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Fuzzy Logic Control of Quasi Z-Source Multilevel Inverter for Photovoltaic Applications

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ABSTRACT

A single phase H-bridge quasi-Z-source multilevel inverter for the photovoltaic (PV) system with an integrated fuzzy logic controller is presented in this paper. Quasi Z-source inverters are the newly added Z-source inverter topologies with the features of taking continuous current from input, lower switch stress and smaller component ratings in addition to single stage buck/boost operation, DC to AC inversion capabilities. The cascaded multilevel structure with separate PV arrays as inputs is selected for high voltage and high power applications. The carrier based pulse width modulation techniques are analyzed for this topology. In this work, a five level quasi-Z-source inverter is designed, modeled and integrated with PV system. A fuzzy logic control scheme is developed to track the maximum power point of the PV array under variable solar irradiance and temperature conditions.

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INTRODUCTION

There are many renewable energy sources such as solar, wind, biomass, fuel cells, etc. Electrical energy generation from these renewable energy sources increases the attraction in power sector because conventional fossil fuel energy sources are being drained rapidly. Among these, power generation from solar energy by photovoltaic technology and its integration with the grid are gaining higher degree of exposure in that area. Generally, the power converters are used as the power conditioning equipments in PV power generation. These converters usually consist of a DC-DC boost converter stage and DC-AC inverter stage. These two stages of conversion process reduce the efficiency and quality of power. These drawbacks are eliminated after the development of Z-source inverter (ZSI) topologies (Peng, 2003).

Quasi-Z-source inverters (QZSI) have been derived from the basic Z-source inverter by inheriting all its advantages. The QZSI possesses several more advantages over the ZSI such as continuous current from the input DC source, reduced component ratings, and enhanced reliability (Yuan Li Joel Anderson *et al*., 2009). In high power PV applications, new inverter topologies or modification in existing one were proposed by many researchers to improve the quality of power at the inverter terminals and to increase the efficiency. Usually, in these methods, the PV array and a DC-DC converter controlled by a MPPT algorithm is followed by a PWM inverter for DC-AC conversion is used. This paper proposes the use of a multilevel structure of QZSI, which eliminates the two stage power conversion process. It can increase the efficiency of the system. The power quality parameters will also be improved because of the elimination of dead time in the inverter operation.

In this paper, fuzzy logic based control is proposed to be implemented for tracking the maximum power point of the PV array under varying solar irradiance and temperature. Fuzzy logic based MPPT techniques are developed for DC-DC converter based PV systems. Fuzzy is comparatively easy to design since it does not require any information about the exact model.

QZSI Cascaded Multilevel Inverter:

Figure 1 shows considered five level topology of the QZSI cascaded multilevel inverter consisting of series single-phase H-bridge inverter cells, impedance networks and PV array as input sources. Each H- bridge inverter cell basically consists of four IGBT with antiparallel diode and a driver circuit and can develop maximum three possible output voltage levels such as $+V_{in}$, 0 and $-V_{in}$. In general, if n is the

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number of DC sources, then the output voltage has 2n+1 levels.

Like the two level QSZI, this cascaded topology can utilize the additional switching state known as shoot-through state for voltage boost. The impedance network inductors are getting charged by the capacitors during shoot-through states. In the non-shoot-through states these inductors along with input DC source discharge through the load. So in a cycle, the output voltage is boosted. But the DC link voltage and hence the output voltage of the inverter becomes zero during the shoot-through state. Shoot-through states are integrated in the switching pattern only if a voltage boost is required (Thomas Lannert *et al*., 2013). In this shoot-through integration some or all of the zero states are replaced by shoot-through states depending on the PWM technique used (Shajith Ali and Kamaraj, 2013).

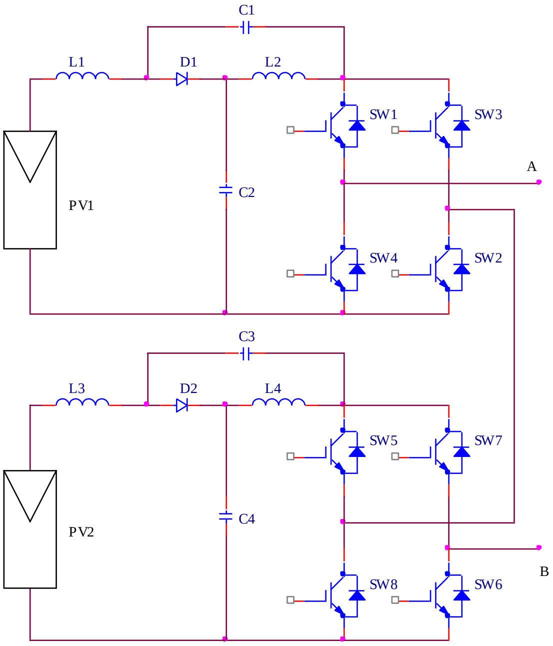

Fig. 1: Quasi-Z-source cascaded 5-level multilevel inverter.

For a H-bridge QZSI, if the shoot-through time duration is T_o and the non-shoot-through time is T_1; then the switching cycle T can be written as $T = T_o + T_1$. The voltage gain of the QZSI is given as,

$$\frac{V_{ac}}{V_s/2} = MB \qquad (1)$$

where M is the modulation index and B is the boost factor. B is calculated using equation (2).

$$B = \frac{1}{1 - 2\frac{To}{T}} \qquad (2)$$

$T_o / T = D$ is defines as the shoot through duty ratio.

The details of the switching states and corresponding output voltage level of multilevel QZSI are shown in Table I.

Review of PWM Techniques:

There are many carrier based PWM techniques under the categories of multi-carrier bipolar/ unipolar PWM and trapezoidal PWM developed by the researchers for traditional multilevel inverters. These techniques are derived from the conventional sinusoidal PWM used to mitigate the harmonic distortion in inverters (Poh Chiang Loh *et al*., 2005, Tahri and Draou, 2005, Malathy and Shajith Ali, 2012, Yushan Liu *et al*., 2013). In multilevel QZSI, the shoot through states can be inserted within the zero states to acquire voltage boost. Two straight DC lines equal to or greater than the peak value of the sinusoidal reference voltage are used to control shoot-through duty cycle. The high frequency triangular carrier is compared with these DC lines and produces the shoot-through pulses. This shoot-through state integration in the sinusoidal PWM technique will concede new PWM control techniques for the multilevel QZSI (Shajith Ali and Kamaraj, 2013). Some of the popular bipolar multi-carrier PWM schemes are:

Phase disposition (PD) PWM:

This PWM technique requires four carrier waveforms are arranged as in Figure 2 in phase disposition. Reference sinusoidal waveform has an amplitude of A_m and a frequency of f_m is is centered in the middle of the carrier set. This signal is compared with each of the carrier signals and produces pulses to the switches of QZSI.

Table 1: Switching States of Multilevel QZSI.

Output Voltage	State	ON Switches
$2V_{in}$	Active	SW1, SW2,SW5,SW6
V_{in}	Active	SW1,SW3,SW5,SW6
V_{in}	Shoot-through	SW1,SW2,SW3,SW4,SW5,SW6
V_{in}	Active	SW1,SW2,SW5,SW7
V_{in}	Shoot-through	SW1,SW2,SW5,SW6,SW7,SW8
0	Zero	SW1,SW3,SW5,SW7
0	Shoot-through	SW1,SW2,SW3,SW4,SW5,SW7
0	Shoot-through	SW1,SW3,SW5,SW6,SW7,SW8
$- V_{in}$	Active	SW1,SW3,SW7,SW8
$- V_{in}$	Shoot-through	SW1,SW2,SW3,SW4,SW7,SW8
$- V_{in}$	Active	SW3,SW4,SW5,SW7
$- V_{in}$	Shoot-through	SW3,SW4,SW5,SW6,SW7,SW8
$-2 V_{in}$	Active	SW3,SW4,SW7,SW8

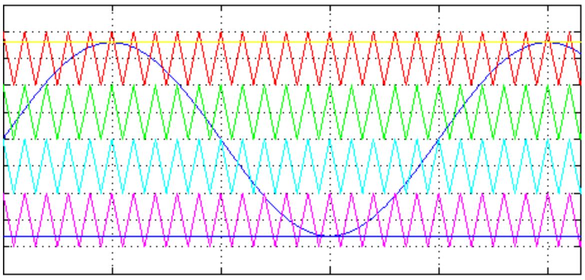

Fig. 2: Carrier Arrangement of PD PWM.

Phase opposition disposition (POD) PWM:

In this technique also four carrier waveforms with same amplitude and frequency are used for an 5-level inverter. The carriers above the zero line are arranged in phase and the carriers below the zero line are also arranged in phase but are phase shifted by 180° with respect to that above the reference. Figure 3 shows the arrangement of POD PWM.

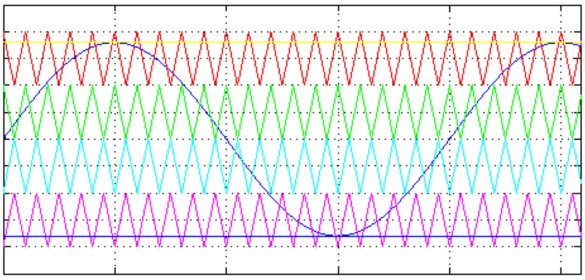

Fig. 3: Carrier Arrangement of POD PWM.

Alternative phase opposition disposition (APOD) PWM:

Here the four carrier signals are arranged such that adjacent signals are phase shifted by 180°. Figure 4 demonstrates the APOD PWM arrangements.

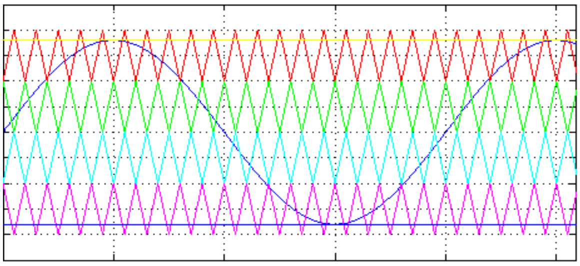

Fig. 4: Carrier Arrangement of APOD PWM.

Fuzzy Logic MPPT Control:

Many significant MPPT techniques have been formulated like simple voltage and current feedback MPPT, perturbation and observation MPPT, incremental conductance MPPT techniques. Recently, intelligence-based MPPT control techniques have been introduced (Tsai-Fu Wu *et al.*, 2000, Pongsakor Takun *et al.*, 2011, Md Fahim Ansari *et al.*, 2012). In this paper, a fuzzy logic based intelligent control technique associated with an MPPT controller is developed in order to improve tracking efficiency. Fuzzy logic MPPT controller measures the values of the voltage and current at the output of the PV array and calculates the PV power to derive the inputs of the controller. The inputs to the fuzzy logic controller are taken as the error *E* and change in error *CE*. The error *E* is defined as the change in power with respect to change in voltage and is expressed as:

$$E = \frac{P(k) - P(k-1)}{V(k) - V(k-1)} \qquad (3)$$

Hence *CE* can be written as:

$$CE = E(k) - E(k-1) \qquad (4)$$

where *P(k)* and *V(k)* are the instantaneous power and voltage of the PV array. Figure 5 and Figure 6 show the input membership functions.

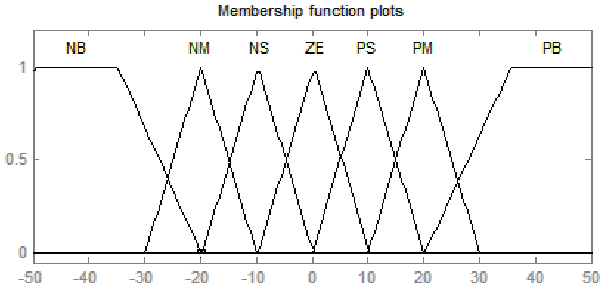

Fig. 5: Membership function plots for *E*.

The crisp output of the controller is the shoot-through duty ratio of the QZSI H-bridge and its membership function is shown in Figure 7. There are 49 inference rules applied and are summarized in Table 2 and shown in Figure 8.

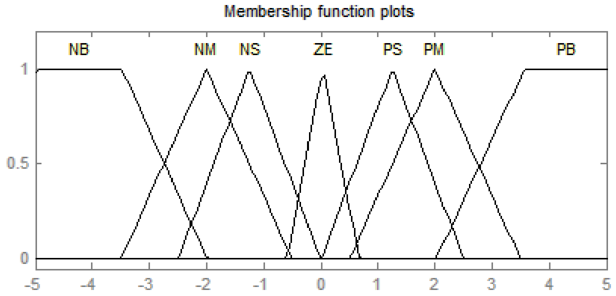

Fig. 6: Membership function plots for *CE*.

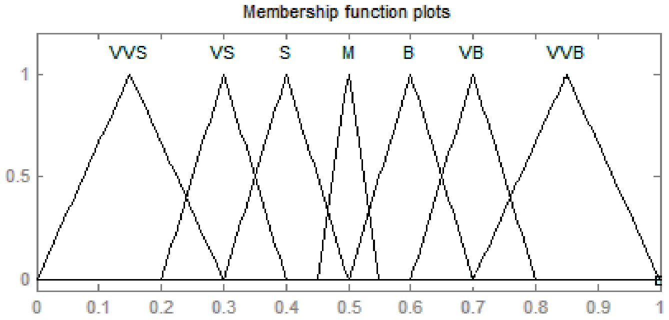

Fig. 7: Membership function plots for *D*.

Table 2: Fuzzy Rule Base Table.

E CE	NB	NM	NS	ZE	PS	PM	PB
NB	MD	MD	MD	VVS	VVS	VVS	VVS
NM	MD	MD	MD	VS	VS	VS	VS
NS	SM	MD	MD	SM	SM	SM	SM
ZE	VS	SM	MD	MD	MD	BG	VB

PS	VB	BG	BG	BG	MD	MD	BG
PM	VB	VB	VB	VB	MD	MD	MD
PB	VVB	VVB	VVB	VVB	MD	MD	MD

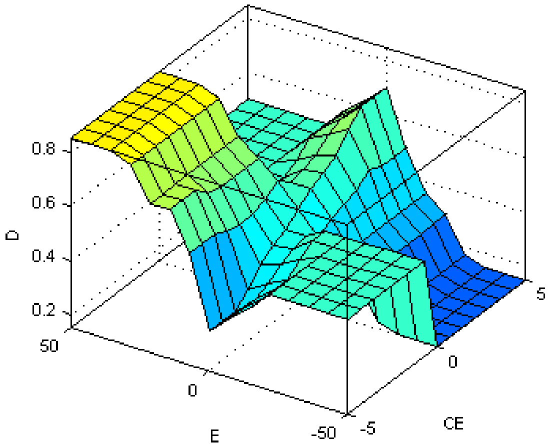

Fig. 8: Input variables and output variable mapping.

RESULTS AND DISCUSSION

In the multilevel QZSI, each H-bridge is integrated with a PV array. A 37 W PV module from SOLKAR manufacturer is taken in this work for modeling, simulation and experimentation. The key specifications of the PV module at the standard test conditions are listed in Table 3. A PV array is formed with two series connected PV panel. Here each panel consists of 4 parallel SOLKAR PV modules. So at standard conditions (1000 W/m^2 and 25^o C), each PV array gives the following V_{mp} , P_m ,I_{mp}

V_{mp} = 2 x 16.48 = 32.96V

P_m = 2 x 4 x 37.08 = 296.6W

I_{mp} = 4 x 2.25 = 9A

The Z- network inductors limit the current ripple through the devices during boost mode with shoot-through. The capacitors in the Z-network absorb the voltage ripple and maintain a reasonably constant voltage across the Z-network. The values of Z-network elements are designed and listed along with other specifications in Table 4. Simulation and experimental readings are obtained at the solar irradiance of 800 W/m^2 and at the temperature of 38^o C. The maximum power obtained from a PV array under these conditions is 292W at a V_m of 31.4 V.

Table 3: Specifications Of PV Module.

Characteristics	Variable	Specification
Maximum power	P_m	37.08W
Voltage at maximum power	V_m	16.56 V
Current at maximum power	I_m	2.25 A
Short circuit current	I_{sc}	2.25 A
Open circuit voltage	V_{oc}	21.24 V
Series resistance	R_s	0.47 Ω
Shunt resistance	R_{sh}	145.62 Ω
Diode ideality factor	A	1.5

Table 4: Circuit Parameters.

Inductors L_1,L_2,L_3,L_4	1.1mH
Capacitors C_1,C_2,C_3,C_4	1000μF
Load Resistance R	24Ω
Load Inductance L	10mH
Carrier Frequency f_c	10kHz
Output Frequency f_o	50Hz

The tracking of the maximum power point of the PV array with this fuzzy controller is shown in Figure 9 and is compared with that of normal P&O MPPT controller. It is inferred from Figure 9 that the fuzzy controller based MPPT tracks the maximum power point quickly and is faster than the conventional controller. Figure 10 shows the variation of PV power in the steady state conditions. Fuzzy logic based MPPT produces very little oscillations around the maximum power as compared to normal P&O controller. The output voltage of the multilevel QZSI is obtained using the digital storage oscilloscope and is shown in Figure 11.

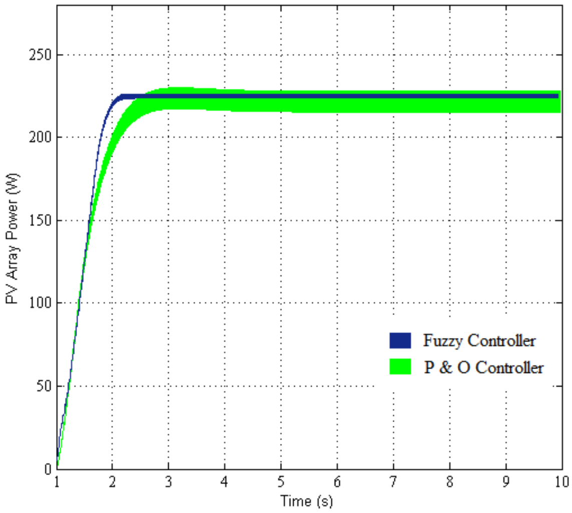

Fig. 9: PV Power Tracking with P&O and Fuzzy Controller.

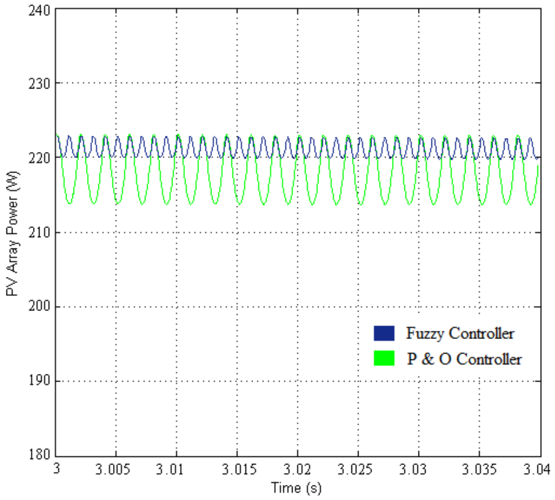

Fig. 10: Variation of PV Power in the Steady State.

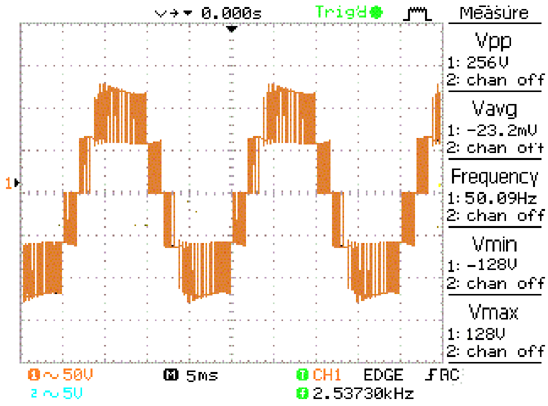

Fig. 11: Output voltage.

Conclusion:

A five level cascaded quasi-Z-source inverter topology is taken in this work as the power conditioning converter for PV applications. The switching states of the multilevel QZSI and the insertion of shoot-through states are described. Classical bipolar PWM techniques of PD, POD and APOD are analyzed for multilevel QZSI in the boost mode. This is achieved by inserting the shoot-through states within the zero states. This paper presented the fuzzy logic control maximum power point tracking of photovoltaic system. The results show that the fuzzy controller produces better performance than the P&O controller. It can be deduced that the fuzzy controller is faster in the transient part of maximum power point tracking. An also very small oscillation in the steady state is obtained as compared to the P&O controller. Thus it is possible to find the maximum power point of the PV array in short time and receiving the maximum power with much more accuracy with fuzzy controller.

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