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# Simulation of Multilevel Inverter for Grid Connected Solar PV Plant Employing Fuzzy Controller

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*Abstract*— **In this paper a single-phase multi-level photovoltaic (PV) inverter topology for grid-connected PV systems with a novel pulse width-modulated (PWM) control scheme is used for performance analysis of grid connected solar PV plants.**

**Among all renewable energy sources solar energy is one of the abundant sources of energy which is widely available throughout the globe, except towards the poles. Capturing solar energy is possible by means of photovoltaic (PV) solar cells which produce direct current by the principle of photoelectric effect. A number of PV cells connected in series and parallel generate the desired power.**

**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. Furthermore, both the grid voltage and the grid current are in phase at near-unity power factor**

***Keywords—PV Cell; inverter; fuzzy logic; converter; total harmonic distortion.***

## I. INTRODUCTION

This 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 by 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 (-Vdc) 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, , -1/2Vdc , and -Vdc . As the number of output levels increases, the harmonic content can be reduced. This inverter topology uses

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two reference signals, instead of one reference signal, to generate PWM signals for the switches. Both the reference signals Vref1 and Vref2 are identical to each other, except for an offset value equivalent to the amplitude of the carrier signal Vcarrier, as shown in Figure.

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.

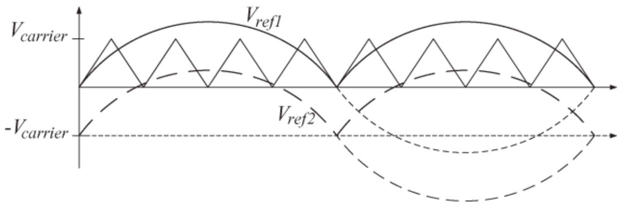


Figure: Carrier and Reference Signals

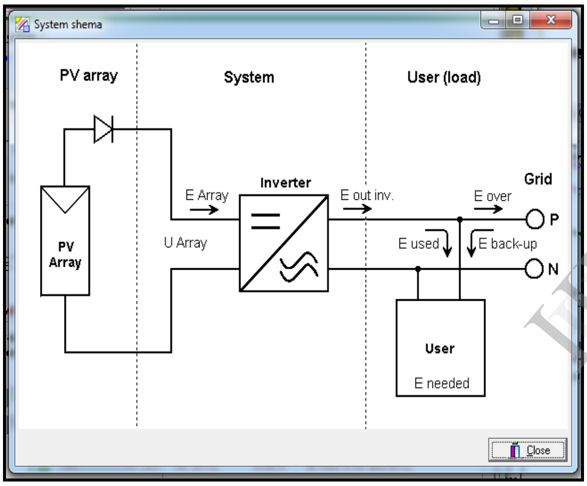


Figure 1: Scheme of the System

## II. MAJOR SYSTEM COMPONENTS

Solar PV system includes different components that should be selected according to your system type, site location and applications.

The major components for solar PV system are solar charge controller, inverter, battery bank, auxiliary energy sources and loads (appliances).

- PV module: - converts sunlight into DC electricity.
- Solar charge controller: - regulates the voltage and current coming from the PV panels going to battery and prevents battery overcharging and prolongs the battery life.
- Inverter: - Converts DC output of PV panels into a clean AC current for AC appliances or fed back into grid line.
- Battery:-stores energy for supplying to electrical appliances when there is a demand.
- Load:-are electrical appliances that connected to solar PV system such as lights, radio, TV, computer, refrigerator, etc.
- Auxiliary energy sources: - is diesel generator or other renewable energy sources.

## III. FIVE LEVEL INVERTER TOPOLOGY

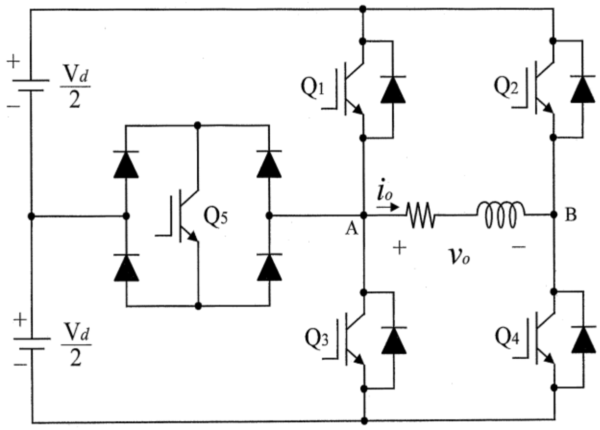


Figure 2: Five level Inverter Topology

Fig.2 shows a configuration of the proposed single-phase five-level PWM inverter. One switching element and four diodes added in the conventional full-bridge inverter are connected to the centre-tap of dc power supply. Proper switching control of the auxiliary switch can generate half level of dc supply voltage. The operation of proposed inverter can be divided into 10 switching states as illustrated in Fig. 2. Operational states of the conventional inverter are shown in Fig. 2(a),(b), (e), (f), (i), and (j) in sequence, and additional states in the proposed inverter synthesizing half level of dc bus voltage are shown in Fig. 2(c), (d), (g), and (h). The additional switch must be properly switched considering the direction of loadcurrent.

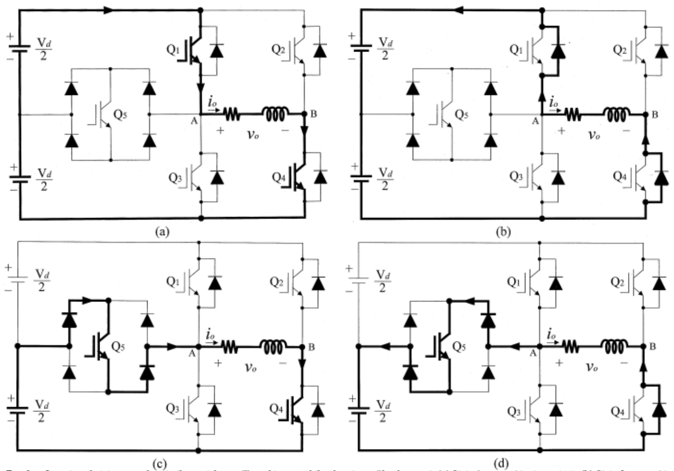


Fig. 2. Operational states according to the switch on-off conditions and the direction of load current. (a) State 1: $v_o = V_d$, $i_o = (+)$. (b) State 2: $v_o = V_d$, $i_o = (-)$. (c) State 3: $v_o = V_d/2$, $i_o = (+)$. (d) State 4: $v_o = V_d/2$, $i_o = (-)$. (e) State 5: $v_o = 0$, $i_o = (+)$. (f) State 6: $v_o = 0$, $i_o = (-)$.

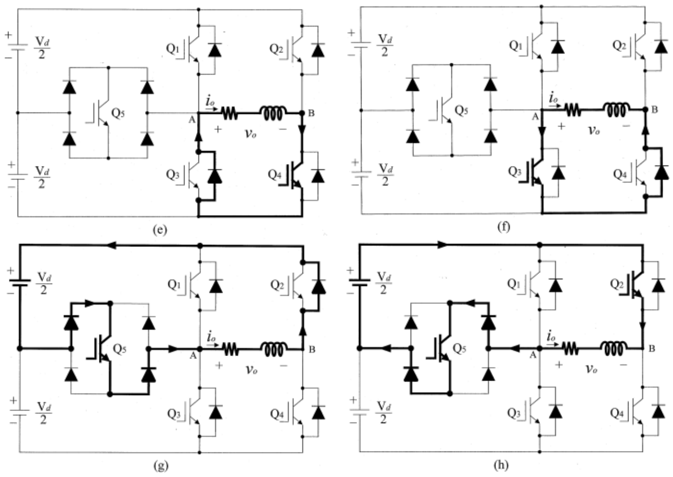


Fig. 2. (Continued) Operational states according to the switch on-off conditions and the direction of load current. (g) State 7: $v_o = -V_d/2, i_o = (+)$. (h) State 8: $v_o = -V_d/2, i_o = (-)$. (i) State 9: $v_o = -V_d, i_o = (+)$. (j) State 10: $v_o = -V_d, i_o = (-)$.

The switching patterns adopted in the proposed inverter are illustrated in Fig. 3,

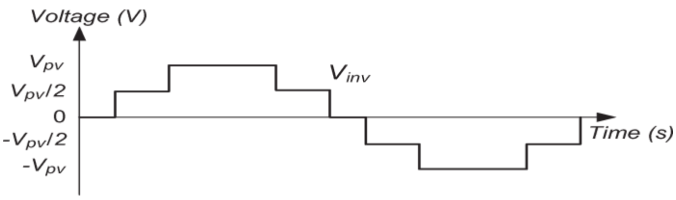


Figure 3: Ideal five-level inverter output voltage Vinv

The output voltage levels according to the switch on off conditions are shown in below

| ON switches | Node A voltage ($V_A$) | Node B voltage ($V_B$) | Output voltage ($V_{AB} = V_o$) |
|---|---|---|---|
| $Q_1$, $Q_4$ | $V_d$ | 0 | $+V_d$ |
| $Q_5$, $Q_4$ | $V_d/2$ | 0 | $+V_d/2$ |
| $Q_3$, $Q_4$ (or $Q_1$, $Q_2$) | 0 ($V_d$) | 0 ($V_d$) | 0 |
| $Q_2$, $Q_5$ | 0 | $V_d/2$ | $-V_d/2$ |
| $Q_2$, $Q_3$ | 0 | $V_d$ | $-V_d$ |

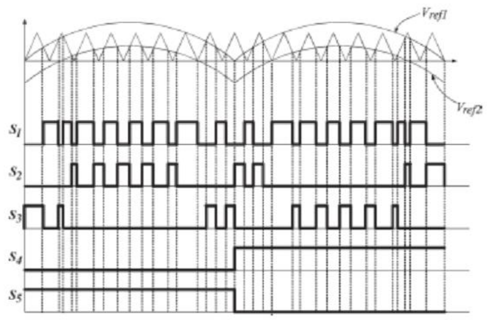


Figure 4: Switching pattern for the single-phase five-level inverter

## IV. PWM STATERGY AND OPERATING PRINCIPLE

Modulation index M for five-level PWM inverter is given as

$$M = \frac{2A_c}{A_m}$$

If M>1, higher harmonics in the phase waveform is obtained. Therefore, M is maintained between 0 and 1. If the amplitude of the reference signal is increased higher than the amplitude of the carrier signal, i.e. M>1, this will lead to over modulation. Large values of M in sinusoidal PWM techniques lead to full over modulation.

## V. REVIEW OF FUZZY LOGIC

Fuzzy logic uses fuzzy set theory, in which a variable is a member of one or more sets, with a specified degree of membership. Fuzzy logic allow us to emulate the human reasoning process in computers, quantify imprecise information, make decision based on vague and in complete data, yet by applying a “defuzzification” process, arrive at definite conclusions.

The FLC mainly consists of three blocks

- Fuzzification
- Inference
- Defuzzification

(i) Fuzzification

The fuzzy logic controller requires that each input/output variable which define the control surface be expressed in fuzzy set notations using linguistic levels. The linguistic values of each input and output variables divide its universe of discourse into adjacent intervals to form the membership functions. The member value denotes the extent to which a variable belong to a particular level. The process of converting input/output variable to linguistic levels is termed as Fuzzification.

(ii) Inference

The behaviour of the control surface which relates the input and output variables of the system are governed by a set of rules. A typical rule would be If x is A THEN y is B When a set of input variables are read each of the rule that has any degree of truth in its premise is fired and contributes to the forming of the control surface by approximately modifying it. When all the rules are fired, the resulting control surface is expressed as a fuzzy set to represent the constraints output. This process is termed as inference.

(iii) Defuzzification

Defuzzification is the process of conversion of fuzzy quantity into crisp quantity. There are several methods available for defuzzification. The most prevalent one is centroid method, which utilizes the following formula:

$$\frac{\int (\mu(x)x)\,dx}{\int \mu(x)\,dx}$$

Where μ is the membership degree of output x.

## VI. PROPOSED FUZZY LOGIC CONTROLLER

Fuzzy logic is implemented to assist the conventional MPPT technique to obtain the MPP operating voltage point Faster and also it can minimize the voltage fluctuation after MPP has been recognized.

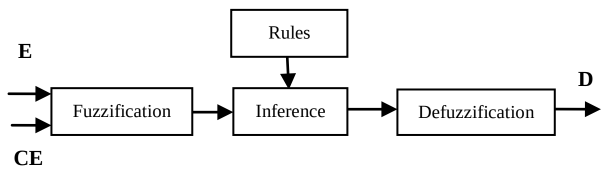


Figure 5: General diagram of a Fuzzy Controller

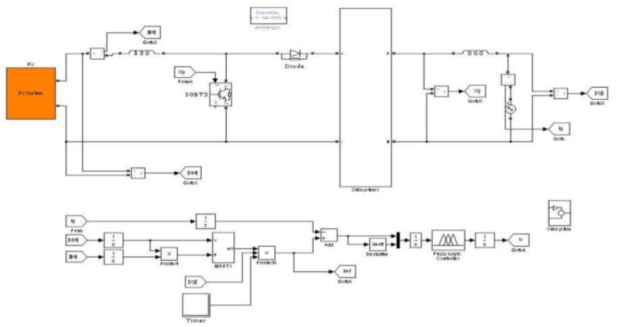

Figure 6: Simulink diagram for Five level inverter

## VII. PV PANEL MODELLING

The physics of the PV cell is very similar to that of the classical diode with a p-n junction. When the junction absorbs light, the energy of absorbed photons is transferred to the electron-proton system of the material, creating charge carriers that are separated at the junction. An ideal PV cell is assumed to have no series loss and no leakage to ground. However, due to its non-ideal structure in nature, there are some losses occurred in real PV cells. Therefore, these losses are expressed by using resistances in equivalent circuits. An equivalent model of a PV cell is as shown in figure 6.

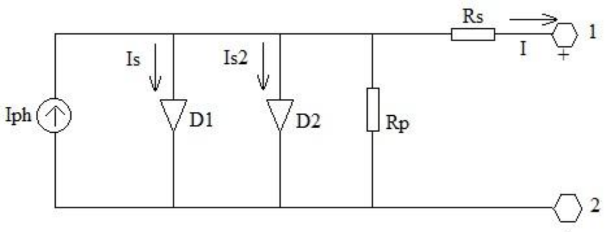


Figure 7: Equivalent Circuit Model of a PV Cell

The shunt resistance Rp is usually very high and hence the current through it can be assumed to be zero. From Kirchhoff's current law it follows that

$$I = Iph - Is - Is2 \quad (6)$$

## VIII. 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 Vinv and the grid current Ig. Vinv and Ig for different values of M. The dc-bus voltage is set at 400 V (> √2Vg; in this case, Vg is 240 V) in order to inject current into the grid. Vinv is less than √2Vg 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. Over modulation condition, which happens when M >1.0. 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. To optimize the power transferred from PV arrays to the grid, it is recommended to operate at $0.5 \leq M \leq 1.0$. Vinv and Ig for optimal operating condition. As Ig is almost a pure sine wave, the THD can be reduced compared with that under other values of M.

## IX. 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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