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Closed Loop Control of Boost Converter for a Grid Connected Photovoltaic System

Ebin Nelson[1] and J. Jasper Gnanachandran[2]

[1]PG Student Francis Xavier Engineering College
Tamil Nadu, India.
E-mail: ebinroshan86@gmail.com
[2]Head of the Department, EEE Francis Xavier Engineering College
Tirunelveli, Tamil Nadu, India.
E-mail: Jasper_fx@yahoo.co.uk

Abstract

In this paper, the common mode leakage current in the transformerless photovoltaic grid connected system is eliminated. This can be obtained by using an improved transformerless inverter which can sustain the low input voltage as the full bridge inverter and hence eliminating the common mode leakage current. Both unipolar sinusoidal pulse width modulation as well as the double frequency sinusoidal pulse width modulation control strategy can be used to obtain the three-level output. High frequency and lower current ripples are obtained by applying the double-frequency sinusoidal pulse width modulation and hence the total harmonics distortion of the grid-connected current is reduced. Also the variation of the input to the boost converter affects the input to the inverter circuit. Hence a closed loop operation is used to maintain the input to the inverter as a constant. This leads to the constant output from the inverter and can be connected to the grid directly.

Keyword: Photovoltaic system, Sinusoidal Pulse Width Modulation (SPWM), Boost converter.

Introduction

The increase in the demand of sources for the current generation leads to the increase in solar photovoltaic system. The current produced by a solar PV system is a DC [1]. Hence to convert the produced DC to AC so that the produced current can be used, single phase, high efficiency, s mall size, light weight and low-cost grid connected inverters are used. The inverter s thus designed for either line-frequency or high-frequency isolation transformers [2]. The line-frequency transformers are large and bulky and hence the whole system becomes huge and difficult to install [3]. The high-frequency transformers include any power stages. This decreases the complexity of the system and the efficiency gets reduced. Hence the transformerless configure ration for a PV system is developed to achieve a high efficiency, high power density and low cost. But there are so me safety problems due to the galvanic connection between the PV array and the grid in the transformerless systems. In a transformerless inverters, the common mode leakage currents flows through the parasitic capacitor due to the variable common-mod e voltage which flows though the parasitic capacitor [4].

In conventional method, to avoid the common mode leakage current the half-bridge or the full bridge inverter with bipolar sinusoidal pulse width modulation(SPWM) since variable common-mode voltage is not generated [5].

The half-bridge inverter requires a high voltage as the input. Approximately around 700V for 220 Vac applications. Hence more numbers of PV modules in series are required. Or else a nigh conversion ratio dc/dc boost converter is required. But the full-bridge inverter requires jus t half the input voltage of the half bridge inverter which is about 350V for a 220Vac [6].

In this paper, an improved transformerless grid-connected inverter topology for a PV system is presented. This ca n sustain the low input voltage like the full-bridge inverter and doesn't generate the common-mode leakage current.

To offer the advantages of high efficiency, high power density and low cost transformerless PV configure ration is developed. But there are some sa fety problems due to the galvanic connection between the PV array and the grid in the transformerless system. The common mode leakage current flows between the PV array and the ground through the parasitic capacitor. When a common- mode voltage is produced in the transformerless inverter connected to the grid.

Design of Photovoltaic Module

The characteristics of a PV cell can be given by the Figure 1. Which represents the equivalent circuit of a PV cell.

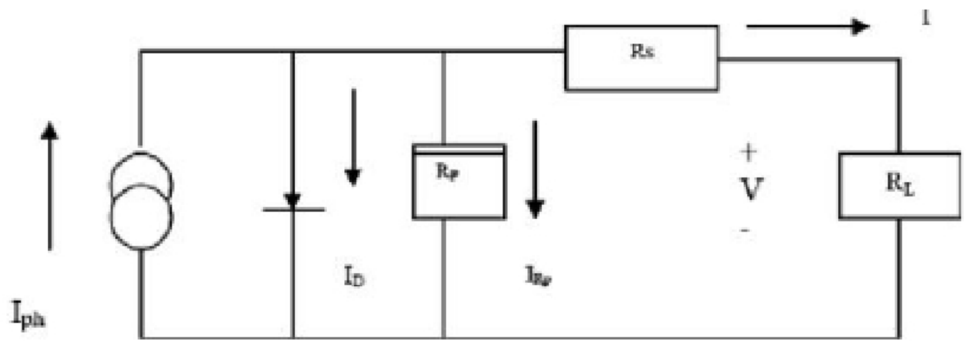


Figure 1: Equivalent circuit of a PV cell.

An ideal is modeled by a current source in parallel with a diode. However no solar cell is ideal and thereby shunt and series resistances are added to the model as shown in the PV cell diagram above. R_S is the intrinsic series resistance whose value is very small. R_P is the equivalent shunt resistance which has a very high value.

Applying Kirchoff's law to the node where Iph, diode, Rp and Rs meet, we get

$$I_{ph}=I_D+I*R_p+I \quad 3.1$$

We get the following equation for the photovoltaic current:

$$I=I_{ph}-I*R_p-I_D \quad 3.2$$

Where, I_{ph} is the Insolation current, I is the Cell current, I0 is the Reverse saturation current, V is the Cell voltage, R_s is the Series resistance, R_p is the Parallelresistance, Vt is the Thermal voltage, K is the Boltzman constant, T is the Temperature in Kelvin, q is the Charge of an electron.

The output from a single photovoltaic cell is 0.5V. The cells are connected in series such that the output from the single array is 19V. Hence in our paper, two arrays are connected in series to obtain an output voltage of 38V as shown below in Figure 2.

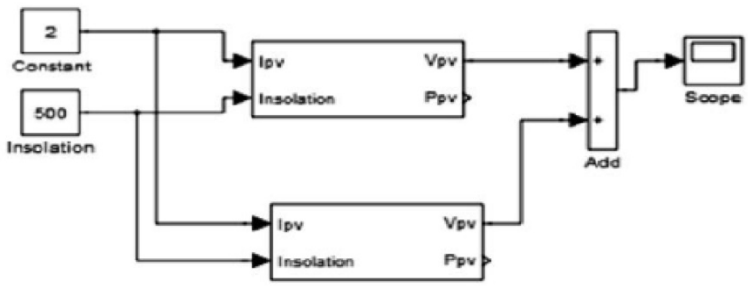


Figure 2: Matlab implementation of photovoltaic panel.

Boost Converter Design

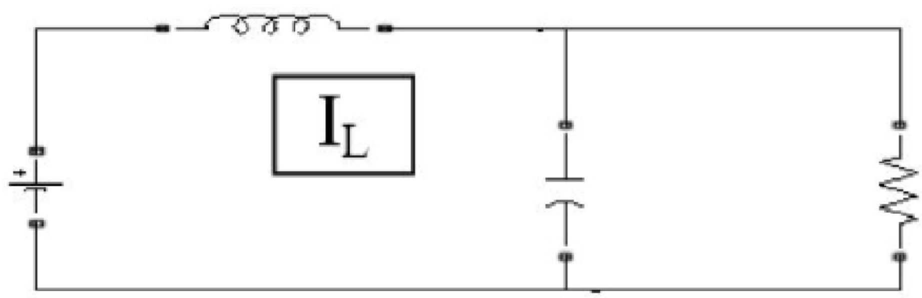


Figure 3: Circuit diagram of boost converter.

Boost converter is used to increase the voltage from the PV module. The Figure 3 below shows a step up or PWM boost converter. It consists of a dc input voltage source V_g, boost inductor L, controlled switch S, diode D, filter capacitor C, and the load resistance R. When the switch S is in the on state, the current in the boost inductor increases linearly and t he diode D is off at that time. When the switch S is turned off, the energy stored in the inductor is released through the diode to the output RC circuit.

Steady State Analysis of the Boost Converter

Off State

In the OFF state, the circuit becomes as shown in the Figure 4. below.

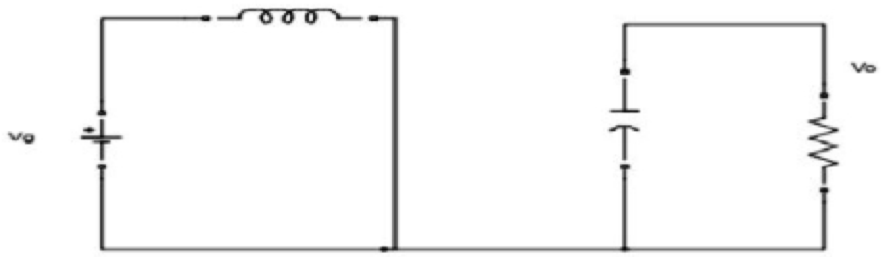


Figure 4: The OFF state diagram of the boost converter.

When the switch is off, the sum total of inductor voltage and input voltage appear as the load voltage.

On State

In the ON state, the circuit diagram is as shown below in Figure 5:

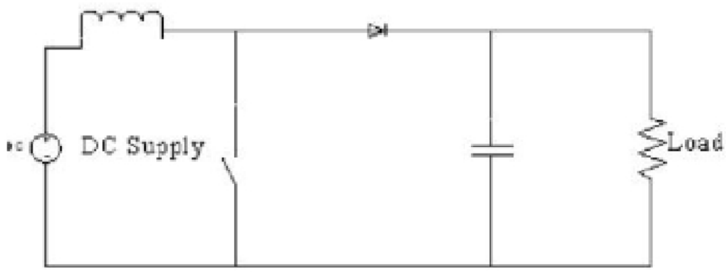


Figure 5: The ON state diagram of the boost converter.

When the switch is ON, the inductor is charged from the input voltage source Vg and the capacitor discharges across the load.

Using the above basic boost DC-DC converter, the boost converter in this paper is designed as shown in Figure. The Boost DC-DC converter converts the input DC voltage of 38V to the required voltage of 380V which is to be fed to the inv erter module.

The specifications of the Boost DC-DC converter used in this paper is:

Elements	Rating
Input Voltage	38v
Boost Inductor	.5e-4
Filter Capacitor	100 µf

The open loop DC-DC boost converter is designed using the above aid specifications as shown in the below Figure 6. The inductor L1 acts as the boost inductor. The capacitor C is used as the filter capacitor.

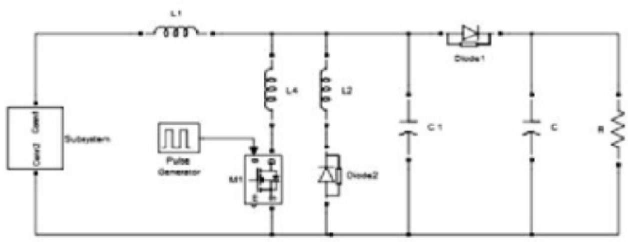


Figure 6: Boost converter without the closed loop control.

The closed loop DC-DC boost converter is designed using the PI controller as shown in the below Figure 7. The output voltage from the boost converter is taken as the feedback and given to the PI controller. The measured value is compared with the reference value and an error signal is produced which is given to the PI controller. The PI controller produces the triggering pulses for the switch in the boost converter. Hence the closed loop operation is obtained.

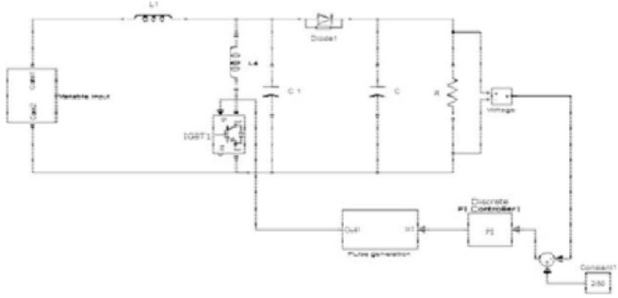


Figure 7: Boost converter with the closed loop control.

Design of Improved Inverter Topology

The process of converting dc to a c has been called inversion. An inverter converts the dc voltage to ac voltage of a definite frequency. Controlled semiconductor dev ices, such as SCR, GTO, thyristors, and transistors are used in inverters. The input dc may be from an independent source, such as a dc voltage source or a battery. The ac output frequency of an inverter is precisely adjustable by control of the switching frequency of the inverter devices. This is usually determined by the frequency of a “clock oscillator” in the switching control section of the inverter.

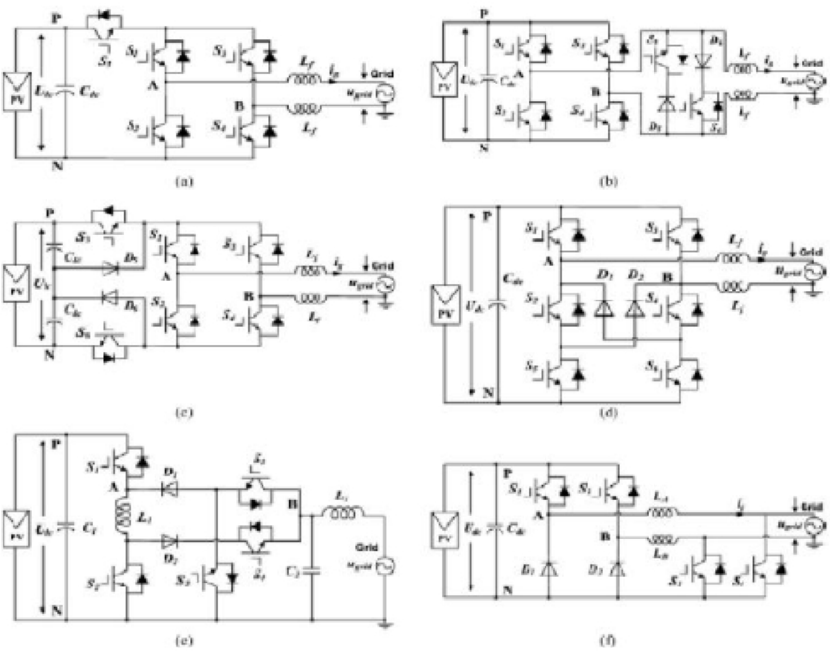


Figure 8: Inverter types.

The basic inverters are the full-bridge inverter and the half bridge inverter. The half bridge inverter requires a very high input voltage approximately 700V for the output of 220Vac. But the number of stages can be increased. But the full bridge inverter requires just the half the input voltage of the half bridge inverter i.e., 350Vdc for the output of 220Vac. But the number of stages that can be obtained from the full bridge converter will be only two stages. Hence an improved inverter has been designed using the H5 inverter as the basic inverter topology from the available transformerless inverter as shown in the below Figure ure. The number of switches in the H5 inverter is less when compared to the other transformerless inverters.

Types of Inverters

- H5 inverter.
- HERIC inverter.
- Full-bridge inverter with dc bypass.

- High-efficiency inverter with H6-type configure ration.
- Karschny inverter.
- Inverter with two paralleled buck converters.

Taking the H5 inverter as the base inverter, the modified inverter has been designed using Matlab. The power semiconducting devices IGBTs is used in the inverter design as shown in Figure : 6. It consists of six IGBTs. During the positive half cycle, S5 and S6 commutate at switching frequency whereas S1 and S4 are ON in order to modulate the input voltage. On the other hand, when negative half cycle is present, S5 and S6 commutate at switching frequency whereas S3 and S2 are ON.

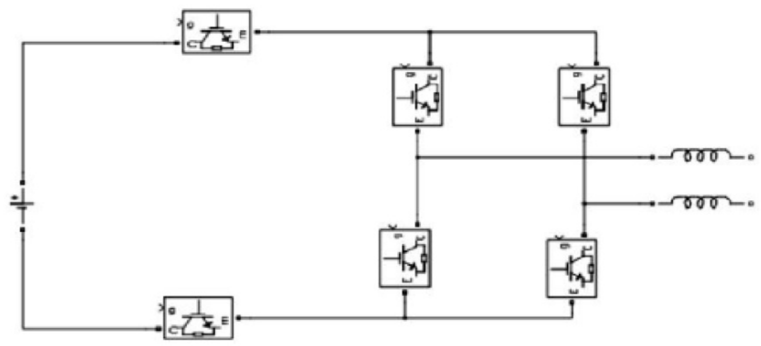
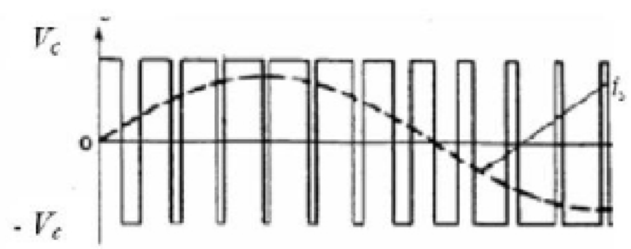
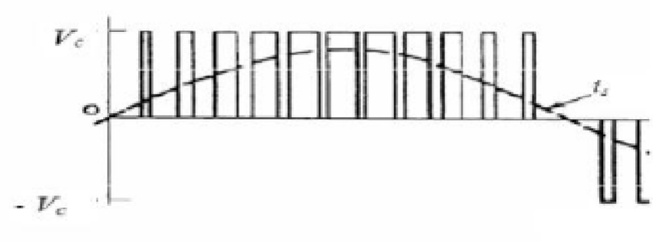


Figure 9: Improved Inverter Topology.

With the single-phase bridge, using the pulse width modulation (PWM) scheme, the electronic switches in the cur rent loop can be switched using either the bipolaar or the unipolar mode. In the bipolar mode, the diagonally opposite switches of the two legs of the inverter bridge are s witched as pairs. The output voltage swing (v c) is shown in Figure 7 (a). In the unipolar mode, the two legs of the bridge are not switched simultaneously but are controlled separately. Figure 7 (b) shows the inverter output voltage. In the unipolar mode, the output voltage swing is half of that in the bipolar mode for the same input DC voltage.



Bipolar voltage switching.



Unipolar voltage switching.

Figure 10: PWM with unipolar and bipolar voltage switching.

Simulated Results

The output voltage of the photovoltaic cell is given Figure 11. This shows that the obtained voltage from a single cell of a photovoltaic cell is 0.55V.

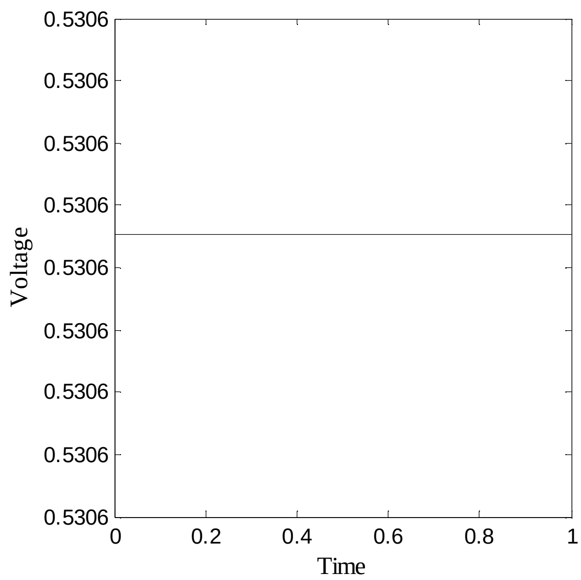


Figure 12: Output of photovoltaic Cell

The Figure 12 shows the output from a single photovoltaic module. This shows that, the obtained voltage from a single photovoltaic module is 19V.

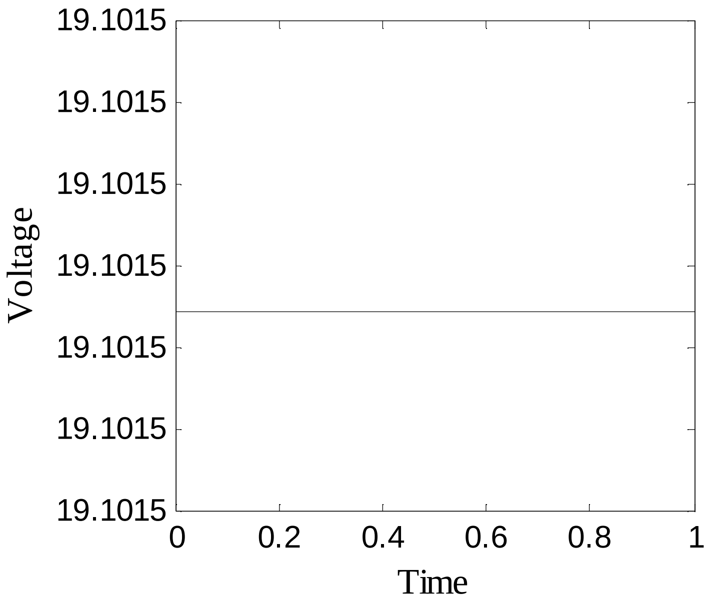


Figure 12: Output of photovoltaic module.

The output of the whole photovoltaic system for the project is shown in the below Figure 13. From the output obtained from the whole photovoltaic system shows the output of the two modules connected in series gives an output of 38V.

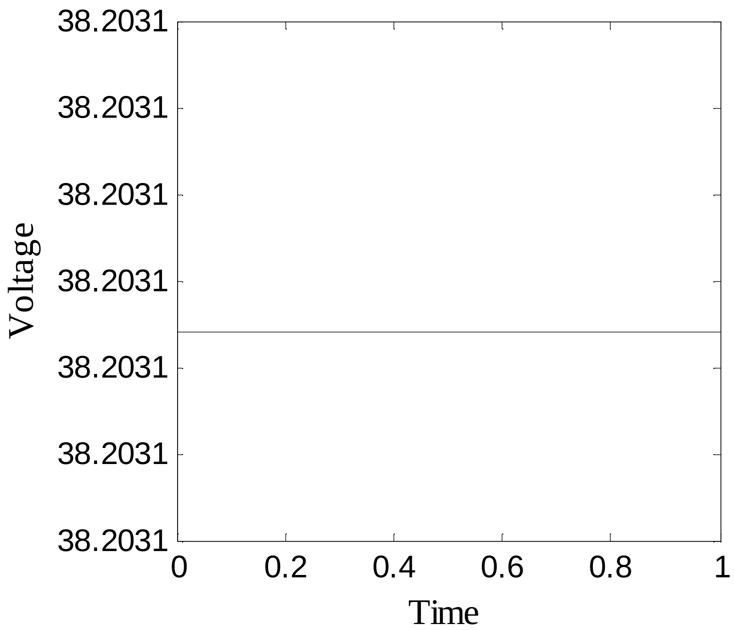


Figure 13: Output of photovoltaic array

The output of 38V is given as the input to the DC-DC boost converter and is boosted to an amplitude of 380V using the boost converter which is designed using the specifications that is explained in the above chapter.4. The output of the DC-DC boost converter is shown in the below Figure 14. From the Figure, it’s found that the input of 38V is boosted up to 380V DC.

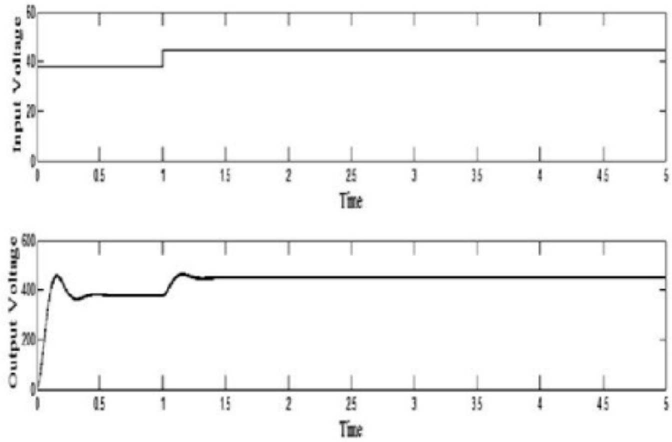


Figure 14: Input and Output waveform of a open loop boost converter.

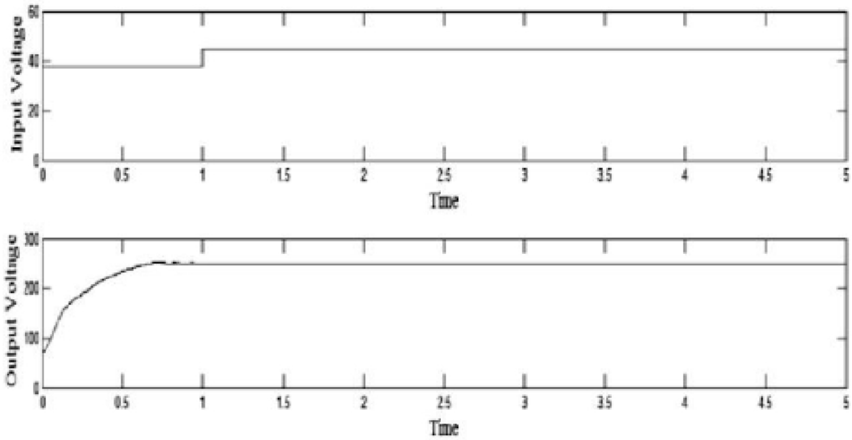


Figure 15: Input and Output waveform of a closed loop boost converter.

The Figure 16. shows the output from the modified inverter with the unipolar switching technique. The output voltage from the inverter is found to be AC with the amplitude of 380V.

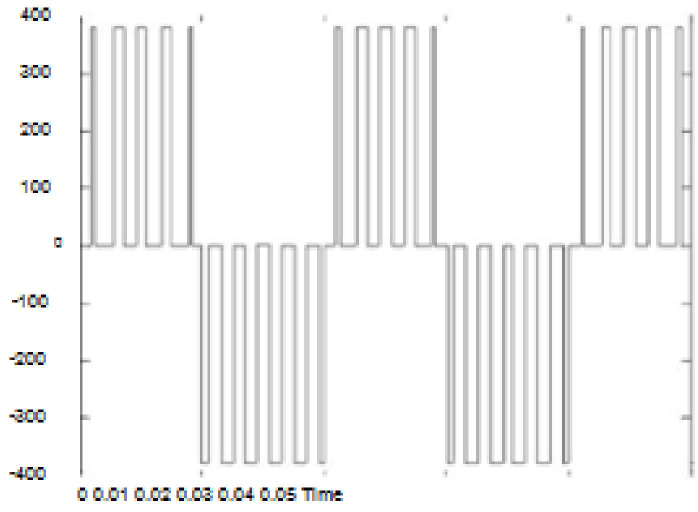


Figure 16: Output of Unipolar system.

The output of the modified inverter with the bipolar switching sequence is shown in Figure 17. From the obtained voltage, the amplitude is found as 380V with an AC current.

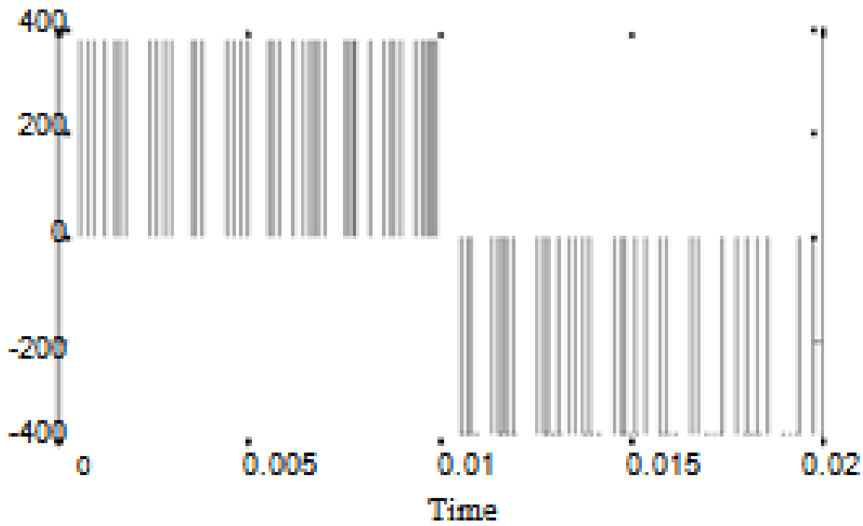


Figure 17: Output of a Bipolar system

The switching sequence for the unipolar mode is operation in inverter is shown in Figure 18.

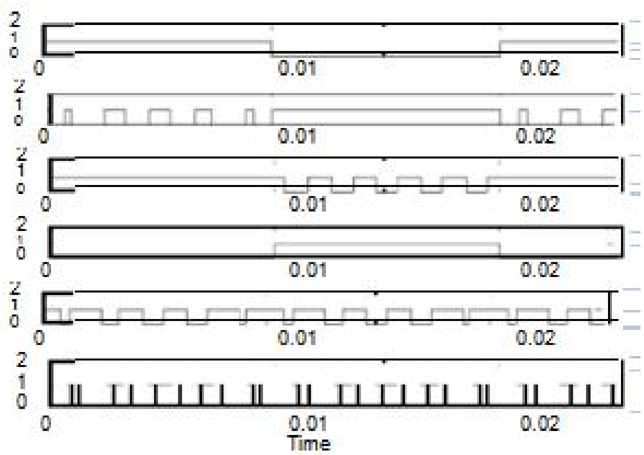


Figure 18: Triggering pulses for a Unipolar SPWM.

The switching sequence of the Bipolar PWM technique is shown in the below Figure 19.

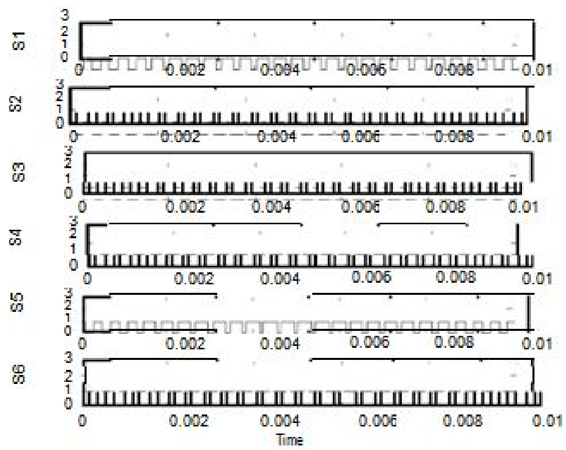


Figure 19: Triggering pulses for a Bipolar SPWM.

The above discussed modules in various chapters are implemented using Matlab SIMULINK. The DC source of 38V from the PV module is given in the form of a DC source. The source from the PV module is given as the input to the DC-DC boost converter. Thus the obtained output from the converter is a 380V DC. The output from the DC-DC boost converter is given as the input to the inverter. The DC source is converter into a 380V AC in the modified inverter. Then using the reference of a 230V AC, which is considered as a grid is compared with the obtained output from the inverter and the value is given as the input to the PWM. Which leads to a output of 230V AC, which is the required voltage for connecting a photovoltaic inverter to the grid.

Conclusion

A concept of an inverter without transformer for grid connected photovoltaic systems has been presented. Using a three level half bridge parasitic capacitance between solar array and ground can be eliminated and tolerable levels of blocking voltage of IGBTs can be achieved. A suited control has been developed. An optimization procedure results in an optimal combination of switching frequency and filter elements to minimize inverter losses.

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