Simulation and Analysis of APOD Pulse Width Modulation Technique for Z-Source Cascaded Multilevel Inverter For Photovoltaic System

M.Sundaraperumal[1], M.Valan Rajkumar[2], D.Aravind[3]
[1]Department of Electrical and Electronics Engineering, Gnanamani College of Engineering, Namakkal-637018, India
[2, 3]Department of Electrical and Electronics Engineering, Gnanamani College of Technology, Namakkal-637018, India

Abstract- *This paper presents the simulation and analysis of multi carrier alternative phase opposition disposition (APOD) pulse width modulation (PWM) technique for z-source cascaded multilevel inverter for photovoltaic (PV) system. The ultimate aim of the paper is, this modulation technique is used to minimize harmonics in the output voltage. The power generation module is built by PV panels which are connected to z-source cascade H-bridge inverter. The z-source cascaded multilevel inverter can achieve the distributed maximum power point tracking (MPPT) to increase the system efficiency, achieve high voltage and high power grid or load tie without a transformer. The effectiveness of the proposed system is proved with the help of simulation. The simulation is performed in MATLAB/Simulink. From the simulation results, it shows that the proposed multilevel inverter works properly to generate the multilevel output waveform with minimum number of semiconductor devices and to achieve high dynamic performance with low total harmonic distortion (THD). The simulation results obtained from the proposed topology provides extended boost output voltage with reduced THD.*

Keywords- Photovoltaic (PV) System, Pulse Width Modulation (PWM), Z-Source Cascaded Multilevel Inverter, Total Harmonic Distortion (THD)

I. INTRODUCTION

Multilevel inverters enable the synthesis of a sinusoidal output voltage from several steps of voltages. For this reason, multilevel inverters have low *dv/dt* characteristics and generally have low harmonics in the output voltage and current [1-5]. In addition, the switching of very high voltages can be achieved by stacking multilevel inverter modules. Due to these advantages, multilevel inverters have been applied in various application fields. Among various topologies for multilevel inverters, the multilevel cascaded inverter structure is one of the prominent topologies because of its simple structure for modularization and fault-tolerant capability. Therefore, multilevel cascaded inverter are used for many applications, such as dynamic voltage restorer, static synchronous compensator, high-voltage energy storage device, photovoltaic inverters, medium-voltage drives, electric vehicle traction drives, and so on In multilevel cascaded inverter applications, a modulation strategy to generate gating signals is very crucial to achieve high-performance control [6-15].
Alternate energy sources such as solar, fuel cell, and wind have a wide voltage change range due to the nature of these sources. Photovoltaic cell voltage varies with temperature and irradiation. Fuel cell stack voltage drops greatly with load current. And wind generator voltage varies with wind speed and control. The traditional voltage source inverter that has been the power conversion technology for these energy sources cannot cope with the wide voltage change and often requires additional voltage boost by additional dc-dc converter, which increases cost, system complexity, and power loss [16-28].

Regarding this issue, many studies have been conducted, and Pulse Width Modulation (PWM) is roughly categorized into multilevel selective harmonic elimination pulse width modulation, multilevel carrier-based PWM, and multilevel space vector methods. Generally, a carrier-based PWM is preferred in applications such as motor drives, where dynamic properties are very important, whereas carrier-based PWM is preferred in some high-power static power conversion applications. To reduce the common-mode voltage, a multilevel carrier-based PWM has been proposed. The series carrier-based PWM method has been reported to easily implement carrier-based PWM for the multilevel cascaded inverter. Carrier-based PWM is proposed for hybrid inverters consisting of neutral point clamp and H-bridge inverters to improve output voltage quality and efficiency. As with two-level inverters, it is also possible to implement carrier-based PWM which are equivalent to traditional carrier-based PWM by injecting a common offset voltage to the three-phase references [29-39].

Some methods to calculate the offset voltages to achieve the optimal space vector switching sequence are addressed. The performances of a carrier-based PWM are compared, and a PWM scheme is proposed to obtain an optimal output voltage in the multilevel inverter. On the other hand, multilevel cascaded inverter requires separated dc links. Therefore, if there are one or more faults present in the dc links in each phase, or if the voltage magnitudes of the dc links are unequal, the output voltage of the multilevel cascaded inverter can be unbalanced without proper compensation. To resolve this issue, some studies have been conducted [40-55].

The Z-source converter or inverter systems can solve this problem. This single stage power conversion technology provides a great alternative with lower cost, higher reliability, and higher efficiency. System configurations, operating principles, features and results will be presented for advanced power conditioning of alternate energy systems. For any grid connected applications we need to use inverters and converters. Especially for renewable energy sources we use energy conversions. Fig. 1 shows the conventional Z-source inverter topology. A number of technical papers for minimization of Total Harmonic Distortion (THD) have been reported for fundamental frequency operation using the most common multilevel inverter topologies [56-64].

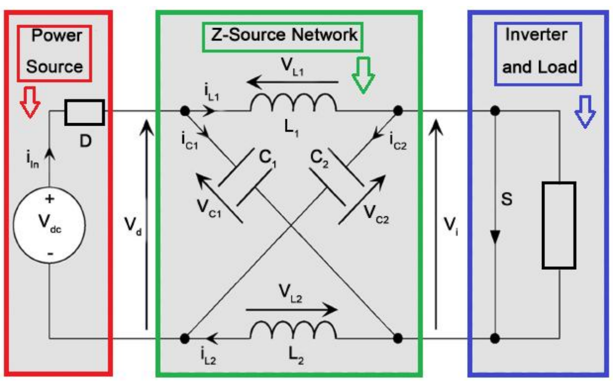

Fig. 1 Conventional Z source inverter topology

The cascaded multilevel configuration has independent dc sources that have same voltage levels. Those dc sources might be capacitors, and have experienced strong development over the past few years. This study deals with the conversion line for a grid-connected photo voltaic system. It is assumed that the PV technology used is a crystalline one, because of its large spreading on the current market. Space vector modulation and carrier based modulation are proposed [65-72].

To reduce conventional losses transformer less multilevel inverter is proposed. A single-phase multi-string five-level photovoltaic (PV) inverter topology for grid-connected PV systems with a novel PWM control scheme is proposed. Fuzzy controller for cascade multilevel inverter is adopted. Comparisons have made with PWM and carrier based modulation. It focused on harmonic elimination in non equal dc voltage source. The available modulation index is reduced under faulty conditions on switch modules in multilevel inverters, and compensation algorithms are proposed for alternate phase-disposition PWM and phase-shifted. Under these conditions, the PV field works under mismatching conditions that can lead to important power losses. Due to the climatic conditions and location, the solar panels produce different power output. Therefore while cascading PV power loss and string current exists. To minimize the string current, string current diverter should be used. The proposed system should decrease the drawbacks and keep the system reliable. This work focuses on total harmonics minimization efficient conversion. An asymmetric topology of this inverter is proposed here.

II. Z SOURCE CONVERTER AND CASCADED H BRIDGE INVERTER TOPOLOGY

To overcome the problems of the traditional voltage and current source converters, an impedance source power converter and its control method for implementing dc-to-ac power conversion. It employs a unique impedance network to couple the inverter main circuit to the power source for providing unique features that cannot be observed in the traditional voltage and current source converters where a capacitor and inductor are used, respectively. The z-source converter overcomes the abovementioned limitations of the traditional voltage and current source converter and provides a novel power conversion concept.

The z-source inverter based Solar Power Generation System fed induction motor drive, where a unique impedance network is introduced to couple the inverter main circuit to the power source. A z-source inverter based solar power generation system fed induction motor drive system has four major parts: a PV array-Source of DC voltage, Z-Source network containing two series inductors and two equal diagonally connected capacitors, a three-phase IGBT or Diode based inverter bridge and a three-phase induction motor drive. For feeding the required DC voltage to the Z-source Network, a PV array is used to generate the DC voltage with proper series and parallel combination of PV cells. Reverse current flow can be prevented by connecting a diode in series with the load circuit. The L_1, L_2, C_1 and C_2 are forming the Z-Source network.

In Fig. 2, a two-port network that consists of a split-inductor L_1 and L_2 and capacitors C_1 and C_2 connected in X shape is employed to provide an impedance source coupling the converter to the dc source. The dc source or load can be either a voltage or a current source or load. Therefore, the dc source can be a battery, diode rectifier, thyristor converter, fuel cell, an inductor, a capacitor, or a combination of those. Switches used in the converter can be a combination of switching devices and diodes such as the anti-parallel combination, the series combination etc.

The boost function of the generated DC voltage is achieved by this z-source network. The z-source inverter Bridge can boost the DC capacitors (C_1 and C_2) voltage to any value that is the above the average DC value of the PV array. The output voltage is always obtainable regardless of the line voltage with the help of z-source Bridge. Comparing the z-source inverters with the traditional inverters, a shoot through state that the upper and lower switches of any one phase leg are shorten and this is the added state besides the zero state and active state. The z-source concept can be applied to all dc-to-ac, ac-to-dc, ac-to-ac, and dc-to-dc power conversion. To describe the operating principle and control, this paper focuses on an application example of the z-source converter: a z-source inverter for dc-ac power conversion needed for fuel-cell applications. The diode in series with the dc source is for preventing reverse current flow. The cascaded multilevel inverters are made from series connected full bridge inverters, each with their own isolated dc bus. This multilevel inverter can generate almost sinusoidal waveform voltage from several separate dc sources. This type of converter does not need any transformer or clamping diodes or flying capacitors. Each level generates three different voltage outputs *+Vdc*, *0* and *–Vdc* by connecting the dc sources to the ac output side by different combinations of the four switches. The output voltage of multilevel inverter is the sum of all the individual inverter outputs.

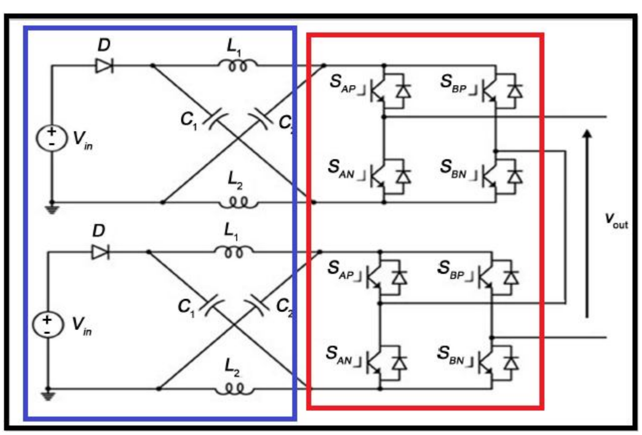

Fig. 2 Proposed Z source cascade H bridge inverter

Each of the H-bridge's active devices switches only at the fundamental frequency, and generates a quasi-square waveform by phase-shifting its positive and negative phase legs switching timings. Further, each switching device always conducts for 180˚ (or half cycle) regardless of the pulse width of the quasi-square wave. This switching method results in equalizing the current stress in each active device. This topology of inverter is suitable for high voltage and high power inversion because of its ability of synthesize waveforms with better harmonic spectrum and low switching frequency.
Considering the simplicity of the circuit and advantages, Cascaded H-bridge topology is chosen for the presented work. A multilevel inverter has four main advantages firstly; the voltage stress on each switch is decreased due to series connection of the switches therefore, the rated voltage and consequently the total power of the inverter could be safely increased. Second, the rate of change of voltage *(dv/dt)* is decreased due to the lower voltage swing of each switching cycle. Third, harmonic distortion is reduced. Fourth, lower acoustic noise and electromagnetic interference (EMI) is obtained.

III. Z ALTERNATIVE PHASE OPPOSITION AND DISPOSITION (APOD) PWM STRATEGY

In this strategy, carries are seem to be invert their phase in turns from previous one so it is named as Alternate Phase Opposition Disposition (APOD) PWM strategy. Carrier set placed above the zero reference with Amplitude. The carrier arrangement for this scheme with respect to the sine and trapezoidal reference wave is shown in the following Fig. 3 and Fig. 4.

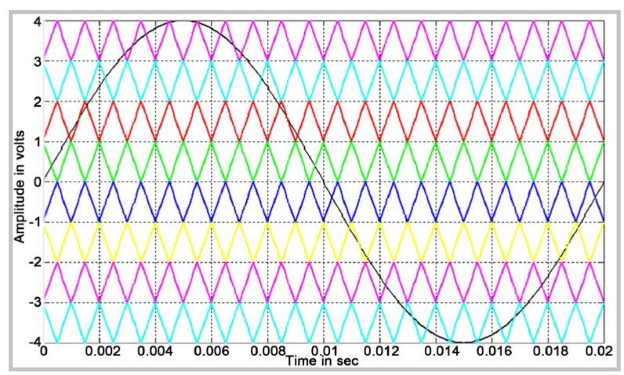

Fig. 3 Pulse waveform for APOD PWM strategy with sine reference

This technique requires each of the *n−1* carrier waveforms for an *n*-level phase waveform, to be phase displaced from each other by 180 degrees alternately. For even and odd *mf*, the most significant harmonics are sidebands of the carrier frequency. But there is no harmonics *fc*. For odd *mf*, the APOD-PWM waveform has odd symmetry resulting in only even harmonics. For even *mf*, the waveforms have quarter wave symmetry resulting in only odd harmonics.

For reducing the number of carrier signals and also improvement of the THD and harmonic spectrum of inverter output voltage, a new modulation strategy is proposed in this paper. The proposed multi-carrier PWM method uses *(n -1)/2* carrier signals to generate the *n*-level at output voltage. The carrier signals have the same amplitude, *Ac* and the same frequency, *fc*, and are in phase. The sinusoidal reference wave has a frequency *fr* and an amplitude *Ar*. In the proposed method, the sinusoidal reference and its inverse are used for generating the required gate signals. The frequency of the output voltage is determined by the frequency of the sinusoidal reference waveform.

The amplitude of the fundamental component of the output voltage is determined by the amplitude modulation index, *ma*. The proposed method uses two reference signals and two carrier signals. This method is based on a comparison of the sinusoidal reference waveforms with carrier waveforms. For even and odd values of frequency modulation index, *mf*, and the significant harmonics are located in two sidebands around the frequency, *2fc*. As a result, the frequency spectrum of the output voltage is improved.

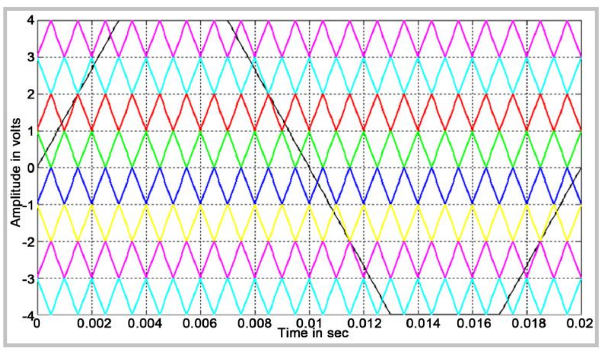

Fig. 4 Pulse waveform for APOD PWM with trapezoidal reference

So, the size of the required filter will be small. It is important to note that the design of filter is not the objective of this work. Reduction of the THD of the output voltage is other important advantage of the proposed method.

IV. SIMULATION RESULTS

The simulation results of various PWM schemes of corresponding Z-Source cascaded H bridge multilevel inverter fed with motor load is shown in figures below. The THD obtained for trapezoidal APOD PWM scheme is dissipated in Fig. 5.

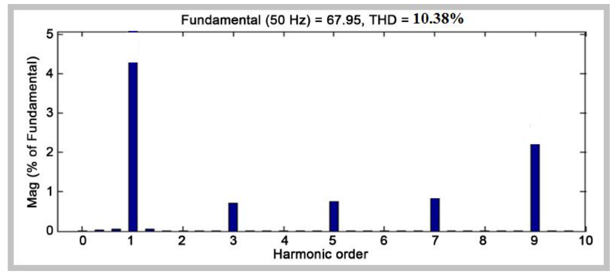

Fig. 5 FFT analysis of trapezoidal APOD PWM scheme

The fundamental frequency 50 Hz, the fundamental voltage obtained 67.95 V and the total harmonic distortion is 10.38%. PWM circuit to generate the gating signals for the multilevel inverter switches is shown Fig.3 and Fig.4. To control a three phase multilevel inverter with nine output voltage levels eight carriers are generated and compared at each time to a set of three reference waveforms. One set of carrier wave is above the zero reference and another set below the reference. Fig. 6 shows the motor speed and torque obtained for nine-level inverter for trapezoidal APOD PWM strategy in which the motor attains the maximum speed in three seconds. The output voltage of Z source integrated nine-level inverter with motor load is show in Fig. 7.

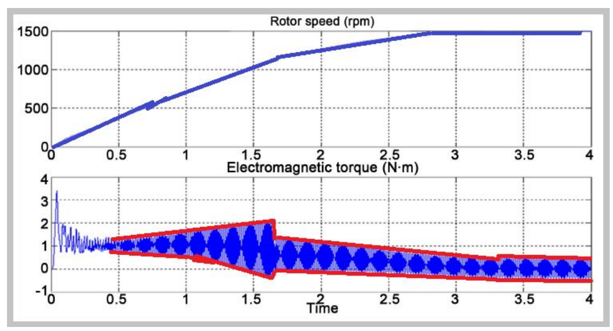

Fig. 6 Motor speed and torque of Z-source integrated nine-level inverter for trapezoidal APOD PWM strategy

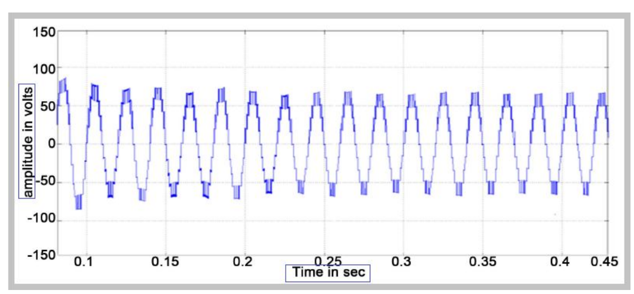

Fig. 7 Output voltage of Z-source integrated nine-level inverter

These carriers are same in frequency, amplitude and phases except in PWM but they are just different in DC offset to occupy contiguous bands. The frequency of reference signal determines the inverter output frequency and its peak amplitude controls the modulation index. The variation in modulation index changes the RMS output voltage of the multilevel inverter. By varying the reference signal frequency as well as modulation index, the output voltage is varied. Hence there can be voltage control.

The total harmonic distortion obtained for sinusoidal APOD PWM scheme is dissipated and which the fundamental frequency 50 Hz, the fundamental voltage obtained 67.95 V and the total harmonic distortion is 10.36%. The motor speed and torque are obtained, the nine-level inverter for sinusoidal APOD PWM strategy, in which the motor attains the maximum speed in three seconds. The output wave form obtained 67 V. The proposed modulation technique reduces the amplitude of significant harmonics and its sidebands for all modulation indexes thus making filtering easier, and with its size being significantly smaller.

V. CONCLUSION

This paper presents the simulation and analysis of alternative phase opposition disposition (APOD) pulse width modulation (PWM) technique for z-source cascaded multilevel inverter for photovoltaic (PV) system. The proposed circuit has fewer power semiconductors compared with the existing three-phase seven-level cascaded multilevel inverter. The passive component ratings are reduced to eliminate harmonics which exists in ZSI module. The balanced dc-link peak voltage is achieved by the control schemes and obtained that the trapezoidal PODPWM strategy has better %THD. The validity of the proposed method is shown through extensive simulation investigations applied to z-source cascaded multilevel inverter fed induction motor for photovoltaic (PV) system.

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