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Single Phase Grid Connected Seven Level Photovoltaic Inverter using PI Controller

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Abstract - This paper presents a grid connected single phase seven level inverter fed by a photovoltaic cell with PI closed loop controller. The PV effect is the most important, renewable and sustainable way because solar energy is a never ending source of energy. In this inverter topology a switching pulse width modulation (PWM) technique used with three identical reference signals and one carrier signal as a triangular waveform. A PI closed loop control scheme is implemented for constant sinusoidal voltage level with the rapid change in load conditions. The inverter gives the seven level output voltage which can be expressed as Vdc, 2Vdc/3, Vdc/3, 0,−Vdc,−2Vdc/3 and−Vdc/3. Inverter prototype is also verified using Matlab/Simlink. This seven level inverter produces minimal total harmonic distortions (THD) and offers constant grid voltage with variable load.

Keywords *- Multilevel inverter, Grid connected, Photovoltaic (PV) cell, PWM technique, PI controller, Total harmonic distortion (THD).*

I. INTRODUCTION

The increasing demand, high cost and environmental problems are the main concerns of the energy resources. Due to these problems the renewable energy sources like solar energy and wind energy becoming very popular and the generation of these energy resources growing rapidly. Solar energy systems are gaining interest because these are low in maintenance and pollution free. The use of Photovoltaic (PV) cell is increasing consistently, mainly due to the reducing cost of PV cells. High efficiency, low maintenance and technology improvement are also the important factors of growing demand of PV cell. The PV cell converts sunlight into DC electricity.

Now a day's multilevel inverters are gaining interest of researchers and industries. The DC electricity obtained from PV cell provided to the multilevel inverter.Multilevel inverter isused to convert the DC to AC electricity which is directly fed to the grid. The conventional three and five level inverters can fulfill the requirements through high switching.

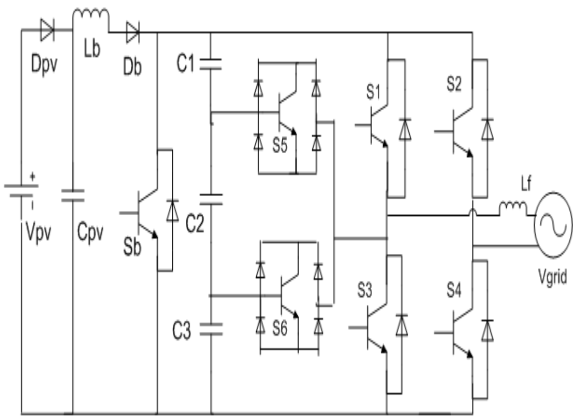

Fig.1.1 - Proposed circuit diagram of single phase grid connected seven level photovoltaic inverter systems

However unfortunately there are some consequences involved like high switching losses, electromagnetic interference and noise. This paper presents a seven level inverter with modified H-bridge technique with two diode bidirectional switches to mitigate these problems as shown in Fig.1.1[1] [2]. This topology makes the system compact, reliable and cheap. This seven level inverter provides improved output voltage waveform with minimal total harmonic distortions. It is also capable of generating constant output voltage with varying load conditions [3].

The topology involves pulse width modulation (PWM) and a proportional integral (PI) close loop control scheme. This inverter uses three reference signals and a carrier signal togenerate the signals for theswitches. The PI controller identifies the error by comparing the reference voltage and grid

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output voltage. The whole model is simulated on MATLAB/Simulink for theverification of seven level inverters output.

II. SEVEN LEVEL INVERTER TECHNIQUE

The Seven level inverter technique was proposed from three and five level inverter.There are three capacitors C1,C2and C3 are connected for voltage division. The modified H-bridge technique has several advantages over other conventional topologies. A DC-DC boost converter was connected between PV input source and inverter because the PV output volatage is less than the grid voltage. A inductor Lf is used for current filteration process which is fed into the grid. The inverter gives the seven level output voltage that can be expressed as Vdc, 2Vdc/3, Vdc/3, 0,−Vdc,−2Vdc/3 and−Vdc/3[4]. These level are generated by the on-off condition of the switches, which is describedbelow in Table 2.1.

Vo	S1	S2	S3	S4	S5	S6
Vdc	On	Off	Off	On	Off	Off
2Vdc/3	Off	Off	Off	On	On	Off
Vdc/3	Off	Off	Off	On	Off	On
0	Off	Off	On	On	Off	Off
0*	On	On	Off	Off	Off	Off
-Vdc/3	Off	On	Off	Off	On	Off
-2Vdc/3	Off	On	Off	Off	Off	On
-Vdc	Off	On	On	Off	Off	Off

Table 2.1 - Voltage level acoording to on-off condition of switches

III. SPWM MODULATION TECHNIQUE

A sinusoidal pulse width modulation (SPWM) process was implemented for the proper switching signals. One triangular carrier signal is compared with the three reference signals. These reference signals have same frequency and amplitude with an offset value that is equal to the carrier signals which is shown in Fig 2. The first reference signal compared with the carrier signal until it exceeds the peak value, second reference signal compared until it exceeds the peak valuethen third reference signal compared with carrier signal. The resulting switching patterns of the signals are shown in Fig 3.

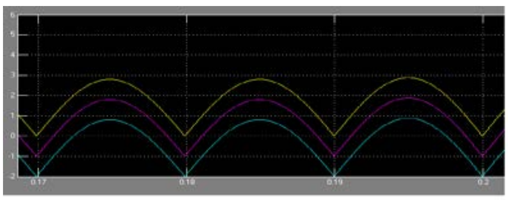

Fig.3.1- Reference signals

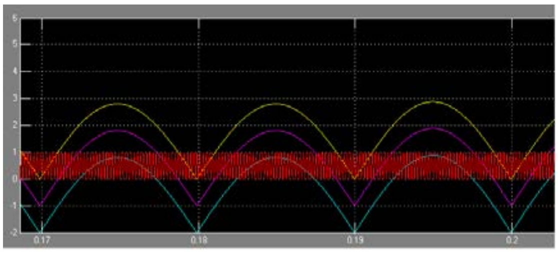

Fig.3.2 -Reference signals with carrier signal

For one complete cycle the inverter operates by six modes of operation which is depends on the Modulation Index [5].The modulation index is defined as the ratio of amplitude of the reference signal and the carrier signal.

$$Ma=\frac{Ar}{Ac}$$

For one reference signal and two carrier signals, the modulation indexcan be represented as:

$$Ma=\frac{Ar}{2Ac}$$

TheSeven Level inverteruses three carrier signals and the modulation index can be represented as:

$$Ma=\frac{Ar}{3Ac}$$

Where, Ac=Peak to peak value of the carrier signals.

Ar=peak value of reference signals.

Here,

Peak to peak value of the carrier signal=1

Peak value of reference signal=2.5

So, Modulation index is:

$$Ma=\frac{2.5}{3*1}=0.83$$

The modulation index is greater than0.66 for the Seven Level inverter. The angle displacement is defined in Table 3.1.

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Θ_1	$\text{Sin}^{-1}(\frac{Ac}{Am})$
Θ_2	$\text{Sin}^{-1}(\frac{2Ac}{Am})$
Θ_3	$\pi-\theta_2$
Θ_4	$\pi-\theta_1$
Θ_5	$\pi+\theta_1$
Θ_6	$\pi+\theta_2$
Θ_7	$2\pi-\theta_2$
Θ_8	$2\pi-\theta_1$

Table 3.1 - Angle displacement

IV. CLOSE LOOP CONTOL PROCESS USING PI CONTROLLER

The main purpose of close loop control system is to create sinusoidal voltage with least number of harmonics under variable load condition. A PI

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controller is implemented for getting the constant voltage by comparing the dc voltage, reference dc voltage and get back the error signal again to the PI controller. This process maintains the output voltage on a fixed value which is greater than the √2*Vgrid. The control block consists a sinup look up table, PI controller,Anti-wind up and a tringular block.The output of the PI controller goes to the anti wind up process for generating the three reference signals wth off set value which is equivalent to the carrier signal [6].The reference signals and carrier signal are taken part in the process of PWM to generate the switching signals, for switches 1 to 6.The close loop control system modelis shown in Fig.4.1.

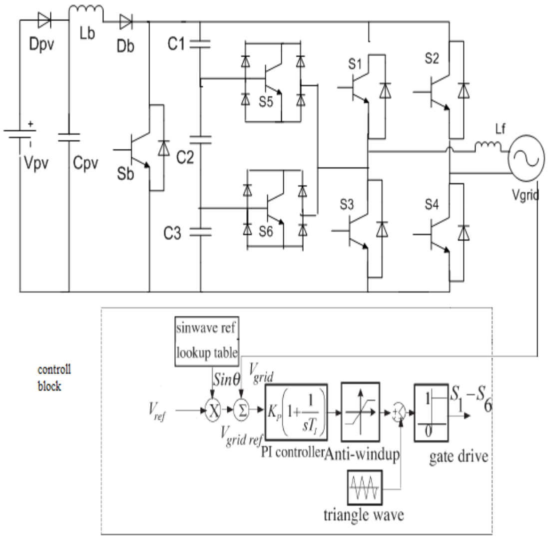

Fig.4.1 - The close loop control system

V. SIMULATION AND EXPERIMENT RESULTS

The single phase grid connected Seven Level photovoltaic inverter model is implemented on the MATLAB-SIMULINK. The Photovoltaic (PV) module is used here as an input source, which is available in thesim power library shown in Fig.5.1.

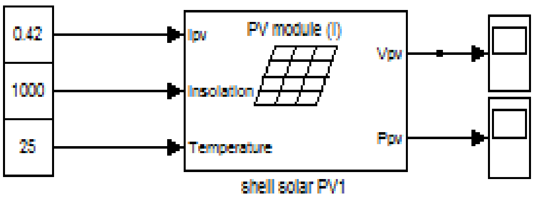

Fig.5.1 - Photovoltaic module

The initial parameters of the module are PV current, irradiation and temperature. The input parameters are definedin table 5.1. The output voltage value of the PV cell was not sufficient for the inverter this can be increased by DC-DC boost converter. The generated voltage after boost converter is represented in Fig.5.2.

S. N.	Parameters	Value
1.	Short circuit current	4.8 A
2.	MPP Current	4.4 A
3.	Open Circuit Voltage	21.7 V
4.	MPP Voltage	17.0 V
5.	Solar Radiation	1000W/m^2
6.	Temperature	25^0 C

Table 5.1 - Input parameters of PV cell

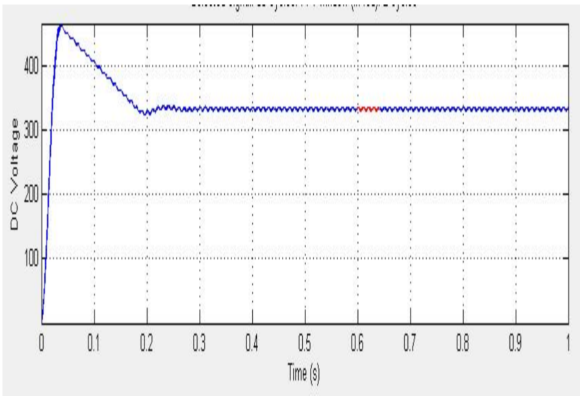

Fig.5.2 - Boost converter output voltage

The output voltage of the boost converter works as an input for the inverter. The proper switching for the switches gives the seven level output voltage shown in Fig.5.2. The switches S1, S3, S5, and S6 are operated at the frequency that is equal to the carrier signal frequency and the switches S2 and S4 are operated at the fundamental frequency. The switching signals for S1-S6 generated by PWM process are shown in Fig.5.4(a), (b) and (c) [7] [8]. The desired output sinusoidal voltage gets generated after the filtration process of the seven level voltage waveform at level of 300 V.

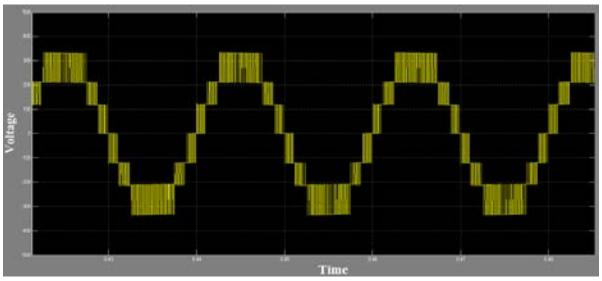

Fig.5.3 - Seven level output voltage

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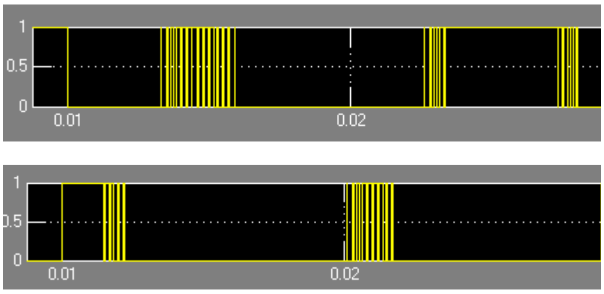

Fig.5.4 (a) - Switching signal for S1 and S3

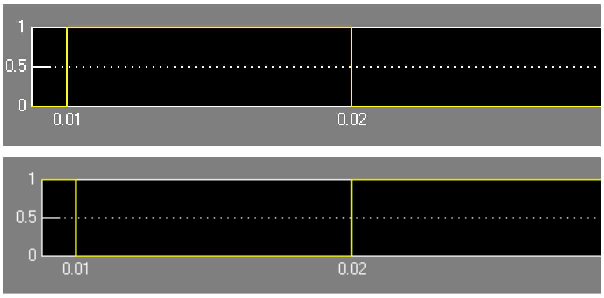

Fig.5.4 (b) - Switching signal for S2 and S4

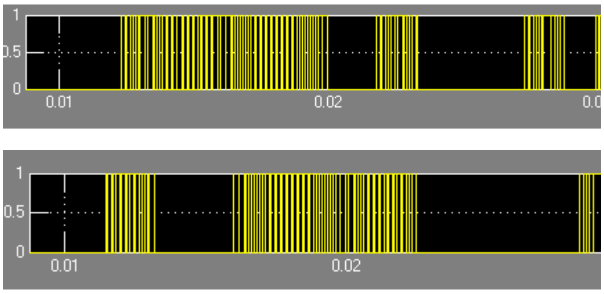

Fig.5.4 (c) - Switching signal for S5 and S6

The DC bus voltage is set at the value of 311.8 V i.e. equal to the $V_m*\sqrt{2}$,where the Vm stands for maximum value of voltage. The output voltage remains same at the variable load condition with minimum THD value represented in table 5.2.

Load		THD	voltage
R	180 Ω	0.47%	300
	200 Ω	0.38%	300
	220 Ω	0.34%	300
	230 Ω	0.31%	300
R, L	40 Ω ,0.623H	0.53%	300
	50 Ω, 0.538H	0.52%	300

Table 5.2 - Different load condition with THD values

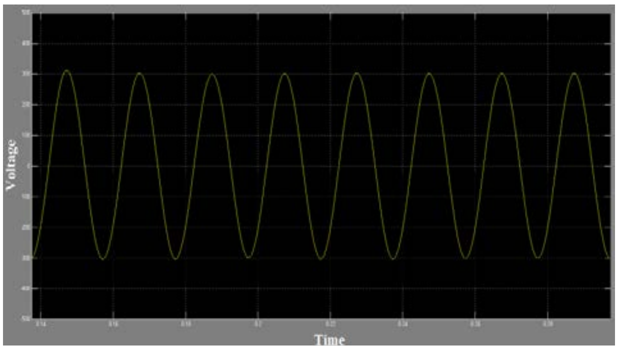

Fig.5.5 - Sinusoidal output voltage

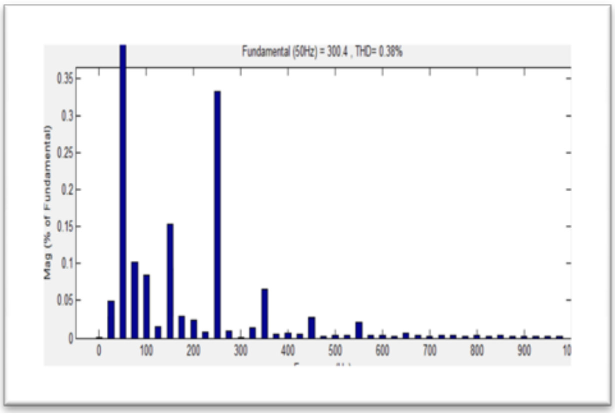

Fig.5.6 - THD value of load value R=180Ω

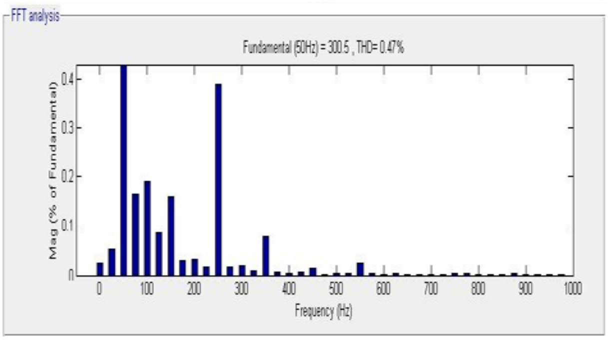

Fig.5.7 - THD value of load value R=180Ω

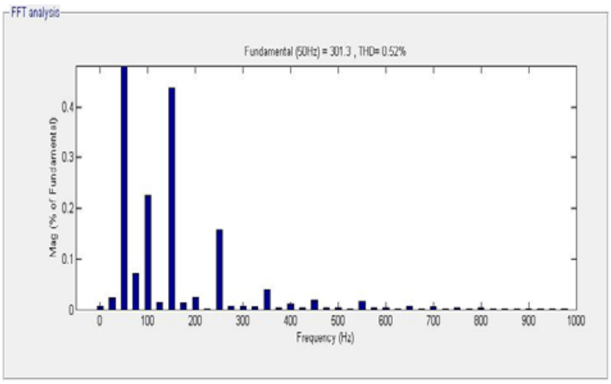

Fig.5.8 - THD value for load value R=50Ω, L=0.538H

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VI. CONCLUSION

Multilevel inverter gives a proper balance output with minimum THD value by changing the load conditions. A PWM technique is used for the proper switching of signals with the use three reference signals and one carrier signal. By calculation of correct modulation index the seven level inverter generates a pure sinusoidal wave form. By comparing conventional three and five multilevel inverterswith the seven level inverter. The seven level inverter gives better results with less THD count. The behavior of the proposed seven level inverter also analyzed and results are verified on the MATLAB/Simulink.

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