Modelling and implementation of MRAC controller for nine level QZS inverter

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Abstract: *The Model Reference Adaptive Controller (MRAC) is implemented for the model of nine- level Cascaded H Bridge (CHB) asymmetrical Quasi Z Source Inverter (QZSI). The proposed MRAC controller forces the output current to be sinusoidal. The advantages of using MRAC over conventional proportional-integral control are its flexibility, adaptability, and robustness; moreover, MRAC can self-tune the controller gains to assure system stability. Since the QZSI is a non linear system, it is hard to design the controller. MRAC is simple and predict the future values of output variables using a dynamic model of the process comparing conventional PI controller. In this work, the performance of MRAC is compared with conventional PI controller based on the settling time and harmonic distortion. The simulation results clearly showed that the MRAC can lead to reduction in the settling time and harmonic distortion of the obtained output for the system. In addition to this the cascaded nine level QZSI with asymmetrical input voltage in the ratio of 1:3, whose performance is analyzed to provide a boosted output voltage and due to the asymmetrical input configuration the output voltage can be obtained with more voltage levels with lesser number of component thus lead to better output voltage quality with the reduction in filter size .The simulation results are validated with the experimental results to analyse the effectiveness of the proposed control strategy*.

Keywords*: MRAC, QZSI, Shoot through, Matlab Simulink*

1. Introduction

The first known impedance network is known by "Z-source network" having two inductors and two capacitors are connected at both ends which are in Z-shape [1].Derived from the ZSI circuit [2-4] a new topology designated and denoted as QZSI is proposed in [5-10].This new topology is widely used for renewable energy power generation system due to some of its unique properties that include voltage boost/buck and power conversion operation simultaneously in a single stage, and improve the efficiency due to the shoot-through cases with no longer damaging the inverter. It also features lower device ratings and constant current from the source comparing to the conventional ZSI. Another advantage of the QZSI is the feasibility of inquiring the multi level QZSI based on conventional topologies, known as the cascaded multi level QZSI .This topology is derived by the combination of two asymmetrical QZS networks with a nine-level cascaded multilevel inverter .The asymmetric QZSI into the CHB has several advantages such as individual dc sources for each cascaded unit, less number of diodes, less unequal current loading and all switches carry equal current in both positive and negative half cycle comparing other multi level inverter.It is demonstrated from the theoretical analysis and simulation results that the proposed QZSI can realize voltage buck or boost and DC-AC inversion in a single stage with high reliability and efficiency. The unique features that are provided by the QZSI which cannot be obtained in the conventional VSI and CSI where devices like capacitor, diode and inductor are used, respectively. In addition to this, the system properties and non linearity can be easily implemented and manipulated.

2. Operation principle of multilevel Quasi Z-source inverter

The equivalent circuit of single phase QZSI as shown in Fig.1.The QZSI with the two types of operation states at the source side: the non-shoot through states i.e. the six active states and two conventional zero states of the conventional VSI and the shoot-through state i.e. both switches of at same leg conduct simultaneously.

During the non-shoot-through state, the inverter bridge look from the source side which is equal to a current source. The equivalent circuits of the two states are as shown in Fig.2 and Fig 3. The shoot-through state is hidden in the conventional VSI, as it might cause a short circuit to the voltage source which damage the device in the circuit. With the QZSI and ZSI, the main component of LC and diode circuit combined to the inverter bridge change the operation of the circuit, allow the mode of shoot-through. This network might selectively protect the circuit from damage during the occurrence of shoot-through and by using the shoot-though state, the QZS network will boost the dc-link voltage of the system.

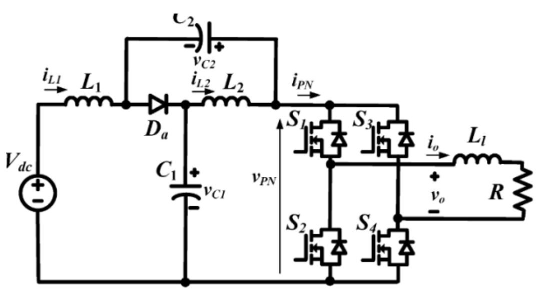

Fig. 1. Single phase QZS connected inverter

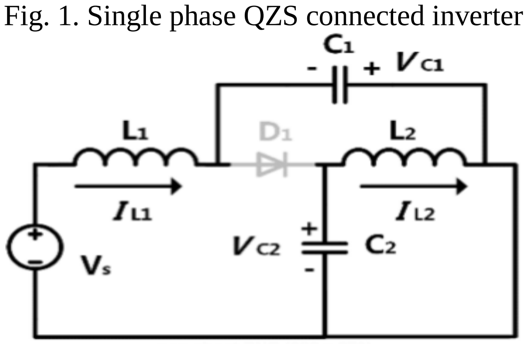

Fig. 2. Non Shoot through State

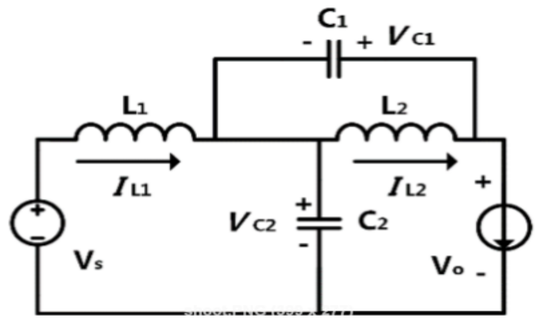

Fig. 3. Shoot through State

The main differences between the ZSI and QZSI are the QZSI draws a continuous constant current of dc component while the ZSI draws a discontinuous dc current from the source and the voltage on capacitor C2 is absolutely reduced. The constant and continuous current from the source by this QZSI make the system with reducing the component size.

PI controller does not provide trusted control during the uncertainties and disturbances occur in the system. To overcome these problems MRAC is to be used. MRAC provides robustness (insensitive to changes to plant parameters and disturbance). MRAC is simple and less computation. The objective function can be minimized according to the requirement by using MRAC. MRAC can be implemented for all the non-linear system during uncertainties. The use of PI controller reduce harmonics in the system output but it cannot able to adapt to the change in parameter in according to the change in the environmental condition. Whereas, MRAC controller has inbuilt PI controller with adaptive mechanism, thus the gain values can be auto tuned whenever there is a wide unpredictable variation in input voltage.

3. Design of QZSI

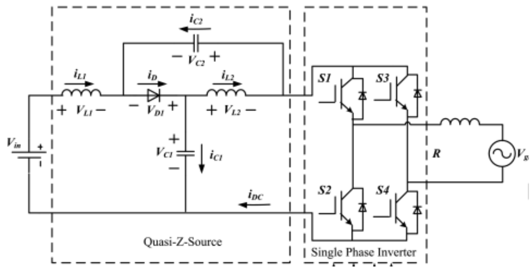

Fig. 4 QZSI circuit diagram

The QZSI circuit is shown in Fig.4. the frequency of the carrier f_c is 10 kHz, and the shoot-through frequency f_s is doubled to 20 kHz . When the network is in shoot through operation, the maximum time of the shoot through T_0, , can be computed as,

$$T_{0\,max}=2-\sqrt{3M_{min}}/f_s \quad (1)$$

The two inductors present in the system smoothens the flow of current by reducing the ripple content during the conversion of boost operating state. When the QZS network act as voltage source, T_0 get divided along with the increasing inductor current.. Choose distortion , $r_c\%$, e.g. 10% can be computed as below,

$$L_1=L_2=V_L\Delta T/\Delta I=mv_{in}/I_{L-max}r_c\%*\frac{1}{2}T_{0-max} \quad (2)$$

Both the capacitors are in series in the QZSI network during the non-shoot-through states. Both these capacitors consume the current distortion and reduce the voltage distortion in the inverter output to keep the sinusoidal output voltage. On making the same value of capacitor for the two capacitors, this capacitor value is required to keep the ripple at dc link by $r_v\%$, e.g. 1.1%, can be formulated by

$$C_1=C_2=2*I_C\Delta T/\Delta(v_{c1}+v_{c2})=2*I_L/Bv_{in}r_v\%*\frac{1}{2}T_{0-max} \quad (3)$$

4. Modelling of MRAC controller

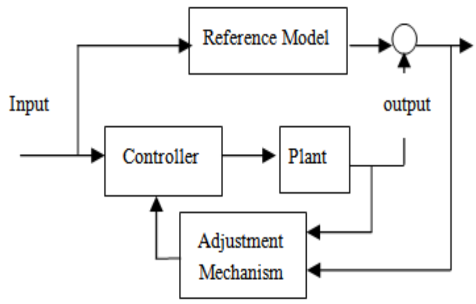

Fig. 5. Block diagram of MRAC

Adaptive Control consists of a range of techniques which give a systematic approach in automatically adjusting the controllers in the real time, in order to maintain a required level of control system performance when the plant dynamic model parameters are unknown or change with respect to time. Adaptive control is nothing but the method used by MRAC which must adapt to a controllable system with parameters that keeps on varying or initially uncertain. The reference model is used to attain an ideal response for the adaptive control system to the reference input. MRAC is described by a set of adjustable parameters.

In this work only one parameter Θ is used in describing the control law. The value of Θ is dependent primarily on the adaptation gain. The adjustment mechanism is used for altering the parameters of the controller so that the actual plant could track the reference model. . To present the MIT rule, Let us consider the closed loop system in which the controller has one adjustable parameter(known parameter). The desired response of the plant is specified by a model whose output is y_m . Let e be the error between the output y of the closed loop system and the output y_m of the model. The parameters are adjusted in such a way that the loss function or cost function denoted by $J(\Theta)$ is to be minimized.

$$J(\Theta)=-\frac{1}{2}e^{2} \quad (4)$$

$$\frac{d\theta}{dt} = -y\frac{dJ}{d\theta} \quad (5)$$

$$\frac{d\theta}{dt} = -ye\frac{de}{d\theta} \quad (6)$$

$$\frac{d\theta}{dt} = -y\,\frac{\partial e}{\partial\theta}\,sign\,e \quad (7)$$

MRAC provide important features for the system. This algorithm is simple and the objective function can be modified according the requirement.It can used for automatic control.

The reference model computation is based on undershoot, rising time and falling time,etc. The reference model parameters can be altered to enhance the performance of the controller in obtaining the desired output of the network. Though different model algorithms are available, MRAC is said to be better for the below reasons:

1. Increase the system stableness
2. It provides a automatic control for the non linear system.
3. Reference model can be modeled with
   the required enumeration.

5. Simulation result

The PI controller performance was compared with the performance of MRAC controller for QZSI. The QZSI model simulated in MATLAB/SIMULINK with the parameters specified in Table 1.

Table 1. Parameter specification of inverter

Symbol	Description	Value	
Vin	Input dc voltage	120V	
L1,L2	QZSI inductance	564μH	
C1,C2	QZSI capacitance	24.5µf	
F_{sw}	Switching frequency	1000Hz	
Lf	Filter inductance	1mH	
L	Load inductance	100µH	
R	Load resistance	100Ω	

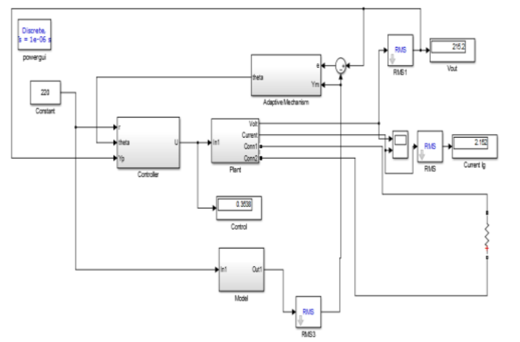

Fig.6. Simulation model of proposed system

For the load resistance of 100Ω.The following results were observed:

- The load current was about 3 A and load voltage of about 300V obtained with modulation index of *m*=0.75.
- It was observed that on increasing then gamma value of the adaptive mechanism, THD value decreases. The optimal gain value was -0.01 at which the Voltage THD was reduced to 2.29% and the current THD was reduced to 2.08%.
- MRAC was used to automatically tune the gain values by using the adaptive mechanism ,and the internal PI controller gain values of *kp* as 0.01 and *ki* as 0.02.It was observed that internal PI controller gain values were changed between 0 to 1 with respect to the input voltage variations.

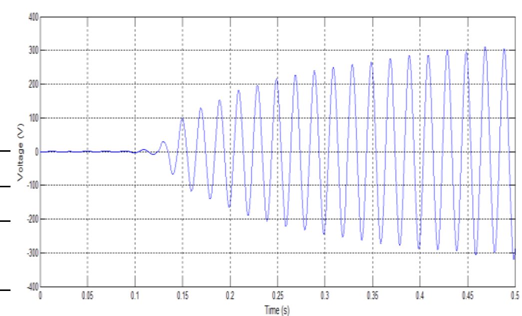

Fig.7. Output voltage waveform

From Fig.7, it was found that the settling time of the QZSI output voltage with the use of MRAC controller was reduced to 0.3 sec. from 0.5 sec. The output peak value of current for asymmetrical QZSI was 3A obtained as a result of simulation shown in Figure.8.

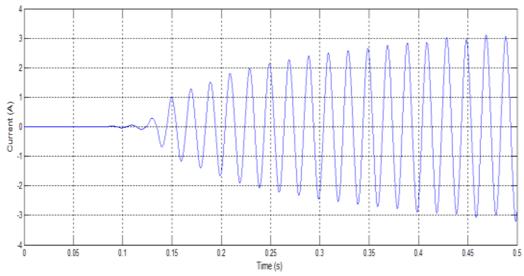

Fig.8. Output current waveform

Thus it was evident that both the current and voltage of the QZSI were in phase which ensured unity power factor operation shown in Fig.6 and Fig.7.The value of voltage THD shown in Fig.9 and Fig.10.The value of current THD illustrated in Fig.11 and Fig.12.

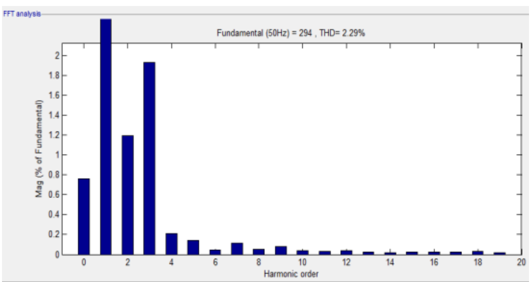

Fig.9. Voltage THD with MRAC

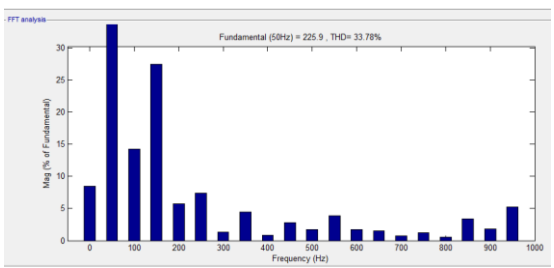

Fig.10. Voltage THD with PI controller

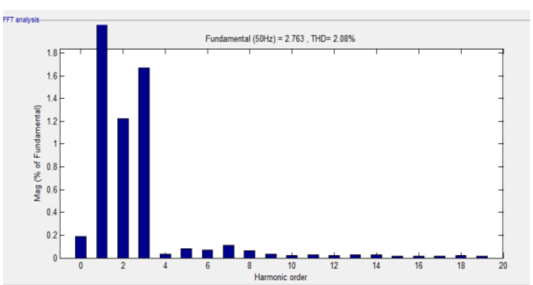

Fig.11. Current THD with MRAC

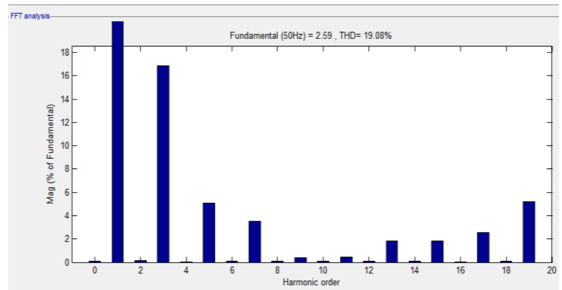

Figure.12 Current THD with PI controller

The performance of PI controller and MRAC were compared shown in Table 2. Simulations were performed to verify the performance of MRAC controller compared with PI controller. By using MRAC, the effect of THD of voltage and current waveform present in the system was minimized and the higher order of harmonics obtained reduced to a large extend thus the stability was improved. On the other hand, this MRAC performance similar to that of the conventional PI controller except that the gain values were automatically tuned in case of MRAC according to the wide input variation. In addition to this the MRAC performed better than the PI controller as it reduced the settling time to 0.3 sec.

Table 2 Comparison result between the MRAC and PI controller

	PI controller	**MRAC controller**
Settling time	0.5	0..3
no of calculation of convergence	Less	More
Voltage THD	33.78	2.29
Current THD	19.08	2.08

6. Experimental verification of QZS-CMI

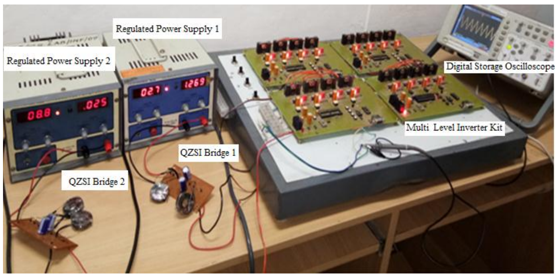

Fig.13. Experimental setup

The prototype model of the QZSI as shown in Fig.13. The power is provided from the regulated power supply through the Quasi-Z-Source impedance to the multilevel inverter kit. The stepped output voltage obtained was 12V for the given input dc voltage of 3V for the module 1 and 9V for the module 2..The DC link voltage of bridge 1 obtained was about 8V shown in Fig.13and about 20V for bridge 2 shown in Fig.14.

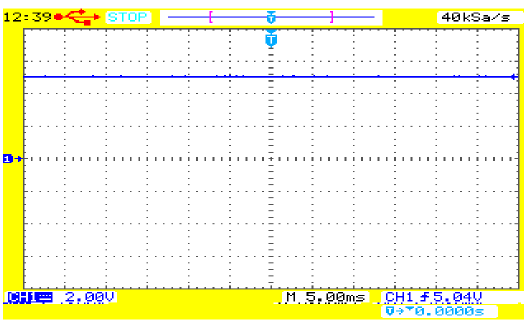

Fig.14. DC link voltage of bridge1

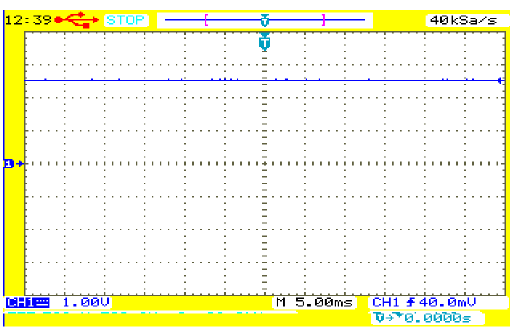

Fig.15. DC link voltage of bridge2

The nine level output voltage waveform was obtained shown in Fig.16 with the use of only 2 modules. Thus, the component requirement is reduced. .The above simulation results validated using the prototype of the QZSI.The input DC voltage in the ratio of 1:3 was provided from the regulated power supply through the QZS impedance to the multilevel inverter kit. The program for nine- level inverter was developed in PIC16F877A and then the THD observed was 21 %.MRAC controller is implemented in PIC16F877A and the THD obtained is 15%. Hence the MRAC reduce the THD by 6% compared to controller designed by using switching time. Further, the MRAC reduce the settling time of about 0.5 sec thus made the nonlinear system more stable.

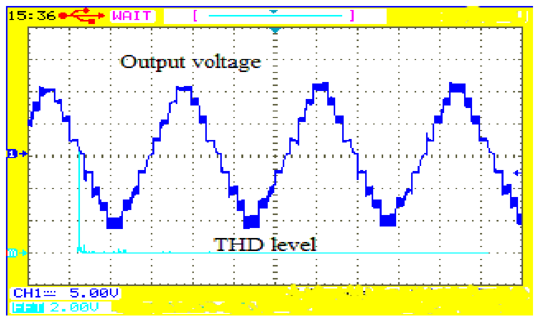

Fig.16. Output voltage waveform and THD without MRAC

The THD level obtained was 21% for the fundamental voltage of 7V shown in Figure.16.

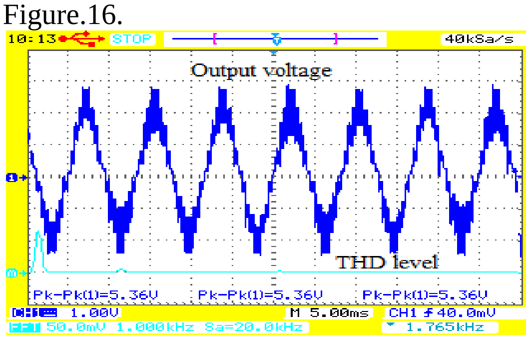

Fig.17. Output voltage waveform and THD with MRAC during shoot through state of QZSI

It was observed that the output voltage obtained during the shoot through state of the system shown in Fig.17 with distortion because during the shoot through state the high frequency shoot through pulses added with switching pulses to obtain the desired boosted peak voltage of about 26.5V for the given input voltage of 24V.

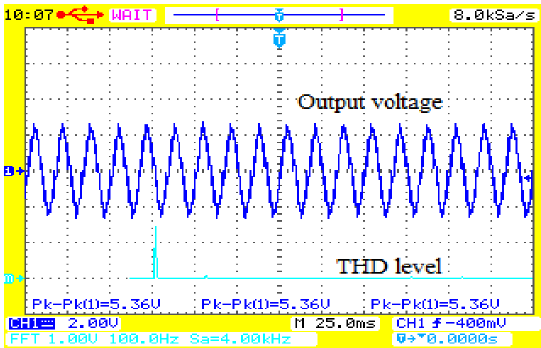

Figure.18 Output voltage waveform with using filter

On using 440V capacitive filter except 3rd harmonics all other harmonics were eliminated and the output voltage waveform was almost sine wave shown in Fig.18.

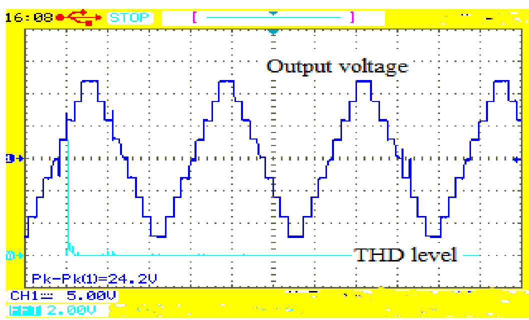

Figure.19 Output voltage waveform and THD with MRAC during non-shoot through state of QZSI

The output voltage waveform and THD with MRAC during non-shoot through state of QZSI. shown in Fig.19. The THD level was reduced to 15% for the fundamental voltage of 7V.

7. Conclusion

The simulation results were performed to verify the effectiveness of this controller. The output voltage of 9-level CHB QZSI with unequal dc input voltage in the ratio of 1:3 resulted in more voltage levels in output voltage with less number of component and with increased output voltage quality. Thus the performance of MRAC and conventional PI controller compared and proved that MRAC provide improved effectiveness in nonlinear system control.

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