Control Scheme Based On Quasi Z-Source Network For Four-Switch Three-Phase Brushless Dc Motor

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***Abstract*- In this paper Quasi Z-source network based control scheme is proposed with the help of Fuzzy Logic Control, which results the improvement in utility ratio of DC voltage, extends the range of speed and reduces torque ripples. As compared to other electrical machines, Brushless DC machine is becoming most popular in selection of drive technology. Reason behind this popularity is its numerous advantages like low maintenance, high efficiency, high power density and robustness. The drawbacks of FSTP BLDC motor are studied and simulations for QZFSTP BLDC were designed in MATLAB Simulink. During the investigation, a novel topology is presented which is combination of quasi Z-source converter and FSTP drive circuit. The Simulation results are obtained and discussed in that paper.**

***Index Terms*- BLDC Motor, Quasi Z-Source Network, FSTP, Fuzzy Logic Controller, MATLAB/Simulink, torque ripple.**

1. INTRODUCTION

The BLDC motor having advantageous features like high torque, high power density, high efficiency, high speed, robustness and low maintenance. Due to this features it is becoming more popular in drive technology. Conventionally, most used control scheme for BLDC motor was six step commutation whereas study suggests that such scheme has poor dynamic response, poor efficiency as well as high pulsating torque. Furthermore, the proposed system has four switch which reduces switching losses and reduces its cost.

Consequently, the current control based voltage vector is adopted in paper [1-2]. It can make the C phase current converge to zero through inserting adjusting vectors. The strategy is easy to implement and has merits of fixed frequency, high stability and rapid dynamic response. In paper [3], the double closed-loop control that contains speed and current hysteresis is restrained effectively. Meanwhile, the phase error is significantly decreased for no need of delaying 30 or 90 electrical angles. To further reduce controlling costs, a novel control scheme of four-switch three-phase brushless dc motor without current sensor is presented in paper [4-5]. It combines four-switch three-phase inverter with the boost circuit to increase the input voltage of inverter by three effective- vector current control. Furthermore, it features the compact structure and simple arithmetic. The commutation time of motor can be determined through the zero-crossing detection for terminal voltage. The paper [6] introduces a novel topology of five-switch three-phase brushless dc motor to extend the range of speed and improve the load capacity when supply voltage is low or battery.

A novel topology for FSTP brushless dc motor is presented in the paper. The quasi Z-source converter boosts the input voltage of brushless dc motor to enhance its dynamic performance.

MERITS OF QZFSTP OVER FSTP

- QZSI draws continuous constant dc current due to inductor L1 which reduce input stress from the source, while in ZSI draws discontinuous current and voltage on capacitor C2 is greatly reduce.
- Two capacitors in ZSI sustain same high voltage, while the voltage in capacitor C2 in QZSI is lower, which require lower capacitor rating.
- For QZSI there is common dc rail between source and inverter which is easier two assemble and causes less EMF problem

II.PROBLEM STATEMENT

The overall operating modes of FSTP motor are divided into six modes. In the traditional Four Switch Three Phase Brushless DC motor the inverter was composed of four switches instead of six switches, and two capacitors in series constitute the bridge arm of C phase. According to dc-link voltage utilization, there are two cases. One is that input voltage is responsible for the power supply of the load in many modes and other is that only half of input voltage is utilized in another mode. In addition, maximum output voltage obtainable can never exceed the dc bus voltage. The asymmetrical voltage utilization restricts the change rate of the phase current when half of input voltage is operating. Also in traditional voltage source inverter, the two switches of same phase leg can never be gated on at the same time because doing so would cause a short circuit to occur that would destroy the inverter. In result, the actual current cannot reach the reference value. Then the distortion of phase current and torque ripple will occur. So the speed of BLDC motor dramatically decreases.

III.BASIC STRUCTURE OF QUASI Z-SOURCE NETWORK

A network as shown in fig.1 that consists of a split-inductor and capacitors are connected in X shape is employed to provide an impedance source (Z-source) coupling the inverter. Therefore, the dc source can be a battery, diode rectifier, thyristor converter, fuel cell, an inductor, a capacitor, or a combination of those. The inductance can be provided through a split inductor or two separate inductors. The dc source/or load can be either a voltage or a current source/or load.

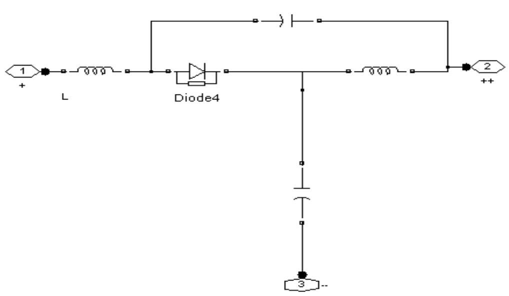


Figure 1: Quasi Z-source Network

WORKING: -

As shown in fig.2, its employs Z-Source topology which consists of inductors (L_1 and L_2) and capacitors (C_1 and C_2) connected in X shape to couple the inverter to the dc voltage source. The ZSI can produce any desired ac output voltage regardless of the dc input voltage. Because of this special structure, the ZSI has an additional switching state, when the load terminals are shorted through both the upper and lower switching devices of any phase leg, which called the shoot-through (ST) state besides the eight traditional non-shoot through (NST) states. The ZSI has two operating modes: non shoot- through mode and shoot-through mode. During the ST switching state, the input diode is reverse biased; the input dc source is isolated from the load, and the two capacitors discharge energy to the inductors and to the load. During the NST switching states, the input diode turns ON, and the dc input voltage source as well as the inductors transfer energy to the load and charge the capacitors, as a result the dc-link voltage of bridge is boosted.

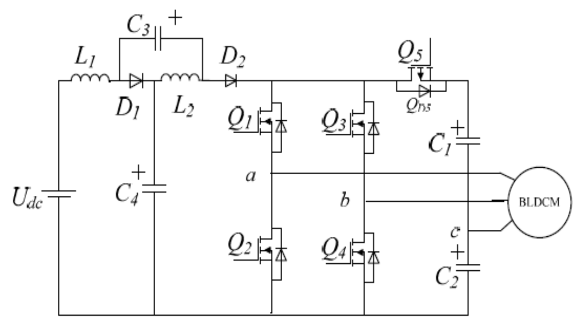
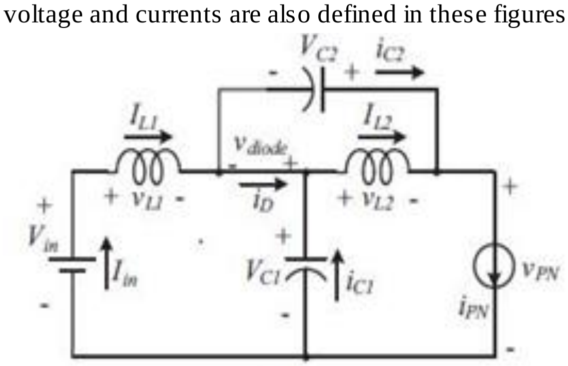


Figure 2: Circuit Diagram of QZFSTP

Non-shoot through state and shoot-through state of QZS network with equivalent circuits are illustrated in Fig. 3 (a) and (b), respectively. The polarities of voltage and currents are shown with arrows and voltage and currents are also defined in these figures.



(a)

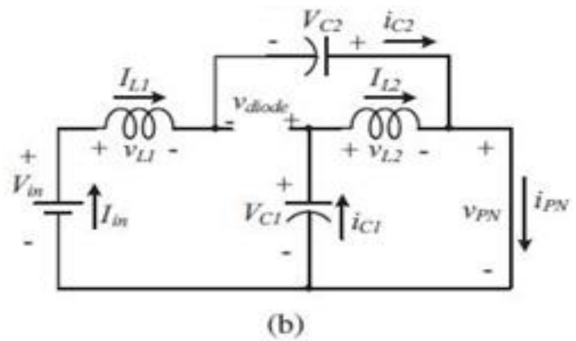


Figure 3: Equivalent Circuit of QZS Network. (a) in non-shoot through state, (b) in shoot-through state

1. *Non-shoot-through state:* During the non-shoot-through state four-leg inverter model is represented by a constant current source, it can be seen from Fig. 2 (a). By applying Kirchhoff's voltage law to Fig. 2 (a), inductors voltages (v_{L1} and v_{L2}), dc-link voltage (v_{PN}), and diode voltage (v_{diode}) are written as

$$v_{L1} = V_{in} - V_{C1}, \qquad v_{L2} = -V_{C2} \text{ - - - - - - - - - (1)}$$
$$v_{PN} = V_{C1} - v_{L2} = V_{C1} + V_{C2}, \; v_{diode} = 0 \text{ - - - - - - (2)}$$

2. *Shoot-through state:* During the shoot-through state four-leg inverter model is represented by short-circuit as shown in Fig. 3 (b). By applying Kirchhoff's voltage law to Fig. 3 (b), inductors voltages (v_{L1} and v_{L2}), dc link voltage (v_{PN}), and diode voltage (v_{diode}) are written as

$$v_{L1} = V_{C2} + V_{in}, \qquad v_{L2} = V_{C1} \text{ - - - - - - - - - - (3)}$$
$$v_{PN} = 0, \qquad v_{diode} = V_{C1} + V_{C2} \text{ - - - - - - - - - (4)}$$

At steady state, the average voltage of the capacitors over one switching cycle are

$$VC1 = \frac{T1}{T1-T0} Vin, \qquad VC2 = \frac{T0}{T1-T0} Vin \text{ - - - - (5)}$$

where T_0 is the duration of the shoot-through state and T_1 is the duration of the non-shoot-through state, and *Vin* is the input dc source voltage.
From (2), (4), (5), the peak dc-link voltage across the inverter bridge is

$$V_{PN=} V_{c1} + V_{c2} = \frac{T0}{T1-T0} Vin = B\, V_{in} \text{ - - - - - - - - - - (6)}$$

where *T* is switching cycle, *B* is the boost factor of the qZSI.

IV.CONTROL STRATEGY

According to Fig.2, it is the circuit topology of QZFSTP brushless dc motor driver. The partial circuit of quasi Z-source converter is added before the input of FSTP inverter. Moreover, the power switch *Q5* is applied between the bridge arm of phase A and phase B.

TABLE I.
STATUS OF DEVICES IN SIX MODES OF FSTP MOTOR

Mode	Hall	Active phase	Silent phases	Conducting device
I	001	C/B	A	Q_1
II	101	A/B	C	Q_1,Q_4
III	100	A/C	B	Q_1
IV	110	B/C	A	Q_3
V	010	B/A	C	Q_3 ,Q_2
VI	011	C/A	B	Q_2

V. FUZZY LOGIC CONTROL OF THE BLDC MOTOR

Fuzzy logic expressed operational laws in linguistics terms instead of mathematical equations. Many systems are too complex to model accurately, even with complex mathematical equations; therefore, traditional methods become infeasible in these systems. However fuzzy logics linguistic terms provide a feasible method for defining the operational characteristics of such system. Fuzzy logic controller can be considered as a special class of symbolic controller. The configuration of fuzzy logic controller block diagram is shown in Fig.4

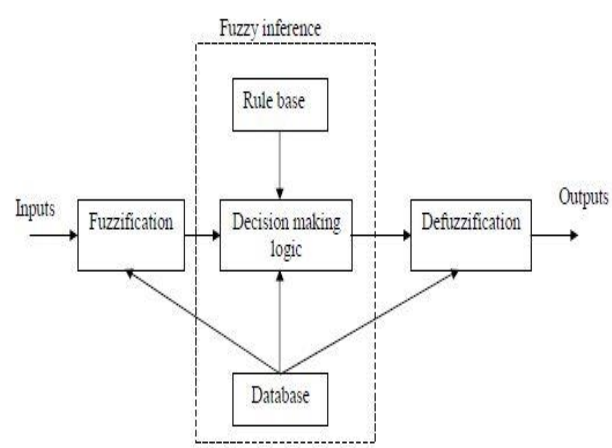


Figure 4: Structure of Fuzzy Logic Controller

The fuzzy logic controller has three main components

1. Fuzzification
2. Fuzzy inference
3. Defuzzification

The inputs of the fuzzy controller are expressed in several linguist levels. As shown in Fig.5 these levels can be described as Positive big (PB), Positive medium (PM), Positive small (PS) Negative small (NS), Negative medium (NM), Negative big (NB) or in other levels. Each level is described by fuzzy set.

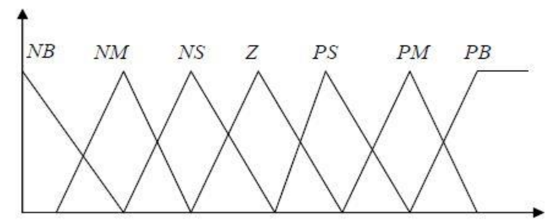


Figure 5: Seven levels of fuzzy membership functions.

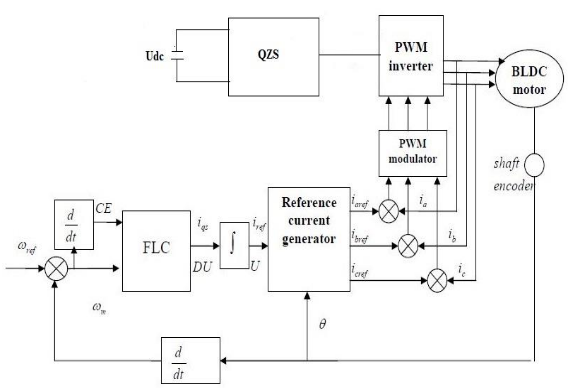


Figure 6: Fuzzy Logic Control Block Diagram of BLDC Motor.

The fuzzy logic controller was applied to the speed loop by replacing the conventional controller. The fuzzy logic controlled BDCM drive system block diagram is shown in Fig.6.

The input variable is speed error (E), and change in speed error (CE) is calculated by the controller with E. The output variable is the torque component of the reference (i_{ref}) where i_{ref} is obtained at the output of the controller by using the change in the reference current. The controller observes the pattern of the speed loop error signal and correspondingly updates the output DU and so that the actual speed ω_m matches the command speed ω_{ref}. There are two inputs signals to the fuzzy controller, the error $E = \omega_{ref} - \omega_m$ and the change in error CE, which is related to the derivative

$$\frac{dE}{dt} = \frac{\Delta E}{\Delta t} = \frac{CE}{Ts}$$

Where CE=ΔE in the sampling Time T_s, CE is proportional to $\frac{dE}{dt}$. The controller output DU in brushless dc motor drive is $\Delta\, i^*_{qs}$ current. The signal is summed or integrated to generate the actual control signal U or current i^*_{qs}. where K_1 and K_2 are nonlinear coefficients or gain factors including the summation process shown in Fig 6. We can write

$$\int DU = \int K1Edt + \int K2CEdt - - - - - - (7)$$

U= $K_1 \int Edt$+KE - (8)

The fuzzy member's ship function for the input variable and output variable are chosen as follows:

Positive Big: PB Negative Big: NB
Positive Medium: PM Negative Medium: NM
Positive Small: PS Negative Small: NS
and zero: ZO

The input variable speed error and change in speed error is defined in the range of

$-1 \le \omega_e \le +1$ - - - - - - - - - - -(9)

And

$-1 \le \omega_{ce} \le +1$ - - - - - - - - - - -(10)

and the output variable torque reference current change $\Delta\, i_{qs\ is}$ define in the range of

$-1 \le \Delta\, i_{qs} \le +1$ - - - - - - - - - - - - (11)

The triangular shaped functions are chosen as the membership functions due to the resulting best control performance and simplicity. The membership function for the speed error and the change in speed error and the change in torque reference current are shown in Fig.7. For all variables seven levels of fuzzy membership function are used. Table. II show the 7* 7 rule base table that was used in the system.

Table II. 7*7 Membership Functions for fuzzy logic control

e/ce	NB	NM	NS	ZO	PS	PS	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

The steps for speed controller are as

- Sampling of the speed signal of the BLDC.
- Calculations of the speed error and the change in speed error.
- Determination of the fuzzy sets and membership function for the speed error and Change in speed error.
- Determination of the control action according to fuzzy rule.
- Calculation of the Δ i_{qs} by Centre of area defuzzyfication method.
- Sending the control command to the system after calculation of Δ i_{qs}.

VI.SIMULATIONS AND RESULTS

The proposed solutions have been designed using MATLAB/Simulink. The designed system with fuzzy control of BLDC motor is shown in fig. 7

PERFORMANCE WITH FUZZY LOGIC CONTROL SYSTEM

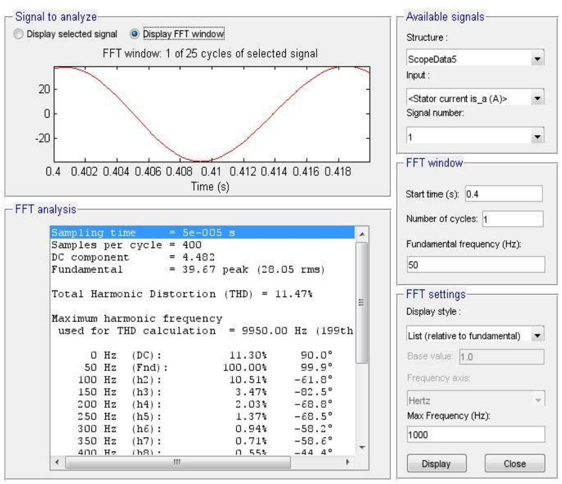


Figure 7: THD of Stator Current Phase A

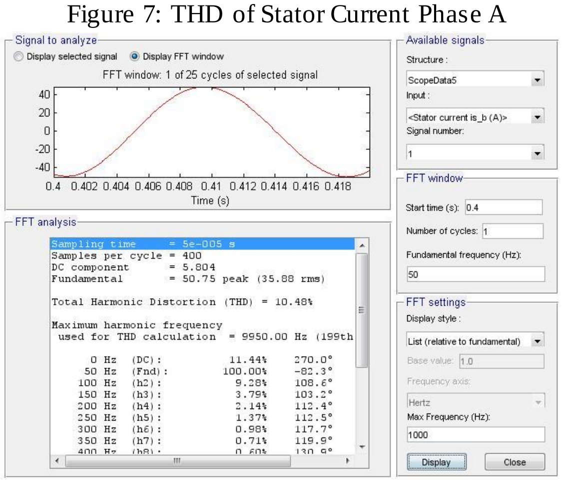


Figure 8: THD of Stator Current Phase B

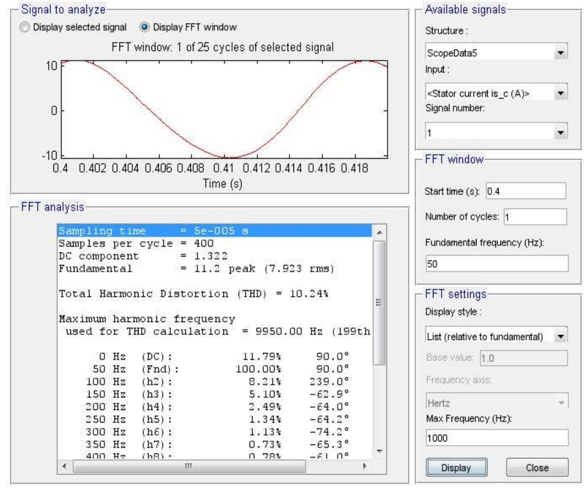


Figure 9: THD of Stator Current Phase C

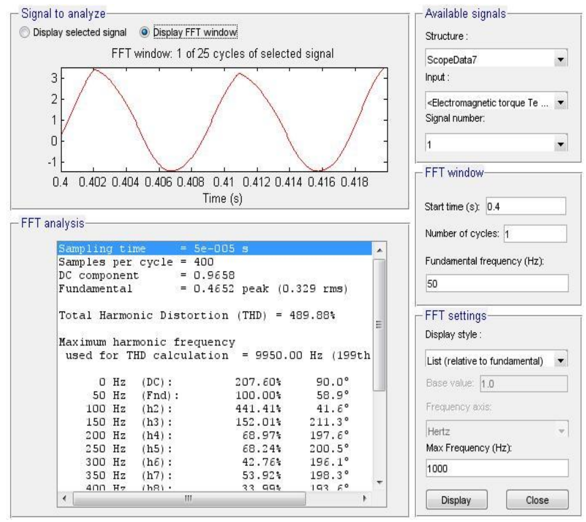


Figure 10: THD of Electromagnetic Torque

As shown in above figures the FFT analysis has been done and calculated Total Harmonic Distortion for every phase current and electromagnetic Torque with modified fuzzy logic controller. Comparison of conventional system and proposed system has been shown in Table III.

Table III. Comparison of Conventional & Proposed System

Parameters		Conventional System (THD in %)	Proposed System (THD in %)
Stator Phase Current	Phase A	23.20	11.47
	Phase B	17.47	10.48
	Phase C	11.56	10.24
Torque		677.78	489.88
Speed		2872 RPM	3373 RPM

VII.CONCLUSION

This Paper presented an outline of the worked novel four-switch three-phase brushless dc motor control scheme based on quasi Z-source network, which combines FSTP BLDC motor and quasi Z-source network. The input voltage of FSTP inverter has been boosted to enlarge the range of speed. The new topology circuit will be easy to implement and having Fuzzy Logic Control technique instead of Current Control Technique which gives rapid response and its control method will be simple. The QZFSTP motor circuit is simulated; the new topology having some advantages such as boosting DC voltage, rapid response and extending the range of speed. During the investigation, it is found that modified fuzzy logic controller system adopted for BLDC motor to reduce torque Ripple as well as current distortion is most convenient than that of conventional one system.

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