitors of the quasi-Z-network were discharged, the quasi-Z-network switch SZ1 was turned off. In this duration, we have

$$i_{in} + i_{L1} + i_{L2} = i_{inv},$$

$$U_{in} = U_{Lin},$$

$$i_{L1} = i_{L2},$$

$$U_{C1} = U_{C2},$$

$$-U_{L1} + U_{C1} = -U_{L2} + U_{C2} = 0$$

In equivalent circuit (c), the inverter operates in the unique open-circuit zero state, all the switches of the inverter bridge are turned off simultaneously, and the power also flows to the quasi-Z-network. In this case, the current of the input side inductor could also be looked as a constant value, the inductors of the quasi-Z-network were discharged, and the capacitors of the quasi-Z-network were charged, the quasi-Z-network switch SZ1 was turned on. In this duration, we have

$$i_{in} + i_{L1} = i_{C2},$$

$$U_{in} + U_{L1} = {}_{ULin} + U_{C1},$$

$$i_{L1} = i_{L2},$$

$$U_{C1} = U_{C2},$$

$$iL1 + iC1 = iL2 + iC2 = iSZ1$$

Evidently, in a power frequency period, the average value of the input inductor voltage should be zero, and in a switching period, the average value of the inductor voltage and the capacitor current of the quasi-Z-network should be zero. The current-fed qZSI-based adjustable speed drive system,as shown in Fig. 1, if the inductance of the input side inductors

Are low enough and the voltage drops on them is very small,

$$Uin = 2.34\ Uph,$$

Wherein Uph is the RMS value of the inputphase voltage. Thus, by choosing an appropriate modulation index m, the desired output voltage could be obtained. Except SVPWM, SPWM control method is also suitable to the currentfedquasi-

ZSI-based adjustable speed drive system, the simple boost control, maximum boost control, third harmonic injection control, maximum constant boost control method that used in voltage-fed Z-source inverter and current-fed Z-sourceinverter are also applicable.By varying the carrier frequency (in SPWM-based controlmethod) or the current vector rotating frequency (in SVPWM) the different frequency output voltage could be obtained. If the adjustable speed drive system need to transmit bidirectional power flow, the inverter bridge will operates as a rectifier and the thyristor bridge will operates in active inverter mode,the quasi-Z-network power switch SZ2 will on duty.

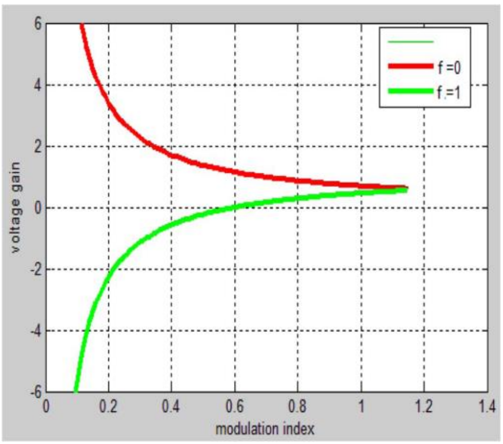

Fig. 5. The relationship between voltage gain and modulation index *m* when $\cos\varphi = 0.8$, $\eta = 1$, $f = 0$ or $f = 1$.

When the current-fed quasi-Z-source rectifier operates in the non-open circuit state, SZ2 will be turned off, and when the rectifier operates in the open-circuit zero state, SZ2 will be turned on. In this case, the dc-link voltage is controlled by choosing suitable modulation index m and open-circuit zero state duty cycle Dopto obtain a desired DC value and make the control angle of the thyristors close to π, here, it is needed to avoid the inversion failure. Since the current direction of the input and output of the quasi-Z-network could not be changed, the inversion of voltage polarity guarantees the inversion of power flow.

3. FUZZY CONTROLLER

The principle components of an FLC system are: a fuzzifier, a fuzzy rule base, a fuzzy knowledge base, an interference engine and a defuzzifier. It also includes parameters for normalization. When the output from the defuzzifier is not a control action, then the system is a fuzzy logic decision system. The fuzzifier present converts the crisp quantities into fuzzy quantities. The fuzzy rule base stores the knowledge about all the input-output fuzzy relationships. It includes the membership functions defining the input variables to the fuzzy rule base and the output variables to control process. The inference engine is the kernel of an FLC system, and it possesses the capability to simulate human decisions by performing approximate reasoning to achieve desired control strategy. The defuzzifier converts the fuzzy quantities into crisp quantities from an inferred fuzzy control action by the inference engine.

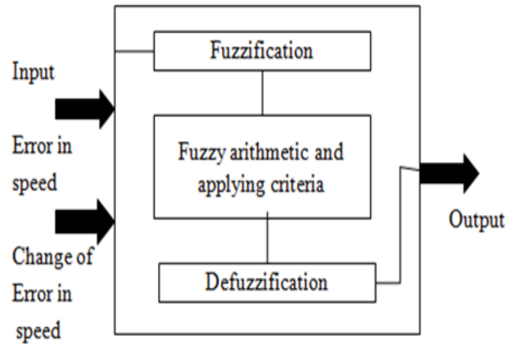

Fig. 6. Fuzzy Logic Controller Block Diagram

The basic configuration of an fuzzy logic controller comprises of four principles components. The components are depicted in fig. 6

- Fuzzification Interface.
- Knowledge Base.
- Decision-making logic.
- Defuzzification Interface.

Fuzzification Interface.

The fuzzification interface measures the values of input variables. It performs a scale mapping that transfers the range of values of input variables into corresponding universe of discourse. It performs the function of fuzzification that converts input data into suitable linguistic values, which may be viewed as labels of fuzzy sets.

Knowledge Base

The knowledge base comprises knowledge of the application domain and the attendant control goals. It consists of a data base and a linguistic (fuzzy) control rule base.The database provides necessary definitions, which are used to define linguistic control rules and fuzzy data manipulation in a fuzzy logic controller.The rule base characterizes the control goals, and control policy of the domain experts by means of a set of linguistic control rules.

Decision-making Logic

The decision-making logic is the kernel of an fuzzy logic controller; it has the capability of simulation human decision-making based on the fuzzy concepts and of inferring fuzzy control actions employing fuzzy implication and the rules of inference in fuzzy logic.

Defuzzification Interface

The defuzzification interface perform the scale mapping, converts the range of values of output variables into corresponding universe of discourse.Defuzzification,which yields a non-fuzzy control action from an inferred fuzzy control action.

Design Aspects of Fuzzy Logic Controller

Various steps in designing fuzzy logic control system are the following

Step 1: Define the inputs and outputs for the fuzzy logic control system.

Step 2: Set up fuzzy membership functions for the input.

Step 3: Set up fuzzy membership functions for the output.

Step 4: Create a fuzzy rule base.

Step 5: Defuzzify the outputs.

Fuzzy logic systems can emulate human decision-making more closely than many other classifiers through the processing of expert system knowledge, formulated linguistically in fuzzy rules in an IF–THEN form. Fuzzy logic is recommended for very complex processes, when no simple mathematical model exists, for highly non-linear processes and for multi-dimensional systems. The input variables in a fuzzy control system are usually mapped into place by sets of membership functions (mf) known as 'fuzzy sets'; the mapping process is called 'fuzzification'. The control system's decisions are made on the basis of a fuzzy rules set, and are invoked using the membership functions and the truth values obtained from the inputs; a process called 'inference'. These decisions are mapped into a membership function and truth value that controls the output variable. The results are combined to give a specific answer in a procedure called 'defuzzification'. Elaboration of the model thus requires a fuzzy rules set and the mf associated with each of the inputs. The ability and the experience of a designer in evaluating the rules and the membership functions of all of the inputs are decisive in obtaining a good fuzzy model. However, a relatively new design method allows a competitive model to be built using a combination of fuzzy logic and neural-network techniques. Moreover, this method allows the possibility to generate and optimize the fuzzy rules set and the parameters of the membership functions by means of fuzzy inference systems' (FISs) training.

4. IMPLEMENTATION OF FUZZY LOGIC CONTROLLER IN CURRENT FED QUASI Z SOURCE INVERTER

The fuzzy logic controller takes two inputs, processes the information and outputs. The input to fuzzy controller is error in voltage and change of error in voltage and the output is current. The capacitor voltage is compared with the reference voltage and error and change in error are given as input to the fuzzy logic controller. Before the details of the fuzzy controller are dealt with, the range of possible values for the input and output variables are determined. These (in language of fuzzy set theory) are the membership functions are used to map the real world measurement values to the fuzzy values, so that the operations can be applied on them. Values of the input variables (error voltage) and (change in error voltage) are normalized range-(1 to 100). The decision which the fuzzy controller makes is derived from the rules which are stored in the database. These are stored in a set of rules. The rules are if-then statements that are Intuitive and easy to understand, since they are nothing but common English statements. Rules used in this project are derived from common sense, data taken from typical home use, and experimentation in a controlled environment. There are five steps in implementing the Fuzzy Logic. They are,

- Defining inputs and outputs.
- Fuzzification of input.
- Fuzzification of output.
- Create Fuzzy rule base.
- Defuzzification of output.

Reference Voltage

Power VI

e \ ce	NB	NM	NS	ZO	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZO
NM	NB	NB	NB	NM	NS	ZO	PS
NS	NB	NB	NM	NS	ZO	PS	PM
ZO	NB	NM	NS	ZO	PS	PM	PB
PS	NM	NS	ZO	PS	PM	PB	PB
PM	NS	ZO	PS	PM	PB	PB	PB
PB	ZO	PS	PM	PB	PB	PB	PB

Fig.7. Fuzzy rule base

Fuzzy Logic based Algorithms

The pivotal contribution of fuzzy logic is a methodology for computing with words which can deal with imprecision and granularity. The human brain can interpret and process imprecise and incomplete sensor information which are received from the perceptive organs. Analogously the fuzzy set theory can also provide a systematic approach to deal with such information linguistically. It can also perform numerical computation by using membership function for the stipulated linguistic labels.

The Fuzzy inference system (FIS) is based on the concepts of fuzzy set theory, fuzzy if-then rules and fuzzy reasoning. The framing of the fuzzy if-then rules forms the key component in FIS. FIS is a very popular technique and has been widely applied in different fields like data classification, automatic control, expert system, decision making, robotics, time series analysis, pattern classification, system identification etc. The basic structure of a fuzzy inference system consists of three principal components viz a rule base comprising of the selected fuzzy rules, a database defining the membership functions of the fuzzy rules, and a reasoning mechanism which performs a fuzzy reasoning inference with respect to the rules so as to derive a reasonable output or conclusion.

Analysis with Fuzzy Inference System

For the analysis of a fuzzy system whose inputs and outputs are described by linguistic variables, the following steps have to be carried out:

Fuzzification: The linguistic variables of the fuzzy rules are expressed in the form of fuzzy sets where these variables are defined in terms of degree of their associated membership functions. This method of calculating the degree of belongingness of the crisp input in the fuzzy set is called the fuzzification. The membership functions may be triangular, trapezoidal, gaussian or bell shaped. As the information about the degree of the membership is used for further processing, considerable amount of information may be lost during the course of fuzzification. This is because the procedure can be seen as a nonlinear transformation of the inputs. For example in the case of triangular or trapezoidal membership functions information is lost in the regions of membership functions where the slope is zero, as at these points the membership functions are not differentiable. Therefore fuzzy systems having triangular or trapezoidal membership function can encounter problems of learning from data. Smoother membership functions like gaussian or bell function may be used to overcome this difficulty.

5. SIMULATION RESULTS

The input three phase supply is given to the universal bridge. The universal bridge converts AC to DC. The output DC supply is fed to the Z Source network. The Z Source network contains capacitor and inductors. The output voltage from the Z Source network is given to the inverter. When the fuzzy logic controller generates pulse to the gate signals the inverter gets turned on. Now, the inverter converts DC supply into AC supply. The output voltage from the inverter is given to the three phase induction motor and the motor gets rotate. The speed is sensed by the proximity sensor. The output speed is fed back to the fuzzy logic controller. The fuzzy logic controller compares the actual and reference speed and provides the constant speed.

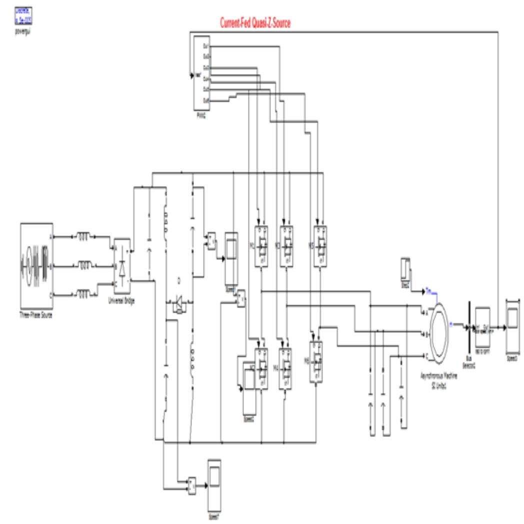

Fig.8. Current fed Quasi Z source inverter with Bidirectional power flow

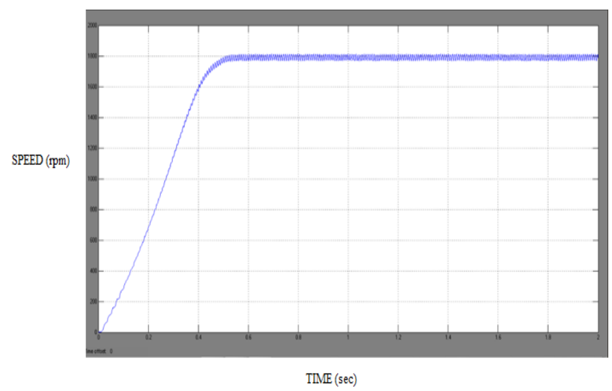

Fig.9. Simulation result of output speed using fuzzy controller

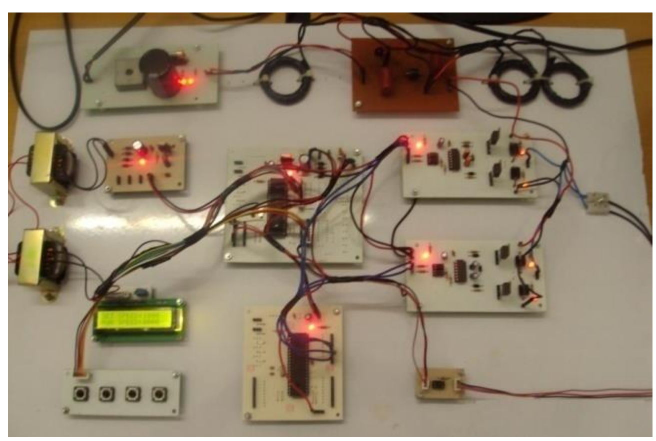

Fig 10. Hardware circuit

6. CONCLUSION

This paper presents and describes the current-fed quasi-Z-source inverter-based 3 phase induction motor, gives their circuit topologies for full controllable device front-end type topology. The presented systems could provide buck-boost function and output variable frequency voltage. The current-fed quasi-ZSI based fuzzy logic controller are widely used in the applications such as wind generation, motor drive, active power filter (APF), unified power flow controller (UPFC), etc. Based on the second order mathematical model of the process, the tuning parameters were obtained and the fuzzy logic controller was designed. The responses revealed that the fuzzy logic controller has comparatively less offset, overshoot and settling time than those of the conventional controller.

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