CHAPTER 5

SL-QZS INVERTER FED SENSOR LESS BLDC MOTOR USING FUZZY PID CONTROLLER

In the previous chapters, we have discussed solar power generation system for sensorless BLDC motor control which involved a multiple power conversion system that is buck boost converter with suitable MPPT algorithm. The operation of BLDC motor, when powered from solar, is a taunting task, because certain drawbacks exist in solar power generation schemes is discussed by Villalva et al., 2009. Low power is available from a solar source even with high installation cost, intermediate dc-dc converters are required and exhibit poor power factor when applied for ac applications. Solar power system with dc-dc converters offers low power for BLDC motor drives is explained by X. Zhou et al., 2017. Certain advancements have to be made in classical boost converter fed drives to deliver high power to motors with the help of improved converter schemes and with appropriate MPPT algorithms. Y. Tan et al., 2004 a switched inductor quasi z-source network is added to PV source which avoids multiple power conversion system and the above-mentioned drawbacks. This belongs to the typical family of Z-source inverters which are derived from a classical z-source topology and has advantages over conventional Z-source inverter and buck boost converter fed inverters. The SLQZS inverters do not involve any voltage clamping unit, Transformers and coupled inductors rather uses only an additional inductor to the quasi z-source topology. The proposed SLQZS inverter delivers high power to the motor at high efficiency, and switching losses are minimized in this inverter topology compared to the conventional Z-source inverter. The switched inductor quasi Z-source inverter is controlled with low-frequency PWM control unit when compared to Z-source inverter high-frequency pulses are involved which leads to high switching loss. A self-tuning fuzzy PID controller with simple maximum boost PWM technique is included to enhance both speed and torque performance of the motor. Incremental conductance based MPPT algorithm is used to tune modulation index of proposed maximum boost PWM control.

5.1 Switched Inductor Quasi Z-source Inverter

This inverter topology is derived from classical Z-source inverter topologies where only two inductors and capacitors are used. For extracting high power from solar PV source using incremental conductance algorithm, a switched inductor quasi Z-source inverter is proposed in this work. This circuit topology is different from other z-source topology by the use of additional passive elements and by using only smaller values of passive elements. The SLQZS inverter circuit topology consisting of three inductors (L_1, L_2, L_3) , two capacitors (C_1, C_2) and four diodes (D_1, D_2, D_3, D_n) are shown in Figure 5.1.

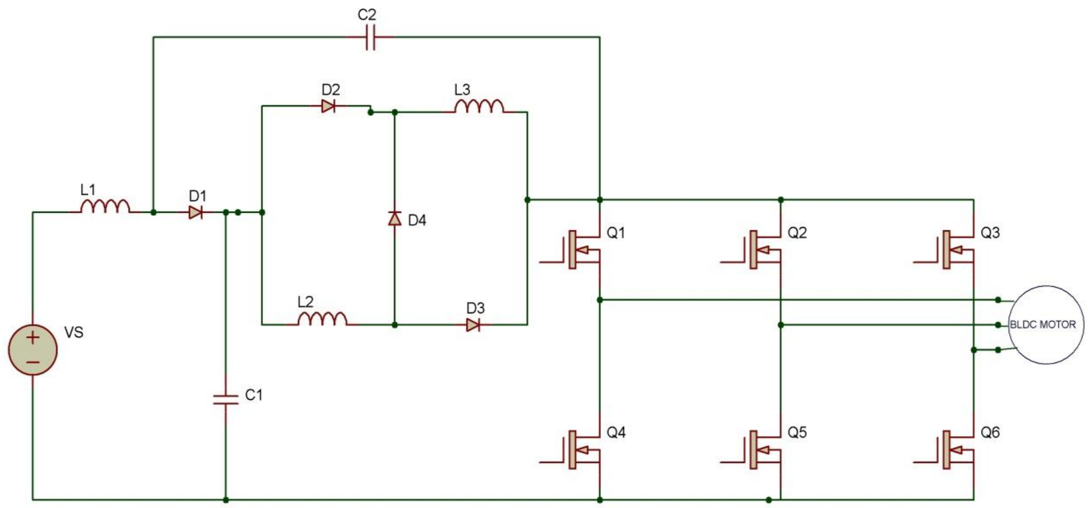


Figure 5.1 Circuit Diagram of Switched Inductor Z –Source Inverter

5.1.1 Modes of Operation

In general Z-source inverter has two different switching states active and zero switching states. During zero states inverter do not supply power to load and charges the energy in inductor and voltage in the capacitor. Similarly, during active state Z-source inverters functions as a normal inverter and utilizes dc-link voltage to the maximum to deliver power to the load is introduced by Y.J. Lee et al., 2009.

Shoot through state

In this mode of operation, there is no power transfer from source to load. Normally in any inverter, both the switches of a particular leg are not turned on simultaneously to avoid damaging the source is discussed by Z. Zhao et al., 2012. Here to charge the capacitors and inductors to the supply energy one top and other bottom switch of the same inverters leg are turned on for a particular time interval during every conduction period. During shoot through state, both D_1 and D_4 are turned off while remaining diodes are turned on. This makes the two inductors (L_1, L_2) to be connected in parallel with the source and capacitor circuit. In this mode the capacitors (C_1, C_2) get discharged to get the inductors to be charged that is it will store energy from the source. The following equations show the relation between energy storing inductors and the voltage developed across capacitors to the input source voltage. Figure 5.2 shows the shoot through state.

$$V_{L3} = V_{in} + V_{C1} \tag{5.1}$$

$$V_{L1} = V_{L1} = V_{in} + V_{c2} \tag{5.2}$$

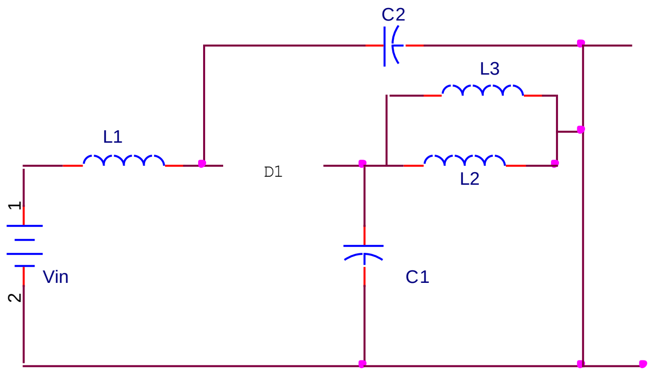


Figure 5.2 Shoot through State of SLQZSI

Non shoot through state

During this mode of operation energy stored in the inductor during shoot through the state is transferred to the load and the capacitors (C_1, C_2) gets charged to the supply voltage. In this mode conventional inverter operation is carried out normally any conduction mode of the inverter is applied according to the requirement of the load. During shoot through state, both D_1 and D_4 are turned on while remaining diodes are turned off. Figure 5.3 shows the non shoot through state.

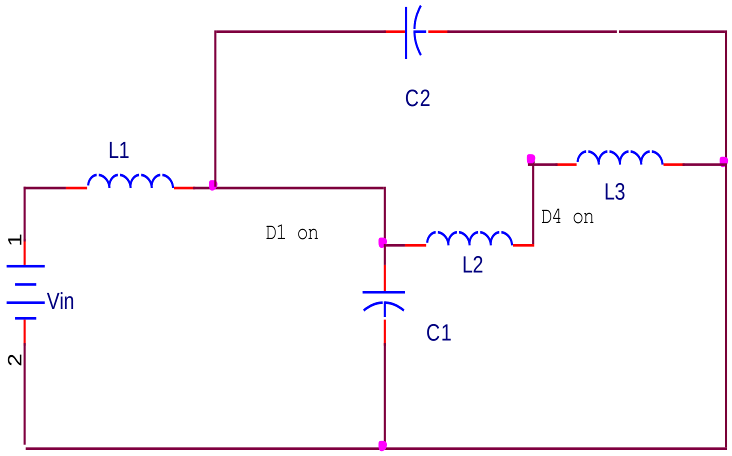


Figure 5.3 Non Shoot through State of SLQZSI

In this mode inductors, discharge and the relation between input DC Link voltage, capacitor voltage, and inductor voltage is obtained by

$$V_{in} = V_{dc} - V_{c1} + V_{L3} \tag{5.3}$$

$$V_{L3} = -V_{C2} \tag{5.4}$$

$$V_{L1} = V_{L2} = -{}^{1}/_{2}\, V_{C1} \tag{5.5}$$

$$V_{dc} = V_{in} + V_{c1} + V_{c2} \tag{5.6}$$

The inductor voltage V_{L3} is calculated by applying voltage-second balance principles on (1) and (2) equation is resulting as (3); similarly, voltage-second balance principles are applied to equation (2) and (5) is resulting as (8)

$$V_{C1} = (1 - D)V_{dc} - V_{in} \tag{5.7}$$

$$V_{C2} = \frac{(1-D)V_{dc} - (1+D)V_{in}}{1+D} \tag{5.8}$$

The equation (14) and (15) is used to calculate V_{dc} is expressed by

$$V_{dc} = \frac{1+D}{1-2D-D^2} V_{in} \tag{5.9}$$

The boost factors of proposed switched inductor z source inverter is calculated by the following expression as (17), and peak DC-Link voltage across present inverter circuit is calculated as equation (18)

$$B=\frac{1+D}{1-2D-D^2} \tag{5.10}$$

Maximum DC-Link voltage across three phase inverter circuit is obtained from

$$V_{PN} = BV_{DC} \tag{5.11}$$

5.2 Fuzzy PID based vector control using simple maximum boost PWM

In the proposed control technique based on sensorless brushless DC motor is implemented with sensing current, incremental conductance MPPT algorithm and self-tuning PID using the fuzzy logic controller is discussed by Y.C. Kuo and T.J. Liang 2001. The overall structure of proposed control technique is shown in figure 5.4. Maximum boost PWM control methodology is implemented for generating PWM pulses for switched inductor quasi Z-source inverter and for producing reference current for maximum boost PWM technique fuzzy PID controller is used.

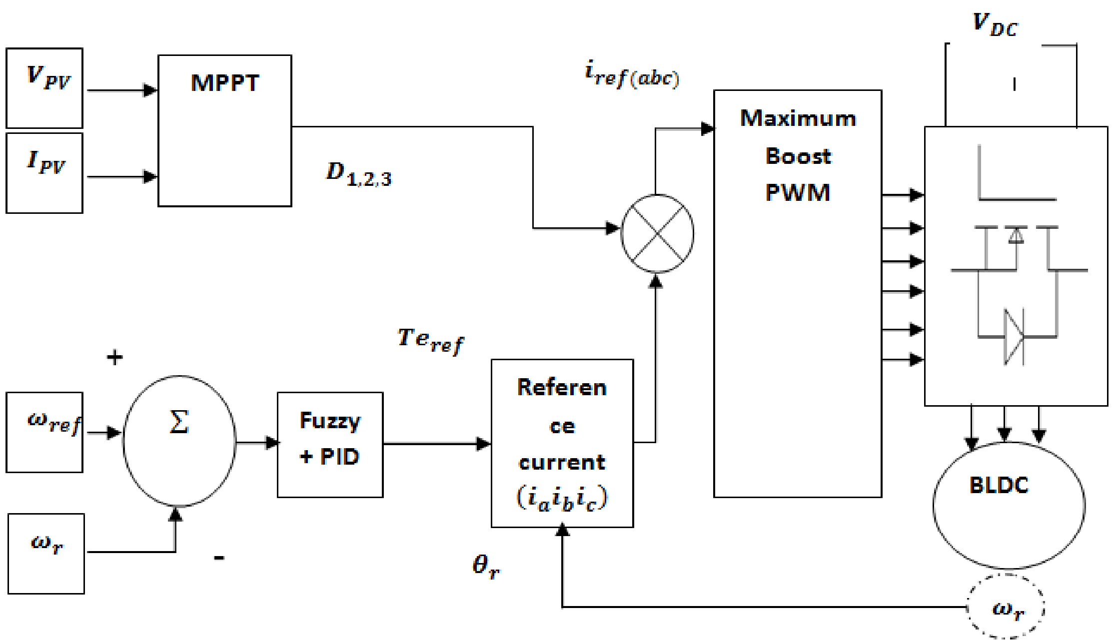


Figure 5.4 Control Circuit for Sensor less Vector Control of BLDC Motor using Maximum boost PWM technique

In the control circuit, incremental conductance MPPT algorithm is used for generating voltage reference signal which is treated as duty cycle for boost converter and PV topology. But in switched inductor quasi Z-source inverter topology the voltage reference signal or duty cycle obtained from incremental conductance algorithm based on solar photovoltaic conditions vary the modulation index of PWM scheme. After sensing three phase currents from BLDC motor the reference current obtained $i_a, i_b,\ i_c$ from torque reference using fuzzy PID speed controller calculates the value of theta (θ), then the reference current signal calculated from theta value $\left(I_{ref\,(abc)}\right)$ is given as input to a comparator where another input is voltage reference signal obtained from incremental conductance MPPT technique. The triangular carrier signal and voltage reference signal should be higher than calculated current reference signal i_a, i_b, i_c used for maximum boost PWM control.

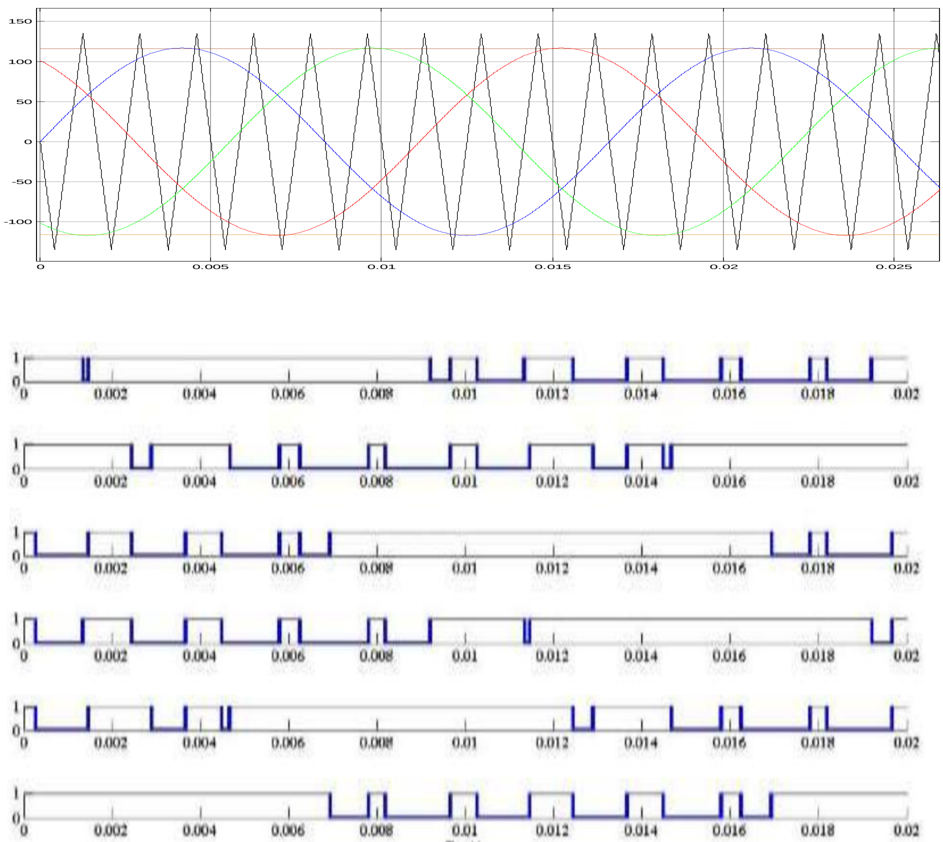


Figure 5.5 PWM generation using maximum boost technique carrier signal, reference voltage and current signal $\left(V_{carrier},\ V_{ref}, i_{abc}\right)$

Comparison diagram of three phase reference currents, the reference voltage signal for both positive and negative, the triangular carrier signal and PWM pulses generated using the simple maximum boost PWM technique is shown in figure 5.5.

5.2.1 Self-Tuning Fuzzy PID for Reference Torque Generation

In the proposed control technique estimation of the reference, torque is accomplished by Fuzzy logic controller along with PID controller, this is done by using PID controller as a speed regulator for the control of BLDC motor, and the tuning of PID controller is done through the same principle of speed control using fuzzy logic control is presented by A. A. Rajan et al., 2010. The combined use of fuzzy and PID eliminates the requirement of manual tuning of PID controller and combines the advantages of both fuzzy and PID controller. The duty ratio of fuzzy controller system is 0.8. The overall block diagram of applied fuzzy PID controller is shown in Figure 5.6. Fuzzy controller input and output membership functions and fuzzy rules are shown in Figure 5.7. The surface diagram of Fuzzy system is shown in Figure 5.8.

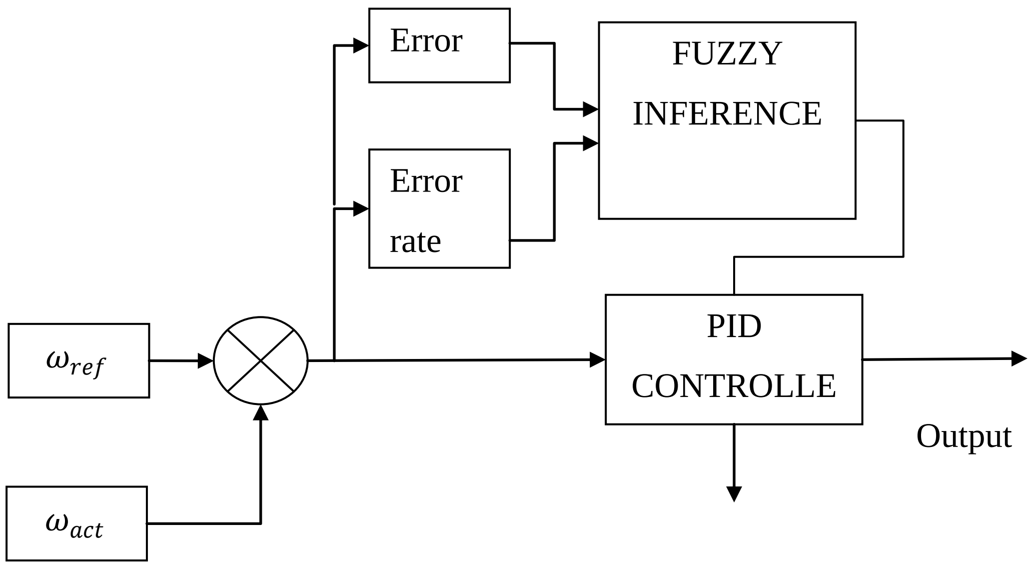
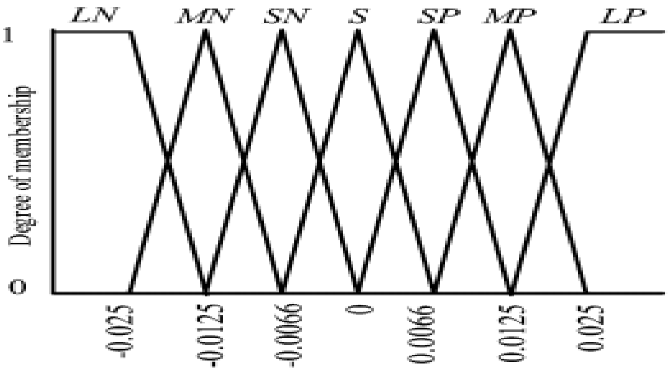
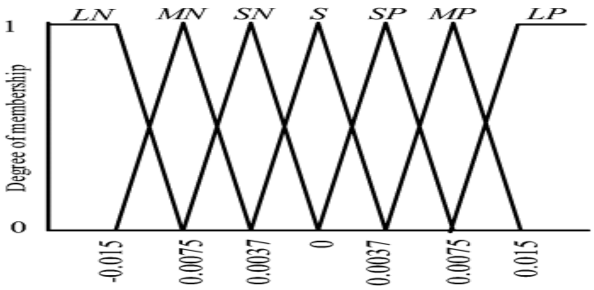


Figure 5.6 Block Diagram of self-tuning fuzzy PID controller

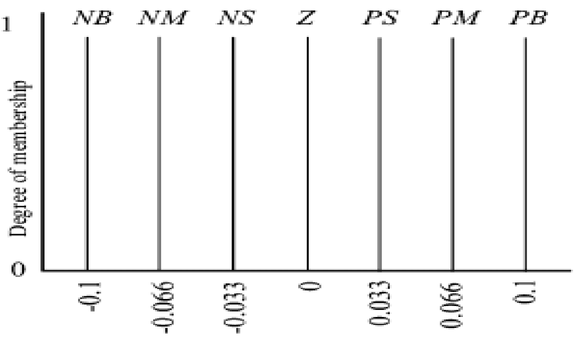
Input variable “error”



Input variable" error rate."



Output variable "actuating."



Fuzzy decision table

E/Δe	LP	MP	SP	S	SN	MN	LN
LP	PB	PB	PB	PM	PM	PS	Z
MP	PB	PB	PM	PM	PS	Z	NS
SP	PB	PM	PM	PS	Z	NS	NM
S	PM	PM	PS	Z	NS	NM	NM
SN	PM	PS	Z	NS	NM	NM	NB
MN	PS	Z	NS	NM	NM	NB	NB
LN	Z	NS	NM	NM	NB	NB	NB

Figure 5.7 Membership Functions of I/O Fuzzy and Control Rules Assignment

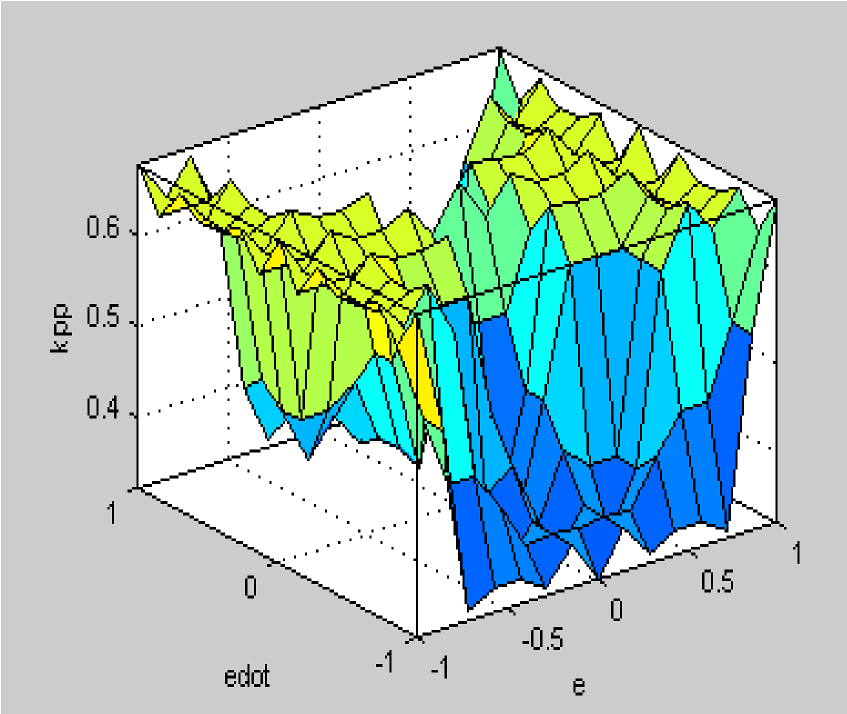


Figure 5.8 Surface Diagram of Fuzzy

V. Nigam et al., 2016 has introduced the advantage of Fuzzy logic controllers is that it can be developed in any tool and are cheaper compared to other controllers. Fuzzy is a most robust controller than PI controller further pi controllers cannot handle non-linear inputs and if inputs are not within the specified range. The drawbacks of the conventional pi controller over the fuzzy controller and its merits are combined by using fuzzy as tuning algorithm for the pi controller. In defuzzification the centroid method is used. The combined use of fuzzy and PID controller increases the quality of the control system. The applied fuzzy PID controller regulates BLDC motors speed to the specified reference accurately, and it controls the developed torque by the motor in an indirect manner is explained by F. Naseri et al., 2017. This controller can produce reference current signal based on speed error minimization between actual speed (ω_r) and reference speed (ω_r^*) . It generates both reference currents direct axis current (I_d) and quadrature axis $\left(I_q\right)$ current. It reduces the overshoot obtained from speed regulation using classical PID controller and maintains the constant speed over wide load conditions.

5.3 Simulation Results and Discussion

The proposed switched inductor quasi Z-source inverter for sensor less vector control of brushless DC motor powered from a photovoltaic source using self-tuning fuzzy PID controller is simulated in MATLAB/Simulink software is shown in figure 5.9. The switched inductor quasi z-source inverter parameters, PV specification and sensor less BLDC motor specification are given in Table 5.1. The SLQZS inverter topology can boost the voltage with the reduction in power conversion stage. It does not require a boost converter when fed from a low voltage low power source like photovoltaic when supplying motors like BLDC which draws lagging current.

Table 5.1 Simulation parameters

Name	Range
Impedance source inductors (L_1, L_2, L_3)	330mH,215mH, 215mH
Impedance source capacitors(C_1, C_2)	200F,20F
Switching frequency (f)	1kHz
Photovoltaic voltage (PV_V)	50V
DC-Link Voltage (V_{DC})	100V
Motor specification	
Stator resistance (Ω)	7.6187
Stator inductance (mH)	8.5
Number of poles (N_P)	4
Load Torque constant (k)	0.1
Rotor speed (ω_r)	2000

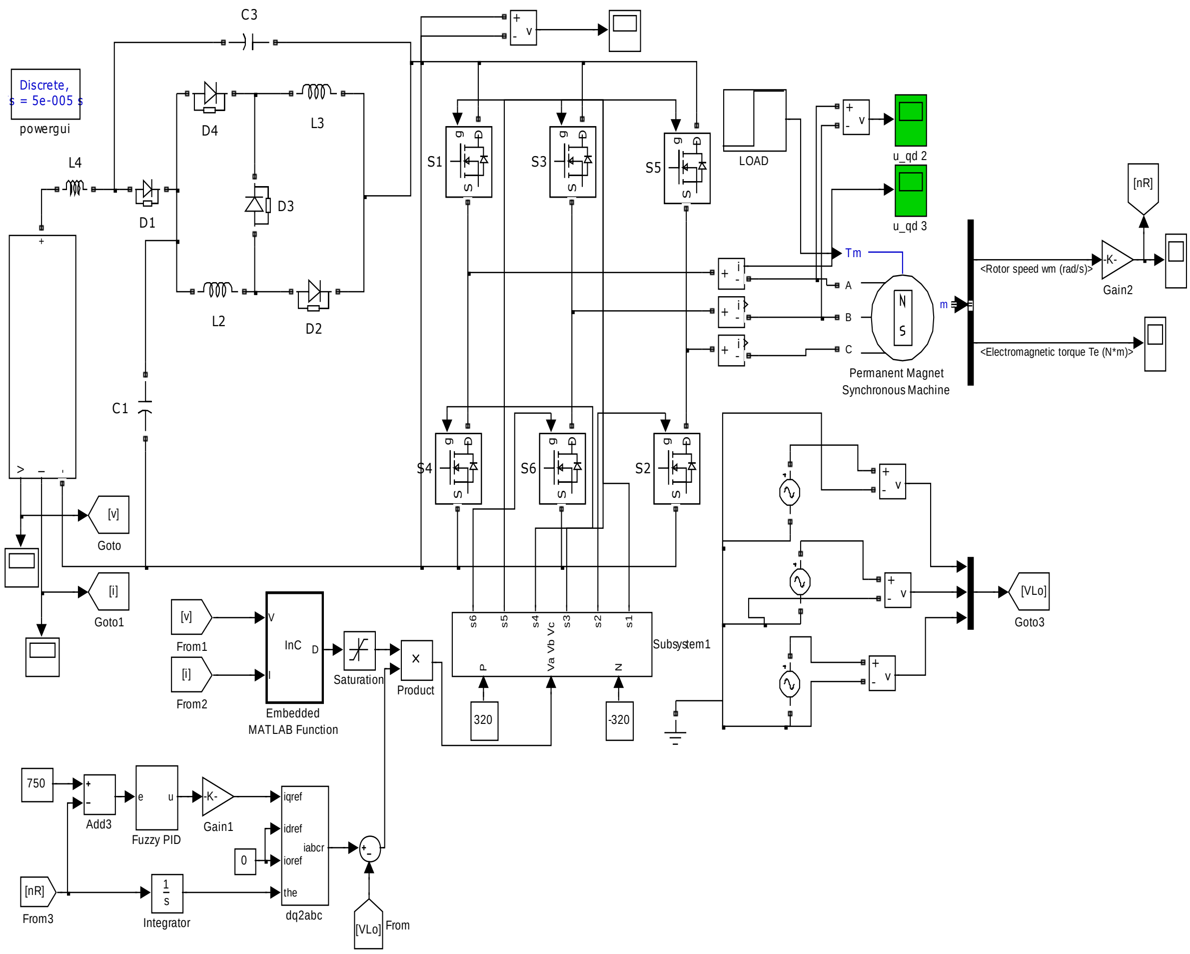


Figure 5.9 Overall Simulation Implementation of Proposed Circuit and Control System

Reference torque is generated from fuzzy PID controller using the actual speed of the motor and actual three phase current drawn by the motor. Fuzzy PID control technique is extended to utilize incremental conductance MPPT algorithm which produces reference voltage signal. For minimizing the switching loss and for generating appropriate pulses required for SLQZS inverter switches a simple maximum boost pulse width modulation technique is employed. The shoot through period of 375 μsec provides excellent voltage boosting ratio with lesser values of passive elements in switched inductor quasi Z-source inverter. From the implemented circuit topology and control scheme one can observe that torque, speed, stator current and inverter voltage of BLDC motor.

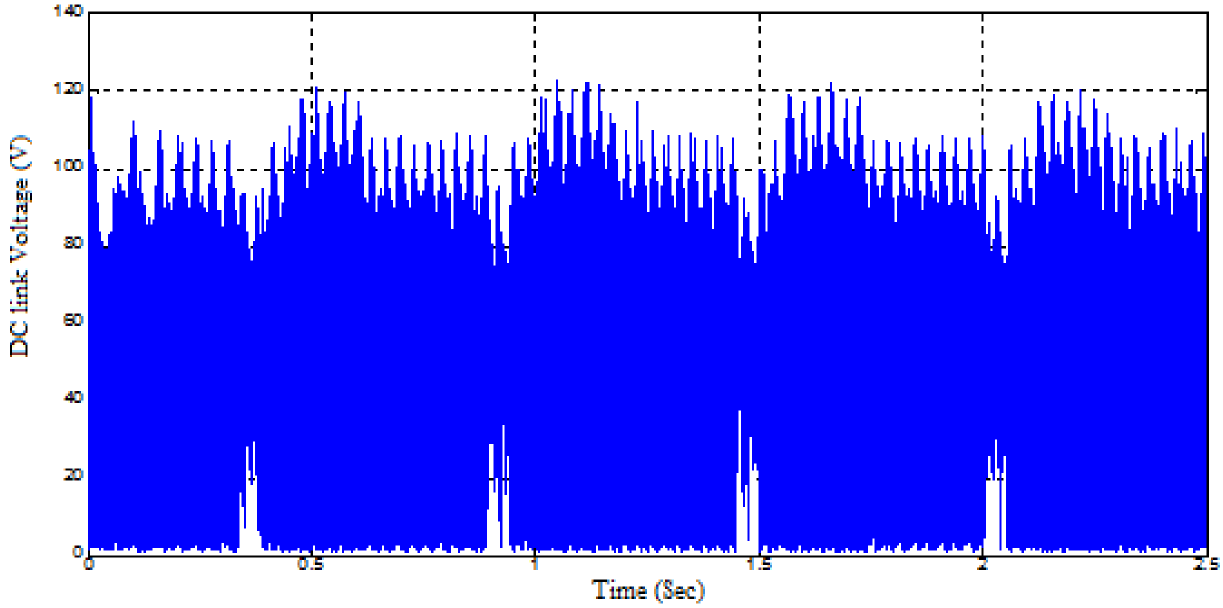


Figure 5.10 DC-link voltage response of SLQZS Inverter

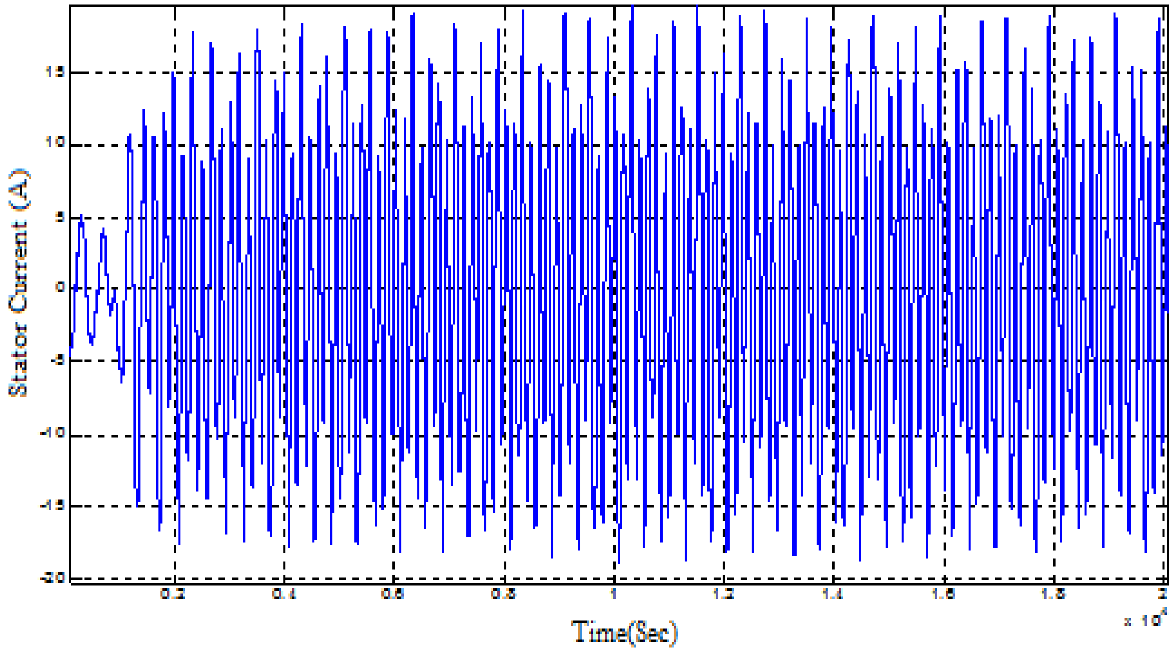


Figure 5.11 Response of Stator current

The speed response of motor is improved by reducing an overshoots occurred in control scheme and three phase voltage are also improved for BLDC motor from no load to the full load condition. The dc-link performance using SLQZS network is shown in Figure 5.10.

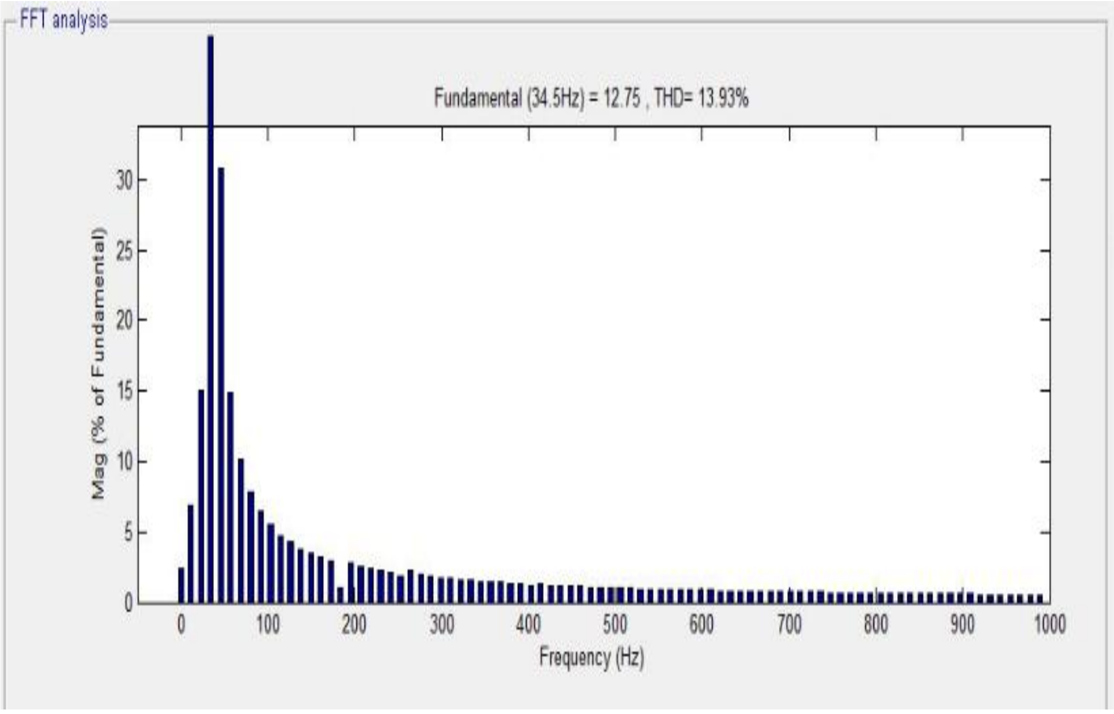


Figure 5.12 FFT Analysis on Stator Current using Simple Maximum Boost PWM

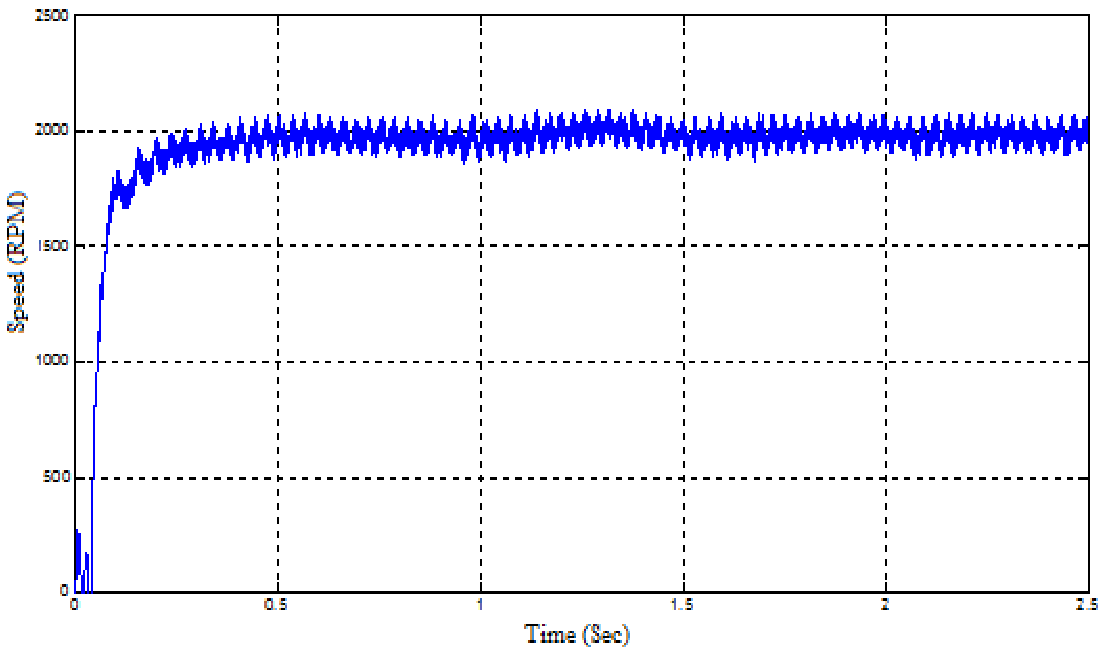


Figure 5.13 Response of BLDC motor Speed

The stator current of BLDC motor is shown in Figure 5.11. The FFT Analysis on Stator Current using Simple Maximum Boost PWM is shown in Figure 5.12. The speed and torque characteristics of BLDC motor is shown in Figure 5.13 and 5.14.

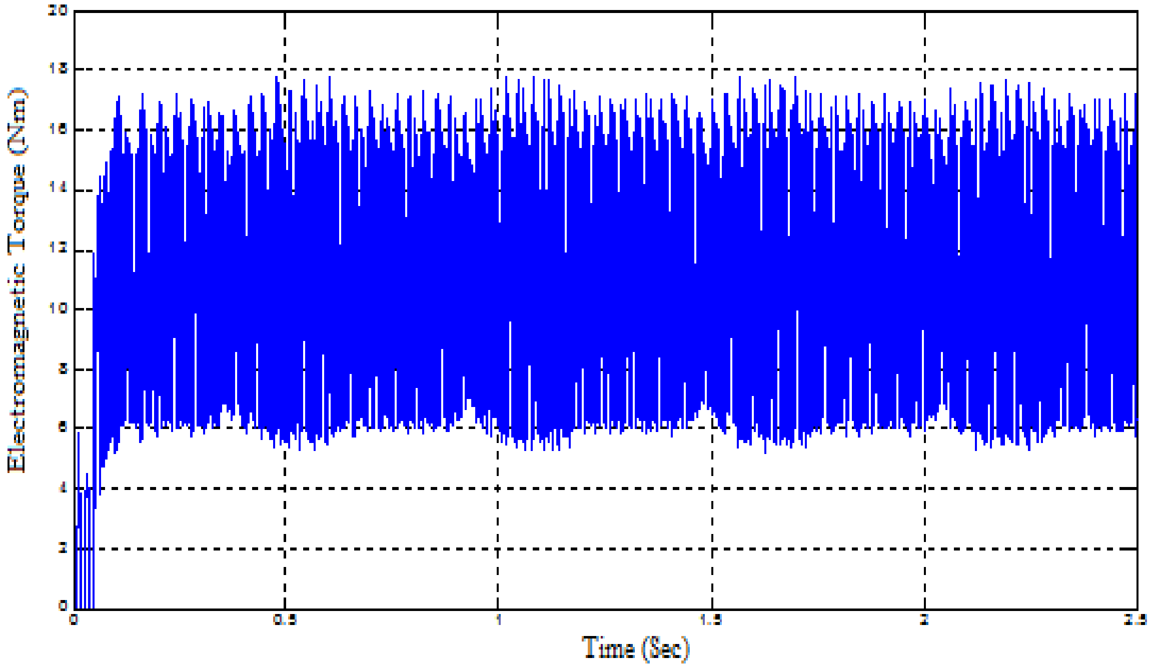


Figure 5.14 Response of BLDC motors Electromagnetic Torque

5.4 Summary

In this chapter reduction in power conversion stages for solar fed motor drives are considered for reducing the cost involved in solar power generation while maintaining or with increasing the performance of the PV generation system. The proposed scheme works as a single stage power conversion system with maximum power extraction and supplies sufficient power to BLDC motor for operating at even full load conditions. An SLQZS inverter is proposed for solar fed sensor less control of BLDC motor which has certain advantages which make it a suitable converter for motor control applications. High starting inrush current in the classical Z-source inverter is avoided in this SLQZS inverter topology. Electrical motors, in general, draws high current during starting hence this topology is suitable for drives. For extracting high power from solar SLQZS inverter along with incremental conductance MPPT technique and a simple maximum boost, PWM control is applied to BLDC motor drive. This scheme has shown excellent voltage boosting at dc-link of inverter and supplies continuous current to inverter driving BLDC motor. A simple maximum boost PWM technique with self-tuning fuzzy PID controller has accurate performance of motor speed and torque. Simulation results verify that lossless power conversion from solar to BLDC motor and show the effectiveness of proposed control scheme for BLDC motor.