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# Modeling of Inverter for Photovoltaic Module with Grid Synchronization System

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**ABSTRACT: This paper describes a model of an inverter for grid connected photovoltaic arrays. It is shown that the use of a multi level voltage source inverter without transformer is a reasonable solution for the input to grid in the lower power range (< 2kW). The structure of the photovoltaic power system is presented. Each component of the system is discussed in detail. Simulation results demonstrate the PV inverter voltage and grid connected voltage.**

## I. INTRODUCTION

Photovoltaic (PV) power supplied to the utility grid is gaining more and more attention nowadays. Photovoltaic cells generate electric energy from the solar energy. Although solar energy is available abundantly and free of cost, the cost of the photovoltaic cells is very high. Hence the initial investment on solar energy will be very high. The electrical energy form the solar cells, is dc form and it has to be stored and processed to required form to suite the load requirements.

In recent years, multilevel converters have shown some significant advantages over traditional two-level converters, especially for high power and high voltage applications. In addition to their superior output voltage quality, they can also reduce voltage stress across switching devices. Since the output voltages have multiple levels, lower dv/dt is achieved, which greatly alleviates electromagnetic interference problems due to high frequency switching. Over the years most research work has focused on converters with three to five voltage levels, although topologies with very high number of voltage levels were also proposed. In general, the more voltage levels a converter has the less harmonic and better power quality it provides. However, the increase in converter complexity and number of switching devices is a major concern for multilevel converter. There are several topologies available, being the Neutral Point Clamped [5], Flying Capacitor [6] and Cascaded H bridge inverter [7] . In above different topology we use in the paper cascaded bridge. In recent years many variations and combinations of these topologies have been reported, one of them is the cascaded H-bridge.

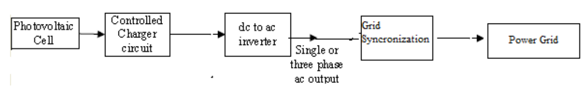


**Fig. 1.** Functional block diagram of photovoltaic power supply unit.

A general arrangement used in photovoltaic standby power supply units is shown in Fig.1. AC to dc inverter circuits are employed to convert the dc voltage to ac voltage of required frequency and voltage. Fundamentally there are two approaches; one is to connect the cells in series to generate high voltage dc and use high voltage dc to ac inverter circuit. [1] This configuration requires devices of higher voltage rating for the inverter. Another approach is to use low voltage power devices for the inverter and step up the voltage using transformers. [2] In both the cases high switching frequency is employed to generate sinusoidal output voltage and to reduce filter requirements. High switching frequency will result in increased switching losses and EMI problems, which in turn calls for the proper design of heat sinks and layout of the power circuit. In order to reduce the switching losses, resonant converters can be used, but the design of these resonant type inverters is complicated and costly.

In this paper a fifteen level multilevel inverter is employed as dc to ac inverter for photovoltaic power supply system. The working principles of this inverter are explained in section II. Fifteen level inverter results in sinusoidal output voltage and current, hence there is no need of filter circuits. Since the output voltage is compatible with the load, there is no need of output transformer. Seven Bridge circuits are connected in cascade.

The voltage across each of the device is 1/7th of the peak output voltage. Hence low voltage MOSFETs are employed. The low voltage MOSFETs have low on state resistance ($R_{ds(on)}$ ), hence the conduction losses are reduced. Step modulation is employed in the proposed inverter, which results in low switching losses. The simulation results are presented. The experimental implementation of the system is present and some aspects of the experimental implementation are given in section V.

## II. INVERTER TOPOLOGIES

The power in the PV cell is in DC mode and grid power in AC mode, therefore there should be a conversion from DC to AC by a power converter. Inverters can do this conversion. The simplest topology that can be used for this conversion is the fifteen level inverter that consists of two switches in each bridge. Each switch needs an anti-parallel diode, so there should be also two anti parallel diodes. There are also other topologies for inverters. A multilevel inverter is a power electronic system that synthesizes a sinusoidal voltage output from several DC sources. These DC sources can be fuel cells, solar cells, ultra capacitors, etc. The main idea of multilevel inverters is to have a better sinusoidal voltage and current in the output by using switches in series. Since many switches are put in series the switching angles are important in the multilevel inverters because all of the switches should be switched in such a way that the output voltage and current have low harmonic distortion. Multilevel inverters have three types. Diode clamped multilevel inverters, flying capacitor multilevel inverters and cascaded bridge multilevel inverter.

The concept of this inverter is based on connecting 7 half bridge converter in series to get a DC voltage output. The output voltage is the sum of the voltage that is generated by each cell. The number of output voltage levels are 2n+1, where n is the number of cells. After that this output voltage injected of an H-bridge inverter. The switching angles can be chosen in such a way that the total harmonic distortion is minimized. One of the advantages of this type of multilevel inverter is that it needs less number of components comparative to the Diode clamped or the flying capacitor, so the price and the weight of the inverter is less than that of the two former types. The Half H-Bridge Configuration is shown in Fig. 2. By using single Half H-Bridge we can get 2 voltage levels. The switching table is given in Table 1.

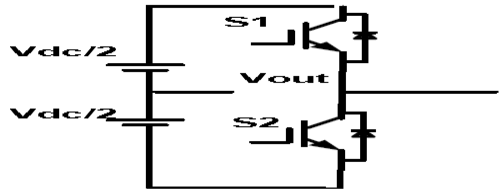


**Fig. 2.** One phase of a cascaded Half bridge multilevel inverter.

**Table 1. Switching table for Half Bridge.**

| Switches Turn ON | Voltage Level |
|---|---|
| S2 | Vdc/2 |
| S1 | -Vdc/2 |

## III. PHOTOLTAIC MODULE –INVERTER INTERFACE

*A. Nominal Power*

The maximum power generated by the investigated PV modules is 100 W at an irradiation of 1000 W/m$^2$, and an ambient temperature of 25 °C. This operating point is however very seldom reached. The nominal power for the inverter is therefore selected to 100 W / 1.2 ≈ 90 W, with the capability of operating at 120% power during short time.

*B. Starting Power*

The inverter should be able to invert even small amounts of DC power into AC power. In other words, the inverter must be able to operate at very low irradiation. The weighted average of efficiencies down to 5%. Thus, the inverter should be able to operate at 5% or less of the nominal power, which is 8 W

*C. Maximum Open-Circuit Voltage*

The worst-case open-circuit voltage across the investigated PV modules is estimated to 48 V at 1000 W/m$^2$, and a cell temperature of 25 °C. Thus, the inverter must withstand at least 48 V without being damaged, and 50 V is selected

*D. Over Voltage Protection*

The inverter must be capable to withstand over-voltages caused by nearby lightning, etc. It is recommended to use a surge arrestor (Metal Oxide Varistor) with an inception voltage of 1.2 times nominal voltage [3]. The arrestor should be connected from the positive to the negative input terminals. The inception- and inclination voltage should therefore be higher than 50 V.

*E. Maximum Short Circuit Current*

The maximum short-circuit current generated by the investigated PV modules is 7.2 A. A maximum current of 8 A is therefore chosen.

## IV. INVERTER – GRID INTERFACE

*A. Voltage*
The nominal voltage for Indian grids is 230 V ±10%.

*B. Maximum Power*
The Indian and some Asian countries allow connection of small inverters to normal feeders, if the total maximum power generation does not exceed 500 W for a regular feeder.

*C. AC-Current*
The amount of AC current injected into the grid is important when speaking about saturation of the distribution transformers. The amount of injected current is 16A.

*D. Frequency*
The nominal frequency for Indian grids is 50 Hz ± 2.

*E. PLL*
The Phase Locked Loop (PLL) is to track the fundamental grid voltage, even though that severe background harmonics are present. Thus, the PLL can be regarded as a high-order band-pass filter, with zero phase distortion.

## V. SIMULATION SETUP

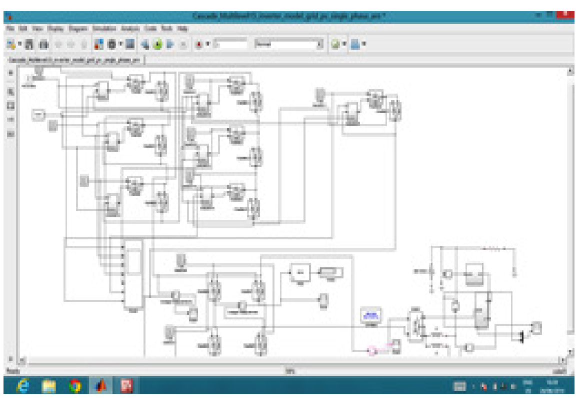

**Fig. 3.** Simulation model of PV inverter.

MATLAB 12 version with simulink is used for simulation purposes under windows xp sp2 platform. A single-phase photovoltaic power supply unit is designed. The distribution system in INDIA is three-phase four wire 415 Volts, 50Hz ac supply. Bulk of the domestic loads operates from single phase 230V, 50 Hz ac system. So the output voltage of the proposed power supply is designed for 230 Volts ac supply for the grid. The peak output voltage of the inverter is 400 volts. For a fifteen-level inverter, seven half-Bridge cells are connected in cascade. The dc bus voltage of individual half bridge cells is 54volts.

The arrangement of photovoltaic cells and single Half-Bridge converter with H-bridge inverter which is connected to grid is shown in Fig.3. Each photovoltaic cell has a rated power of 54W with voltage variation of 16 to 20 volts (nominal 18V) depending on the operating conditions such as light intensity, etc. Three photovoltaic cells are connected in series to get a nominal voltage of 54 volts. Three numbers of 18 volts PV cell packs are connected in series to get a nominal dc bus of 48volts. These batteries are charged from the photovoltaic unit through a controlled charging circuit. The photovoltaic grid voltage and the battery voltage of commercially available photovoltaic power supply units are also 54 Volts and 48 volts respectively.
The photovoltaic panels are mounted such that the panels are given maximum solar energy for most part of the day. Since the capacity of the projected unit is low, photovoltaic panels are mounted on a permanent structure and no maximum power tracking methods are employed.

## VI. RESULT

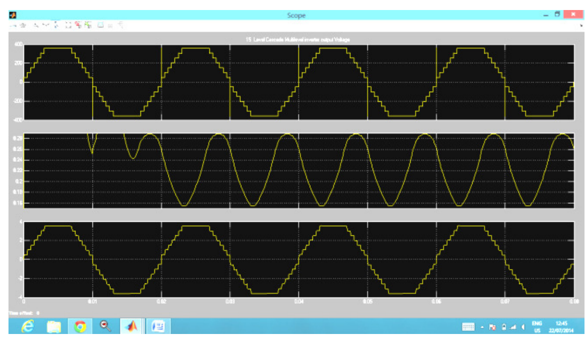

**Fig. 4.** Simulation result 15 level inverter for PV system.

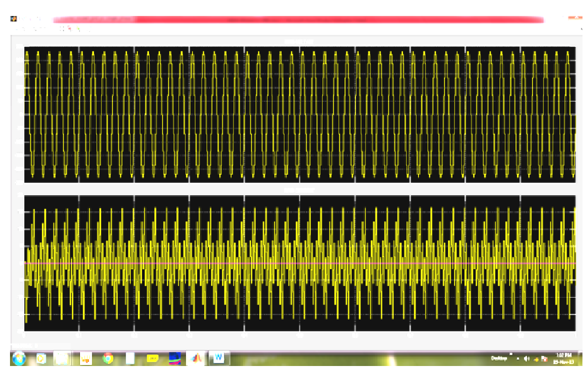

**Fig. 5.** Simulation result of grid injected voltage and current.

A single-phase, 1KVA, R-L load simulation model is taken. The simulation results of phase voltage and the load current are shown in Fig. 4.

Phase voltage is 400V of PV inverter system with output of 15 levels.

The grid injected voltage and injected current waveform are depicted in Fig.5. According to waveform 230V voltage and 16A current is injected in grid supply. Due to the inverter voltage and grid voltage synchronization 15 level inverter output waveform is reduce and it contain 11 level to maintain 230V supply.

## VII. CONCLUSION

The photovoltaic (PV) module is an all-electrical device that converts sunlight into electrical DC power. Solid-state power electronic inverters have been used to connect PV modules to the AC utility grid since the early seventies. The inverter has two major tasks: to inject a sinusoidal current into the grid, and to optimize the operating point of the PV modules, to capture the maximum amount of energy.

Large, Megawatt, PV systems were connected to the grid in the eighties, but the trend is now to connect smaller systems to the grid, in order to overcome certain problems, like non-flexible designs, mismatch losses between the PV modules, etc. These systems are either based on the string-concept, with multiple modules connected in series, or on a single PV module.

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