Fuzzy Logic Controller for Cascaded H-Bridge Multilevel Inverter

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ABSTRACT

This paper proposes fuzzy logic controller based seven-level hybrid inverter for photovoltaic systems with sinusoidal pulse width-modulation (SPWM) techniques. Multi-Level Inverter technology have been developed in the area of high-power medium-voltage energy scheme, because of their advantages such as devices of high dv/dt rating, higher switching frequency, unlimited power processing, shape of output waveform and desired level of output voltage, current and frequency adjustment.This topology can be used there by enabling the scheme to reduce the Total Harmonic Distortion (THD) for high voltage applications. The Maximum Power Point Tracking algorithm is also used for extracting maximum power from the PV array connected to each DC link voltage level. The Maximum Power Point Tracking algorithm is solved by Perturb and Observer method.It has high performance with low Total Harmonic Distortion and reduced by this control strategy. The proposed system has verified and THD is obtained by using MATLAB/simulink.The result is compared with the hardware prototype working model.

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1. INTRODUCTION

Multilevel voltage source inverter has many advantages compared to their conventional methods.Cascaded H-bridge inverter provides stepped AC voltage wave form with lesser harmonics at higher levels by combining different ranges of DC voltage sources.The components of inverter filter circuit are reduced by increasing step level of the inverter to the shaped voltage wave form, reduced switching volume, very low THD and reduced cost. The several voltage sources on the DC side of the converter makes multilevel technology a gorgeous for photovoltaic applications. Because the multilevel inverters are classified into two types namely distinct source and multisource multilevel inverter. In the conventional nine and seven level H-bridge multilevel inverters, the THD considerably high and the output performance is low when compared to the proposed hybrid H-bridge multilevel inverter. It is found that the THD will be reduced with increases in output levels.

As solar energy is one of the most promising non-conventional energy, the PV systems are becoming more and more popular. In recent years applying multilevel inverters to PV energy systems is getting more and more attraction due to the large power demands. Photovoltaic (PV) Converters are usually consisting of two stages [3], a dc/dc booster and a PulseWidth Modulated (PWM) inverter. The cascading technique of converters has some disadvantages such as efficiency issues, interactions between its stages and problems with the Maximum Power Point Tracking (MPPT). Therefore the part of the electrical energy produced is utilized for maintain the utilities. In this paper we proposed a single-phase H-bridge multilevel converter for PV systems governed by a fuzzy logic controller (FLC)/modulator with SPWM.

This paper is organized as follows, brief about cascade h-bridge multi-level inverter in section 2, Section 3 discussed about principle and operation of CHBMLI .Section 4 discusses the fuzzy logic control strategy and Modulation techniques of CHBMLI.Section 5 discussed about hardware implementation. The Simulation results are discussed in section 6 and concluding in section 7.

2. CASCADE H-BRIDGE MULTI-LEVEL INVERTER

A CHBMLI consists of a series of H-bridge (single-phase full-bridge) inverter units. The general function of this CHBMLI is to synthesize a desired voltage from several separate dc sources, which may obtain from batteries, fuel cells, or solar cells. Figure 1 shows a Single-Phase Structure of a CHBMLI with separate dc sources. Each separate dc source is connected to a single-phase full-bridge inverter. Each inverter level can generate three different voltage outputs, +Vdc, 0, and –Vdc. The output phase voltage level is defined by m = 2s+1, s = no. of dc sources.

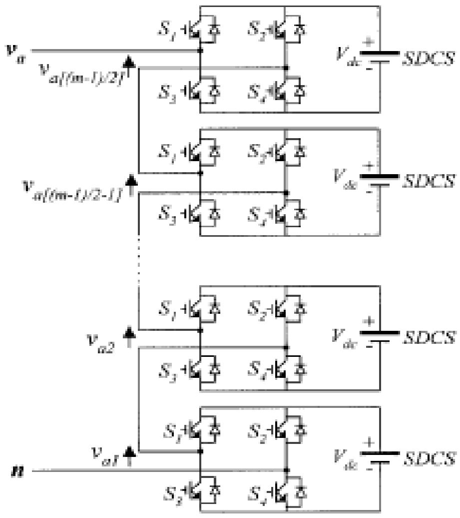

Figure 1. Single-Phase Structure of a Cascaded H-Bridge Multi-Level Inverter

CHBMLI has been receiving wide attention due to its numerous advantages as a dc/ac interface. CHBMLI is the focus of this paper due to its components required is the least to achieve the same number of voltage levels. The circuit layout is in modular structure, which means a faulty module can be replaced with another module without affecting the rest of the circuit. The ac outputs of the inverters are connected in series such that the synthesized voltage waveform is the sum of the inverter outputs. It requires the least number of components compared to other MLI.It can generate almost sinusoidal waveform voltage while only switching one time per fundamental cycle improved .High efficiency is obtained due to its minimum switching frequency.

3. PRINCIPLE AND OPERATION OF CHBMLI

A CHBMLI consists of basic H-bridge modules connected in series. This section will explain the working principle of the H-bridge module and how the CHBMLI modules are able to generate a single-phase ac output voltage.The structure of the single H-bridge module as shown in Figure 1, it consist of a separate dc source (SDCS), four semiconductor switching devices and four diodes. Switches, SW1, SW2, SW3 and SW4 are switched in 3 different sequences to generate output voltages across AB of the H-bridge module.The output voltage consist of three voltage levels, which are +Vdc, -Vdc and zero volt. To obtain +Vdc, switches SW1 and SW4 are turn 'ON'. To obtain –Vdc, switches SW2 and SW3 are turn 'ON'. To obtain zero volt, switches SW1 and SW2 or SW3 and SW4 are turn 'ON'.

The first mode of operation of single H-bridge CHBMLI as shown in Figure 2 and its sequence of operation for the first mode as revealed in following points,

1. SW1 & SW4 are turn ‘ON’
2. SW2 & SW3 are turn ‘OFF’
3. Resulted a +Vdc at terminal AB.

The second mode of operation of single H-bridge CHBMLI as shown in Figure 3 and its sequences operation of the second mode as revealed in following points,

1. SW2 & SW3 are turn ‘ON’
2. SW1 & SW4 are turn ‘OFF’

Resulted a -Vdc at terminal AB.

The third mode of operation of single H-bridge CHBMLI as shown in Figure 4 and its sequence of operation for the second mode as revealed in following points,

1. SW1 & SW2 are turn ‘ON’ and SW3 & SW4 are turn ‘OFF’. Alternately,
2. SW3 & SW4 are turn ‘ON’ and SW1 & SW2 are turn ‘OFF’.
3. Resulted a zero volt at terminal AB.

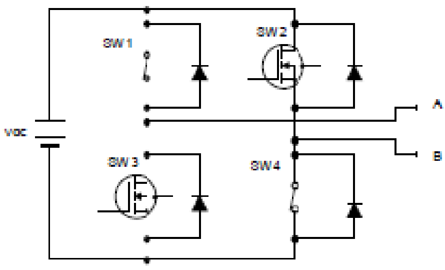

Figure 2. First Mode of Operation

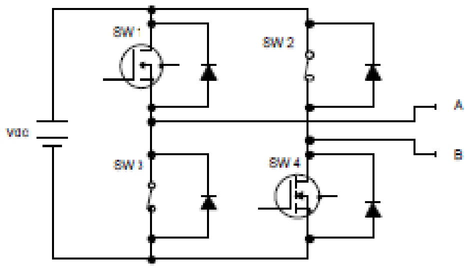

Figure 3. Second Mode of Operation

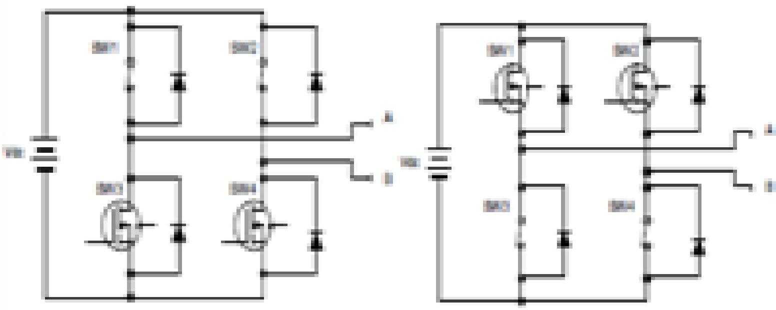

Figure 4. Third Mode of Operation

The principle of operation is to synthesize the output voltage of each module to form a step-like ac voltage waveform across terminal Van. The number of output phase voltage levels in a CHBMLI is defined by m=2s+1, Where, s is the number of dc sources. Figure 5 shows the output waveform produced by summing up the inverter outputs of a parallel level inverter. In general, the Van output voltage is produced by summing up the output voltage of each module with different duty cycle.

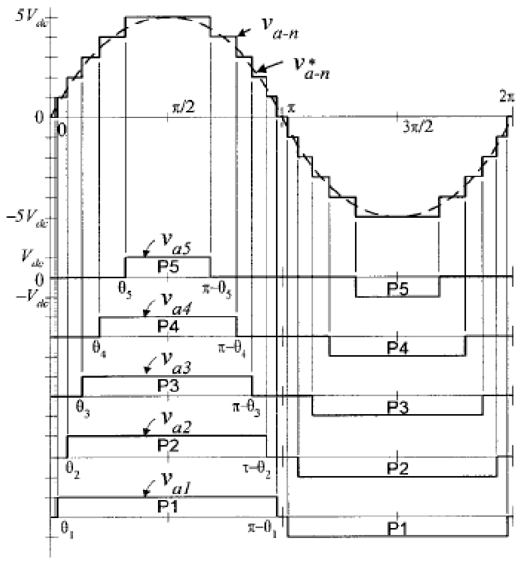

Figure 5. Output Waveform of Cascaded H-Bridge Multilevel Inverter

The output voltage is almost sinusoidal. The greater the number of H-bridge modules in a single-phase structure, the more step the Van output voltage will be therefore producing an AC waveform closer to a sinusoidal waveform. Each H-bridge module generates a quasisquare waveform by phase shifting its positive and negative phase legs' switching timings.

4. FUZZY LOGIC CONTROL STRATEGY

PI control is developed using the control system toolbox. The gate signals are generated using SPWM strategy. The seven level output of the cascaded inverter is fed to the load through LC filter to produce sinusoidal output (Vo) which is compared with the reference voltage (Vref) to generate the error signal (e). The input to the PI controller is e. The output of the PI controller i.e the compensating signal (Cs) is added with the reference signal to yield the required modulating signal (ms) and is used to generate the gating pulses. Thus a voltage feedback loop is established to realize the required sinusoidal output voltage. Figure 6 shows the block diagram of MLI with PI control. PI controller settings Kp and Ki are designed in this work using Ziegler – Nichols tuning technique. The designed values of Kp and Ki are 0.1 and 0.01 sec-1 respectively.

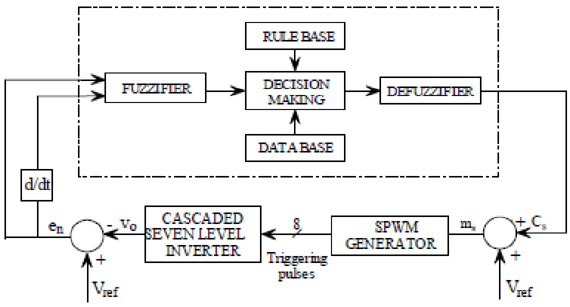

Figure 6. Block Diagram of MLI with PI Control

4.1. Sinusoidal pulse width modulation

The control principle of the Sinusoidal PWM is to use several triangular carrier signals keeping only one modulating sinusoidal signal. For an m-level inverter, Equation (2) is given, the (m-1) triangular carriers are needed for set the frequency and amplitude value. The carrier has the same frequency fc and the same peak-to-peak amplitude AC. The modulating signals are sinusoidal of frequency fm and amplitude Am. Each carrier signal is compared with the modulating signals at every instant. Each comparison switches the switch "on" if the modulating signal is greater than the triangular carrier assigned to that switch. Figure 7 shows the phase opposition and disposition of PWM.

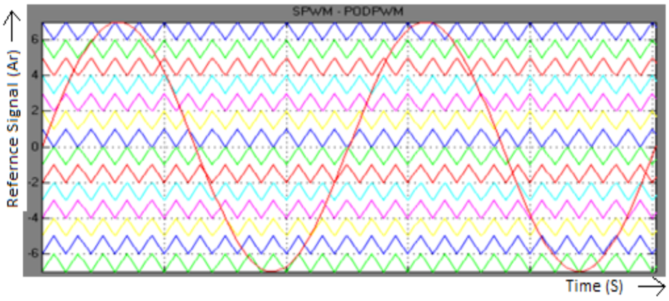

Figure 7. Phase Opposition Disposition PWM

The main parameters of the modulation process are the frequency ratio k=fc/fm, where fc is the frequency of the carriers, and fm is the frequency of the modulating signal. The definition of Modulation Index (MI) can be clarified in the Equation (1) is given by,

$$MI=Am / (m *Ac) \tag{1}$$

Where Am the amplitude of the modulating signal, A is the peak-to-peak value

$$m'= (m- 1)/2 \tag{2}$$

Where m is the number of level (which is odd)

5. HARDWARE IMPLEMENTATION

The hardware unit of the proposed method includes the solar energy sources, hybrid multilevel inverter, buck-boost converter, MOSFET Driver circuit, and controller. Also it explains the result analysis of renewable energy systems for an alternate form of power under their hardware implementation. At different intensities of sunlight, provides different levels of input voltage to the buck-boost converter and then to the battery which thereby provides a constant output voltage. This is further converted to AC using a single phase asymmetric multilevel inverter which feeds the non-linear loads. Figure 8 shows the hardware setup of CHMLI.

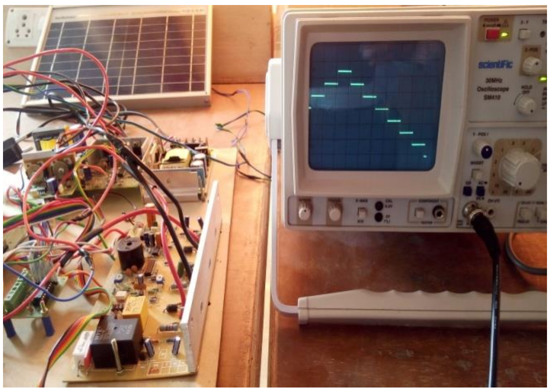

Figure 8. Hardware Setup of CHMLI

The solar panel is energized due to the light intensities on the surface of the panel. The buck-boost converter is used after the solar energy source to step up/step down the DC voltage. The boost converter produces regulated output voltage.The output of the panel charges the battery and then it is given to the inverter. The battery discharges whenever there is absence of sunlight. The controller can control the switching angle of the inverter, and buck-boost converter. The DC supply is given to the Hybrid multilevel inverter which converts the DC into AC voltage. The duty cycle of the MOSFET switch adjusts itself automatically to produce a constant .The output of the AC is seven level stepped output voltages. The available AC voltage is applied to extend non-linear loads.

5.1. Buck-boost converter

The basic principle of a Buck-Boost converter consists of two distinct states that is in the on state, the switch S is closed, resulting in an increase in the inductor current and in the off state, the switch is open and the only path offered to inductor current is through the fly back diode D, the capacitor C and the load R. These results in transferring the energy accumulated during the on state into the capacitor. Figure 9 shows the circuit diagram of boost converter.

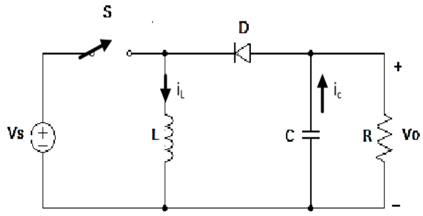

Figure 9. Buck –Boost Converter

When a Boost converter operates in continuous mode, the current through the inductor (IL) never falls to zero. In some cases, the amount of energy required by the load is small enough to be transferred in a time smaller than the whole commutation period. In this case, the current through the inductor falls to zero during part of the period and the converter is said to be operated in discontinuous mode and the inductor is completely discharged at the end of the commutation cycle.

6. SIMULATION RESULT AND DISCUSSION

In this proposed 7 level CHBMLI can be simulated by using MATLAB/Simulink tool box. In this setup we are using six IGBT switches instead of nine and seven switches in the existing topology. Figure 10 shows the simulation diagram of CHBMLI.

The driver circuit produces pulses according to the voltage sensed from the voltage measurement block. The inverter has been built using MOSFETs as the switching devices. Through the controller circuit the controlled gate signal are given as input to the MOSFET. At that time the pulse of the first MOSFET is shown in Figure 11.

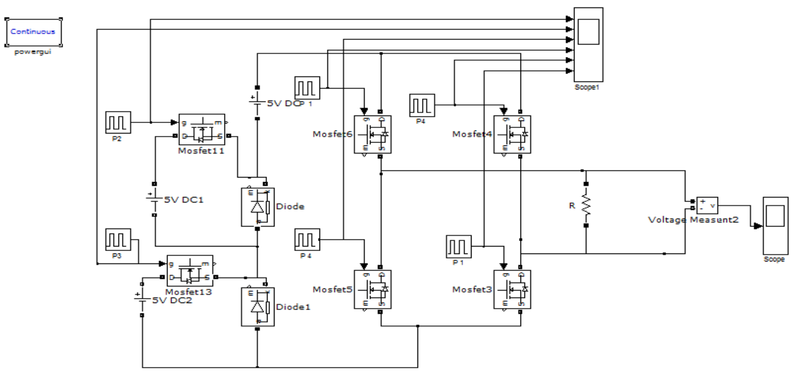

Figure 10. Simulation Diagram of CHBMLI Circuit

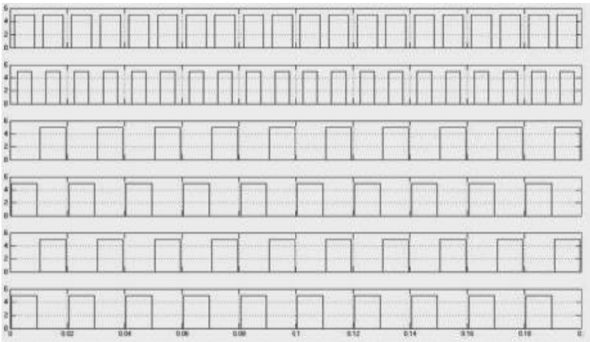

Figure 11 Switching Pulses for MOSFET

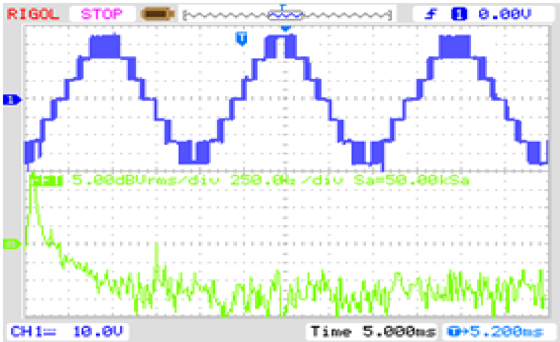

Figure 12 Experimental Result for the Proposed 7 Level Inverter

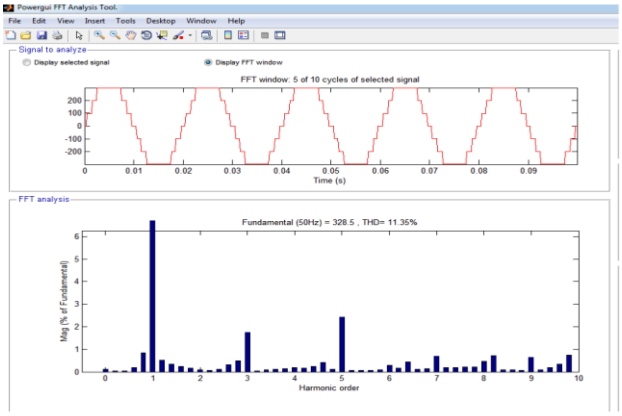

Figure 13. FFT Analysis of CHBMLI using 6 Switches

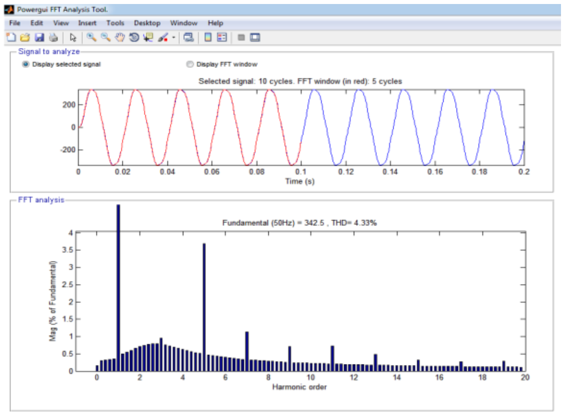

Figure 14. FFT Analysis of 7-Level Inverter using 6 Switches with RL Load

7. CONCLUSION

This paper has presented a fuzzy logic controller based seven-level hybrid inverter for photovoltaic systems with minimum number of switches. A sinusoidal pulse width-modulation (SPWM) technique has been proposed here. From the obtained result it is found that fuzzy logic controller gives a reduced THD compared to conventional single carrier modulation and it gives a better quality output. From the simulation result it is observed that the current distortion is greatly reduced after harmonic reduction and it is within the limit to meet the IEEE 519-1992 standard.Therefore, the use of Photovoltaic (PV) model is recommended for the proposed inverter with reduced and minimum number of switches. Hence, seven-level inverter with reduced component along with fuzzy logic controlled SPWM technique will enhance the quality of the output voltage and provides a better efficiency suited for PV applications.

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