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Closed Loop Control Of ZSI Fed Induction Motor Drive Using Pi And Fuzzy Logic Controllers

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Abstract: Z Source Inverter (ZSI) is a best interface between Photovoltaic system and induction motor. This study investigates the performance of Z-Source inverter fed induction motor drive (ZSIIMD) using different controllers. The main objective of this work is to improve the dynamic performance of the ZSIIMD system. The ZSI exhibits a variable frequency output to control the speed of ZSIIMD system. ZSIIMD system is designed and simulated with PI and FLC controllers using MATLAB/Simulink. The results indicate that ZSIIMD with FLC have better dynamic performance with reduced steady state error. A 1/4 HP ZSIIMD is designed and simulated with the help of MATLAB/Simulink.

Keywords — Impedance Source Inverter (ZSI), Photovoltaic (PV), proportional integral (PI), fuzzy logic controller and Total Harmonic Distortion (THD).

I. Introduction

Demand for sustainable source of energy are increasing during the past few decades due to the exhaustion of conventional energy sources, environmental pollution and global warming. Among all the renewable energy sources such as wave power, wind power, fuel cell etc. solar power is one of the inexhaustible sources of energy and elegant in nature. Solar power is converted into electrical power using Photovoltaic cells. Generally, PV systems generate small voltage and needs high step up converter for the adequate utilization of the system. [1]- [6].

Traditional boost converter can obtain high voltage gain with intense duty ratio, but results in poor conversion efficiency, reverse recovery and electromagnetic interference [EMI] problems. When the PV system is linked to the AC load two level of power conversion is required, DC to DC converter to step-up the low DC output voltage of the PV system into high DC voltage and inverter for converting high DC voltage into AC voltage to supply the AC load. Traditional voltage source inverter (VSI) is used to convert the DC voltage into AC voltage. But the VSI has the following issues and limitations. The output AC voltage of VSI is always lesser than the DC link voltage and it performs buck (step-down) operation. VSI performs boost (step-up) operation for AC to DC conversion.

The upper and lower switches of equivalent phase are gated on simultaneously that results in shoot-through state of the VSI, which could blow the switches. Additional LC filter is required to provide sine wave voltage from VSI. These problems are overwhelmed by the Z-Source inverter presented in [7] which provides single stage of power conversion. Various PWM techniques have been adopted to boost the voltage gain, decrease the voltage stress across the switches [8]- [11]. Various topologies of Z-Source converter have been developed and implemented [12], [13]. Z-Source inverters are developed for applications such as adjustable speed drives (ASD) [14], uninterruptable power supplies [15]. Three phase qZSI with constant common-mode voltage for Photovoltaic applications is presented [16], leakage current flows through the stray capacitances of the PV panel when there are fluctuations in common-mode voltage. Shoot-through states increase the magnitude of high-order harmonics of common mode voltage in qZSI. Using odd pulse width modulation and minor change in the impedance network of the three phase qZSI, the leakage current is blocked. To improve the performance of Buck Boost Converter with Coupled Inductor the closed loop control is employed using Fractional order PID controller [17].

Voltage source inverter (VSI) fed three phase induction motor drive is presented in [18]. Proportional plus integral (PI) controller based active front end super lift converter is proposed in this paper to provide ripple free DC link. A simulation is conducted using MATLAB/Simulink software and a prototype is developed with a field programmable gate array (FPGA) sparten-6 processor. The THD in the supply current is below 4% in the presence of AFE and it is

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above 60% in the absence of AFE.

Induction heating system with a full bridge series resonant inverter is presented in [19]. Fuzzy self-tuning PID controller is used to control the output power of induction heating system. The performance of proposed system is compared with PID and fine-tuned PID controller.

In [20], presented a fuzzy control strategy to implement the neutral-point (NP) potential balance based on the power stage of three level boost DC-DC converter. The proposed FLC can solve the imbalance problem of NP potential in the process of starting up and can suppress the influence of inverter circuit modulation strategy on NP potential and FLC can adaptively change duty cycle ratio to implement the balance between the output capacitor voltages. The simulation and experimental results verify the possibility and reliability of this method.

In [21], proposed a single phase H-bridge multilevel converter for PV systems governed by a new integrated fuzzy logic controller. The novelties of the proposed system are the use of a FLC and the use of an H-bridge power-sharing algorithm. Most of the required signal processing is performed by a mixed-mode field programmable gate array (FPGA), resulting in a fully integrated system on-chip controller. The proposed system offers improved performance over two-level inverter, particularly at low-medium power.

A detailed modelling of fuzzy logic controller based three phase multilevel inverter with separate DC source for grid connected photovoltaic (PV) system is presented [22]. DC link voltage is connected by fuzzy logic controller and switching signals for inverter are generated through unit current vector and triangular sampling controller method. Simulation results are presented to validate components models and control schemes.

The above literature survey does not deal with comparison of closed loop control of ZSIIMD with PI and FLC. This paper presents the dynamic performances of simulation of ZSIIMD with PI controller and FLC controlled ZSIIMD. Z-source inverter fed three phase induction motor drive under closed loop control has been simulated using MATLAB/Simulink.

II. SYSTEM DESCRIPTION

Block diagram of VSI system is shown in Fig 1. The output of PV is boosted by the boost converter and then DC voltage is converted into AC voltage using VSI. Block diagram of PV based ZSI fed IM Drive with closed loop control is shown in Fig 2. The DC output from PV system is applied to three phase inverter through a impedance (Z) network. ZSI provides single stage power conversion. The output of three phase inverter is applied to three phase induction motor.

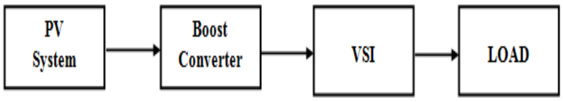

Fig 1. Block diagram of VSI system

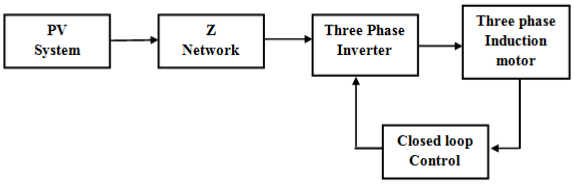

Fig 2.Block diagram of PV based ZSI fed IM Drive with closed loop control

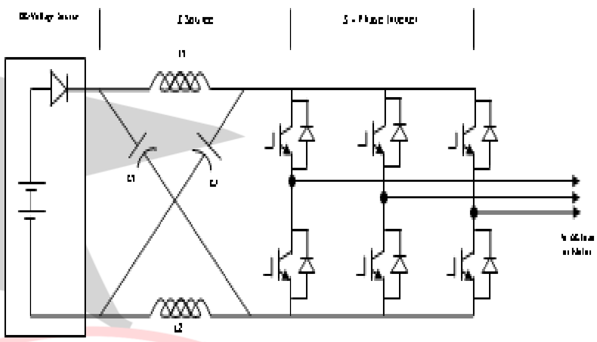

Fig 3. Circuit diagram of three phase ZSI

The circuit diagram of three phase ZSI is shown in Fig.3. Two inductors and two capacitors forms the LC impedance network. This network can perform both buck and boost operation. The VSI has eight switching states, six active states and two non-shoot through states. Non shoot though state exists when the inverter load terminals are shorted by either upper or lower three switches. But the ZSI has 9 switching states, one additional state known as shoot-through zero state exist when the load terminals are shorted by both upper and lower switches, any one of the phase or any two of the phases or all the three phases. The shoot through zero state of ZSI provides boosting ability for the Z network.

Three phase ZSI -Circuit Analysis

The Z-network is designed by assuming $L_1 = L_2 = L$ and $C_1 = C_2 = C$, so that the network performs as a symmetrical network. Therefore, from the equivalent circuit we can write [7],

$$V_{C1} = V_{C2} = V_C$$
$$v_{L1} = v_{L2} = v_L \qquad \text{.......... (1)}$$

During the shoot-through zero state for an interval of T0, the inverter bridge is equivalent to a short circuit and no voltage impressed across the load, the inductors present in the network are charged by the capacitors. This shoot through zero state provides the unique buck-boost capability. By adjusting the time period for shoot through state, the buck-boost operation is performed. PWM technique used to control the output voltage of VSI is

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modified by allocating shoot through zero states without changing the total zero-time interval to control the output voltage of ZSI.

$$v_L = V_C$$
$$v_d = 2V_C$$
$$v_i = 0 \quad \text{……… (2)}$$

The inverter bridge is equivalent to the current source, during its six active states and the stored energy of the inductors and DC source voltage are transferred to the load, thus performing the boost operation. During the non-shoot through zero state, the inverter bridge is equivalent to a current source with zero value. The expression for

Voltage across the inductors and capacitors are given as,

$$v_L = V_0 - V_C$$
$$v_d = V_0$$
$$v_i = V_C - v_L = 2V_C - V_0 \quad \text{……… (3)}$$

$$V_L = \overline{v_L} = \frac{T_0.V_C + T_1.(V_0 - V_C)}{T} = 0 \quad \text{……. (4)}$$

$$\frac{V_C}{V_0} = \frac{T_1}{T_1 - T_0} \quad \text{…… (5)}$$

The average dc-link voltage across the inverter bridge

$$V_i = \bar{v}_i = \frac{T_0.0 + T_1.(2V_C - V_0)}{T} = \frac{T_1}{T_1 - T_0} V_0 = V_C \quad \text{……. (6)}$$

The peak value of dc-link voltage is written as,

$$\hat{v}_i = V_C - v_L = 2V_C - V_0 = \frac{T}{T_1 - T_0} V_0 = B.V_0 \quad \text{…… (7)}$$

Where B is the boost factor, T_0/T is the shoot-through duty ratio

$$B = \frac{T}{T_1 - T_0} = \frac{1}{1 - 2\frac{T_0}{T}} \geq 1, \quad \text{…. (8)}$$

The output peak phase voltage of the inverter is given by

$$\hat{v}_{ac} = M.\frac{\hat{v}_i}{2} \quad \text{…… (9)}$$

$$\hat{v}_{ac} = M.B.\frac{V_0}{2} \quad \text{……. (10)}$$

Where M is the modulation index and Buck-boost factor is given by the following expression.

$$B_B = M.B = (0 \sim \infty) \quad \text{….. (11)}$$

Voltage across the capacitors can be expressed as,

$$V_{C1} = V_{C2} = V_C = \frac{1 - \frac{T_0}{T}}{1 - 2\frac{T_0}{T}} \quad \text{…. (12)}$$

III. SIMULATION RESULTS

A. SIMULATION CIRCUIT THREE PHASE ZSI FED INDUCTION MOTOR SYSTEM WITH PI CONTROLLER

The PI controller produces an output signal consisting of two terms, one proportional to error signal and the other proportional to the integral of error signal. The proportional part is responsible for following the desired set-point while the integral part accounts for the accumulation of past errors. Fig 3. Shows the basic structure of Proportional Integral (PI) controller. In spite of simplicity, they can be used to solve even a very complex control problem, especially when combined with different functional blocks, filters (compensators or correction blocks), selectors, etc. The PI controller output is given as

$$u(t) = K_p.e(t) + K_i \int e(t)\, dt \quad \text{……….(13)}$$

Where K_p and K_i are proportional and integral constants respectively.

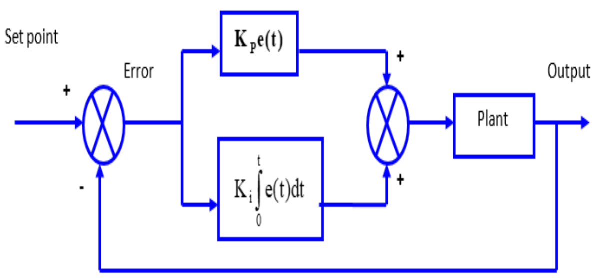

Fig 3.Structure of PI Controller

Simulation circuit for solar powered three phase ZSI fed Induction motor system with PI controller is shown in Fig 4. The output voltage of PV system is applied to ZSI. The value of inductors present in the Z-network are L_1= L_2= 2mH and the capacitors C_1= C_2= 2μF. Closed loop ZSIIM system with PI Controller is shown in Fig 4.

The Ziegler Nichols tuning first method is used for tuning the PI controller with L=0.1and T=0.3, observed from unit-step response of speed characteristics curve. The PI controller proportional gain constant and integral time constants are found using,

$$K_p = 0.9 * \frac{T}{L} \quad \text{------ (14)}$$

$$K_i = \frac{K_p}{T_i} \quad where, \quad T_i = \frac{L}{0.3} \quad \text{-------- (15)}$$

The motor speed is compared with the reference speed and the error is applied to a PI controller. The output of PI controller is applied to a comparator which generates updated pulses for the ZSI. The motor speed is shown in Fig 5 and settles at 332 RPM. The torque response is shown in Fig 6 and settled at the value of 10 N-m.

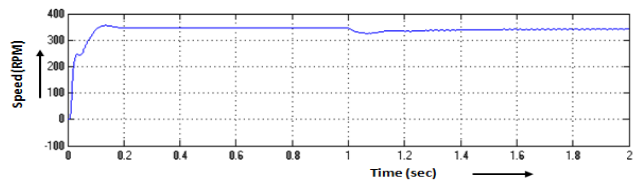

Fig 5.Motor speed

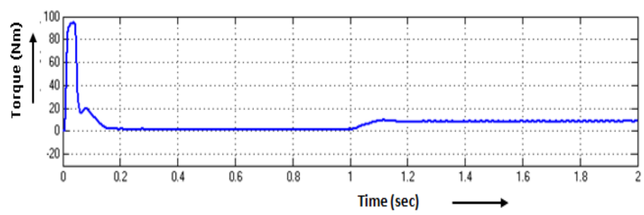

Fig 6. Torque response

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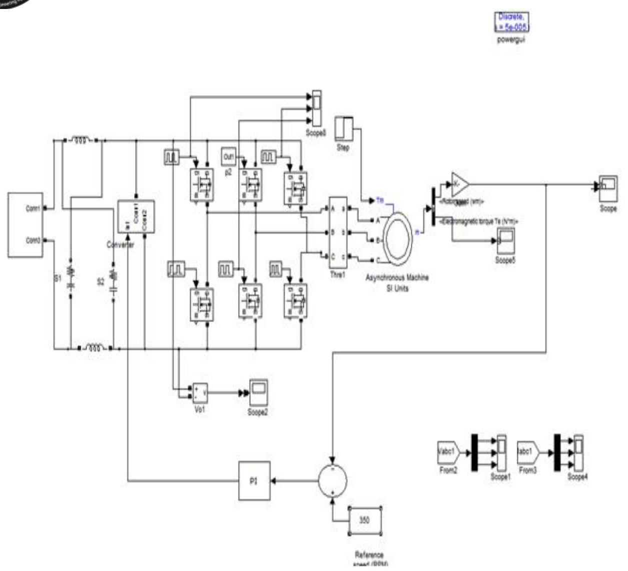

Fig 4. Z-source inverter fed motor load circuit diagram with PI controller

B. SIMULATION CIRCUIT THREE PHASE ZSI FED INDUCTION MOTOR SYSTEM WITH FLC CONTROLLER

The basic structure of a Fuzzy Logic Controller shown in Fig 7. Shows the basic structure of a Fuzzy Logic Controller. The main building units of FLC are,

- Fuzzification unit
- Fuzzy Logic reasoning unit and a knowledge base
- Defuzzification unit

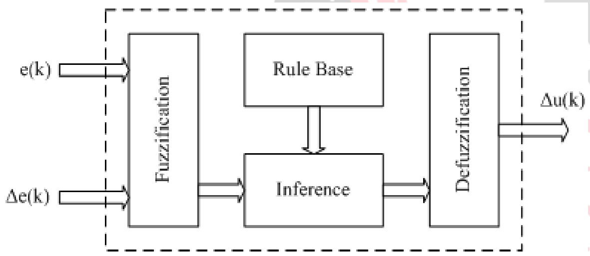

Fig 7. Basic Structure of Fuzzy Logic Controller

The first block inside the controller is fuzzification block which converts each piece of input data to degrees of membership function by a lookup table in one or several membership functions. The fuzzification block matches the input data with the conditions of the rules to determine. The input sensory (crisp or numerical) data are fed into fuzzy logic rule based system where physical quantities are represented into linguistic variables with appropriate membership functions. These linguistic variables are then used in the antecedents (IF-Part) of a set of fuzzy "IF-THEN" rules within an inference engine to result in a new set of fuzzy linguistic variables or consequent (THEN-Part) One of the problems of conventional fuzzy logic control is that it takes a lot of CPU time for calculations, especially for large number of fuzzy rules. This limitation prevents fuzzy logic from being used widely in real time systems Defuzzification is the process of converting inferred Fuzzy Control actions into a crisp control action.

Table-1 Fuzzy Logic Rules

e/Δe	NL	Z	PS
NS	PS	NS	PB
PS	NB	PB	PS
Z	NL	Z	NS

Based on above mentioned rules the FLC controller was interfaced with the ZSIIMD system which is shown in the Fig 8. The speed response of the system was improved with the help of FLC controller. The motor speed settles at 349.05 RPM and the set speed is 350 RPM which is shown in the Fig 9. The torque response of the system settles at 4 N-m which is shown in Fig 10.

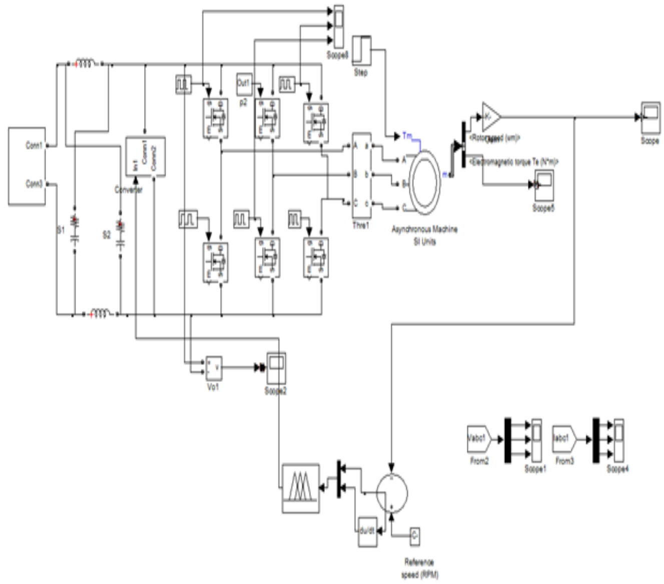

Fig 8. Z-source inverter fed motor load circuit diagram with FLC controller

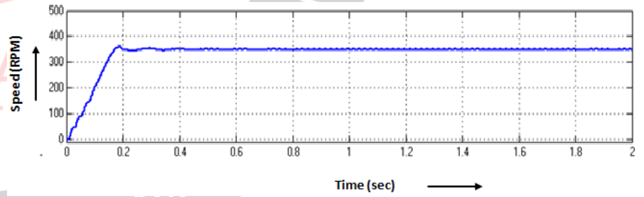

Fig 9. Motor speed

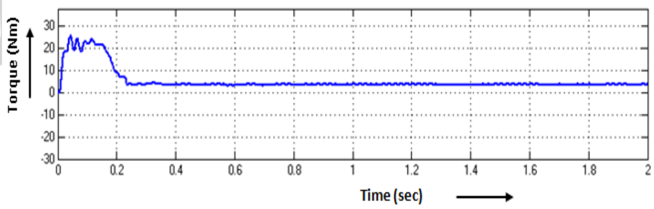

Fig 10. Torque

C. .COMPARISON OF TIME-DOMAIN-PARAMETERS WITH VARIOUS CONTROLLERS

The summary of Time domain parameters with PI & FLC is shown in Table-2. It can be observed from the Table- 2 that the rise time, settling time and steady state error are reduced with FLC control.

By using FLC, Rise time reduces from 0.09 to 0.02 Secs; settling time reduces from 1.21 to 1.05 secs; Steady state

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error reduces from 18 to 0.95 RPM. Therefore, the ZSIIMD with FLC gives improved dynamic response than PI controller.

Table-2 Time-domain-parameters with PI and FLC controllers

Controllers	Rise time (s)	Settling time (s)	Steady state error (rpm)
PI controller	0.09	1.21	18
FLC	0.02	1.05	0.95

IV. CONCLUSION

The closed loop control of ZSI fed induction motor with PI and FLC controllers are simulated. The Simulation results FLC controlled closed loop system provides better dynamic response than PI controlled system. Contribution of this work is to improve dynamic response of the ZSIIMD with feedback system. When ZSIIMD simulated with open loop control, the rise time of the speed curve is about 3.5 seconds and the settling time is about 4 seconds. To improve the dynamic characteristics of ZSIIMD the same system is simulated in closed loop control with PI and FLC controllers. From the simulation results it is observed that FLC controller, reduces the rise time about 0.02 seconds ,the settling time about 1.05 seconds and steady state error with 0.95 RPM. The proposed system has advantages like high power capability and improved time domain response. The experimental or hardware implementation of ZSIIMD closed loop control with fuzzy logic controller can be carried out in future work.

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