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Fuzzy Logic Controlling of a Single Phase Seven & Nine level Grid- Connected Inverter for Photovoltaic System

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Abstract:

This paper proposes fuzzy logic controller based a single-phase seven-level inverter for grid-connected photovoltaic systems, with a novel pulse width-modulation (PWM) control scheme. Three reference signals produces from fuzzy logic controller which are identical to each other are going to compare with the amplitude of the triangular carrier signal. The inverter is capable of producing seven levels(Vab = VdcVab = 2Vdc/3 Vab = Vdc/3 Vab = 0 Vab = −V dc/3 Vab= − 2Vdc/3 Vab = −V dc)of output-voltage levels from the dc supply voltage. The total harmonic distortion is reduces by this control strategy. The proposed system was verified through simulation.

Keywords:

Fuzzy logic Controller, Grid connected, modulation index, multilevel inverter, photovoltaic (PV) system, pulse width-modulated (PWM), total harmonic distortion (THD).

I.INTRODUCTION:

The ever-increasing energy consumption, fossil fuels soaring costs and exhaustible nature, and worsening global environment have created a booming interest in renewable energy generation systems, one of which is photovoltaic. Such a system generates electricity by converting the Sun's energy directly into electricity. Photovoltaic-generated energy can be delivered to power system networks through grid-connected inverters. A single-phase grid-connected inverter is usually used for residential or low-power applications of power ranges that are less than 10 kW [1]. Types of single-phase grid- connected inverters have been investigated [2]. A common topology of this inverter is full-bridgethree-level. The three-level inverter can satisfy specifications through its very high switching, but it could also unfortunately increase switching losses, acoustic noise, and level of interference to other equipment. Improving its output waveform reduces its harmonic content and, hence,also the size of the filter used and the level of electromagnetic interference (EMI) generated by the inverter's switching operation [3]. Multilevel inverters are promising; they have nearly sinusoidal output-voltage waveforms, output current with better harmonic profile, less stressing of electronic components owing to decreased voltages, switching losses that are lower than those of conventional two-level inverters, a smaller filter size, and lowerEMI ,allofwhichmakethemcheaper,lighter,andmore compact [3], [4]. Various topologies for multilevel inverters have been proposed over the years. Common ones are diode-clamped [5]– [10], flying capacitor or multi cell [11]–[17] , cascaded H-bridge [18]–[24], and modified H- bridge multilevel[25]–[29].

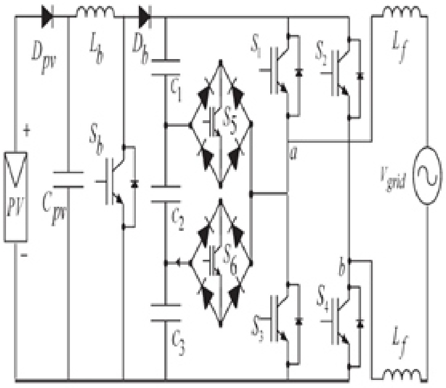

Fig.1.Proposedsingle-phaseseven-levelgrid-connecte-dinverterfor photovoltaicsystems.

This paper recounts the development of a novel modified H-bridge single-phase multilevel inverter that has two diode embedded bidirectional switches and a novel pulse width modulated (PWM) technique. The topology was applied to a grid-connected photovoltaic system with considerations for a maximum-power-point tracker (MPPT) and a current-controlalgorithm.

II.PROPOSED MULTILEVELINVERTER TOPOLOGY:

AFullH-Bridge:

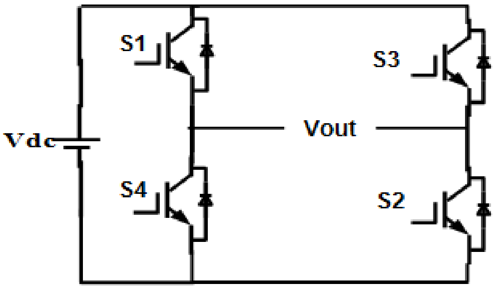

Figure. 2 FullH-Bridge

Fig.2 shows the Full H-Bridge Configuration. By using single H-Bridge we can get 3 voltage levels. The number output voltage levels of cascaded Full H-Bridge are given by 2n+1 and voltage step of each level is given by Vdc/n. Where n is number of H-bridges connected in cascaded. The switching table is given in Table1.

Table 1. Switching table for FullH-Bridge

Switches TurnON	VoltageLevel
S1,S2	V_{dc}
S3,S4	$-V_{dc}$
S4,S2	0

B.HybridH-Bridge:

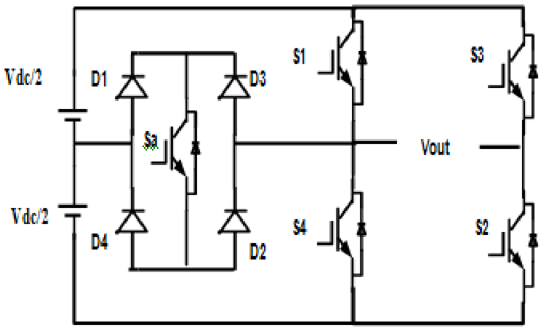

Figure. 3 HybridH-Bridge

Fig. 3 shows the Hybrid H-Bridge configuration. By using single Hybrid H-Bridge we can get 5 voltage levels. The number output voltage levels of cascaded Hybrid H-Bridge are given by 4n+1 and voltage step of each level is given by Vdc/2n. Where n is number of H- bridges connected in cascaded. The switching table of Hybrid H-Bridge is given in Table2.

Table 2. Switching table for HybridH-Bridge

Switches TurnOn	VoltageLevel
Sa,S1	$V_{dc}/2$
S1,S2	V_{dc}
S4,S2	0
Sa,S3	$-V_{dc}/2$
S3,S4	$-V_{dc}$

The proposed single-phase seven-level inverter was developed from the five-level inverter in [25]–[29]. It comprises a single-phase conventional H-bridge inverter, two bidirectional switches, and a capacitor voltage divider formed by C1, C2, and C3, as shown in Fig. 1. The modified H-bridge topology is significantly advantageous over other topologies, i.e., less power switch, power diodes, and less capacitor for inverters of the same number of levels. Photo voltaic (PV) arrays were connected to the inverter via a dc–dc boost converter. The power generated by the inverter is to be delivered to the power network, so the utility grid, rather than a load, was used. The dc–dc boost converter was required because the PV arrays had a voltage that was lower than the grid voltage. High dc bus voltages are necessary to ensure that power flows from the PV arrays to the grid. A filtering inductance Lf was used to filter the current injected into the grid. Proper switching of the inverter can produce seven output-voltage levels (Vdc, 2Vdc/3, Vdc/3, 0,−Vdc,−2Vdc/3,−Vdc/3) from the dc supply voltage. The proposed inverter's operation can be divided into seven switching states, as shown in Fig.4(a)–(g).

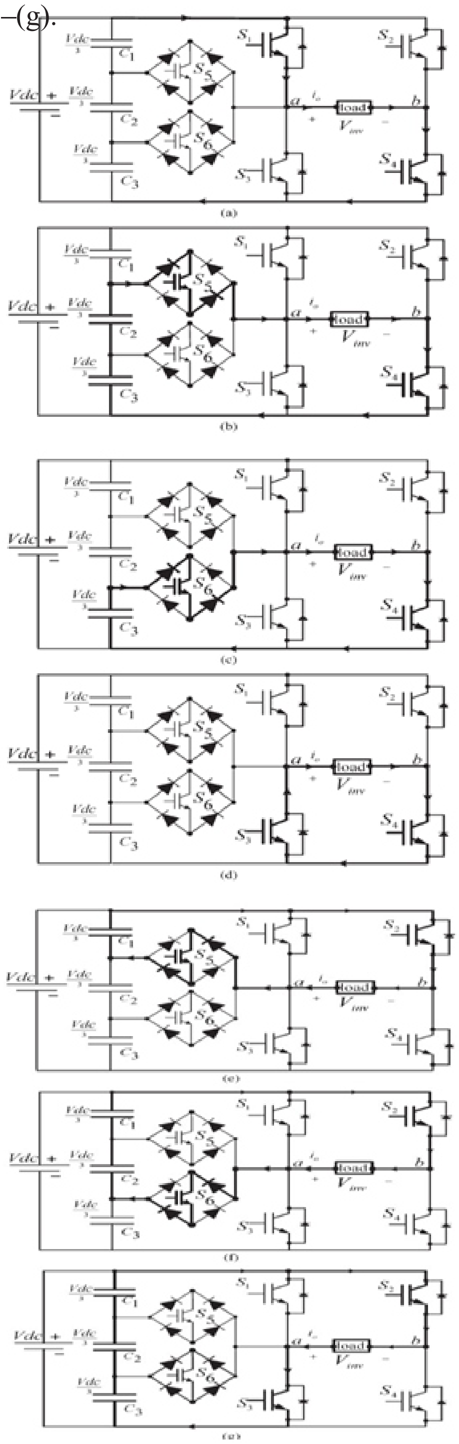

Fig. 4. Switching combination required to generate the output voltage (Vab). (a) Vab= Vdc. (b) Vab= 2Vdc/3. (c) Vab= Vdc/3. (d) Vab= 0 (e) Vab= −Vdc/3.(f) Vab= −2Vdc/3. (g) Vab=−Vdc.

OUTPUT VOLTAGE ACCORDING TOTHE SWITCHES' ON–OFFCONDITION:

v_0	S_1	S_2	S_3	S_4	S_5	S_6
V_{dc}	on	off	off	on	off	off
$2V_{dc}/3$	off	off	off	on	on	off
$V_{dc}/3$	off	off	off	on	off	on
0	off	off	on	on	off	off
0*	on	on	off	off	off	off
$-V_{dc}/3$	off	on	off	off	on	off
$-2V_{dc}/3$	off	on	off	off	off	on
$-V_{dc}$	off	on	on	off	off	off

Table 3.shows the switching combinations that generated the seven output-voltage levels (0,−Vdc,−2Vdc/3,−Vdc/3, Vdc, 2Vdc/3,Vdc/3).

III.PWMMODULATION:

A novel PWM modulation technique was introduced to generate the PWM switching signals. Three reference signals (Vref1, Vref2, and Vref3) were compared with a carrier signal (Vcarrier). The reference signals had the same frequency and amplitude and were in phase with an offset value that was equivalent to the amplitude of the carrier signal. The reference signals were each compared with the carrier signal. If Vref1 had exceeded the peak amplitude of Vcarrier, Vref2 was compared with Vcarrier until it had exceeded the peak amplitude of Vcarrier. Then, onward, Vref3 would take charge and would be compared with Vcarrier until it reached zero. Once Vref3 had reached zero, Vref2 would be compared until it reached zero. Then, onward, Vref1 would be compared withVcarrier.

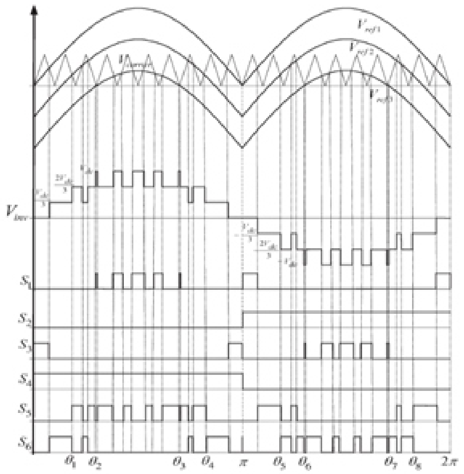

Fig.5.Switchingpatternforthesingle-phaseseven-level-inverter.

Fig.5 shows the resulting switching pattern. Switches S1, S3, S5, and S6 would be switching at the rate of the carrier signal frequency, whereas S2 and S4 would operate at a frequency that was equivalent to the fundamental frequency. For one cycle of the fundamental frequency, the proposed inverter operated through six modes. Fig. 6 shows the per unit output-voltage signal for one cycle. The six modes are described asfollows:

Mode 1 : $0 < \omega t < \theta 1$ and $\theta 4 < \omega t < \pi$
Mode 2 :$\theta 1 < \omega t < \theta 2$ and $\theta 3 < \omega t < \theta 4$
Mode 3 :$\theta 2 < \omega t < \theta 3$
Mode 4 :$\pi < \omega t < \theta 5$ and $\theta 8 < \omega t < 2\pi$
Mode 5 :$\theta 5 < \omega t < \theta 6$ and $\theta 7 < \omega t < \theta 8$
Mode 6 :$\theta 6 < \omega t < \theta 7$.

IV CONTROLSYSTEM:

Fig. 7 shows, the control system comprises a MPPT algorithm, a dc-bus voltage controller, reference- current generation, and a current controller. The two main tasks of the control system are maximization of the energy transferred from the PV arrays to the grid, and generation of a sinusoidal current with minimum harmonic distortion, also under the presence of grid voltage harmonics. The proposed inverter utilizes the perturb-and-observe (P&O) algorithm for its wide usage in MPPT owing to its simple structure and requirement of only a few measured parameters. It periodically perturbs (i.e., increment or decrement) the array terminal voltage and compares the PV output power with that of the previous perturbation cycle. If the power was increasing, the perturbation would continue in the same direction in the next cycle; otherwise, the direction would be reversed. This means that the array terminal voltage is perturbed every MPPT cycle; therefore, when the MPP is reached, the P&O algorithm will oscillate aroundit. A PI algorithm was used as the feedback current controller for the application. The current injected into the grid, also known as grid current Igrid, wassensed and fedback to a comparator that compared it with the reference currentIgridref. Igridrefis the result of the MPPT algorithm. The error from the comparison process of Igrid andIgridrefwasfedinto the PI controller. The output of the PI controller, also knownasVref,goes through ananti windup process before being compared with the triangular wave to produce the switching signals forS1–S6. Eventually,Vrefbecomes Vref1,Vref2andVref3can be derived fromVref1by shifting the offset value, which was equivalent to the amplitude of the triangular wave. The mathematical formulation of the PI algorithm and its implementation in the DSP are discussed in detail in[28]. Fuzzy controllers are uses for controlling consumer products, such as washing machines, video cameras, and rice cookers, as well as industrial processes, such as cement kilns, underground trains, and robots. Fuzzy control is a control method based on fuzzy logic. Just as fuzzy logic can be described simply as ‘‘computing with words rather than numbers‘‘; fuzzy control can be described simply as ‘‘control with sentences rather than equations‘‘. A fuzzy controller can include empiric al rules, and that is especially useful in operator controlled plants [1]. The objective here is to identify and explain design choices for engineers.

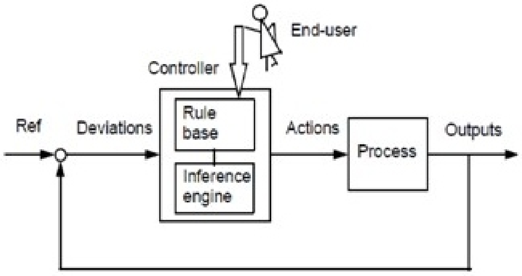

Fig 6. Fuzzy logicprocess

A.Introduction to fuzzylogic:

The logic of an approximate reasoning continues to grow in importance, as it provides an in expensive solution for controlling know complex systems. Fuzzy logic controllers are already used in appliances washing machine, refrigerator, vacuum cleaner etc. Computer subsystems (disk drive controller, power management) consumer electronics (video, camera, battery charger) C.D. Player etc. and so on in last decade, fuzzy controllers have convert adequate attention in motion control systems. As the later possess non-linear characteristics and a precise model is most often unknown. Remote controllers are increasingly being used to control a system from a distant place due to inaccessibility of the system or for comfort reasons. In this work a fuzzy remote controllers is developed for speed control of a converter fed dc motor. The performance of the fuzzy controller is compared with conventional P-Icontroller.

B.Unique features of fuzzylogic:

The unique features of fuzzy logic that made it a particularly good choice for many control problems are as follows,

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It is inherently robust since it does not require precise, noise – free inputs and can be programme to fail safely is a feedback sensor quits or is destroye. The output control is a smoothcontrol function despite a wide range of input variations. Since the fuzzy logic controller processes user-define rules governing the target control system, it can be modify and takeseasily to improve or drastically alter system performance. New sensors can easily be incorporates into the system simply by generating appropriate governing rules.

C.Fuzzification andNormalization:

Fuzzification is relate to the vagueness and imprecision in a natural language. It is a subjective valuation, whichtransforms a measurement into a valuation of an objective input space to fuzzy sets in certain input universes of discourse. In fuzzy control applications, the observed data are usually crisp. Since the data manipulation in a fuzzy logic controller is based on fuzzy set theory, fuzzification is necessary in an earlierstage.

D.Membershipfunctions:

Fuzzysystemuses_4‘differentshapesofMF‘s.,thoseare Triangular, Gaussian, Trapezoidal, sigmoid,etc.,
i.Triangular membershipfunction
The simplest and most commonly used membership functions are triangular membership functions, which are Symmetrical and asymmetrical in shape Trapezoidal membership functions are also symmetrical or asymmetrical has the shape of truncatedtriangle
ii.Gaussian membershipfunction
Two membership functions Triangular and Trapezoidal are built on the Gaussian curve and two sided composite of two different Gaussiancurves.

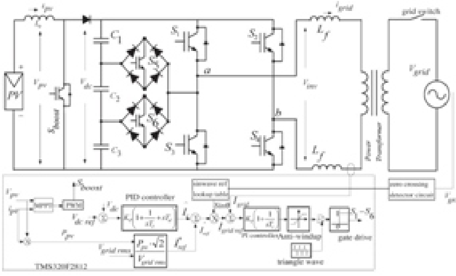

Fig.7.Seven-levelinverterwithclosed-loopcontrolalgorithm.

MATLAB/SIMULINK MODEL andSIMULATION RESULTS:

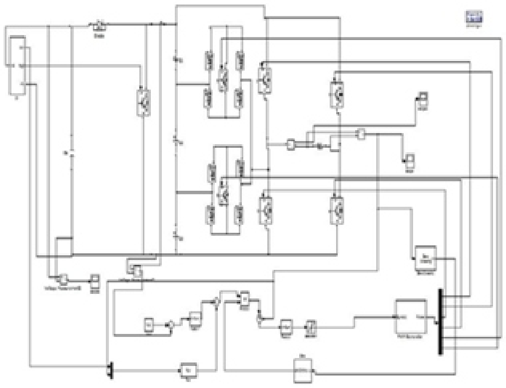

Fig. 8 Matlab/Simulink model of Grid connected PV-system

Fig. 8 shows the Matlab/ Simulink model of grid connected photovoltaic system. It consist of a DC to DC conversion stage and Dc to AC multilevel inversionstage.

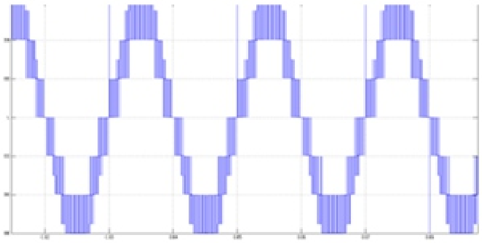

Fig. 9 Seven Level Voltageoutput

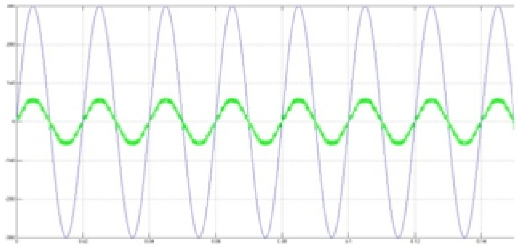

Fig.10 Grid Voltage and GridCurrent

Fig. 9 shows the seven level PWM output. Fig. 10 showthe grid voltage and grid current. From the figure it is clear that grid voltage and current areinpahse.

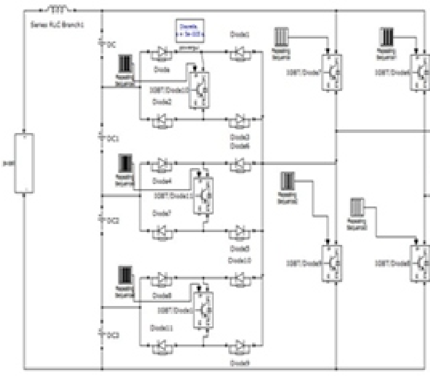

Fig.11Matlab/SimulinkmodleofproposedNinelevelInverter

Fig. 11 shows the Matlab/Simulink model of proposed nine level Hybrid H-Bridgeinverter.

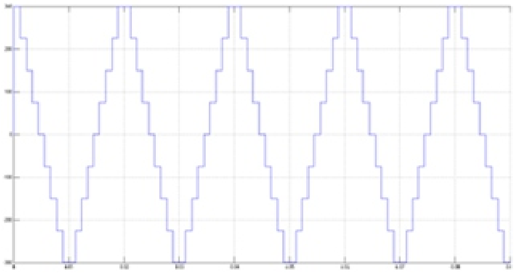

Fig.12 Nine level output of proposedconverter

Fig. 12 shows the output of proposed nine level inverter. In proposed converter for nine level seven switches are required. In order to produce the same levels cascaded H-Bridge requires sixteenswitches.

VCONCLUSION:

Multilevel inverters offer improved output waveforms and lower THD. This paper has presented a novel PWM switching scheme for the proposed multilevel inverter. It utilizes three reference signals and a triangular carrier signal to generate PWM switching signals.

The behavior of the proposed multilevel inverter was analyzed in detail. By controlling the modulation index, the desired number of levels of the inverter's output voltage can be achieved. Finally a nine level hybrid H-bridge inverter is proposed and simulation results arepresented.

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