New Grid connected PV system using Reduced Switch Multilevel Inverter and PID controller

Raghavendra M, S Ramanand, H. Naganagouda

Abstract*— *This paper presents a single-phase five-level photo-voltaic (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. A single-phase phase-locked loop (PLL) is introduced for the grid interfacing system, which enables the PV inverter to get, synchronizes with the utility grid. Also a proportional–integral-derivative current controller is proposed to keep the current injected into the grid sinusoidal and to have high dynamic performance with rapidly changing atmospheric conditions.

Index Terms*—Grid connected PV system, New Multilevel inverter, Solar System, PID controller

I. INTRODUCTION

The demand for renewable energy has increased significantly over the years because of shortage of fossil fuels and greenhouse effect. 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 being unlimited, maintenance and pollution free and its potential to provide sustainable electricity in area not served by the conventional power grid. PV inverter, which is the heart of a PV system, is used to convert dc power obtained from PV modules into ac power and Its control function must follow the voltage and frequency of the utility-generated power presented on the distribution line. Solar grid tie inverters should be designed to operate within allowable power quality limits set by standards like IEEE.In order to maximize the utilization of the solar array for a given insolation and temperature, it is necessary to extract maximum energy from the PV module. Several approaches have been proposed in some literature for tracking MPP accurately in PV cells [1], [8], and [9]. For the synchronization of PV inverter and grid the phase locked loop controller is used [10]-[11].

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This paper presents a single-phase five-level inverter for grid connected rooftop pv system. 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 [4].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 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 Fig. 1.

Here the generated power from the pv module is continuously feed to the residential load. But during the unsuitable atmospheric conditions i.e. when the load demand is not meet by the PV generation at that instant the required energy can be taken out from the utility grid. Also when the PV generation is more than the load requirement then the excess energy can feed to the utility grid. MATLAB/SIMULINK is utilized to predict the dynamic behaviour of the system. This paper proposes the mppt controller and current controller for the grid connected system which enables maximum power extraction from PV module and also the bidirectional energy transformation between utility grid and PV inverter respectively. For synchronization purpose single phase PLL controller has been presented.

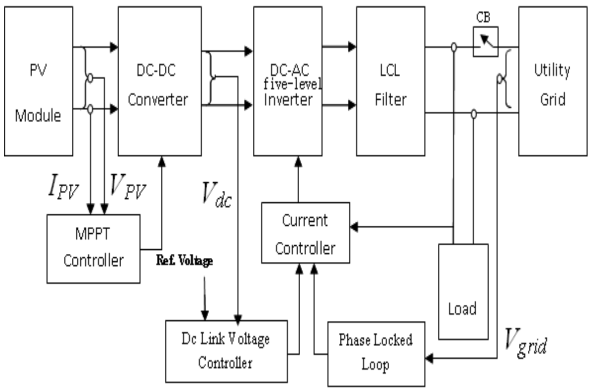

Fig. 1: Complete Block Diagram of Proposed Grid Connected PV System

It is composed of the PV array, the DC–DC converter, the DC–AC (five level) inverter, and the utility grid. The function of the DC– DC converter is to extract the maximum power from the PV array and to transfer the DC energy to the inverter, whereas that of the inverter is to convert the input DC energy into an output AC form and to produce a sinusoidal output current in phase with the utility voltage. For the synchronization between utility grid and PV inverter phase locked loop controller is used.

II. FIVE LEVEL INVERTER TOPOLOGY

The proposed single-phase five-level inverter topology is shown in Fig. 2. The inverter adopts a full-bridge configuration with an auxiliary circuit [4]. PV arrays are connected to the inverter via a dc–dc boost converter. In order to increase the inverter output voltage dc-dc boost converter has been used. The injected current must be sinusoidal with low harmonic distortion. A filtering inductance L_f is used to filter the current injected into the grid. 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.

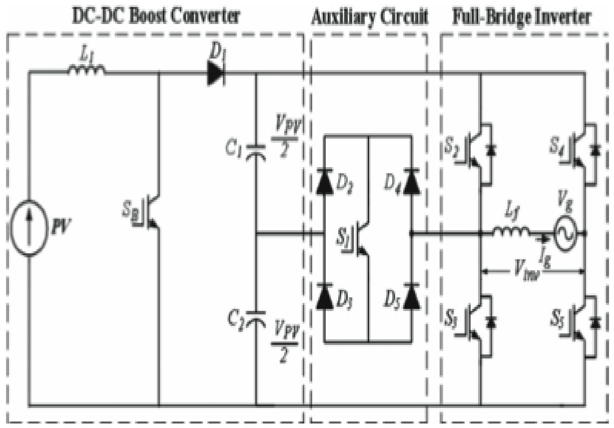

Fig 2: Five level multilevel inverter

The principle of operation of the proposed inverter is shown in fig 1.5. to generate five-level output voltage, i.e., (0,+Vdc/2, +Vdc, -Vdc/2 and –Vdc). An auxiliary circuit, which consists of four diodes and a switch S1, is used between the dc-bus capacitors and the full-bridge inverter. Proper switching control of the auxiliary circuit can generate half level of PV supply voltage, i.e., (+Vdc/2, -Vdc/2) . Two reference signals Vref1 and vref2 will take turns to be compared with the carrier signal at a time. If Vref1 exceeds the peak amplitude of the carrier signal Vcarrier, Vref2 will be compared with the carrier signal until it reaches zero. At this point onward, Vref1 takes over the comparison process until it exceeds Vcarrier. This will lead to a switching pattern, as shown in fig 1.7 and 1.8. 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: Switching Sequence

S_1	S_2	S_3	S_4	S_5	V_{in}
ON	OFF	OFF	OFF	ON	$+V_{pv}/2$
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

Modulation techniques used here is modified sinusoidal pulse width modulation technique. The sine wave is rectified and used here. The technique is shown as waveform in the fig. 3.

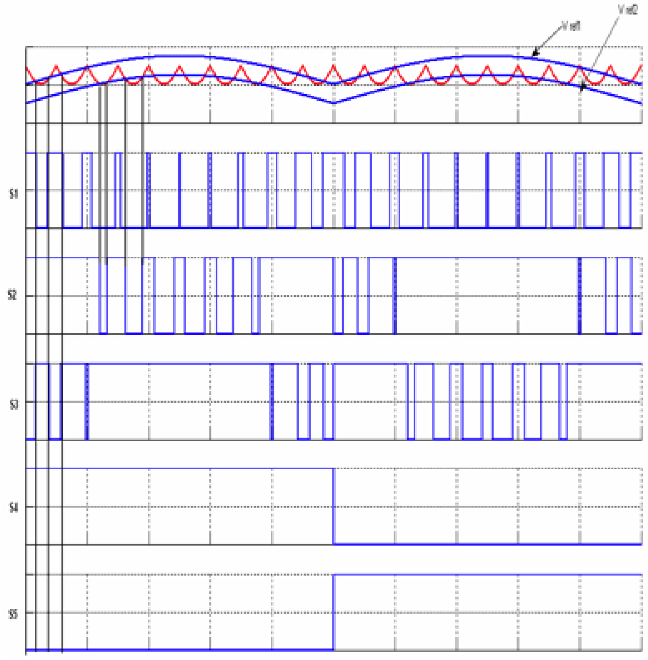

Fig 3. Modulation waveform

III. MPPT

Tracking the maximum power point of a photovoltaic array is usually an essential part of a PV system. As such Many MPP tracking (MPPT) methods have been developed and implemented. Fig. 1.3 shows the characteristic power curve for a PV array. The problem considered by MPPT techniques is to automatically find the voltage V_{MPP} or current I at which a PV array should operate to obtain the maximum power output P_{MPP} under a given temperature and irradiance.

The various MPP tracking (MPPT) methods are
1. Hill climbing method
2. Perturb and observe (P&O) method
3. Incremental conductance method
4. Constant voltage method
5. Short-Circuit Current method

Incremental Conductance Algorithm

The incremental conductance method is based on the fact that the slope of the PV array power curve is zero at the MPP, positive on the left of the MPP, and negative on the right,as given by

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dp/dv=0 at MPP
dp/dv>0 left of MPP
dp/dv<0 right of MPP

where,
dp=change in power ; dv=change in voltage

As power (P) =IV,
dp/dv=d(IV)/dv
dp/dv=I+v dI/dv
dp/dv=I+v ΔI/ΔV

above equation can be written as,

ΔI/ΔV= -I/V,	at MPP
ΔI/ΔV>-I/V,	left of MPP
ΔI/ΔV< -I/V,	right of MPP

The MPP can thus be tracked by comparing the instantaneous conductance (I/V) as shown in the flowchart. Vref is the reference voltage at which the PV array is forced to operate. At the MPP, Vref equals to Vmpp. Once the MPP is reached, the operation of the PV array is maintained at this point unless a change in ΔI is noted, indicating a change in atmospheric conditions and the MPP. The algorithm decrements or increments Vref to track the new MPP. The increment size determines how fast the MPP is tracked. Fast tracking can be achieved with bigger increments but the system might not operate exactly at the MPP and oscillate about it instead; so there is a tradeoff. In [5] and [6], a method is proposed that brings the operating point of the PV array close to the MPP in a first stage and then uses IncCond to exactly track the MPP in a second stage. By proper control of the power converter, the initial operating point is set to match a load resistance proportional to the ratio of the open-circuit voltage (Voc) to the short-circuit current (Isc) of the pv array. This two stage alternative also ensures
that the real mpp is tracked in case of multiple local maxima. In [7], a linear function is used to divide the I-V plane into two areas, one containing all the possible MPPs under changing atmospheric conditions. The operating point is brought into this area and the Incremental Conductance is used to reach the MPP. Incremental Conductance technique is to use the instantaneous conductance and the incremental conductance to generate an error signal.

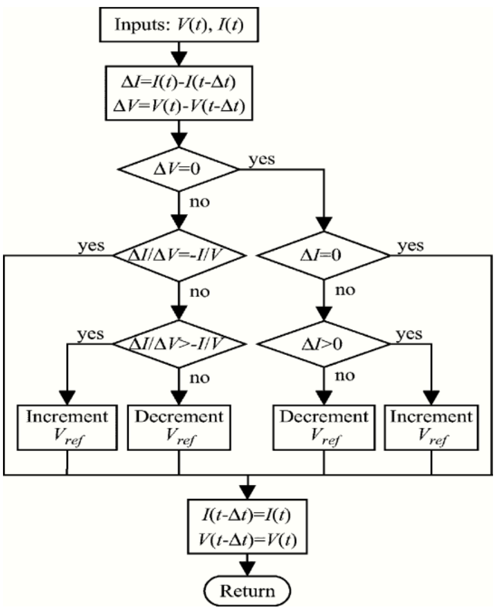

Fig. 4 Incremental Conductance algorithm

Phase Locked Loop Controller

The main goal of the Phase locked loop (PLL) is to track the fundamental grid voltage, even though that severe background harmonics are present [10-11]. Thus the PLL can be regarded as a high-order band-pass filter, with zero phase distortion.

The error into the PID controller included in the PLL structure is given by,

$$\text{Error} = V_{grid} \sin \theta_{grid} \cos \theta_{pll} - V_{grid} \cos \theta_{grid} \sin \theta_{pll}$$

$$= V_{grid} \sin (\theta_{grid} - \cos\theta_{pll})$$

IV. RESULTS AND DISCUSSION

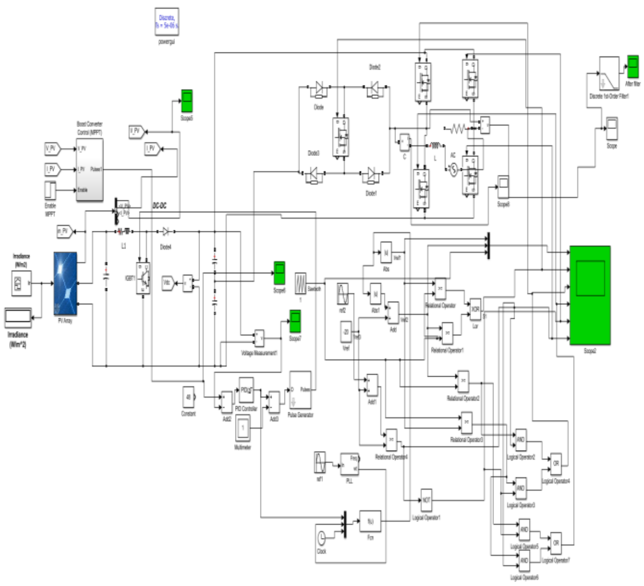

Fig 4. Main circuit

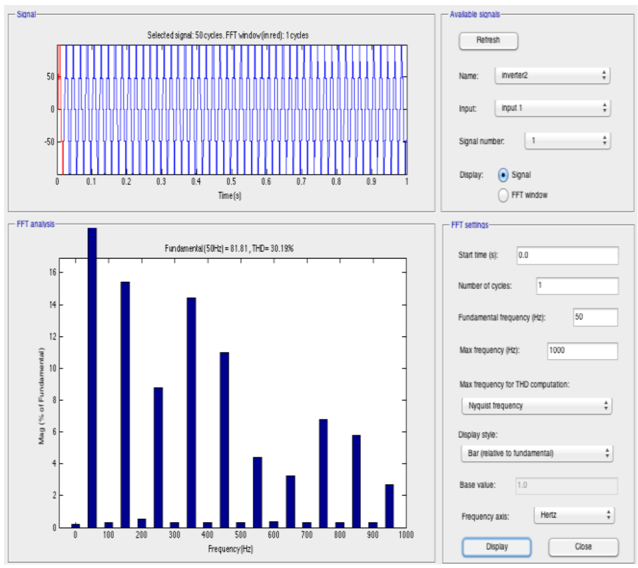

Fig 5 :THD value of Fivelevel level multilevel inverter:

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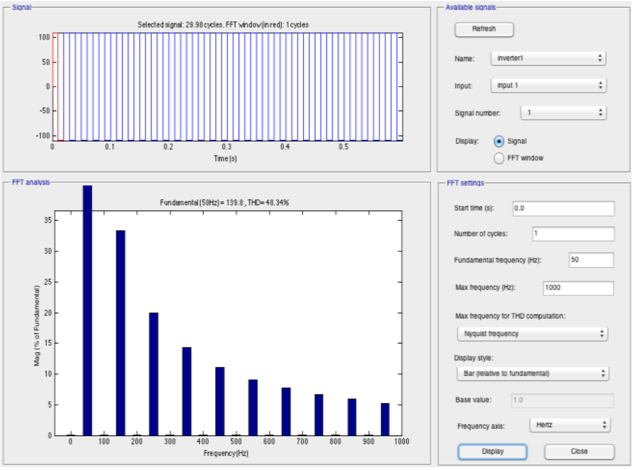

Fig 6: THD value of three level inverter

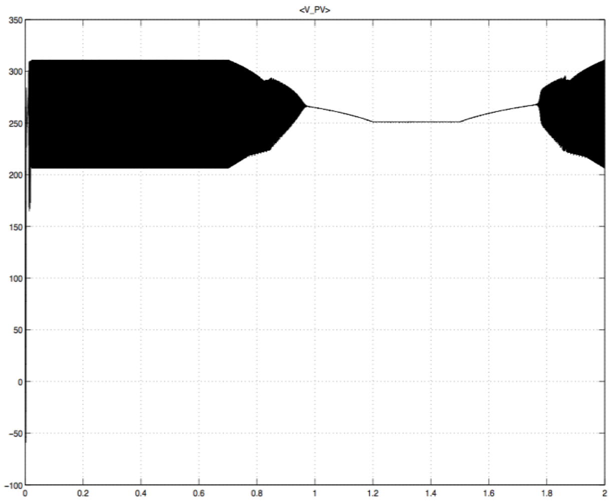

Fig 7:Input solar voltage:

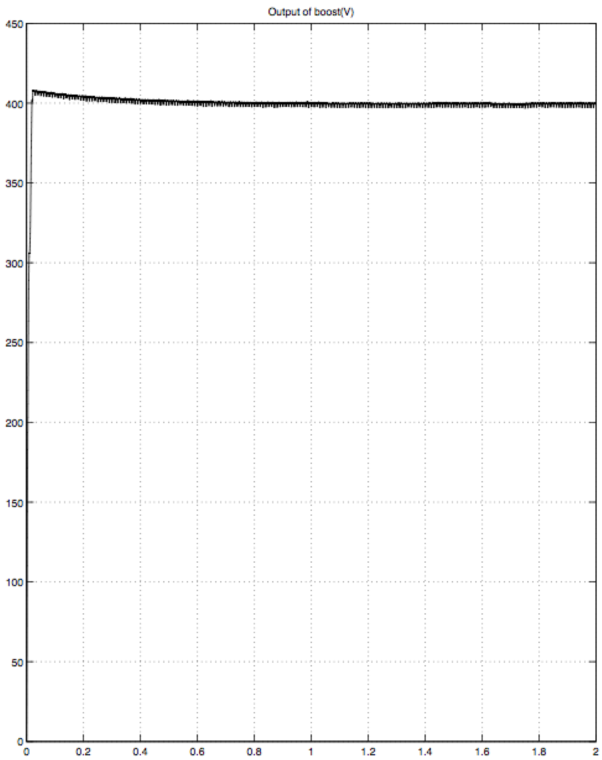

Fig:8 Output Voltage of Boost converter:

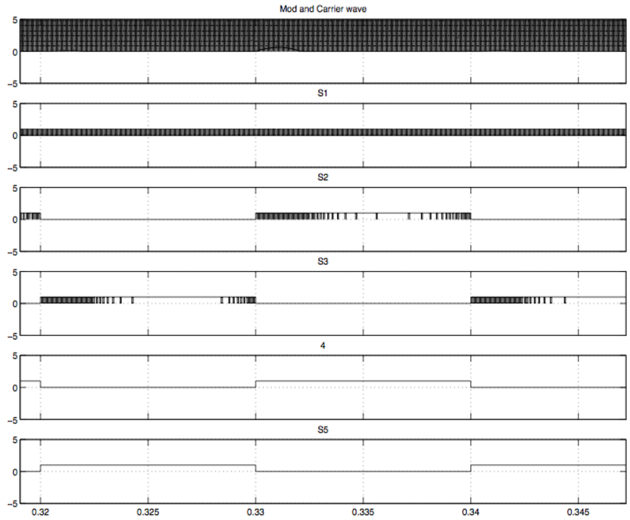

Fig 9: Modulation wave and pulse wave form:

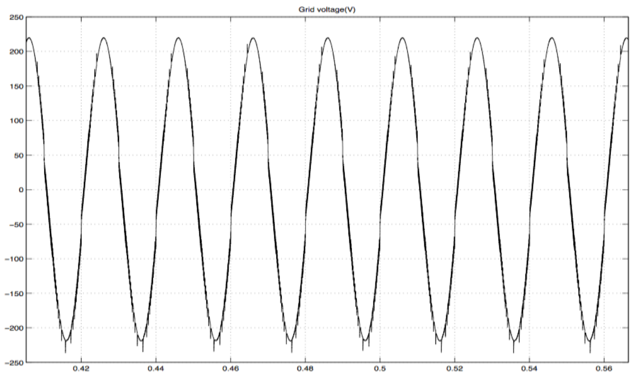

Fig 10: Grid voltage after connecting the solar inverter to grid:

Fig 5 shows the thd value of five level inverter, the value is 30.11% and fig 6 shows the THD value of three level inverter shows the 48.32%. So the reduction of 18.21% is done using the new multilevel inverter.

The fig 7 shows the solar input voltage of 250V and changed suddenly and input voltage is oscillatory. The output of the boost converter produces the boosted constant voltage of 400V shown in fig 8. So the MPPT algorithm gives the voltage with less fluctuation.

Fig 9 shows the new modulation strategy explained in previous chapter. And after connecting it to grid the grid voltage is also presented in fig 10.

V. CONCLUSION

The new five switch multilevel inverter is done using the new control strategy. The multilevel inverter switches are reduced compared to other multilevel inverter. The single phase inverter with H-bridge is compared with the parameter of THD. The new multilevel inverter performs well and it is used in the output of boost MPPT control system and connected to the grid. The MPPT algorithm called incremental conductance method performs good to boost the voltage when the input is oscillatory.

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