A Five Level Inverter for Grid Connected PV System Employing Fuzzy Controller

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ABSTRACT: *This paper presents a single-phase five-level photovoltaic (PV) inverter topology for grid-connected PV systems with a novel pulse width-modulated (PWM) control scheme. Two reference signals identical to each other with an offset equivalent to the amplitude of the triangular carrier signal were used to generate PWM signals for the switches. The inverter offers much less total harmonic distortion and can operate at near-unity power factor. This paper presented a single-phase multilevel inverter for PV application. It utilizes two reference signals and a carrier signal to generate PWM switching signals. The circuit topology, modulation law, and operational principle of the proposed inverter were analyzed in detail. A FUZZY control is implemented to optimize the performance of the inverter. MATLAB/SIMULINK results indicate that the THD of the Fuzzy Controller Circuit is much lesser than that of the THD of the PI Controller Circuit. Furthermore, both the grid voltage and the grid current are in phase at near-unity power factor.*

Keywords: *Grid connected Photovoltaic system, Maximum power point tracking system, Single phase five level inverter and fuzzy logic controller.*

I. INTRODUCTION

The Demand for renewable energy has increased significantly over the years because of shortage of fossil fuels and greenhouse effect. The definition of renewable energy includes any type of energy generated from natural resources that is infinite or constantly renewed. Examples of renewable energy include solar, wind, and hydropower. Renewable energy, due to its free availability and its clean and renewable character, ranks as the most promising renewable energy resources like Solar energy, Wind energy that could play a key role in solving the worldwide energy crisis. Among various types of renewable energy sources, solar energy and wind energy have become very popular and demanding due to advancement in power electronics techniques. Photovoltaic (PV) sources are used today in many applications as they have the advantages of effective maintenance and pollution free. Solar electric energy demand has grown consistently b y 20% to 25% per annum over the past 20 years, which is mainly due to its decreasing costs and prices. This decline has been driven by the following factors.

1) An increasing efficiency of solar cells,
2) Manufacturing technology improvements,
3) Economies of scale.

PV inverter, which is the heart of a PV system, is used to convert dc power obtained from PV modules into ac power to be fed into the grid. Improving the output waveform of the inverter reduces its respective harmonic content and, hence, the size of the filter used and the level of Electromagnetic Interference (EMI) generated by switching operation of the inverter. In recent years, multilevel inverters have become more attractive for researchers and manufacturers due to their advantages over conventional three level PWM Inverters. They offer improved output waveforms, smaller filter size and lower EMI, lower Total Harmonic Distortion (THD). The three common topologies for multilevel inverters are as follows:

1) Diode clamped (neutral clamped),
2) Capacitor clamped (flying capacitors),
3) Cascaded H-bridge inverter.

In addition, several modulation and control strategies have been developed or adopted for multilevel inverters, including the following multilevel sinusoidal (PWM), multilevel selective harmonic elimination, & Space Vector modulation. A typical single phase three-level inverter adopts full-bridge configuration by using approximate sinusoidal modulation technique as the power circuits. The output voltage then has the following three values: zero, positive (+Vdc), and negative(-V dc) supply dc voltage (assuming that Vdc is the supply voltage). The harmonic components of the output voltage are determined by the carrier frequency and switching functions. Therefore, their Harmonic reduction is limited to a certain degree. To overcome this limitation, this paper presents a five-level PWM inverter whose output voltage can be represented in the following five levels: zero,+1/2Vdc, Vdc, , -1/2V dc , and -V dc . As the number of output levels increases, the harmonic content can be reduced. This inverter topology uses two reference signals, instead of one reference signal, to generate PWM signals for the switches. Both the reference signals V ref1 and Vref2 are identical to each other, except for an offset value equivalent to the amplitude of the carrier signal Vcarrier, as shown in Fig.1.

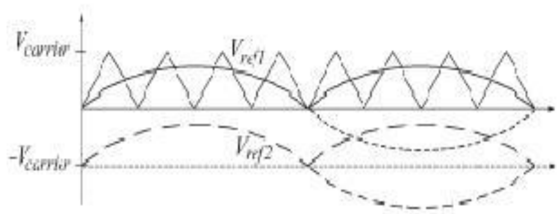

Fig.1 Carrier and reference signals

Because the inverter is used in a PV system, a Fuzzy control scheme is employed to keep the output current sinusoidal and to have high dynamic performance under rapidly changing atmospheric conditions and to maintain the power factor at near unity. Simulation results are presented to validate the proposed inverter configuration.

II. FIVE LEVEL INVERTER TOPOLOGY AND PWM LAW

The proposed single phase five level inverter topology is shown in Fig.2. The inverter adopts a full-bridge configuration with an auxiliary circuit. PV arrays are connected to the inverter via a dc–dc Boost converter.

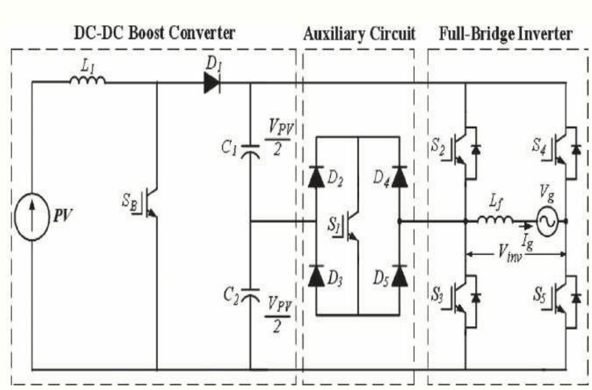

Fig.2 Single phase five level inverter topology

Because the proposed inverter is used in a grid-connected PV system, utility grid is used instead of load. The dc–dc boost converter is to be used to step up inverter output voltage Vin to be more than 2 of grid voltage Vg to ensure power flow from the PV arrays into the grid.

A filtering inductance Lf is used to filter the current injected into the grid. The injected current must be sinusoidal with low harmonic distortion. In order to generate sinusoidal current, sinusoidal PWM is used because it is one of the most effective methods. Sinusoidal PWM is obtained by comparing a high frequency carrier with a low frequency sinusoid, which is the modulating or reference signal. The carrier has a constant period; therefore, the switches have constant switching frequency. The switching instant is determined from the crossing of the carrier and the modulating signal.

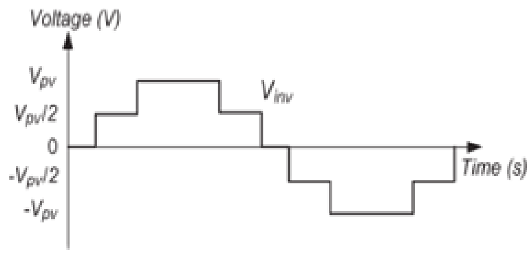

Fig.3 Ideal five-level inverter output voltage V_{inv}.

III. OPERATIONAL PRINCIPLE OF THE PROPOSED INVERTER

Because PV arrays are used as input voltage sources, the voltage produced by the arrays is known as Varrays. Varrays boosted by a dc–dc boost Converter to exceed 2Vg. The voltage across the dc-bus capacitors is known as V pv. The operational principle of the proposed inverter is to generate five level output voltage, i.e., 0, +Vpv/2, +Vpv , -Vpv /2, and -Vpv . Proper switching control of the auxiliary circuit can generate half level of PV. Supply voltage, i.e., +Vpv/2, +V pv, -Vpv /2. Two reference signals V ref1 and V ref2 will take turns to be compared with the carrier signal at a time. If V ref1 exceeds the peak amplitude of the carrier signal Vcarrier, V ref2 will be compared with the carrier signal until it reaches zero. At this point onward, V ref1 takes over the comparison process until it exceeds Vcarrier. This will lead to a switching pattern, as shown in Fig. 4. Switches S1–S3 will be switching at the rate of the carrier signal frequency, whereas S4 and S5 will operate at a frequency equivalent to the fundamental frequency. Table I illustrates the level of *V*inv during S1–S5 switch on and off.

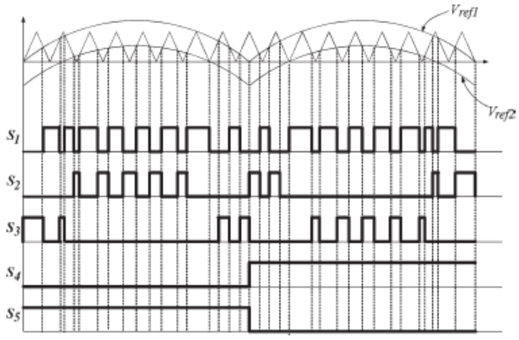

Fig.4 switching pattern for the single-phase five-level inverter

IV. CONTROL SYSTEM ALGORI-THM AND IMPLEMENTATION

The feedback controller used in this application utilizes the FUZZY algorithm. As shown in Fig., the current injected into the grid, also known as grid current I g, is sensed and fed back to a comparator which compares it with the reference current I ref. I ref is obtained by sensing the grid voltage and converting it to reference current and multiplying it with constant m. This is to ensure that Ig is in phase with grid voltage V g and always at near-unity power factor. One of the problems in the PV generation systems is the amount of the electric power generated by solar arrays always changing with weather conditions, i.e., the intensity of the solar radiation.

TABLE I: Inverter Output Voltage during S1-S5 Switch ON and OFF

S1	S2	S3	S4	S5	Vinv
ON	OFF	OFF	OFF	ON	+Vpv/2
OFF	ON	OFF	OFF	ON	+Vpv
OFF	OFF	OFF	ON	ON	0
ON	OFF	OFF	ON	OFF	-Vpv/2
OFF	OFF	ON	ON	OFF	Vpv

A maximum power point tracking (MPPT) method or algorithm, which has quick-response characteristics and is able to make good use of the electric power generated in any weather, is needed to solve the aforementioned problem. Constant m is derived from the MPPT algorithm. The perturb and observe algorithm is used to extract maximum power from PV arrays and deliver it to the inverter. The instantaneous current error is fed to a FUZZY controller. The integral term in the FUZZY controller improves the tracking b y reducing the instantaneous error between the reference and the actual current. The resulting error signal u which forms Vref1 and V ref2 is compared with a triangular carrier signal and intersections are sought to produce PWM signals for the inverter switches.

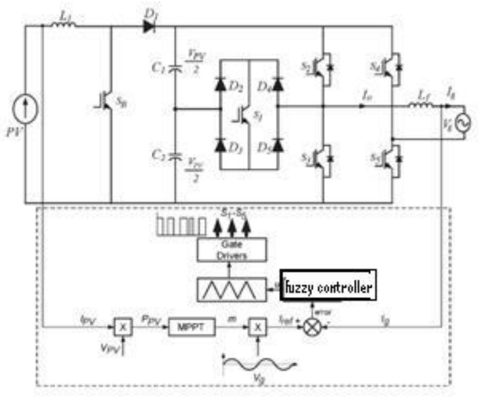

Fig.5 Five level inverter with FUZZY control.

The Trapezoidal sum approximation is used to transform the integral term into the discrete time domain because it is the most straightforward technique. The proportional term is directly used with out approximation. The Simulation result for five level inverter for grid connected PV system

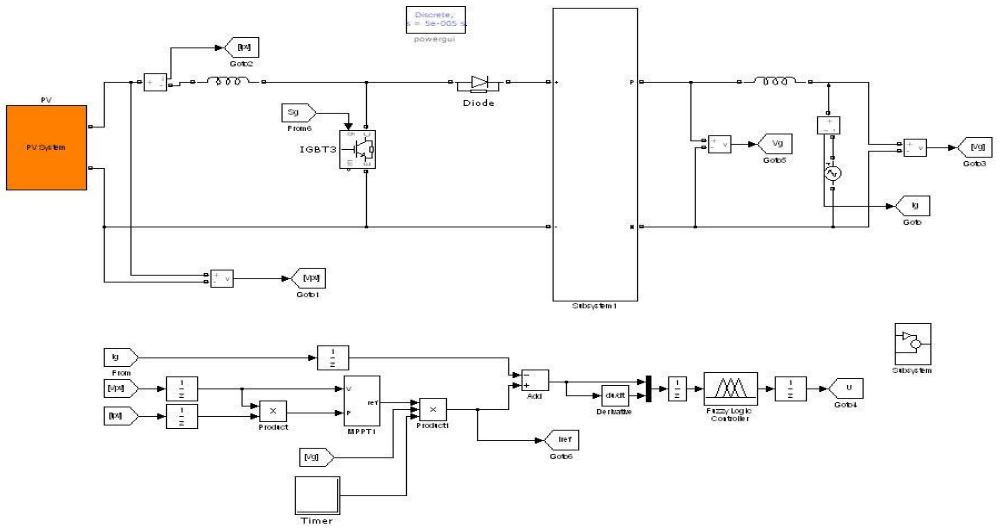

Fig.7 Simulink diagram for five level inverter

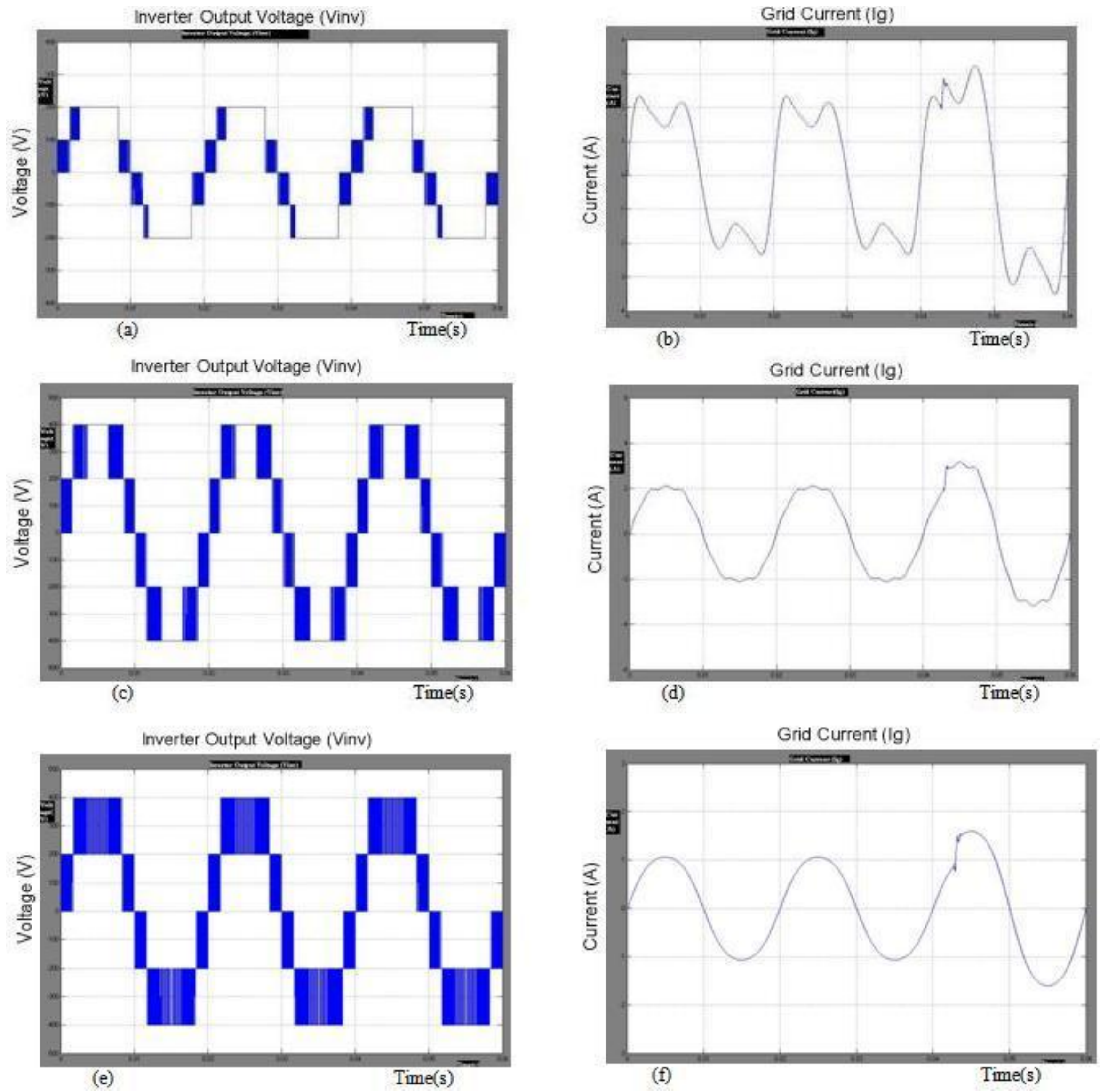

Fig.7 Inverter output voltage (*V*inv) and grid current (*Ig*) for different values of *M*.

(a) *V*inv for $M<0.5$. (b) *Ig* for $M<0.5$. (c) *V*inv for $M>1.0$. (d) *Ig* for $M>1.0$. (e) *V*inv for $0.5 \le M \le 1.0$. (f) *Ig* for $0.5 \le M \le 1.0$.

Table II: THD Analysis Table

Modulation Index(M)	Using Fuzzy Controller
$M<0.5$	39.94%
$M>1.0$	9.39%
$0.5 \leq M \leq 1.0$	4.65%

Table III: PV Multilevel Inverter Specifications and Controller Parameter

S1-S5 & SB	IGBT IRG4PC40UDPBF Vce=600, Ic=20A
D1-D5	RHEP30120 Vrr=1200V, I=30A
L1	2.2mH
Lf	3mH
C1-C2	220μF Vdc=500V
Switching Frequency	20KHz
Sampling Frequency	78KHz

V. SIMULATION RESULTS

In order to verify that the proposed inverter can be practically implemented in a PV system, simulations were performed by using MATLAB SIMULINK. It also helps to confirm the PWM switching strategy which then can be implemented. It consists of two reference signals and a triangular carrier signal. Both the reference signals are compared with the triangular carrier signal to produce PWM switching signals for switches S1−S5. Note that one leg of the inverter is operating at a high switching rate equivalent to the frequency of the carrier signal, whereas the other leg is operating at the rate of fundamental frequency (i.e., 50 Hz). The switch at the auxiliary circuit S1 also operates at the rate of the carrier signal. As mentioned earlier, the modulation index *M* will determine the shape of the inverter output voltage *V*inv and the grid current *Ig*. Fig.7 shows *V*inv and *Ig* for different values of *M*.

The dc-bus voltage is set at 400 V (> $\sqrt{2}Vg$; in this case, *Vg* is 240 V) in order to inject current into the grid. Fig. 7(a) shows that *V*inv is less than $\sqrt{2}Vg$ due to M being less than 0.5.The inverter should not operate at this condition because the current will be injected from the grid into the inverter, rather than the PV system injecting the current into the grid, as shown in Fig. 7(b). Over modulation condition, which happens when $M > 1.0$, is shown in Fig. 7(c). It has a flat top at the peak of the positive and negative cycles because both the reference signals exceed the maximum amplitude of the carrier signal. This will cause *Ig* to have a flat portion at the peak of the sine waveform, as shown in Fig. 7(d). To optimize the power transferred from PV arrays to the grid, it is recommended to operate at $0.5 \leq M \leq 1.0$. *V*inv and *Ig* for optimal operating condition are shown in Fig. 7(e) and (f), respectively. As *Ig* is almost a pure sine wave, the THD can be reduced compared with that under other values of *M*.

VI. CONCLUSION

This paper presented a single-phase multilevel inverter for PV application. It utilizes two reference signals and a carrier signal to generate PWM switching signals. The circuit topology, modulation law, and operational principle of the proposed inverter were analyzed in detail. A FUZZY control is implemented to optimize the performance of the inverter. MATLAB/SIMULINK results indicate that the THD of the Fuzzy Controller Circuit is much lesser than that of the THD of the PI Controller Circuit. Furthermore, both the grid voltage and the grid current are in phase at near-unity power factor.

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