Design of Single Phase Pure Sine Wave Inverter for Photovoltaic Application

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Abstract:- *This paper presents the design of an single phase inverter system which converters the DC voltage available from the solar PV array into AC voltage. The whole system consists of two major stages: DC-DC converter and full bridge inverter with a LC filter (Low-Pass). The output of the system is pure sine wave with the frequency and voltage at standard grid output. The DC-DC converter stage consists of a half bridge push-pull converter with main function of boosting the voltage and providing isolation through transformer. The full bridge inverter circuit uses SPWM (Sinusoidal Pulse Width Modulation) technique and low-pass LC filter to form pure sine wave output from DC input.*
Keywords:- *Photovoltaic; DC-DC Converter; SPWM; Pure Sine Wave; LC Filter*

I. INTRODUCTION

Renewable energy is one of the fastest growing trends in post-industrialized society as they face growing energy demands and requires cost effective solutions. Solar energy is one of the potential sources, which is preferable over other type of resources because of easy availability, simplicity, lower maintenance and better reliability [1]. Photovoltaic (PV) arrays drastically reduce energy expenses and dependency on non-renewable energy sources. Given in reasonable location and well-designed application, PV array can provide an excellent, cost saving solution. For this reason, solar powered electricity can be excellent solution for power crisis in India.

A DC/AC power inverter is required to convert the DC voltage gathered by the photovoltaic cell into AC voltage. But before that the issue is, the single phase grid voltage is of 230Vrms and the output voltage of solar PV array is around 12-36 volts. So before inverting the DC voltage to AC voltage, we first require to step up the DC voltage upto 325V. On inverting it to AC, we get 325Vp (peak voltage) which is equivalent to 230Vrms. So requirement of a DC-DC converter is necessary for this operation which is fulfilled by a half-bridge push-pull converter in our system.

Earlier cheaper square wave inverters were used. It had simpler circuitry but they lagged behind in terms of performance, reliability and quality in comparison to the sine wave inverter. The sine wave inverter gives pure sine wave output. They have higher efficiency, maximizing the output [3]. So while using renewable energy source, the aim should be to maximize the power quality and efficiency. Our main objective is to design an efficient cost-effective system to provide pure sine wave AC voltage.

II. METHODOLOGY

The system uses SPWM (Sinusoidal Pulse Width Modulation) technique to produce sine wave output from DC input. Pulse Width Modulation is a process of varying the width of the pulse to control the output voltage of inverter. In SPWM, the width of each pulse of a pulse train is varied in proportion to the amplitude of a sine wave evaluated at the center of the same pulse [2].

The sine wave is considered as reference signal, while a triangular wave is considered as a carrier wave. The frequency of the reference signal determines the inverter output frequency, and its peak amplitude controls the modulating index. The idea is to change the output state at the intersecting point of the two waves [3]. Fig. 1 shows the SPWM generation in above mentioned method.

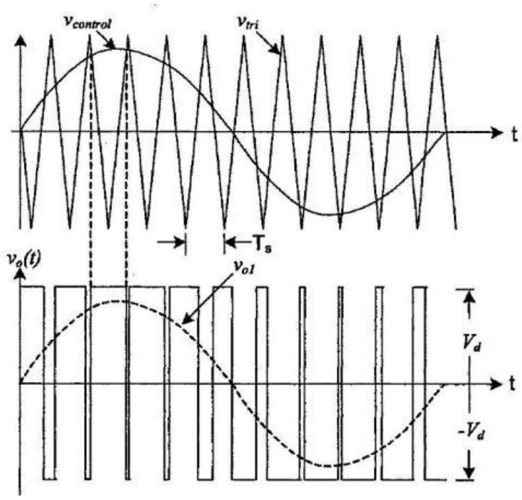

Fig. 1: SPWM Generation

The SPWM can be implemented in both analog and digital method. In simulation we have used analog method to implement SPWM technique, by producing sine and triangular wave using internal blocks.

One stipulation to use PWM technique is assumption that the source voltage is larger than the output voltage. This introduces the need for a DC-DC converter which can provide the inverter with high source voltage. As our desired output of inverter is 230Vrms, the DC-DC converter must supply 325 volts consistently. So the first step is to design a suitable DC-DC converter.

There are many topologies for implementing a DC-DC converter. In our system we have used half-bridge push-pull topology which can work efficiently in the range of 100-500W compared to other topologies. It also isolates the input from the output through a high frequency transformer. The half-bridge push-pull converter, as shown in fig. 2, belongs to the primary switched converter family since there is isolation between input and output.

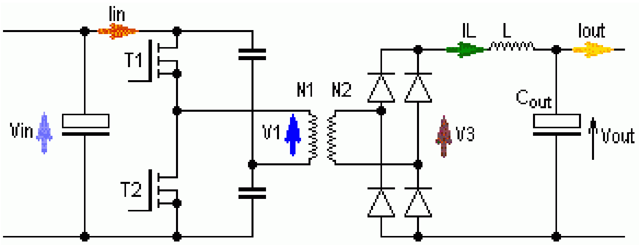

Fig. 2: Half-Bridge Push-Pull Converter

The PWM pulses and their complement are fed to the full bridge inverter circuitry. The output of the half-bridge push-pull converter (which is 325 volts) is given as input of the full bridge inverter circuitry, as shown in fig. 3.

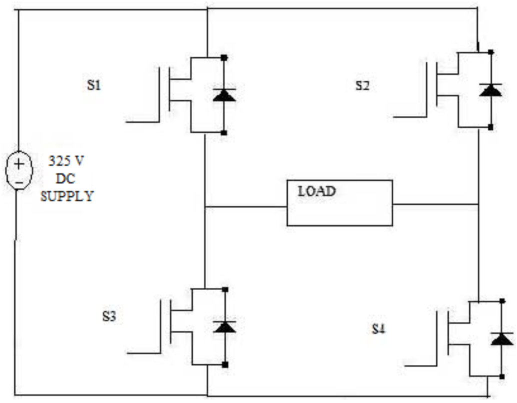

Fig. 3: Full Bridge Inverter Circuit

The output of the inverter circuit is a PWM wave, with the switching frequency of 10 kHz. An L-C filter is attached parallel to the load, which attenuates the PWM and produces pure sine wave. Fig. 4 below represents the overall system architecture [7].

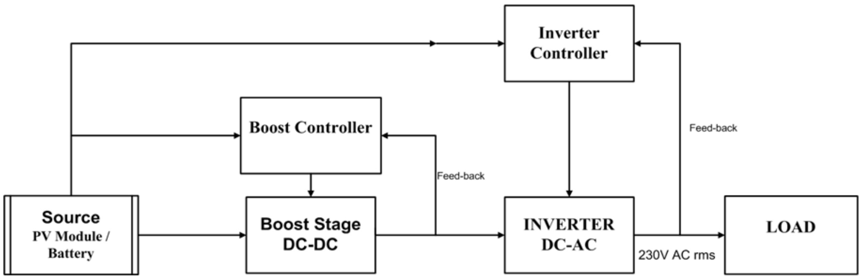

Fig. 4: Inverter System Block Diagram

III. SYSTEM SIMULATION IN PSIM

PSIM is simulation software specially designed for fast simulation and friendly user interphase. PSIM provides a powerful simulation environment to address our simulation needs. It also provides an intuitive and easy-to-use graphic user interphase for schematic editing. In addition, extensive on-line help is available for each component. To anticipate the outcomes of the micro-inverter we simulated the parts of the whole system individually as well as combined and justified the desired output values in PSIM.

A. DC-DC Conversion of 12V DC to 325V DC

At first we converted 12V DC (Output of solar panel) into 325V DC, because to have an output of 230Vrms AC from the inverter, we first require giving inverter the input of √2 times of 230V. That is, 230×√2 ≈ 325V DC.

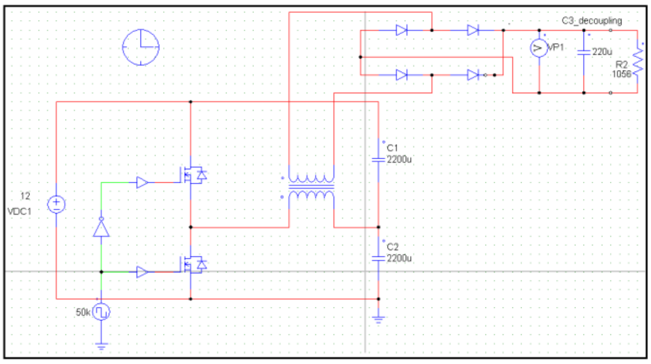

Fig. 5: Push-Pull Converter Circuit Diagram PSIM

As stated earlier, we have used a half bridge push-pull converter for DC-DC conversion purpose. Fig. 5 above shows the PSIM schematic that was used to simulate the output of the DC-DC converter. The two MOSFET switches are operated at 50 kHz frequency to form square wave 12VP-P AC from 12V DC. We calculated the turn ratio of the push-pull transformer to be 1:54, which result in voltage step-up of square wave 12VP-P AC to square wave 325VP AC. This square wave 325VP AC is then passed through a full bridge rectifier to obtain 325V DC. The expected output of the DC-DC converter is 325V DC. As shown in below fig. 6, the result justifies the DC-DC configuration works theoretically in an ideal environment.

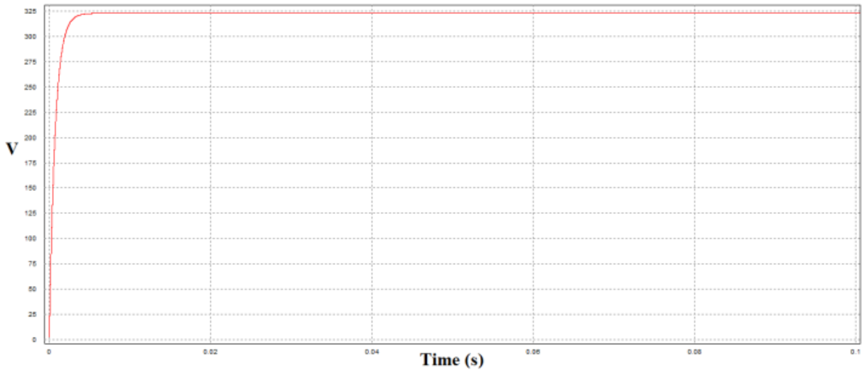

Fig. 6: Voltage Output of Push-Pull Converter

B. DC-AC Conversion of 325V DC to 230Vrms AC

The AC load needs pure sine wave at 230Vrms AC, so we need to convert 325V DC to 325Vp AC. Fig. 7 shows the PSIM schematic that was used to simulate the output of DC-AC inverter. The expected output of the DC-AC inverter is 230Vrms AC, 50Hz sine wave.

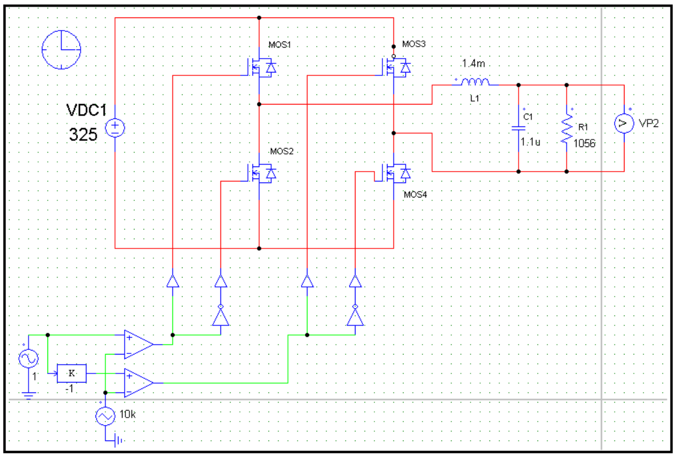

Fig. 7: Schematic diagram of DC-AC Inverter in PSIM

Fig. 8 shows the shows the imposed unfiltered 460V AC (peak to peak) waveform that will be filtered to create the expected sine output. Fig. 9 shows the FFT of the frequency spectrum of the unfiltered output which resembles that major harmonics result around 20 kHz so the LC filter should be designed keeping that in mind. Fig. 10 shows the filtered output and proves that DC-AC inverter should function properly. Fig. 11 is added simulation test result showing that only the 50Hz fundamental frequency remains after filtering with a low-pass LC filter.

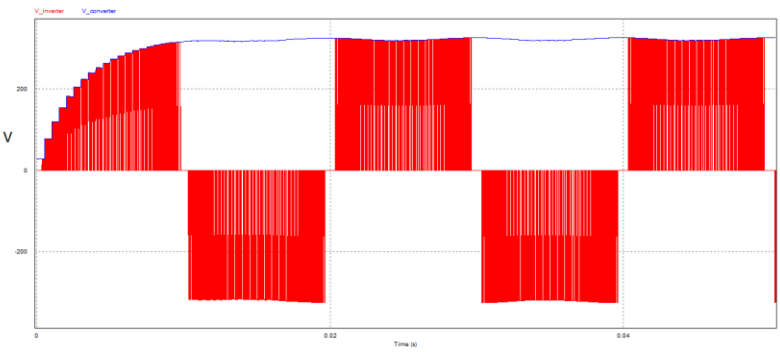

Fig. 8: Unfiltered SPWM output of Inverter

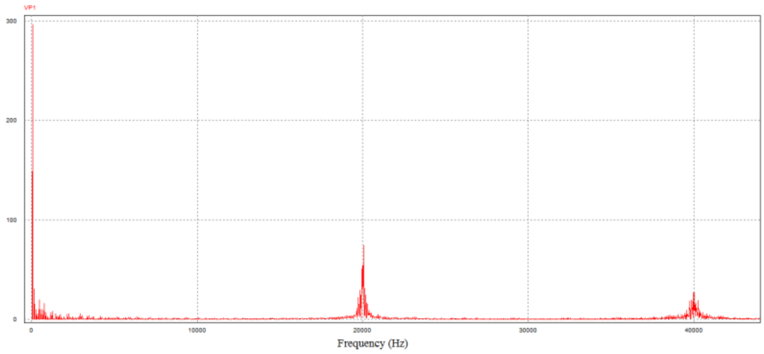

Fig. 9: FFT of unfiltered Voltage at Inverter Output

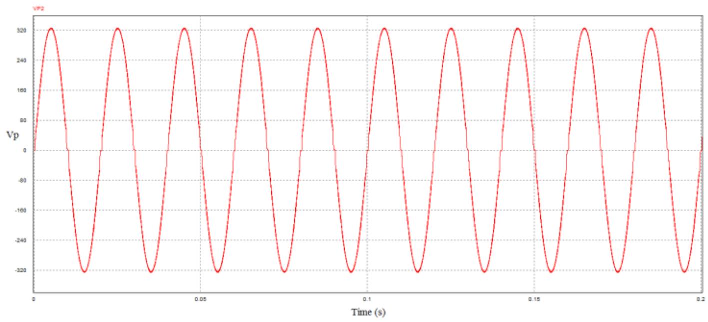

Fig. 10: Pure sine wave output voltage of Inverter

In order to eliminate the switching frequency and all multiples of the switching frequency, a low-pass filter had to be inserted after the output of the full-bridge inverter. The cut-off frequency can be set by the formula (1) shown below [4],

$$F_{CUTOFF} = 1 / (2\pi\sqrt{LC}) \quad (1)$$

Fig. 8 shows the switching harmonics that resulted from a 10 kHz switching frequency. It should be noted that the harmonics are located at the switching frequency and multiples of the switching frequency. The switching frequency was intentionally set to 10 kHz so that it would be rather distant from the 50 Hz fundamental frequency. This would allow for a high cutoff frequency, which by equation allows for small LC component. The large distant between the unwanted harmonics and the fundamental frequency is also beneficial because it allows for a large margin of error in the filter values. An LC low-pass filter was chosen for the power inverter. Cut-off frequency 4055 kHz is calculated based on equation (1).

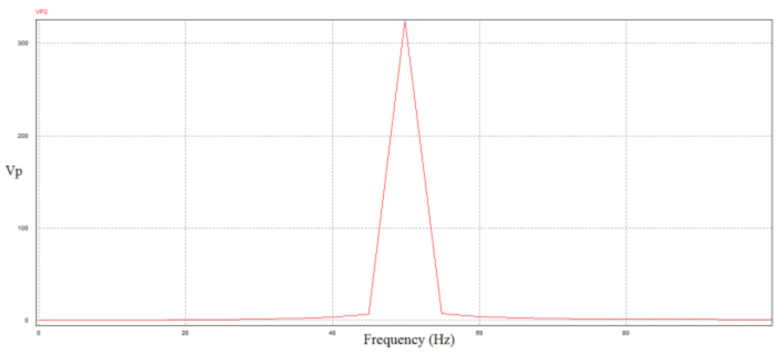

Fig. 11: FFT of filtered Voltage at Inverter Output

Fig. 11 shows that after LC low-pass filter all the unwanted harmonics are removed and the frequency spectrum of only 50 Hz remains which gives us the perfect sine wave required for AC devices.

C. Complete Inverter System – 12V DC to 230Vrms AC

In above two cases we had simulated the two stages individually. But now we will simulate whole system and obtain 230Vrms AC from 12V. Both the stages are combined and a decoupling capacitor is used as dc link between the two stages. Fig. 12 shows the PSIM schematic that was used to simulate the output of complete system.

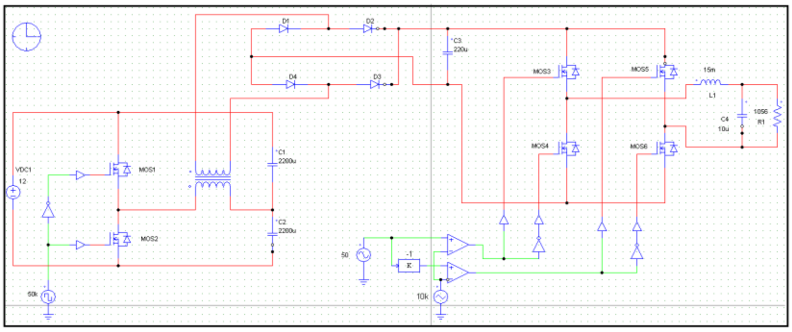

Fig. 12: Schematic diagram of Complete Inverter System in PSIM

The whole system is calculated for a 100W load. The output voltage across the load is 230Vrms AC, which is equivalent to 325 Vp (peak voltage). The load is calculated as 1056Ω, so the current flowing will be 0.3074 A (peak current). The wattage of the load can be calculated as,

$$P = V \times I \qquad (2)$$

which is, 100W. The output voltage across the load of the system is shown in below fig. 13. Also Fig. 14 is a simulation test result showing that only the 50Hz fundamental frequency remains after filtering with a low-pass LC filter.

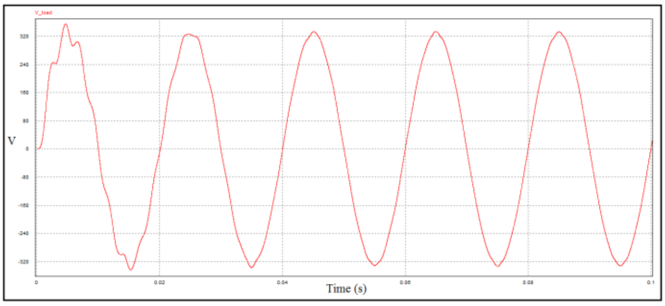

Fig. 13: Pure sine wave output voltage of Complete Inverter System

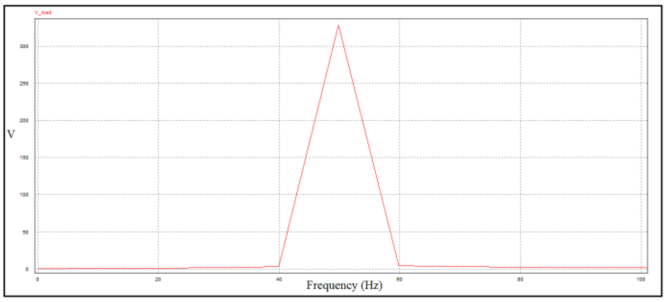

Fig. 14: FFT of Output Voltage of Complete Inverter System

Fig. 14 shows that after LC low-pass filter all the unwanted harmonics are removed and the frequency spectrum of only 50 Hz remains which gives us the perfect sine wave required for AC devices.

IV. FUTURE WORK

In future we intend to implement this design and develop a working hardware model. In the push-pull converter stage, for controlling purpose, IC SG3525 will be used to switch the two MOSFETs at 50 kHz. It will take the feedback from the output of the DC-DC converter and adjust the switching pulses accordingly. Thus constant 325V DC will be obtained regardless of minor variation in the input voltage. In the DC-AC inverter stage, instead of analog method, digital method will be preferred due to his higher efficiency and reliability. PIC controller will be used to generate the switching pulses for firing the four MOSFETS of the full bridge inverter [5]. It will require developing an algorithm and respective program in C language. For designing the inductor of the LC low-pass filter, ferrite core will be used for winding copper enameled wire around it. Also to increase the efficiency for accounting varying irradiance of solar input, an MPPT algorithm will also be developed and implemented [6].

V. CONCLUSIONS

This paper discusses the design and development of a pure sine wave inverter. The main objective of this project was to find an efficient power conversion system to use photovoltaic energy to meet the increasing power demands of residential and power sector. Here we successfully converted 12V DC (solar input) to usable 230Vrms AC with frequency of 50 Hz and pure sine wave, as desired for the single phase AC load. But while designing the circuit and selecting the components, the main objective is to keep the power loss to a minimum. Since on the simulation platform, ideal components are considered, such will not be the case in real world application. Because there will be losses like diode drop, switching losses, transformer loss, losses in reactive components, etc. which are not accounted in the simulation. So we can have better understanding by developing working hardware model and solving the issues that arises in real world application.

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