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NOVEL LEVEL SHIFTED PWM TECHNIQUE FOR UNEQUAL AND EQUAL POWER SHARING IN QUASI Z SOURCE CASCADED MULTILEVEL INVERTER FOR PV SYSTEMS IN FUZZY ENVIRONMENT

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Abstract

Conventional Phase Shifted Pulse Width Modulation (PS-PWM) is a usual switching technique for Z source/Trans-quasi-Z-source inverter (Trans-qZSI) based on Cascaded Multilevel Inverters (CMI). PS-PWM scheme causes higher switching losses and creates electromagnetic interference (EMI) problem for higher number of cascaded modules. To address these issues, novel modified Level Shifted PWM (LS-PWM) technique is proposed with the aim of obtaining equal power from cascaded modules under abnormal condition. The direct use of the alternate Phase Opposed Disposed PWM (APOD-PWM) results in an unequal power sharing between the Trans-qZSI modules, under all operating conditions. An effective carrier rotation is incorporated in the conventional APOD-PWM to make the equal power sharing between the Trans-qZSI modules. Furthermore, the relation between the PS-PWM and APOD-PWM is geometrically obtained, which indicates that the proposed modulation scheme gives higher voltage gain over

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LS-PWM and PS-PWM techniques. Additionally, detailed switching loss analysis for the proposed PWM methods are added to validate low switching losses and thus high efficiency. A fuzzy simulation based analysis of the proposed system was done using MATLAB and the effectiveness of the proposed system was evaluated by doing a comparative study with the existing system.

1. Introduction

Multilevel inverters have recently received many attentions from researchers due to their advantages over the conventional three-level pulse-width modulation (PWM) inverters. Three general multilevel inverter topologies are: flying capacitors, neutral point clamped (NPC), and cascaded H-bridge (CHB) inverters. Among these topologies, the CHB inverter has unique advantages in modularity and its contribution of high power. These advantages make the CHB inverter an attractive option for many applications such as uninterruptible power supplies (UPS), grid-connected system, StatCom system, motor drive, etc. However, the traditional CHB multilevel inverter is a buck DC-AC power conversion, where the peak AC output voltage is limited by the total DC source voltages. An additional DC-DC boost converter is demanded for each module in the CHB topology to achieve the high AC output voltage when the DC input voltages are low. Adding DC-DC boost power converter results in low efficiency and high cost. The boost DC-DC converter is used to control the DC-link voltage on each H-bridge circuit. In the CHB-qZSI, the input DC current is continuous with low ripple. Each module in the CHB qZSI can produce the same DC-link voltage by control the ST duty cycle. Like the CHB-qZSI, an active front end AFE-CHB inverter also has the shoot-through immunity and buck/boost voltage. However, the CHB-qZSI and the AFE-CHB inverter use a large number of passive elements with raising the size, cost, and weight of the power cascaded system. Various converter topologies have been developed, according to recent literature, to overcome the limitations of conventional converter topologies. Vadthya Jagan et al. [1] presented for the enhanced-boost quasi-Z-source inverters (qZSI), namely continuous input current configuration and discontinuous input current configuration of enhanced-boost qZSI with two-switched impedance networks. Anh-Vu Ho et al. [2] proposes the combination of a novel modified quasi-Z-source (MqZS) inverter with a single-phase symmetrical hybrid three-level inverter in order to boost the inverter three-level output voltage. Mohammad Mohammadi et al. [3] present a novel dual switching frequency modulation to mitigate the switching losses of the converter, which results in a more compact impedance network. Petros Karamanakos et al. [4] present a variable switching point predictive current control (VSP 2 CC) for the quasi-Z-source inverter (qZSI). Xiaoquan Zhu et al. [6] deals with a new single-stage high boost quasi-Z-source inverter based on the active switched Z-impedance network. Sideng Hu et al. [7] the impedance-source network converter, utilizing a unique LC network and previously forbidden shoot-through states, provides the ability to buck and boost the input voltage in a single stage and Weihua Liang et al. [8] a DC-link voltage balancing control strategy for quasi-Z-source cascaded H-bridge (qZS-CHB) inverter photovoltaic (PV) power system is proposed by using multidimensional pulse-width modulation (MD-PWM) technique. Ahmed Abdelhakim et al. [10] proposed two modified space vector modulation strategies, aimed at the reduction of the qZSI number of switch commutations at high current level for shorter periods during the fundamental cycle, i.e., reducing the switching loss, simplifying the generation of the gate signals by utilizing only three reference signals, and achieving a single-switch commutation at a time. These modulation strategies are analyzed and compared to the conventional ones, where a reduced-scale 1-kVA three-phase qZSI is designed and simulated using these different modulation strategies.

This research work proposes a seven-level inverter, which uses a quasi-Z-source inverter with reduced components. The paper is organized as follows: Section 2 deals with the existing system. In Section 3, proposed system is discussed with illustrative MATLAB outputs. Section 4 describes the fuzzy simulation analysis method and finally some concluding remarks are drawn in Section 5.

2. Existing System

Multilevel Inverters (MLI) are used for the higher voltage and high power applications, due to lower dv/dt almost sinusoidal output voltage and better current THD. The most examined and commercialized topologies are Cascaded H-Bridge inverter (CHB), Neutral Point Clamped Inverter (NPC), Flying Capacitor Inverter (FC) and Modular Multilevel converter (MMC). The

CHB and MMC also recognized as the multi cell converters, are mainly use in high power applications (over 400KV and over 100MW), because of its modularity and excellent input harmonic current cancellation and lower output THD for the voltage and current. However, these converters have capacitor voltage balancing problem, requires an extra DC-DC converter for MPPT operation for PV systems, requires isolated dc supplies, and always operates in buck mode only. The Impedance source inverters (consisting of ZSI and qZSI) have the ability of one stage power conversion for integrating renewable energy to the utility grid. The input PV voltage is boosted to required level along with the MPPT tracking and simultaneously invert to get required output AC voltage at the desired 50/60 Hz frequency. qZS-CMI for high power level of 1 MW is reported. For qZS-CMI operation, the most popular modulation scheme used is PS-PWM. The basic challenge of qZS-CMI operation is the insertion of Shoot through State (STS) within the Zero State (ZS) to achieve the desired boosting and MPPT control. The PS-PWM scheme achieves all the advantages of the MLIs such as modularity, low dv/dt, almost sinusoidal outputs and power sharing between the modules is inherently equal. However, PS-PWM suffers from high switching losses of the semiconductors and EMI problem at very high frequency (>100 KHz) operation.

(a)

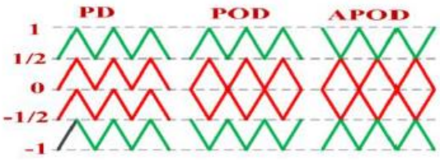


Figure (a) 2.1. Conventional LS-PWM Techniques.

(b)

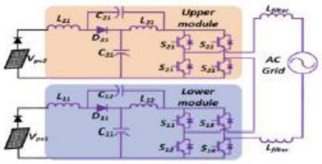


Figure (b) 2.2. Single phase qZS-CMI PV power system.

In the multiple parameters such as qZS inductor currents and capacitor voltages, grid parameters are directly controlled by the Model Predictive Control (MPC). Nevertheless, for the qZS-CMI the control becomes complex and not suitable for the practical solutions. Recently, Multidimensional (MD) PWM is proposed for the qZS-CMI. All the LS-PWM methods are shown in Figure 2.1.

In the direct application of these methods to qZS-CMI is carried out which fails to address the advantages (optimal switching) of LS-PWM. Furthermore, it is observed that this PWM method causes unequal power distribution among operating modules, and hence not suitable for PV systems application. Also, the uneven switching sequence is created at the modules semiconductors thereby prohibiting the harmonic cancellation at the input, which further deteriorates the THD. For the CMI, a novel carrier rotation is applied to achieve the equal power distribution between the modules. As far authors know, neither LS-PWM technique is applied to qZSI-CMI nor the carrier rotation. The effort of this article is to apply the APOD-PWM to the qZS-CMI to improve the efficient switching sequence generation which reduces the switching power loss in the semiconductors and leads to unequal power distribution between the two operating modules. Furthermore, carrier rotation is applied to the APOD-PWM to make the equal power between the operating modules.

3. Proposed System

In the same manner as the traditional ZSI, the qZSI has two types of operational states at the dc side: the non shoot through states (i.e. the six active states and two conventional zero states of the traditional VSI) and the shoot-through state (i.e. both switches in at least one phase conduct simultaneously). In the non-shoot-through states, the inverter bridge viewed from the dc side is equivalent to a current source. The equivalent circuits of the two states are as shown in Figure 3.1 and Figure 3.2. The shoot through state is forbidden in the traditional VSI, because it will cause a short circuit of the voltage source and damage the devices. With the qZSI and ZSI, the unique LC and diode network connected to the inverter bridge modify the operation of the circuit, allowing the shoot through state. This network will effectively protect the circuit from damage when the shoot-through occurs and by using the shoot-though state, the quasi Z-source network boosts the DC-link voltage. The major differences between the ZSI and qZSI are the qZSI draws a continuous constant dc current from the source.

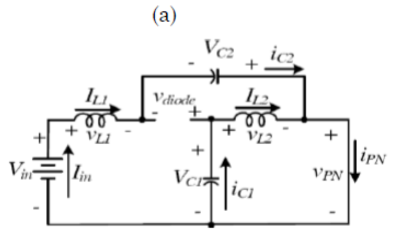


Figure (a)3.1. Equivalent Circuit of the qZSI in Non Shoot-through States.

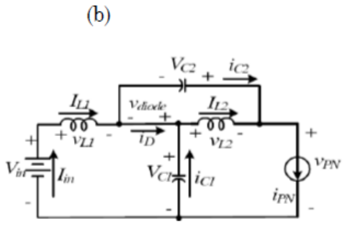


Figure (b)3.2. Equivalent Circuit of the qZSI in Shoot-Through States.

All the voltages as well as the currents are defined in and the polarities are shown with arrows. Assuming that during one switching cycle T, the interval of the shoot through state is T_0, the interval of non-shoot-through states is T_1, thus one has $T = T_0 + T_1$ and the shoot through duty ratio, $D = T_0/T$, which is a representation of the inverter during the interval of the non-shoot through states T_1, one can get

$$VL_1 = V_{\text{in}} - VC_1,\ VL_2 = -VC_1 \tag{1}$$

$$VPN = VC_1 - VL_2 = VC_1 = VC_1 = VC_2\ V_{\text{diode}} = 0 \tag{2}$$

which is a representation of the system during the interval of the shoot through states T_0, one can get;

$$VL_1 = VC_2 - V_{\text{in}},\ VL_2 = VC_1 \tag{3}$$

$$VPN = 0 \quad V_{\text{diode}} = VC_1 = VC_2 \tag{4}$$

At steady state, the average voltage of the inductors over one switching cycle is zero. From (1), (3), one has

$$V_{L1} = V_{L1} = \frac{T_0(VC_2 + V_{\text{in}}) + T_2(V_{\text{in}} - VC_2)}{T} = 0$$

$$V_{L2} = V_{L2} = \frac{(VC2)T_0 + (-VC2)T_2}{T} = 0$$

Thus $V_{C1} = \frac{T_1}{T_1 - T_0} V_{\text{in}}\ V_{C2} = \frac{T_0}{T_1 - T_0} V_{\text{in}}$ (5)

From (2), (4) and (5), the peak DC-link voltage across the inverter bridge is

$$V_{PN} = V_{C1} + V_{C2} = \frac{T}{T_1 - T_n} V_{\text{in}} = \frac{1}{1 - 2\frac{T_0}{T}} V_{\text{in}} = BV_{\text{in}} \tag{6}$$

Where B is the boost factor of the qZSI. This is also the peak voltage across the diode. The average current of the inductors L_1, L_2 can be calculated by the system power rating P.

$$I_{L1} = I_{L2} = L_{\text{in}} = \frac{P}{V_{\text{in}}} \tag{7}$$

According to Kirchhoff's current law and (7), we also can get that

$$I_{c1} = I_{c2} = I_{PN} - I_{L1},\ I_D = 2I_{LL} - I_{PN} \tag{8}$$

In summary, the voltage and current stress of the qZSI are shown in Table 3.1.

The stress on the ZSI is shown as well for comparison, where

(1) M is the modulation index; is the AC peak phase voltage; P is the system power rating.

(2) $M + T_1/T_2 - T_0,\ n = T_0/T_1 - T_0$ thus $m > 1,\ m - n = 1,$

(3) $B = T_1/T_1 - T_0$ thus $m + n = B,\ 1 < m < B.$

Table 3.1. Voltage and average current of the qZSI and ZSI network.

	$v_{L1} = v_{L2}$		v_{PN}		v_{diode}	
	T_0	T_1	T_0	T_1	T_0	T_1
ZSI	mV_{in}	$-nV_{\text{in}}$	0	BV_{in}	BV_{in}	0
qZSI	mV_{in}	$-nV_{\text{in}}$	0	BV_{in}	BV_{in}	0
	V_{C1}		V_{C2}		$\hat{v}_{\text{in}}$	
ZSI	mV_{in}		mV_{in}		$MBV_{\text{in}}/2$	

qZSI	mV_{in}	nV_{in}	$MBV_{\text{in}}/2$
	$I_{\text{in}} = I_{L1} = I_{L2}$	$I_{C1} = I_{C2}$	I_D
ZSI	P/V_{in}	$I_{PN} - I_{L1}$	$2I_{L1} - I_{PN}$
qZSI	P/V_{in}	$I_{PN} - I_{L1}$	$2I_{L1} - I_{PN}$

From Table 3.1, we can find that the qZSI inherits all the advantages of the ZSI. It can buck or boost a voltage with a given boost factor. It is able to handle a shoot through state, and therefore it is more reliable than the traditional VSI. It is unnecessary to add a dead band into control schemes, which reduces the output distortion.

In addition, there are some unique merits of the qZSI when compared to the ZSI:

(1) The two capacitors in ZSI sustain the same high voltage; while the voltage on capacitor C2 in qZSI is lower, which requires lower capacitor rating.

(2) The ZSI has discontinuous input current in the boost mode; while the input current of the qZSI is continuous due to the input inductor L1, which will significantly reduce input stress.

3.1 Simulation Results

The simulation results are examined using a software MATLAB/SIMULINK. One of the primary advantages of employing SIMULINK (and simulation in general) for the analysis of dynamic systems is that it allows us to quickly analyse the response of complicated systems that may be prohibitively difficult to analyse analytically.

3.1.1 Building System

Building the system model is then accomplished through a series of steps:

(1) The necessary blocks are gathered form the library browser and placed in the model window.

(2) The parameters of the blocks are then modified to correspond with the system we are modeling.

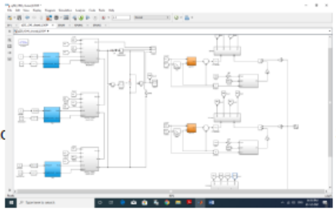
(3) Finally, the blocks are connected with lines to complete the model.

Each of these steps will be explained in detail using our example system. Once a system is built, simulations are run to analyze its behavior.

3.1.2 Running Simulations

Now that our model has been constructed, we are ready to simulate the system. To do this, go to the simulation menu and click on start, or just click on the “Start/pause simulation” button in the model window toolbar (looks like the “play” button. Because our example is a relatively simple model, its simulation runs almost instantaneously. With more complicated systems, however, you will be able to see the progress of the simulation by observing its running time in the lower box of the model window. Double-click the scope block to view the output of the gain block for the simulation as a function of time.

(a)



(b)

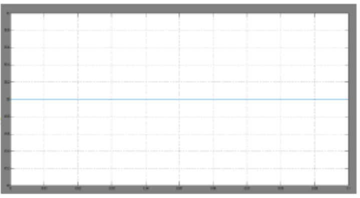


Figure (a) 3.3. Simulation model of proposed system.

Figure (b) 3.4. Input DC voltage to Q-ZSI.

The figure 3.3 shows the simulation model of proposed system and the figure 3.4 shows the input DC voltage which is of 50V.

The figure 3.5 shows the seven level output voltage waveform of the proposed system with amplitude 150V.

(a)

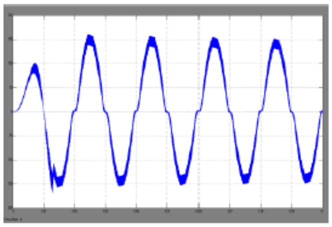


Figure (a) 3.5. Seven level output voltage waveform.

(b)

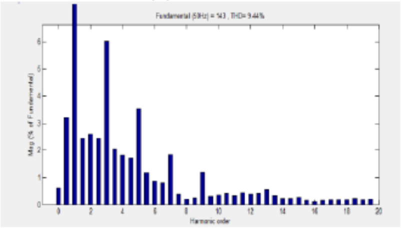


Figure (b) 3.6. THD result of proposed system.

The figure 3.6 shows the total harmonics distortion result of 9.44% with the proposed system. The figure 3.7 shows the five level output voltage waveform of the existing system with amplitude 400V.

(a)

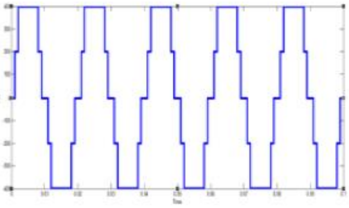


Figure (a) 3.7. Existing system five level output voltage waveform.

(b)

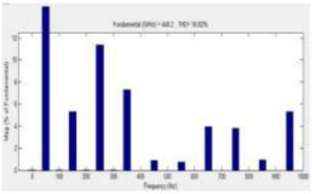


Figure (b) 3.8. THD result of existing system.

The figure 3.8 shows the total harmonics distortion result of 18.82% with the existing system.

In this research work, the comparison of THD for single phase cascaded H bridge multilevel inverter is done between 5 level and 7-level as given in the Table 3.2. Single phase cascaded H bridge inverters are implemented in MATLAB/SIMULINK. A MOSFET is selected as a switch. The switches are triggered at regular intervals.

Table 3.2. THD comparison.

S.NO	NO. OF LEVELS	THD
1	5	18.82
2	7	09.44

4. Fuzzy Simulation Analysis Method for Fuzzy Ranking

H. Sun and J. Wu [11] developed a ranking procedure based on fuzzy simulation analysis in which they generated a large sample of random numbers for the fuzzy numbers to be ranked and compared them by using the formula

$$\frac{(\bar{\varepsilon}-\bar{\eta})-(E_{\varepsilon}-E_{\eta})}{\sqrt{(S_{\varepsilon}^{2}/N_{1})+(S_{\eta}^{2}/N_{2})}}$$

Here the formula may be replaced by $\dfrac{\bar{X}-\bar{Y}}{S\sqrt{\dfrac{1}{N_1}+\dfrac{1}{N_2}}}$, where $S^2=\dfrac{(N_1-1)S_x^2+(N_2-1)S_y^2}{N_1+N_2-2}$ for a small sample of random numbers generated. The following is an algorithm proposed for ranking the fuzzy numbers involved in the proposed system based on fuzzy simulation analysis.

Step 1. Generate a group of random numbers from α-level set of fuzzy numbers $\widetilde{X}$, $\widetilde{Y}$ (which are to be ranked) respectively.

Step 2. Compute the mean values and sample variances of the simulated numbers.

Step 3. Apply hypothesis testing to obtain the ranking result.

Conclusion

This project presents a quasi-Z-source inverter with a new topology, which is derived from the traditional ZSI. The proposed CHB-qZSI inherits all the advantages of the ZSI and features its unique merits. It can realize buck/boost power conversion in a single stage with a wide range of gain that is suited well for application in PV power generation systems. Furthermore, the proposed qZSI has advantages of continuous input current, reduced source stress, and lower component ratings when compared to the traditional ZSI. Theoretical analysis, control method, and system design guide are presented in this project. A simulation based analysis of the proposed system was done using MATLAB and the effectiveness of the proposed system was evaluated by doing a comparative study with the existing system.

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