Utilization of Single Phase Inverters in Photovoltaic System

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***Abstract*—This paper presents a Photovoltaic (PV) system, in which solar energy is taken into consideration as a renewable energy source. Furthermore, the variation in the output responses of PV system because of the effect of various factors, including solar irradiation, temperature, ideality factor and saturation current are shown here in great details. However, it has been noticed that these factors cause reduction in the system's performance. Therefore, in order to improve PV system's efficiency, it is recommended to use a solar panel which follows an ideal solar panel. Finally, with a view to supplying this derived solar energy to the consumer's end, the implementation of inverter is required. For this reason, this paper deals with both half bridge and full bridge single phase inverters with an LC low pass filter appended at their output terminals. It has been found that full bridge inverter gives two times more output than half bridge inverter and this has certainly the advantage of using less valued step up transformer.**

Keywords—Photovoltaic (PV) System; Single Phase Inverters; LC Low Pass Filter and Single Phase Transformers.

I. INTRODUCTION

The research in renewable energy has become an increasingly important topic in the 21st century with the problem of energy crisis becoming more and more aggravated, resulting in increased exploitation and search for new energy resources, such as wind, water, geothermal and solar energy around the world. Solar energy is green energy, which is abundant in nature especially in most summer predominant countries. Photovoltaic (PV) or solar panels are used by solar stand alone systems to supply total electric needs. Apparently, PV systems have a number of advantages over conventional power generating technologies. PV systems can be designed for a variety of applications and operational requirements, and can be used for either centralized or distributed power generation. Moreover, PV systems have no moving parts, are modular, easily expandable and even transportable in some cases. More importantly, energy independence and friendly environmental operation are the two prominent features of solar systems. In general, PV systems that are well designed and properly installed require free fuel such as sunlight, minimal maintenance and have long service lifetimes [1-2]. For this reason, grid connected PV systems are gaining popularity due to the feed in tariff and battery cost reduction.

After the invention of advanced software like PSPICE, MATLAB and so on, it has become easier to carry out the simulations. For example, R. K. Nema carried out computer simulation based study of PV cells using PSPICE [3]. In addition, different researchers have been working on simulation of photovoltaic cells using MATLAB. Hybrid simulation model of PV cell and system using MATLAB and PSPICE was developed by Jiang [4]. The hybrid simulation model includes PV cells and the converter power stage. The model is able to simulate both the I-V characteristics curves and the P-V characteristics curves of PV modules and is used to study different parameters variations' effects on the PV array. J. A. Ramos-Hernanz made the modeling of two solar cells [5] and V. Khanna analyzed the factors that cause changes in the output of solar cell, like: solar irradiation, series resistance, ideality factor, temperature and saturation current [6]. After getting dc output from solar panel, the researchers are working to convert it into ac and then connect it to grid system because most of the equipments, consuming power are rated in ac. Several proposals are given, such as the implementation of pulse width modulated inverters for ac conversion, suitable filters to block the high frequency harmonic components and transformers to control the voltage to a certain value [7-8].

This paper focuses on the simulation based analysis of a PV system, where 36 solar cells and 2 solar modules are considered and also on the various parameters that may cause fluctuation in its responses. The process of integrating this generated solar energy by means of single phase inverters is also depicted here. What is more, this paper contains the design and utility of LC low pass filter, when it comes to suppressing the unwanted components called harmonics.

II. PHOTOVOLTAIC SYSTEM AND THE FACTORS BY WHICH ITS PERFORMANCE IS AFFECTED

A Photovoltaic (PV) system converts light energy directly into electricity. Light shining on the system produces both a current and a voltage to generate electric power. This process requires a material, in which the absorption of light raises an electron to a higher energy state, and the movement of this higher energy electron from the solar cell into an external circuit. The electron then dissipates its energy in the external circuit and returns to the solar panel. All PV energy conversion uses semiconductor materials in the form of a p-n junction. The parameters of PV system are open circuit voltage, short circuit current, maximum power, efficiency and fill factor. Open circuit voltage, V_{oc} is the maximum voltage available from a PV system and this occurs at zero current. Short circuit current, I_{sc} is the current through the PV system when the voltage across the system is zero. Maximum power, P is derived from the system when it delivers power best of its capability. Efficiency, η is defined as the ratio of energy output from the PV system to input energy from the sun and fill factor, FF is defined as the ratio of the maximum power from the PV system to the product of V_{oc} and I_{sc} [9].

In order to simulate the performance of considered PV system consisting of 36 solar cells and 2 solar modules, certain factors are assumed, like solar irradiance=800 W/m^2; ideality factor=1.2; energy gap=1.12; reference temperature=25^0 C; working temperature= 28^0 C; saturation current=10 nA and short circuit current=5.29 A.

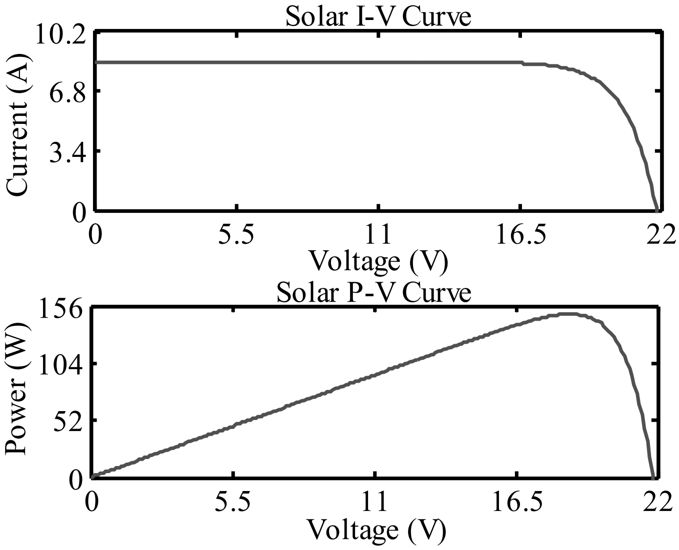

Fig. 1. Performance curves of PV system.

However, the performance of a PV system varies with the change of these factors [10]. Some factors cause large variations while others cause only a slight change.

A. *Effect of Solar Irradiation*

Solar irradiation determines the output quantity of PV system. It usually depends on light intensity, light wavelength, angle of incident light. The output responses of the PV system vary proportionally with solar irradiation.

B. *Effect of Ideality Factor*

Ideality factor of a PV system determines how a particular solar panel follows an ideal solar panel. Ideality factor 1 means the recombination process is limited by minority carrier and ideality factor 2 means it limited by both the carriers. The greater is the ideality factor, the greater is the system's output.

C. *Effect of Temperature*

PV system's output varies with the variation of the temperature. Although the reference temperature is 25^0 C, it varies from time to time. However, the output does not change much with the slight temperature variations.

D. *Effect of Saturation Current*

Saturation current changes the output of the PV system to a great extent. Except the short circuit current, other responses decrease abruptly with the enhancement of saturation current.

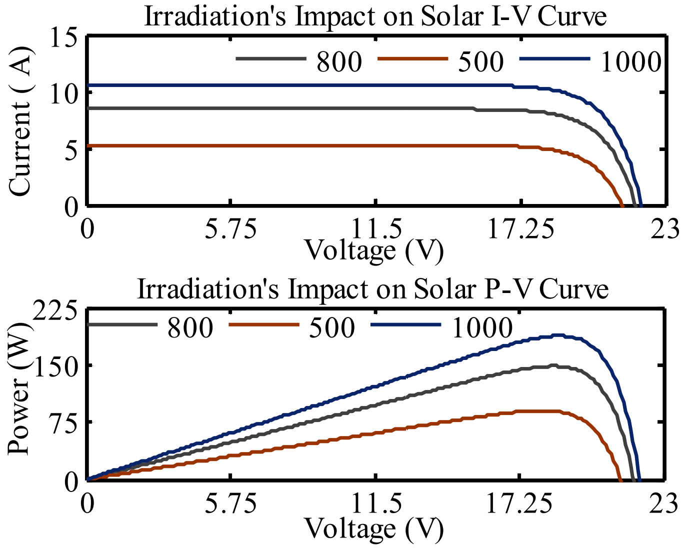

Fig. 2. Impact of solar irradiation on the performance of PV system.

TABLE I. EFFECT OF SOLAR IRRADIATION ON V_{OC}, I_{SC}, P, η, FF

Solar irradiation (W/m^2)	V_{oc} (V)	I_{sc} (A)	P (W)	η	FF
500	21.2	5.2907	90.2104	16.06%	80.42%
800	**21.9**	**8.4651**	**148.5384**	**16.53%**	**80.12%**
1000	22.1	10.5814	188.1612	16.75%	80.46%

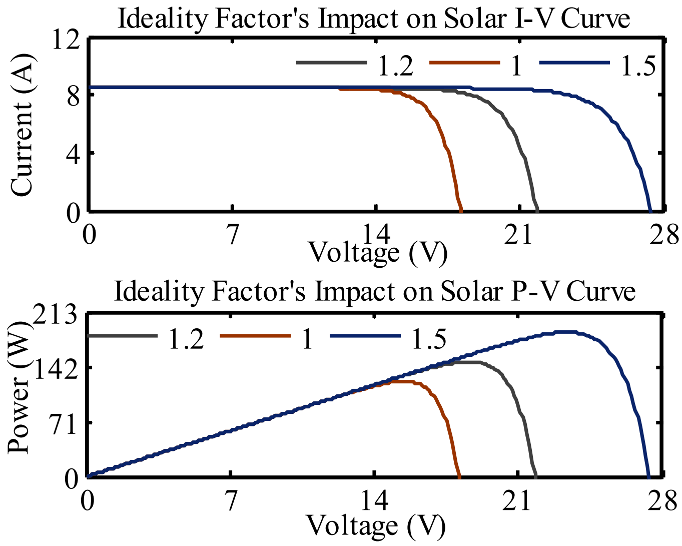

Fig. 3. Impact of ideality factor on the performance of PV system.

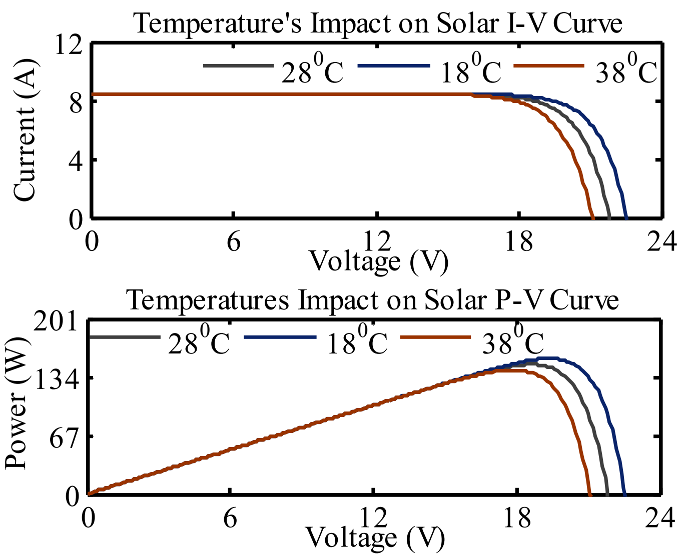

Fig. 4. Impact of temperature on the performance of PV system.

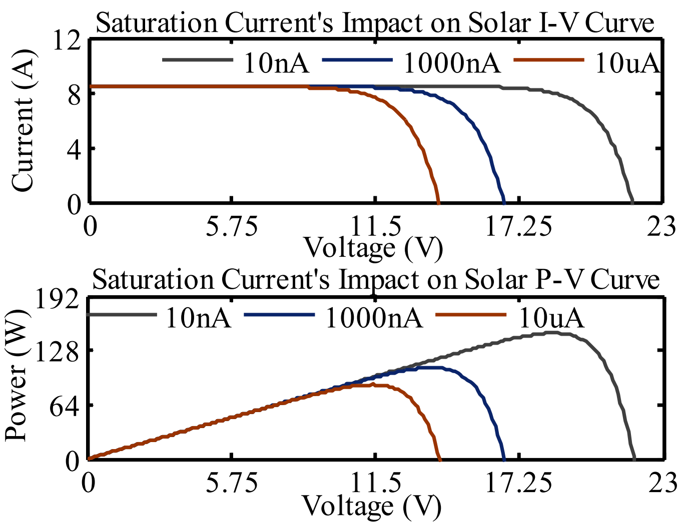

Fig. 5. Impact of saturation current on the performance of PV system.

TABLE II. EFFECT OF IDEALITY FACTOR, TEMPERATURE AND SATURATION CURRENT ON V_{oc}, I_{sc}, P

	V_{oc} (V)	I_{sc} (A)	P (W)
Ideality factor			
1	18	8.4651	123.2347
1.2	**21.9**	**8.4651**	**148.5384**
1.5	27.3	8.4651	186.4756
Temperature (^{0}C)			
18	22.5	8.4614	155.1213
28	**21.9**	**8.4651**	**148.5384**
38	21	8.4688	141.9525
Saturation current			
1000 nA	16.8	8.4651	107.6992
10 nA	**21.9**	**8.4651**	**148.5384**
10 μA	14	8.4651	87.6778

III. SINGLE PHASE INVERTERS

The output of the PV system is delivered to the consumer's end with the help of inverters. An inverter can be defined as dc to ac converter which symbolizes the change of dc voltage into a symmetric ac output voltage of desired magnitude and frequency [11]. However, the waveforms of practical inverters are non-sinusoidal and contain certain harmonics. An inverter is called a voltage fed inverter if the input voltage remains constant.

In this paper, single phase inverters are used to convert solar V_c =21.9 V dc voltage into ac so that the grid connection can be made.

A. Half Bridge Inverter

A half bridge inverter consists of a three wire dc source, in which $V_c/2$ voltage is obtained across the load. When Q_1 is turned on and Q_2 is turned off, the instantaneous voltage across the load is $V_c/2$. On the other hand, if Q_2 is turned on and Q_1 is turned off then $-V_c/2$ voltage appears across the load. The logic circuit is designed in a way that Q_1 and Q_2 are not turned on at the same. Otherwise, dc source may be shorted out. So, there must exist a dead time between the switches.

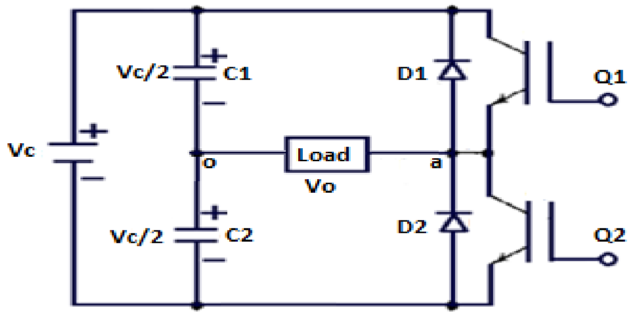

Fig. 6. Single phase half bridge inverter.

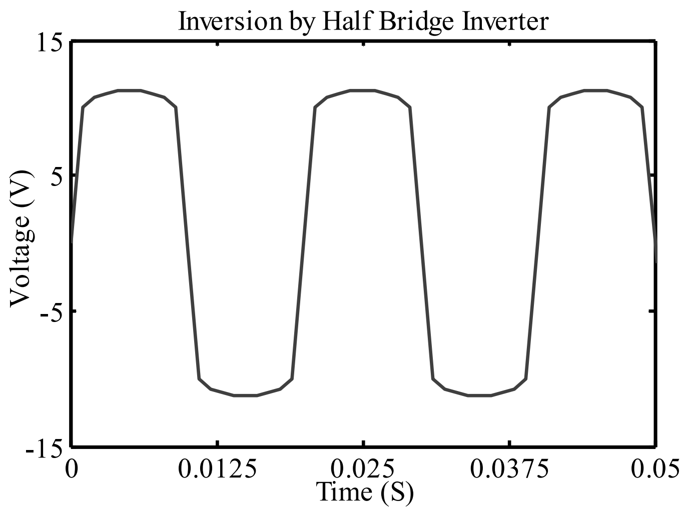

Fig. 7. Output response of half bridge inverter.

B. Full Bridge Inverter

A single phase full bridge voltage source inverter consists of four choppers. When transistors Q_1 and Q_4 are turned on simultaneously, the input voltage V_c appears across the load. If

Q_2 and Q_3 are turned on at the same time, the voltage across the load is reversed and is $-V_c$. Again, when Q_1 and Q_2 are on together they give zero voltage across the load. Moreover, the same result is obtained if Q_3 and Q_4 are turned on [12-13].

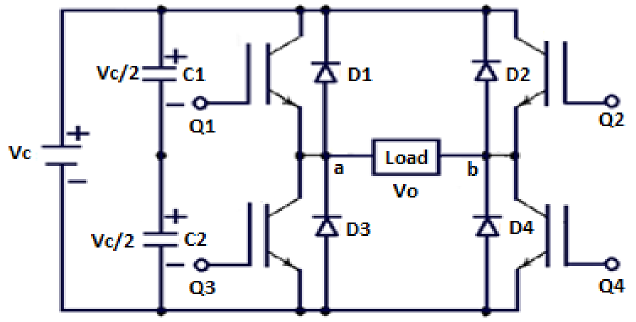

Fig. 8. Single phase full bridge inverter.

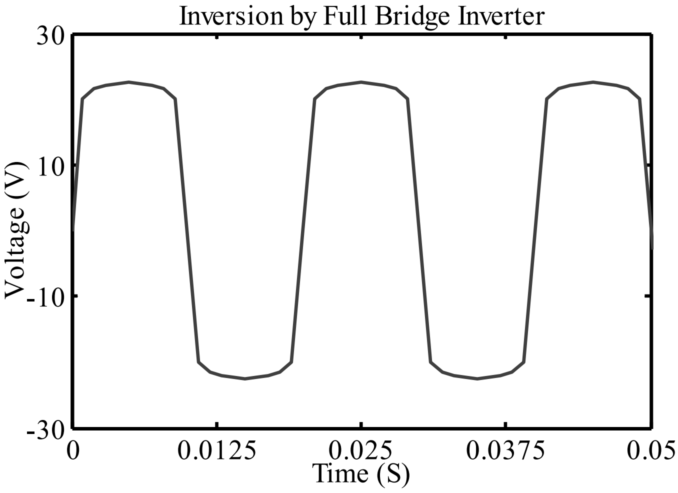

Fig. 9. Output response of full bridge inverter.

As is observed, the output waveforms of single phase inverters are not sinusoidal and contain harmonics. However, the impact of harmonic components is not good at all. This is because they may cause unbalance and excessive neutral currents, interference in nearby communication networks, pulsating torque to the connected motors and complete disturbance in the entire system [14].

IV. Single Phase LC Low Pass Filter

In order to bring the harmonics present in inverter's voltage into lower level, an LC low pass filter can be used as it blocks the harmonics and passes approximately a sinusoidal output. The implementation of an LC filter could trigger a parallel resonance which tends to amplify the harmonic voltages and currents in ac network leading, in some cases, to potential harmonic instabilities owing to the fact that the filter capacitance has a profound impact on the harmonic performance [15-16].

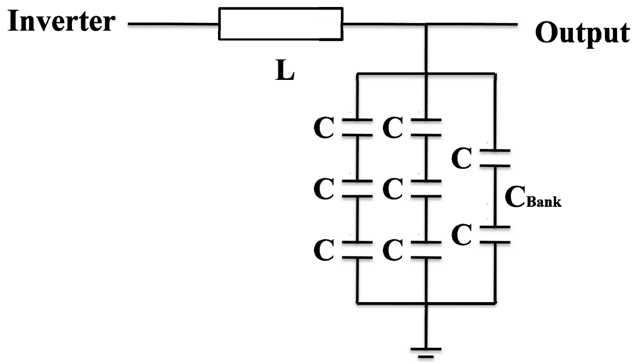

Fig. 10. Single phase LC low pass filter.

Capacitor bank consists of series connection of three capacitor sections. First and second sections contain three capacitors connected in parallel, while the last section is made of the parallel connection of two capacitors.

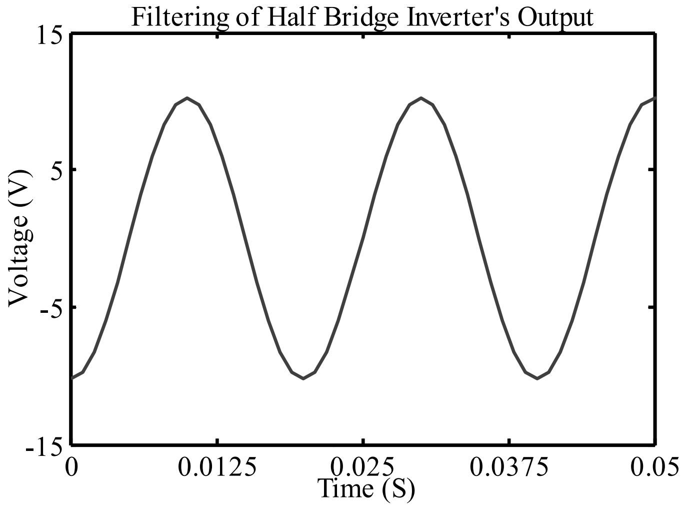

Fig. 11. Filtered output response of half bridge inverter.

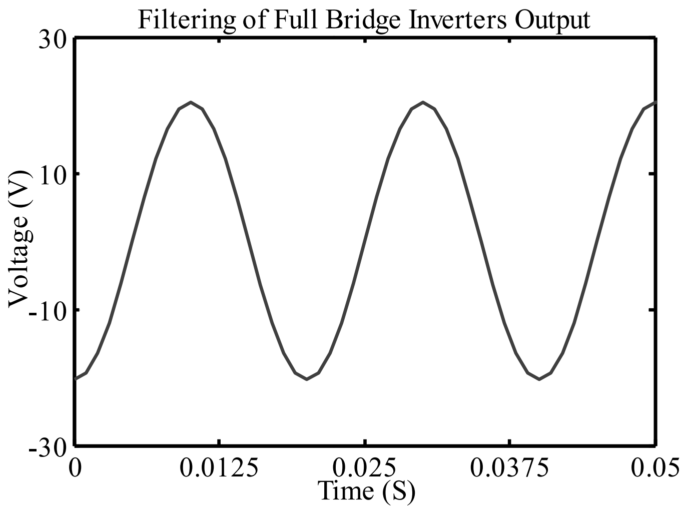

Fig. 12. Filtered output response of full bridge inverter.

V. SIMULATION RESULTS

It has been found that if single phase inverters are needed to use, it is better to use full bridge inverter as it gives double output and therefore, comparatively low rating transformer is enough to get 230 V phase to neutral voltage. For instance, based on the simulation results, 7.2 V : 230 V transformer with 31.94 turn ratio is needed if half bridge inverter is used, whereas 14.4 V : 230 V transformer with 15.97 turn ratio can provide the connection scheme when full bridge inverter is applied.

TABLE III. OUTPUTS OF SINGLE PHASE INVERTERS AND SINGLE PHASE FILTERED INVERTERS

	Maximum value of ac voltage (V)	Rms value of ac voltage (V)
Single phase inverters		
Half bridge inverter	11.26	7.96
Full bridge inverter	22.53	15.93
Single phase filtered inverters		
Half bridge filtered inverter	10.2	7.2
Full bridge filtered inverter	20.4	14.4

VI. CONCLUSION

This paper clarifies that the performance of a PV system remains constant as long as various factors, having profound impact on it, do not vary abruptly. It has been found from simulation results that solar irradiation causes more changes to the performance of solar cell than any other factors. Nonetheless, the precise construction of solar cell by following the characteristics of an ideal solar cell will decrease the effect of these factors. Moreover, the process of converting 21.9 V dc output of PV panel into ac has been described in this paper.

In future, the modeling of a large PV system would be great and a transformer with lower turn ratio would find its utility so as to get 230 V phase to neutral voltage. Besides, the implementation of connection scheme of three phase inverter would an opportunity to drive three phase loads.

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