FUZZY LOGIC CONTROLLER FOR QUASI-Z-SOURCE CASCADE MULTILEVEL INVERTER USED IN GRID-TIE PHOTOVOLTAIC POWERSYSTEM

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Abstract: *This paper presents a new control method for Quasi-Z-Source cascade multilevel inverter based on Grid connected Single phase photovoltaic power system. The control system enables the voltage boost of a PV string to a higher level and produces a balanced DC-link voltage in H-bridge inverters. A novel Space vector modulation for QZS-CMI is presented to control the shoot through states independently and synthesize a staircase output voltage waveform. The system achieves independent Maximum power point tracking for separate PV arrays, independent DC-link voltage and the grid injected power control at unity power factor. A Fuzzy logic control scheme is developed to PV array voltage control loop, it adjusts the sum of pv arrays to track its reference value with reduced transients.. The system demonstrates stable output voltage with reduced total harmonic distortion. The proposed system components are modeled and simulated through software tool using MATLAB/SIMULINK.*

Index Terms: **Quasi-Z-source inverter (QZS), Cascade Multilevel Inverter (CMI), Space Vector modulation (SVM), Fuzzy Logic Control (FLC), Photovoltaic (PV) power system.**

I. INTRODUCTION

Presently the World energy demand is increasing due to population growth and Modern industrial society persuading a lot of investments in alternative energy sources such as Solar, Wind, bio-mass, fuel cells etc; Among the renewable energy sources, Photovoltaic energy consistently shows its great potential to serve as clean and inexhaustible energy source. Multilevel inverters are applying to photovoltaic power systems. Three common multilevel inverter topologies are Capacitor clamped, Diode clamped and Cascade Multilevel inverter. Among these CMI is more widely used due to CMI structure with separate PV arrays as input which yields high voltage and high power grid tie without a transformer and achieving distributed MPPT. Traditionally Voltage source inverters or Current source inverters had been using for the applications of Renewable energy sources. But these have many disadvantages like limited output, no immunity towards short circuits or open circuits and need dead time and overlap in gate pulses to avoid short circuits and open circuits. Also a DC-DC booster is used with PV which increases the size and cost of the system. So, Proposed a new topology of inverter called Z-source inverter. Z-source inverter has the capability to give output in any range i.e.; buck or boost because an additional Shoot-through state is presented. But ZSI has a discontinuous input current during the shoot through state due to the blocking diode. So, QZS are newly added with the feature of taking continuous current from input, with lower switching stress and smaller component ratings in single stage power conversion

In order to properly operate the ZS/QZS-CMI, the Power injection, independent control of dc-link voltages, and the pulse width modulation (PWM) are necessary. The work in focused on the parameter design of the ZS/ QZS networks and the analysis of efficiency. The work in [4] presented the whole control algorithm, i.e., the MPPT control of separate quasi-Z-source H-bridge inverter (QZS-HBI) module, and the grid-injected power control, whereas the phase-shifted sine wave PWM (PS- PWM) is extra dc– the only existing PWM technique for the single-phase ZS/QZS-CMI. The PS-SPWM consumes more resources to achieve the shoot-through states because two more references are compared with the carrier waveform. Additionally, the ZS/QZS-CMI based grid-tie PV system has never been modelled in detail to design the Controllers.

The main contributions of this paper include: 1) a novel multilevel space vector modulation (SVM) technique for the single phase QZS-CMI is proposed, which is implemented without additional resources; 2) a grid connected control for the QZS-CMI based PV system is proposed, where the all PV panel voltage references from their independent MPPTs are used to control the grid-tie current; the dual-loop dc-link peak voltage control is employed in every QZS-HBI module to balance the dc-link voltages; 3) the design process of regulators is completely presented to achieve fast response and good stability. Simulation results verify that the proposed system along with control scheme.

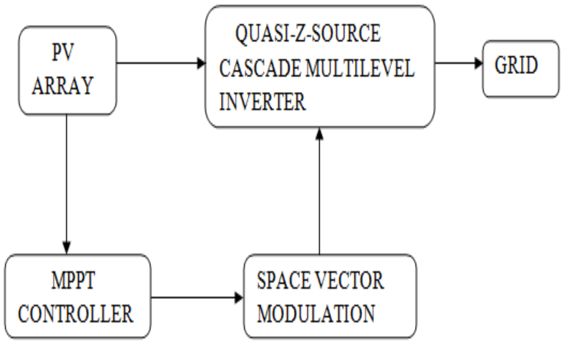

Figure 1 Block diagram

Solar electricity systems capture the sun's energy using PV cells. The output power of the PV cell mainly depends on the level of solar irradiation and temperature. To obtain the maximum efficiency of the PV panel, the system must operate near maximum power point. To obtain the maximum power from the PV array MPPT is inserted in circuit. It varies the electrical operating point of the PV panels. So, they can deliver the maximum available power. In the MPPT technique, Perturb and Observe algorithm is used due to ease of implementation. This technique is based on voltage reference adjustment to achieve maximum power. Space vector modulation is used to control QZS inverter. The main objective of space vector modulation is to approximate the desired output voltage by setting proper switching patterns of the power transistors. Number of switching transition in each cycle is reduced, which indicates less switching power loss.

2. QZS-CMI FOR GRID TIE PV SYSTEM

The configuration of the PV based single phase grid connected QZS-CMI system considered in this paper is illustrated in figure 2. Seven level topology of the QZS-CMI consisting of series single phase inverter cells, impedance network and PV arrays as input sources. It consists of three strings of PV arrays connected to their own QZS network. Each H-bridge inverter consists of four IGBT with anti parallel diode and can develop maximum three possible output voltage levels such as $+V_{in}$, $0, -V_{in}$. In general if n is the number of DC sources, then the output voltage ha 2n+1 levels. The inverter is used in a grid connected PV system, the utility grid is used instead of load.

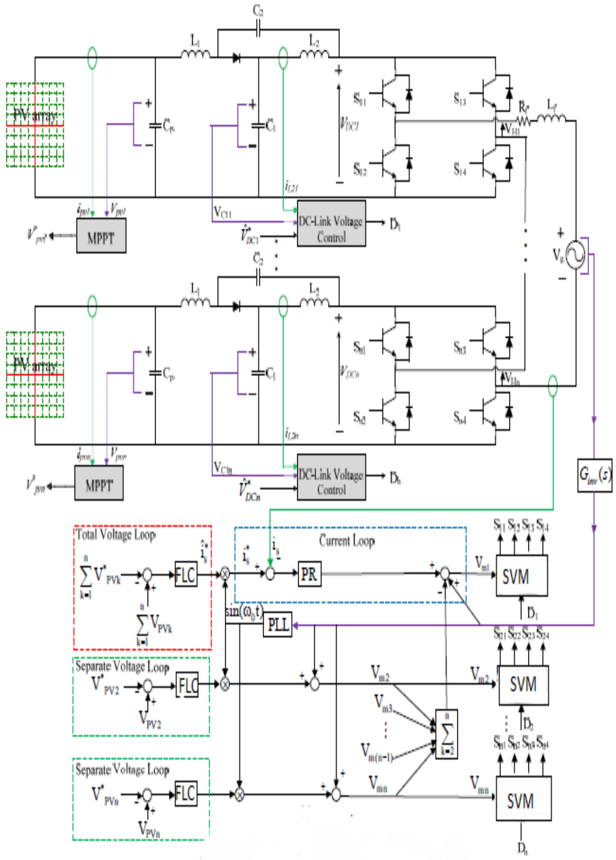

Figure 2 QZS-CMI based grid tie PV power system

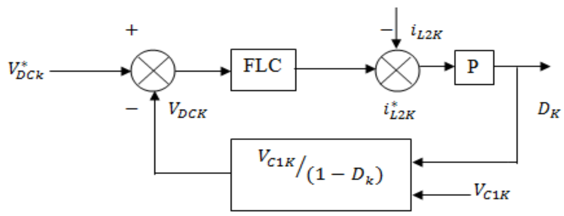

Figure 3 DC-link voltage control

The design of inverter control is a critical issue for all the PV systems. For easier implementation, Proportional integral (PI) controllers are used to control the PV inverter. There have been considerable research works done in the area of single phase grid connected PV inverter using PI control method to reduce harmonic distortion and maintain the frequency stability [8]. However, the well known disadvantages are larger output filter, discretization of grid frequency. The simplest method for inverter to balance dc link voltage is fuzzy logic controller.

2.1 QZS Operation

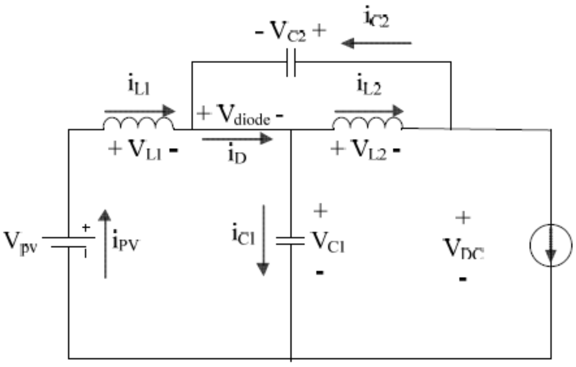

Figure 4 Non Shoot-through state

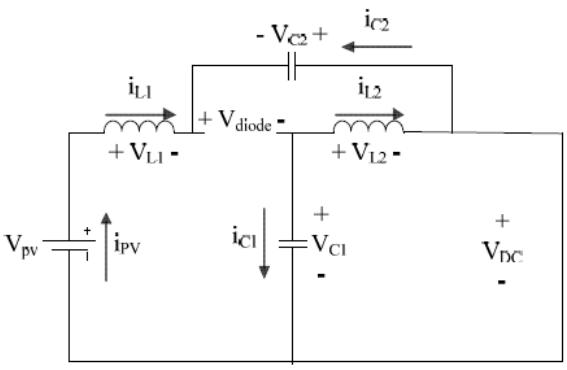

Figure 5 Shoot-through state

QZS inverter has nine switching states, including six active states, shoot through zero state and two non shoot through zero states [14]. The shoot through state can be made by the switches of the phase in the inverter bridge are switched on simultaneously for a very short duration. Figure 4 and 5 shows the QZS inverter equivalent circuits operating in two modes. If the shoot through period id $T_{sh}$and non shoot through period is $T_{nsh}$and switching period is T_s, then the shoot through duty ratio is

$$D = \frac{T_{sh}}{T_s}, \quad T_s = T_{sh} + T_{nsh} \tag{1}$$

In steady state condition,

$$V_{DCK} = \frac{1}{1-2D_K} V_{PVK} = B_K V_{PVK}, \tag{2}$$

$$V_{HK} = S_K V_{DCK} \tag{3}$$

Where, V_{DCK} is the Kth module of DC-link peak voltage; D_K is the Kth module of shoot through duty ratio, B_K is the boost factorof Kth module.

In a shoot through mode, there is no power transmission because the dc link voltage of Kth module is zero.

$$V_{DCK} = 0, \; V_{HK} = 0 \tag{4}$$

For QZS-CMI,

$$V_H = \sum_{K=1}^{n} S_K V_{DCK} = \sum_{K=1}^{n} V_{HK} \tag{5}$$

3. SYSTEM MODELLING AND CONTROL

The proposed control scheme for QZS-CMLI based PV power generation system is shown in figure 2. Each PV module has its own Maximum power point tracking. The grid power control is used to transmit the three modules power to the grid and keep the whole system operating at unity power factor. Grid tie control with the system model for the QZS-CMI based PV power system [16] is discussed in this section.

3.1 Grid injected current control

The current of the inductor L1 in the Kth QZS-CMI module is:

$$i_{L1K} = i_{PVK} - C_P \frac{dV_{PVK}}{dt} \tag{6}$$

Where i_{PVK} is the kth pv arrays current and C_P is the capacitance of the PV array. QZS-CML inverters output voltage is given as

$$V_H = V_g + L_f \frac{di_S}{dt} + r_f i_S \tag{7}$$

V_g is the grid voltage, i_S is the grid current , $r_f$is the resistance , $L_f$is the filter inductance.

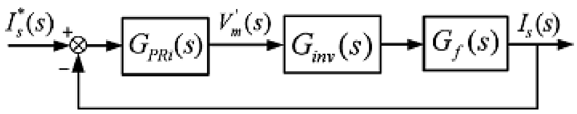

Figure 6 Grid current closed loop block diagram

Transfer function of the grid injected current can be obtained as

$$G_f(s) = \frac{I_S(s)}{V_H(s) - V_g(s)} = \frac{1}{L_f s + r_f} \tag{8}$$

A Proportional Resonant controller is employed to enforce the actual grid injected current to track the desired reference value.

$$G_{PRi}(s) = K_{iP} + \frac{K_{iR}\omega_0}{s^2+\omega_0^2} \quad (9)$$

Kth module for a grid voltage feed forward control loop has the modulation signal V_{mK},

$$V_{mK} = V'_{mK} + V_g(s)G_{vfK}(s) \quad (10)$$

$$G_{vfK}(s) = \frac{1}{nG_{invK}(s)},\ G_{invK}(s) = \frac{V_{HK}(s)}{V_{mK}(s)} = V_{DCK} \quad (11)$$

3.2 PV voltage loop

PV array voltage loop [16] can be obtained by

$$V_{PVK}(s) = \frac{1}{C_P(s)}[I_{PVK}(s) - I_{L1K}(s)] \quad (12)$$

Output power and input power of each QZS-HBI is equal in the non shoot-through state. Power equation of kth QZS-HBI module is

$$\frac{i_s V_{HK}}{2} = V_{DCK}i_{DCK} = V_{PVK}i_{L1K\_nsh} \quad (13)$$

Where $i_{L1K_nsh}$is the average inductor current in non shoot-through mode and it can be solved as

$$i_{L1K\_nsh} = \frac{i_s V_{HK}}{2V_{DCK}(1-2D_K)} \quad (14)$$

In shoot-through mode the average inductor current is

$$I_{L1K} = D_K i_{L1K_{nsh}} + (1-D_K)i_{L1K_{nsh}} \quad (15)$$

3.3 Independent DC-link voltage control

The independent DC-link voltage control scheme is shown in Figure 7.

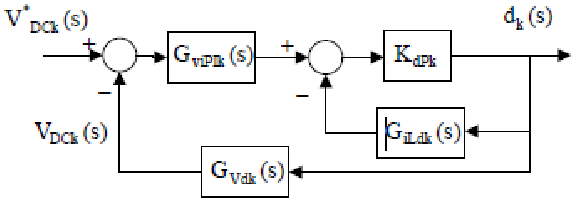

Figure 7 Dc-link peak voltage control block diagram

This control loop, adjust DC-link peak voltage using the capacitor-C_1voltage and the inductor-$L2$current for each QZS-CMI module. Reference [16] presents the *Kth* QZS-CMI module's transfer function from the shoot-through duty ratio to the DC-link peak voltage, $GVdk(s)$ and from the shoot-through duty ratio to the inductor-$L2$current, $GiLdk(s)$ as follows:

$$G_{idcK}(s) = \frac{d_k(s)}{I^*_{L2K}(s)} = \frac{K_{dPK}}{1+K_{dPK}G_{iLdK}} \quad (16)$$

4. FUZZY LOGIC CONTROLLER

In this paper, a Fuzzy logic based intelligent control technique associated with an independent DC-link voltage control is developed to reduce the transients and the system demonstrates stable output voltage with reduced harmonic distortion. The basic structure of Fuzzy Logic control used in the control strategy is shown in fig 8.

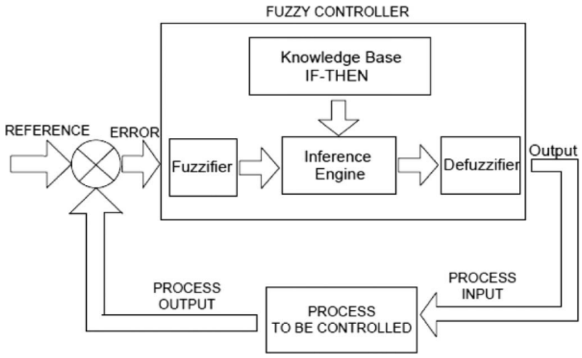

Figure 8 Basic architecture of FLC

The main elements in the control system are the Fuzzifier unit at the input terminal, Defuzzifier at the output terminal, Knowledge base and the inference engine. FLC system requires input and output variables. Generally, an error and its rate of change are chosen for input variables. The change of current and voltage are selected to be the output variables. An error in discrete time is the difference between the $r(k)$and the process output variable$y(k)$. The current sample of error $e(k)$ and the change of error $\Delta e(k)$ are defined as

$$e(k) = r(k) - y(k) \quad (17)$$

$$\Delta e(k) = e(k) - e(k-1) \quad (18)$$

These variables are normalized to fit into the interval value between -1 and +1and require seven membership functions. When any input is not in this range, it is considered as too big which generates large error signals.

For simplification, the triangular and trapezoidal membership functions are utilized. By using these membership functions, the controller manages to reduce the error signal in a faster manner that increases the transient response. The membership functions are labeled as NB for "Negative Big", NS for "Negative Small", NM for "Negative medium", Z for "Zero", PB for "positive Big" and PS for "Positive Small". The input variables are fuzzified through membership functions. Fuzzy output is generated by the essence of the inference process and with the aid of knowledge based rules. The main part of the FLC is the Knowledge base elements; it consists of a list of fuzzy rules [9]. The inference process is to generate a fuzzy output set based on if then rules.

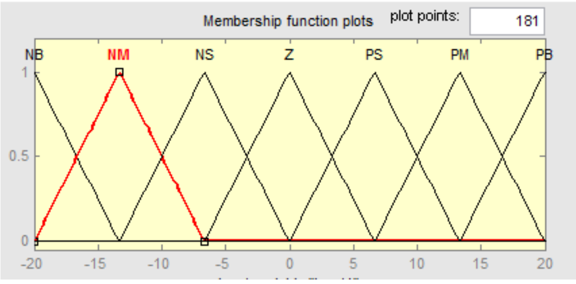

Figure 9 Membership function for error

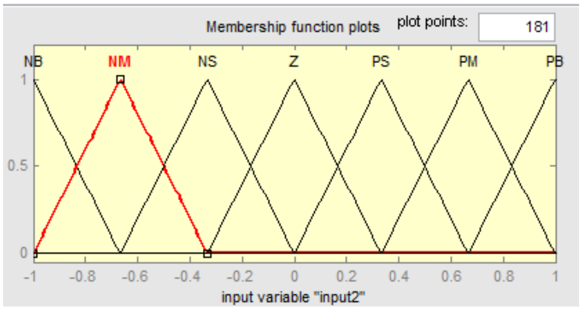

Figure 10 Membership function for change in error

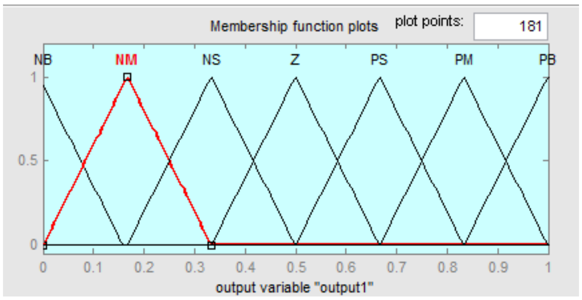

Figure 11 Membership function for Output

The crisp output of the controller is the shoot through duty ratio of the QZS-H bridge and its membership function is shown in figure 9. There are 49 rules applied and are summarized in Table 1 and shown in figure 10.

E / ΔE	NB	NM	NS	Z	PS	PM	PB
NB	PB	PB	PB	PB	PM	PS	Z
NM	PB	PB	PB	PM	PS	Z	NS
NS	PB	PB	PM	PS	Z	NS	NM
Z	PB	PM	PS	Z	NS	NM	NB
PS	PM	PS	Z	NS	NM	NB	NB
PM	PS	Z	NS	NM	NB	NB	NB
PB	Z	NS	NM	NB	NB	NB	NB

Table 1 Rules for fuzzy logic controller

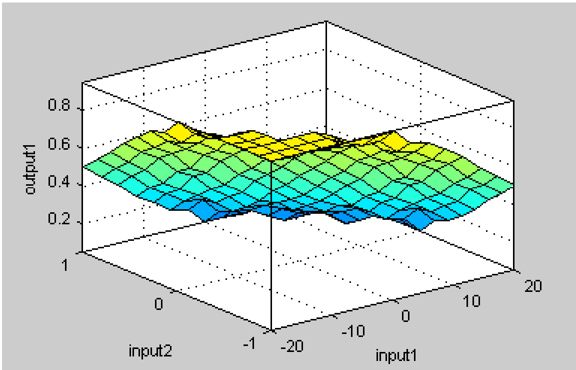

Figure 12 Input variables and output variable mapping.

5. SPACE VECTOR MODULATION FOR QZS-CMI

The space vector modulation for n-layer QZS-CML inverter is shown in figure 2. The Space Vector Modulation Scheme can be modified by inserting shoot-through states in place of non shoot-through zero states. This modified SVM can be used to control the quasi ZSI.[8] The boost can be controlled by adjusting the time of shoot- through conduction. In order to buck/boost dc-link peak voltage of QZS-H bridge inverter to balance the voltage waveform separate pv panels, shoot-through states need to be introduced into the upper and lower switches of one bridge. The voltage vectors are composed of n bridge vectors [3]. SVM is a method where the switching states are viewed in voltage reference frame. Insert the shoot-through into the cell, the switching times for each cell is represented as T. consequently new group of switching times are generated Ta, Tb, Tc. During each control cycle, the time of shoot-through zero states Tsh is equally divided into four parts and inserted into the bridges of the same cell. S_{X1} And S_{Y1} are the switching control signals for the upper switches andS_{X2}, S_{Y2} are those of lower switches respectively. The bridge vector of same cell has a 180 degree phase difference. Additionally, the voltage vectors between two adjacent layers have a phase difference of $2\pi/nk$ in which k is the number of reference voltages in each cycle.

6. SIMULATION RESULTS

A Seven-level Quasi Z source cascade H-bridge inverter for grid connected PV power system is simulated using MATLAB Simulink model and the results are shown below.

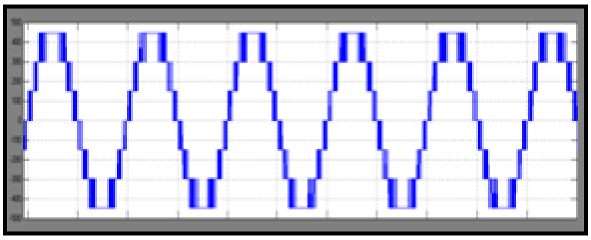

Figure 13 QZS-CMI output voltage

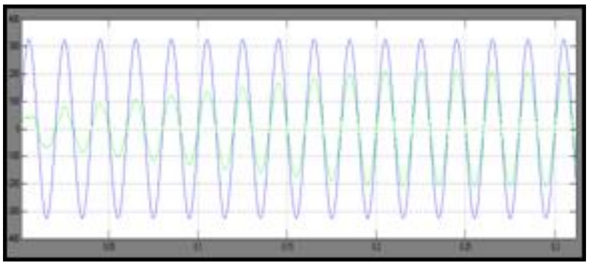

Figure 14 Grid voltage and current

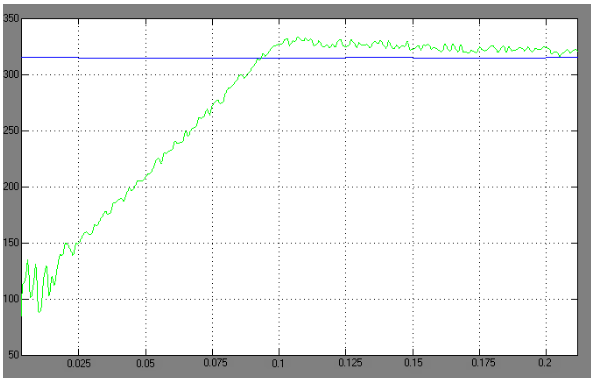

Figure 15 Simulation result of PV array voltage

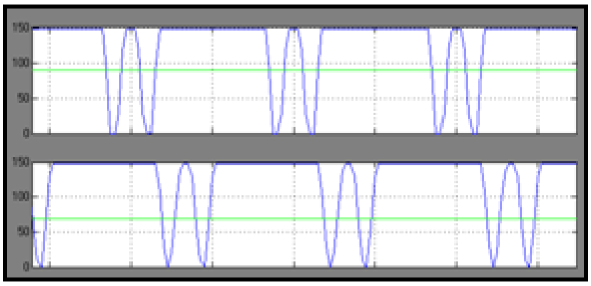

Figure 16 DC-link voltages with their shoot-through modes at different PV arrays

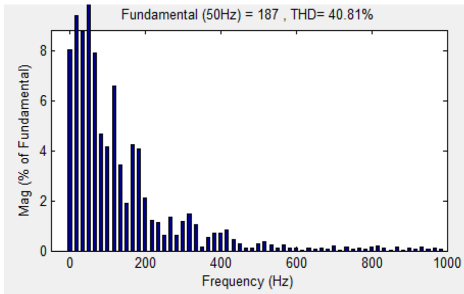

Figure 16: THD of 7-level output voltage

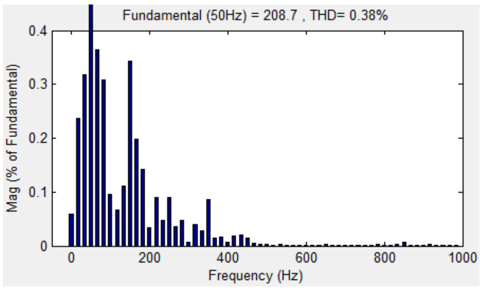

Figure 17: THD of Grid current

A grid-connected system is in invariantly rich transient conditions. PV-based grid-connected system accommodates both the power versatility of solar radiations and the frequency and system load variations. While using PI controller, pv array voltage exhibit much transients and overshoots effect compare to FLC controller. Hence, the FLC is developed to compensate the overall transient effects and the system comes down to steady-state condition quickly, as shown in Fig.15. The short transient condition happens due to the tedious FLC tuning and curse of dimensionality to set up the rules. A quasi z source based cascaded H-bridge multilevel inverter for PV system to achieve minimized shoot through effect, and also reduced harmonics distortions.

7. CONCLUSION

This paper proposed a new control method for QZS-Cascade Seven-level inverter based single phase grid connected PV system. The proposed system enables grid injected current was fulfilled at unity power factor, independent dc-link voltage control enforced all QZS-HBI modules have the balanced voltage. A SVM technique integrating with the shoot-through states, to synthesize the stair case voltage waveform of the single phase QZS-CMI. A fuzzy logic controller is introduced for Quasi-Z-source cascade multilevel inverter Grid connected PV system. Fuzzy controlled is used for PV output voltage to achieve closed loop control which can balance the DC-link voltage and minimize the grid voltages impact on grid current. As compared to the conventional method, results indicated that the proposed FLC scheme reduces the total harmonic distortion and can provide faster response and fewer oscillations around the steady state.

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