

Multilevel Inverter for Grid-Connected PV System Employing Digital PI Controller with an Improved PWM Scheme

Polasa Praveen Kumar¹, Subhash rathod², Chowhan mothilal³

¹M.Tech Student, Department of Electrical Electronics Engineering, VREC, Nizamabad, Telangana, India

²Assistant professor, Department of Electrical and Electronics Engineering, VREC, Nizamabad, Telangana, India

³Assistant professor, Department of Electrical and Electronics Engineering, VCEW, Nizamabad, Telangana, India

Abstract: A single-phase MULTI-level Photovoltaic (PV) inverter topology for grid-connected PV systems with a novel Pulse Width-Modulated (PWM) control scheme. The inverter offers much less Total Harmonic Distortion (THD) and can operate at near-unity power factor. The proposed system is verified through simulation results are compared with that with the conventional single-phase three-level grid-connected PWM inverter. The circuit topology, modulation law, and operational principle of the proposed inverter were explained in detail. The performances of the inverter and Simulation results indicate that the THD of the five-level inverter is much lesser than that of the conventional three-level inverter. Furthermore, both the output voltage and the output current are in phase at near-unity power factor.

Keywords: Grid-connected, multilevel inverter, photovoltaic (PV), pulse width modulated (PWM), inverter, proportional-integral (PI) current.

I. Introduction

Renewable Energy Sources, particularly solar and wind energy, have become very popular and demanding as the world is concerned with fossil-fuel exhaustion and environmental problems caused by conventional power generation. PV sources have the advantage of being maintenance and pollution free. Due to decreasing costs and prices, Solar-electric- energy demand has grown consistency by 20%-25% per annum over the past 20 years. This decline has been driven by Mainly three factors: 1) an increasing efficiency of solar cells; 2) improvements in manufacturing- technology; 3) economics of scale. An inverter, which is an important element in the system, is used to convert dc power from the sources into ac power to be fed into grid.

This paper presents a multisource five-level inverter. In this, a PV panel, an AC source and a DC source are interfaced with their own dc-dc converter to a common dc-ac inverter. This is beneficial compared with the centralized system, because every source can be controlled individually. Further enlargements are easily achieved because a new source with a dc-dc converter can be added into the existing system. A High efficiency is thereby achieved with a flexible design. A five level inverter have great advantages such as improved output waveforms, smaller filter size and lower electromagnetic interference.

In this paper, a single phase multisource five level inverter is presented. It consists of a PV panel, an AC source and a DC source connected to their own dc-dc boost converter. A modified PWM control scheme is presented to generate PWM switching signals for the switches and to produce five output-voltage levels. In this, two reference signals are used instead of one to generate PWM signals for the switches. V_{ref1} and V_{ref2} are the two reference signals and are identical.

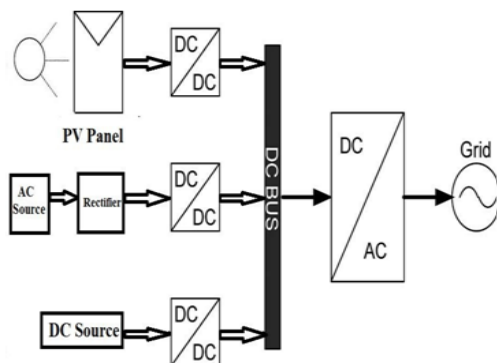


Fig.1. Configuration of multisource inverters.

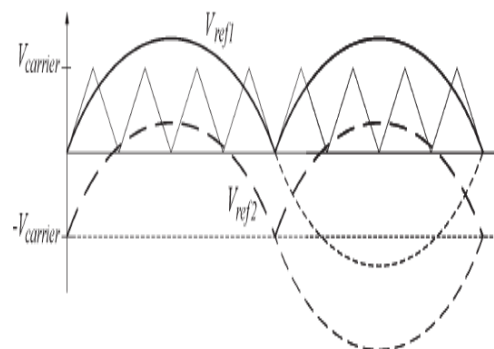


Fig.2. Carrier and reference signals

A Proportional-Integral Current Control Scheme is employed since the inverter is used in PV system in order to keep the output current sinusoidal and to have high dynamic performance under Simulation and experimental results are presented to validate the proposed configuration.

II. Multisource Five-Level Inverter Topology

The single phase multisource five-level inverter topology is shown in fig. 3. It consists of a PV panel, an AC source and a DC source connected to a common.

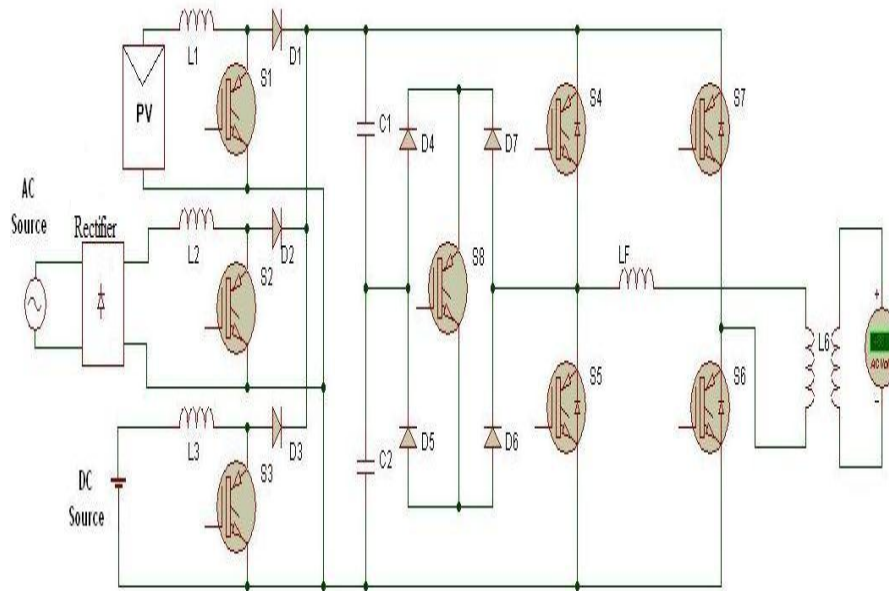


Fig.3. Single-phase multisource five-level inverter topology

dc bus, an auxiliary circuit and a full bridge inverter configuration. Input sources, PV panel, AC source and DC source are connected to the inverter via the dc-dc boost converters. The utility grid is used instead of a load since the inverter is used in a grid-connected system. To track the Maximum Power Point [MPP] independently and to step up inverter output voltage, the dc-dc boost converters are used. A Step-up transformer with a ratio of 1:2 is used.

DC-DC converter can perform MPP tracking [MPPT] for the PV panel. An advantage of using Multisource approach in parallel configuration is that the mixing of different sources becomes possible, i.e., existing PV sources can be extended by adding new higher output sources without comprising the overall system reliability or performance. It also have the advantage of greater safety during installation and maintenance. Each converter module may be able to isolate its connected power source so that wiring of series or parallel connection of these sources can be performed safely depending on the design. Asafelow voltage connection is used for power- source-converter connection To avoid high dc-dc voltage, the dc-dc boost converters are connected in parallel which will eventually increase the size of capacitors and the inverter's cost. Therefore, as the dc bus, only two capacitors with equal capacitance rating are used and the other dc-dc boost converters are connected to this dc bus as shown in fig. 3.

To filter the current injected into the grid, a filtering inductance is used. The current injected into the grid must be sinusoidal with low harmonic distortion. In order to generate sinusoidal current, a sinusoidal PWM is used because it is one of the most effective methods. A sinusoidal PWM is obtained by comparing a high frequency carrier signal with a low- frequency sinusoid signal, 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.

III. Operating Principles of Multisource Five-Level Inverter

Combinations of PV panel, AC source and DC source are used as the input voltage sources. Voltages across the input sources are boosted by dc-dc converters to exceed grid voltage. The proposed inverter produces five output voltage levels. An auxiliary circuit is used which consists of four diodes and a switch connected between the dc-bus capacitors and the full bridge inverter. A five level of input supply voltage is generated by the proper switching control of the auxiliary circuit.

V_{ref1} and V_{ref2} are the two reference signals which will take turns to be compared with the carrier signal at a time.

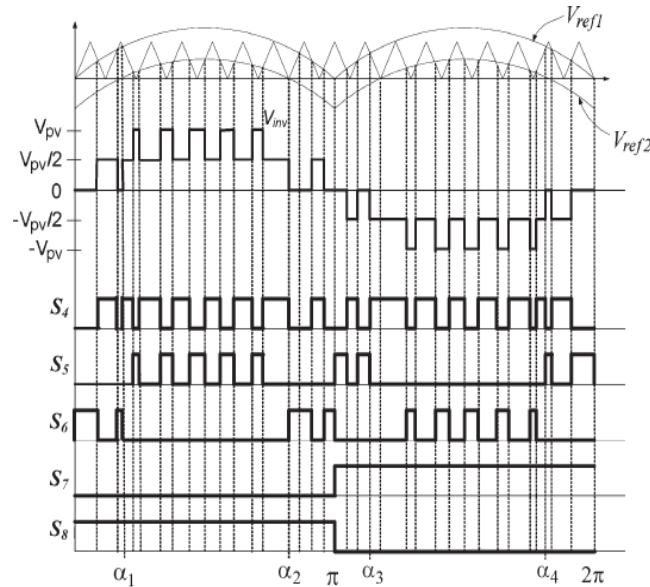


Fig.1 Inverter Output Voltage (V_{inv}) and switching pattern for the single-phase five-level inverter.

TABLE 1
Inverter Output Voltage During S4-S8 Switch On And Off

S_4	S_5	S_6	S_7	S_8	V_{inv}
ON	OFF	OFF	OFF	ON	$+V_{pv}/2$
OFF	ON	OFF	OFF	ON	$+V_{pv}$
OFF	ON or OFF	OFF or ON	ON or OFF	OFF or ON	0
ON	OFF	OFF	ON	OFF	$-V_{pv}/2$
OFF	OFF	ON	ON	OFF	$-V_{pv}$

V_{ref2} will be compared with the carrier signal until it reaches zero when V_{ref1} exceeds the peak amplitude of carrier signal $V_{carrier}$. A switching pattern shown in fig.4 is obtained. Switches S_4 - S_6 will be switching at the rate of the carrier signal frequency whereas Switches S_7 and S_8 will operate at fundamental frequency. Table 1 shows inverter output voltage level V_{inv} during S4-S8 switch on and off.

Since dc-dc boost converters are connected in parallel, if one of the sources is disconnected from the dc bus, the operation of the other dc-dc boost converters will not be affected. Expansion of sources is possible by adding a dc-dc boost converter.

IV. Control System Algorithm

The main problem in PV generation systems is that the amount of electric power generated by the solar arrays is always changing with weather conditions, i.e., the intensity of solar radiation. An MPPT method or algorithm has quick response characteristics and is able to make good use of the electric power generated in any weather. This method is needed to solve the aforementioned problem.

The perturb-and-observe algorithm is used in this paper to extract the maximum power from the PV arrays and deliver it to the inverter. PI algorithm is used as controller for the feedback controller.

The grid current I_g , which is the current injected into the grid is sensed and fed back to the comparator, which compares it with the reference current I_{ref} .

The instantaneous current error is fed to a PI controller. The integral term in the PI controller improves the tracking by reducing the instantaneous error between the reference and the actual current. The resulting error signal is used to control the pulse-width modulation for the switches. Below the minimum power condition or above the maximum power condition, the inverter should not operate to ensure the safety of the PV panel.

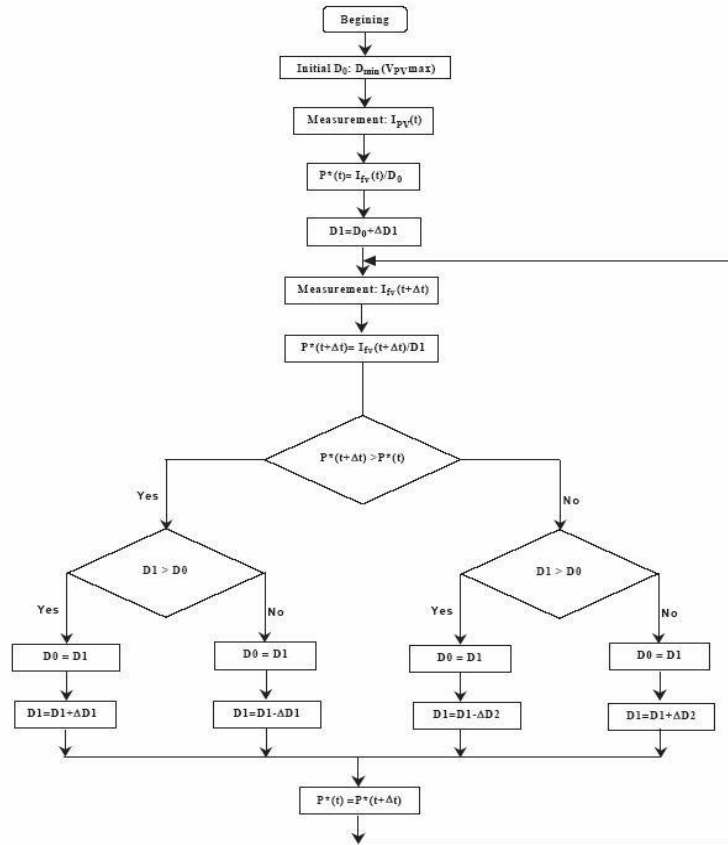


Fig.4 MPPT Flow Chart

V. Simulation Result

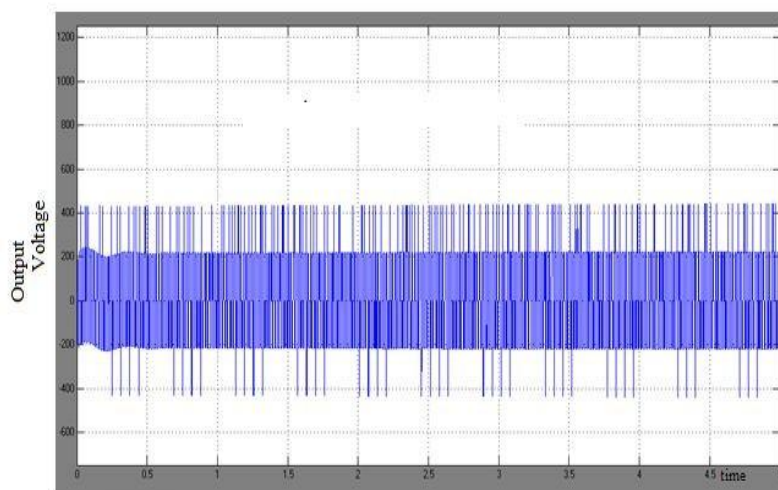


Fig.5 Output Voltage of Multisource Five- Level Inverter.

V. 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 digital PI current control algorithm is implemented in DSP TMS320F2812 to optimize the performance of the inverter. Experimental results indicate that the THD of the five-level inverter is much lesser than that of the conventional three-level inverter. Furthermore, both the grid voltage and the grid current are in phase at near-unity power factor.

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BIOGRAPHIES



Polasa Praveen Kumar

My Self Polasa Praveen Kumar, pursuing my M.Tech from VREC, Nizamabad, Telangana state. And I am having hands on experience in teaching with of two years have been attend ICTIEE (International conference on transformation in engineering education), hubli, Karnataka. Mail id: praveen.polasa@gmail.com



Subhash Rathod

Subhash Rathod, working as assistant professor at Vijay rural engineering college, Nizamabad Telangana state. with having 7 years of teaching experience. And he has done his M.Tech form NIT, Warnagal. Mail id: rathodmt@gmail.com



Chowhan Mothilal

Chowhan Mothilal, he has completed his M.Tech in 2012 and working as assistant professor in Vijay College of engineering for women's, Nizamabad, Telangana state., having 6 years of teaching experience. Mail id: chouhan_bunty@yahoo.com