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A Multilevel Based Grid Connected High Voltage Gain DC/DC Converter

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Abstract:
The usage of increase in switching frequencies has became possible today, with the evolution in power electronics. This is considered as one of the future solutions for grid connection of photovoltaic systems. Module integrated converters were already the focus of several researches and projects. Most of the proposed approaches relied so far on the use of high frequency step-up transformers either in isolated operation or integrated in isolated dc-dc topologies. This paper analyses the possibility of using non-isolated topologies to achieve the necessary high-voltage gain for grid connection. Several circuits were analyzed and the best suited one for the current application was evaluated and optimized. The proposed converter presents in a single stage a large voltage step-up, high efficiency, and reduced voltage stress on switches due to the transformer in order to verify its effectiveness. Theoretical analysis, operation principle and topology details are also presented and studied. High voltage gain, low switching stress, small switching losses, and high efficiency are expected from this topology, the detailed modeling and simulation verifications are carried out by using matlab/simulink environment.

Keywords:*photo-voltaic systems, soft-switching, boost converter, high voltage gain.*

1.Introduction

The first generation of grid connected photovoltaic systems was composed of several strings of panels associated in parallel and connected to a single inverter. Such centralized approach had as disadvantages the necessity of string diodes (with their inherent power losses) and high voltage DC cabling. Furthermore, since operation was limited to only one maximum power point (MPP) for the whole array, mismatch losses reduced the system efficiency. Finally, due to the high power level of the inverter, there was little flexibility on system expansion. At present, most of the systems are composed of a single or multiple strings of modules connected to an inverter, the so-called string and multi-string inverters. This way, in contrast with their predecessors, losses due to maximum power point tracking (MPPT) mismatch were reduced, but not totally eliminated, and string diodes are not necessary anymore.

The next expected evolution on grid connected photovoltaic systems is considered as the integration of the converter in the module and is usually named AC Module, since the output of the panel can now be directly connected to the mains. A major highlight of such an approach is the elimination of MPPT mismatches, allowing optimal coupling between panel and inverter and therefore increasing generated power per module. In addition, the small level of power and modularity allows flexibility in system expansion and low purchase investment, being considered as the best option for end-user applications. Since the output of the panels can be directly connected to the grid, DC cabling and installation expertise are not necessary, allowing considerable reduction in installation expenses. Though a higher production cost per produced Watt is expected for this approach, the mass production of such small units may in the end increase competitiveness due to economy of scale. A disadvantage of the module integrated solution is the strict requirement of a design with long lifetime under harsh ambient conditions that needs to be tackled by a highly robust power electronic design, since maintenance is much more complex than the ones of traditional string inverters.In the use of an interleaved boost converter associated with an isolated transformer was introduced, using a high frequency AC link. Despite of the good performance, this topology uses three magnetic cores. In the converter presents low input current ripple and low voltage stress across the switches. However, high current flows through the series capacitors at high power levels. In converters with high static gain based on the boost-fly-back topology are introduced, which presents low voltage stress across the switches, but the input current is pulsed, as it needs an LC input filter. The step-up switching-mode converter with high voltage gain using a switched-capacitor circuit was proposed in [9]. This idea is only adequate for low power converters as it results in a high voltage stress across the switches and many capacitors are necessary. This paper presents a new high voltage gain DC/DC converter, as can be seen in Figure 1. The main advantage of the proposed structure is the low voltage stress across the switches, which is naturally achieved by the converter characteristic. A single-stage converter with high step-up gain then results, while an integrated system with battery charging from a photovoltaic panel is also obtained. Besides the step-up function, the demands such as low current ripple, high efficiency, fast dynamics, light weight, and high power density have also increased for various applications. Input current ripple is an important factor in a high step-up dc/dc converter [8], [9]. Especially in the fuel cell systems, reducing the input current ripple is very important because the large current ripple shortens fuel cell's lifetime as well as decreases performances [10]. Therefore, current-fed converters are commonly used due to their ability to reduce the current ripple [15]. In applications that require a voltage step-up function and a continuous input current, a continuous-conduction-mode (CCM) boost converter is often used due to its advantages such as continuous input current and simple structure. However, it has a limited voltage gain due to its parasitic components.

The reverse-recovery problem of the output diodes is another important factor in dc/dc converters with high voltage gain [16], [17]. In order to overcome these problems, various topologies have been introduced. In order to extend the voltage gain, the boost converters with coupled inductors are proposed in [18] and [19]. Their voltage gains are extended, but they lose a continuous input current characteristic and the efficiency is degraded due to hard switching's of power switches. For a continuous input current, current-fed step-up converters are proposed in [20] and [21]. They provide high voltage gain and galvanic isolation. However, the additional snubbers are required to reduce the voltage stresses of switches. In order to increase the efficiency and power conversion density, a soft-switching technique is required in dc/dc converters [22]–[27]. Within this context, this paper proposes the integration of the battery charger stage, the photovoltaic power stage and the high voltage step-up stage in a single-stage power converter. From this new concept, many high step-up voltage power converters can be obtained resulting in new topologies with all aforementioned characteristics.

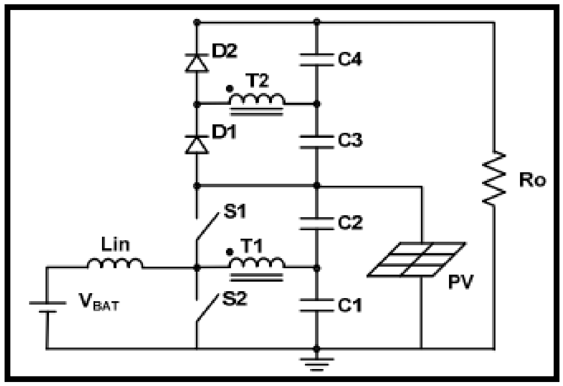

Figure1: A Proposed Topology Used In PV Applications

2.Concept Of Topology

Some high voltage gain topologies have three dc links as

shown in Fig. 2, where VDC3 feeds the inverter with a higher voltage than that of the remaining ones. According to the proposal, the battery bank and the photovoltaic panel can be connected to the low voltage VDC1 or VDC2, depending on the available voltage levels. Considering typical applications under 2kW, battery banks voltage levels can be 12V, 24V or 48V (in order to avoid the connection of many units in series) and photovoltaic panels can be arranged to establish a dc link with voltage level equal to about twice that of the former link.

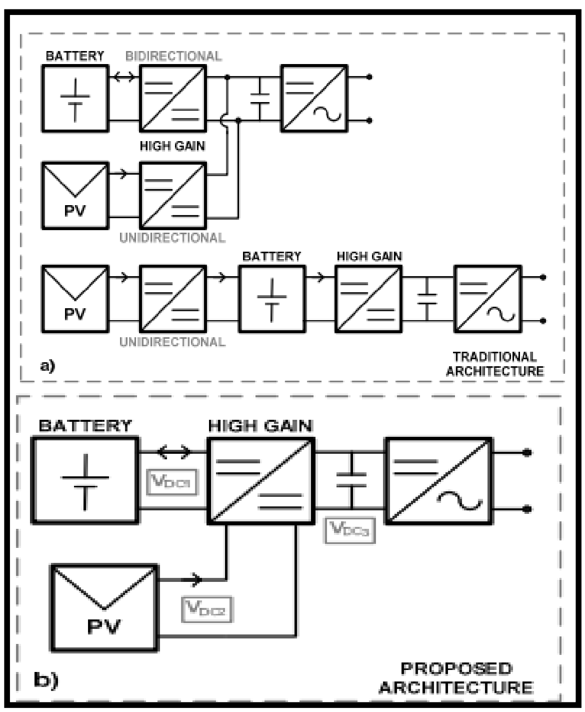

Figure 2:Conventional Architecture B)Proposed Architecture

The bidirectional characteristic of the half-bridge topology allows either charging the battery from the PV array or feeding VDC3. Besides, the use of resonant capacitors in the half-bridge capacitors allows soft switching (ZVS or ZCS) of the switches. The integrated topology resulting from the boost half bridge is then shown in Fig.1.The main advantage of this topology is the low voltage stress across the active switches, low input current ripple and simplicity, what results in higher efficiency.

3.Static Gain

The output voltage at any given moment can be expressed as the sum of the voltages across each output capacitor, C1, C2, C3 e C4, as presented in equation (1).

$$Vo = V_{C1} + V_{C2} + V_{C3} + V_{C4} \qquad (1)$$

Relation (2) can be obtained observing that the voltage across the inductors Lr1 and Lr2 must be null during a switching cycle period, the voltage across the capacitor VC2 can be expressed by (2).

$$V_{C2} = \frac{D.Vin}{1-D} \qquad (2)$$

Due to the transformer relation (n), it must be noticed that the voltage across C1are related to the voltage across
C3 according 4 and.

$$V_{C1} = Vin \qquad (3)$$

$$V_{C3} = n.Vin \qquad (4)$$

Similarly to the condition presented on equation (3), the voltage across C4 has a direct relation to the voltage across C2 and the transformer relation (n), as shown in (5).

$$V_{C4} = n.\frac{D.Vin}{1-D} \qquad (5)$$

Substituting (3)-(5) in (1), it can be determined the static gain, as shown in equation (6).

$$G = \frac{Vo}{Vin} = \frac{1+n}{1-D} \qquad (6)$$

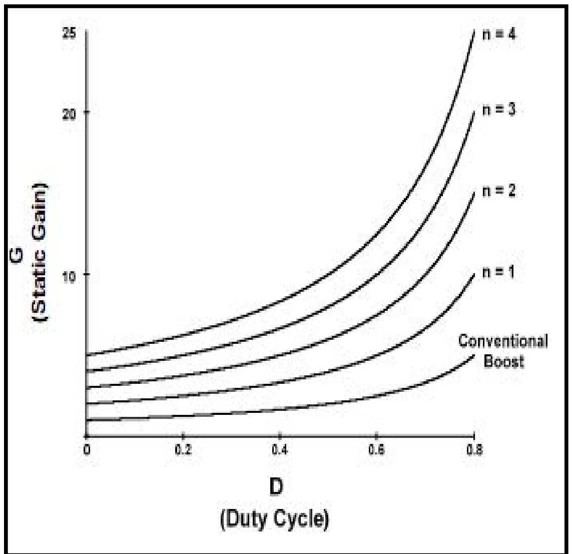

Figure 3: Relation G X D For Different Values Of 'N'.

Figure 3 presents the curves relating the static gain (G) with the duty cycle (D) for different values of n.

4.High Power Converters Classifications

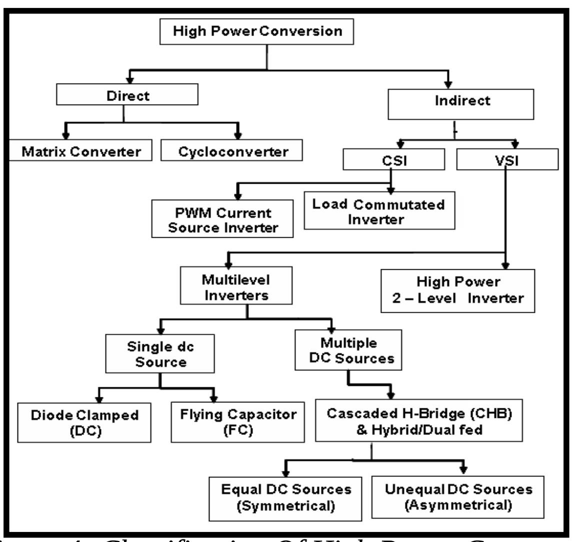

Figure 4 :Classification Of High Power Converters

Fig. 4 shows the classification of high power converters. Out of all converters Cascaded bridge configuration is more popular. Cascaded bridge configuration is again classified into 2 types 1) Cascaded Half Bridge 2) Cascaded Full Bridge or Cascaded H-Bridge. In this paper a novel cascaded hybrid H- Bridge topology is proposed for PV application.

4.1.Half H-Bridge

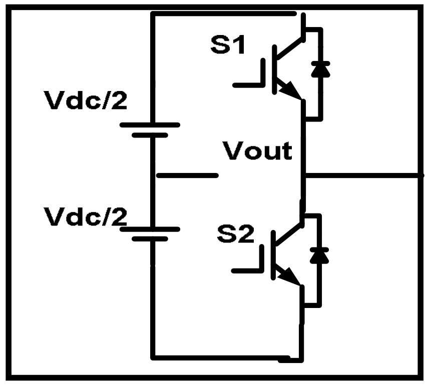

Figure 4.1: Half Bridge

Fig.4.1 shows the Half H-Bridge Configuration. By using single Half H-Bridge we can get 2 voltage levels. The switching table is given in Table 1.

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

Table 1:Switching table for Half Bridge

4.2. Full H-Bridge

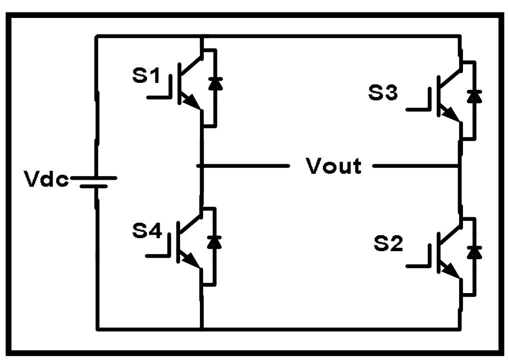

Figure 4.2:Full H-Bridge

Fig.3 shows the Full H-Bridge Configuration. By using single H-Bridge we can get 3 voltage levels. The number output voltage levels of cascaded Full H-Bridge are given by

2n+1 and voltage step of each level is given by Vdc/n. Where n is number of H-bridges connected in cascaded. The switching table is given in Table2.

Switches Turn ON	**Voltage Level**
S1,S2	Vdc
S3,S4	-Vdc
S4,D2	0

Table 2 :Switching Table For Full H-Bridge

5.Operating Principle Of The Proposed Topology

This section presents the operation principle from the high voltage gain boost converter. For the theoretical analysis, it will be considered that the input voltage (Vin) and output current (Io) are ripple free and all devices are ideal. From Figure 4, it can be observed the main theoretical waveforms, which illustrate the details of the operation principle stages explained above.

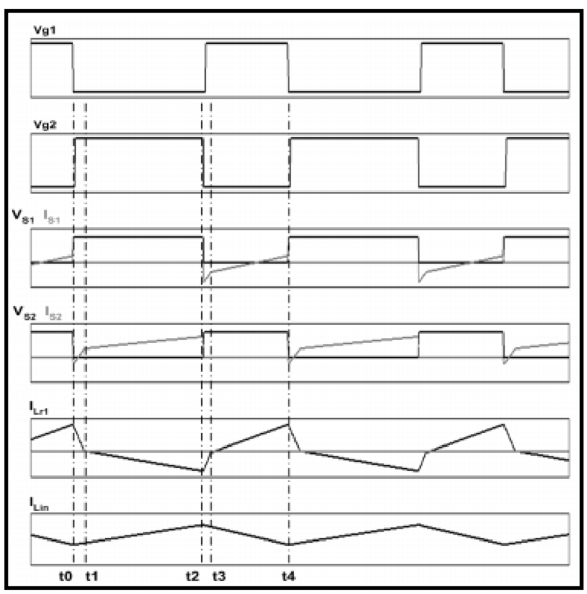

Figure 5: Main Theoretical Waveforms

5.1.First Stage [T0 – T1]

At T0, S1 Is Turned-Off And S2 Is maintained turned-on, as presented in Figure 5. On this stage, the difference between the conduced current due to the transformer leakage and the input current flows through the anti-parallel diode of S2 and decreases linearly. This stage ends when the current on the primary side of the transformer is zero.

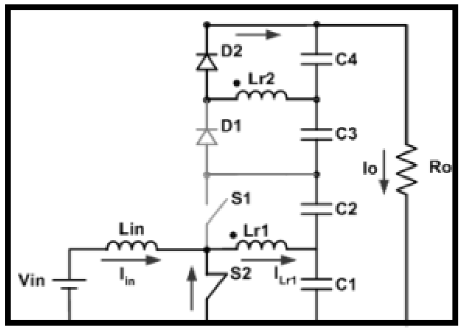

Figure 5.1: First Stage

5.2.Second Stage [T1 – T2]

On This Stage, The Current through the primary side is added to the input current and conduced through the switch S2. The secondary circuit charges the capacitor C3 through diode D1.

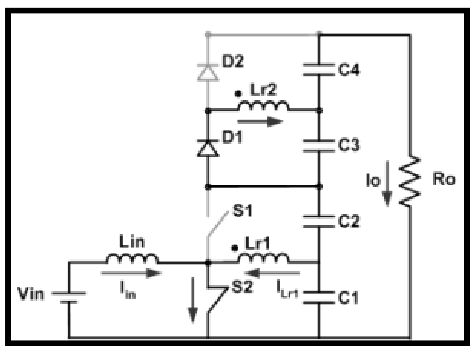

Figure5.2: Second Stage

5.3.Third Stage [T2 – T3]

This stage begins when S2 turns- off and S1 turns-on. The current that flows through S1 is the sum of the input current and the one through thetransformer primary side, and increases linearly.This stage ends when the current on the primary reaches zero.

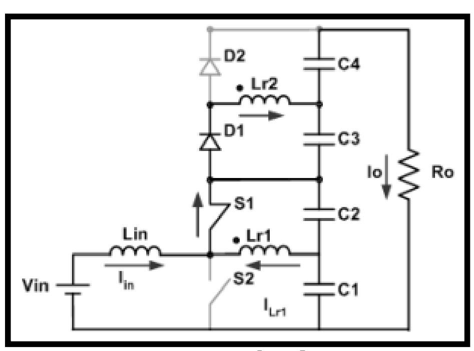

Figure 5.3: Third Stage

5.4.Fourth Stage [T3 – T4]

On this stage, the current on the transformer primary side is the sum of the input current and the one that flows through C2. The secondary circuit charges C4 through diode D2. This stage ends when S2 turns-on and S1 turns-off.

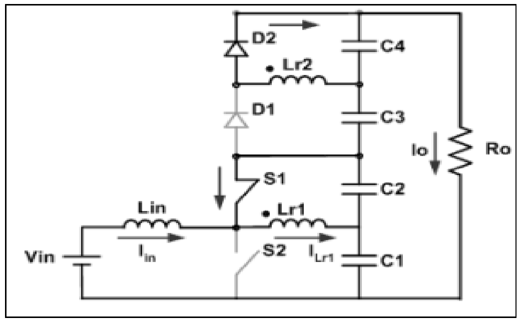

Figure 5.4: Fourth Stage

Input Voltage	24 Vdc
Output Voltage	200 Vdc
Nominal Power	500 W
Switching Frequency	50kHz
Transformer turns ratio (n)	3
Inductance of L_{in}	120µH
Capacitances of C_1, C_2, C_3 and C_4	680µF

Table 3:Converter Specifications

6.Matlab/Simulink Modeling And Simulation Results

Here the simulation is carried out in two cases

A Single Stage High Voltage Gain Boost Converter

Interfacing the boost converter to Grid by using Multilevel Inverter.

6.1.Case - A Single Stage High Voltage Gain Boost Converter

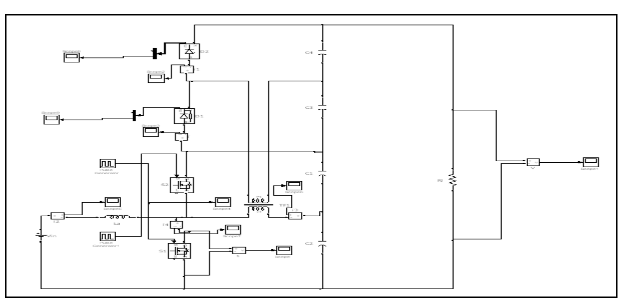

Figure 6.1: The Simulink Model Of The Proposed Circuit

The above figure shows the proposed circuit of simulink model.

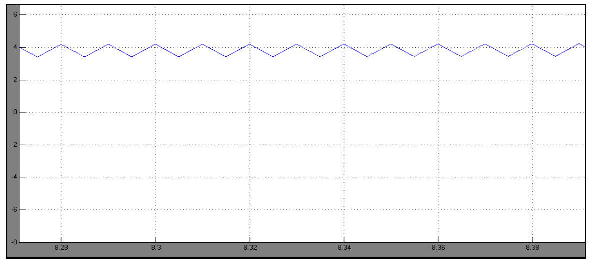

Figure 6.1.1: Inductor Current ILB

The above figure shows the inductor current ILB waveform.

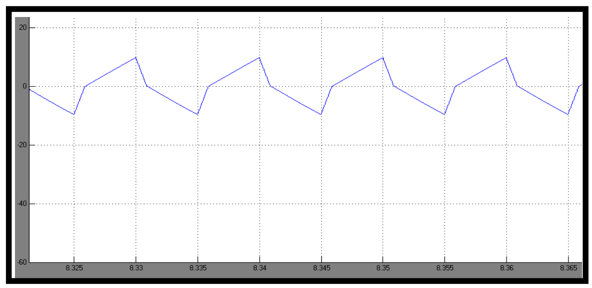

Figure6.1.2: Inductor Current IL

The above figure shows the inductor current IL waveform.

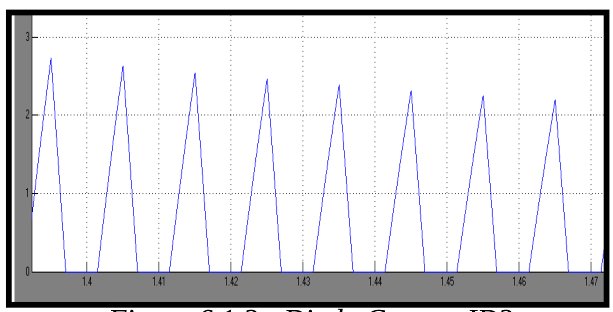

Figure 6.1.3: Diode Current ID3

The figure shows above diode current ID3waveform

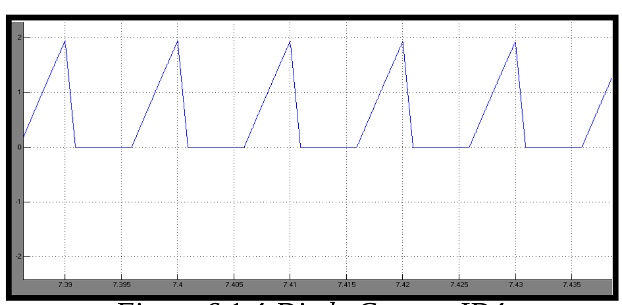

Figure 6.1.4:Diode Current ID4

The above figure shows the diode current ID4.

Fig. 6.1.1. and 6.1.2. shows the inductor currents input current ILB and IL. Fig. 12 and 13 shows the diode currents of D3 and D4.

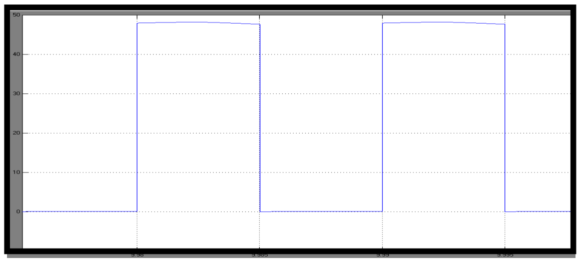

Figure 6.1.5: Voltage Across Switch S1

The above Figure shows the voltage across the switchS1 waveform

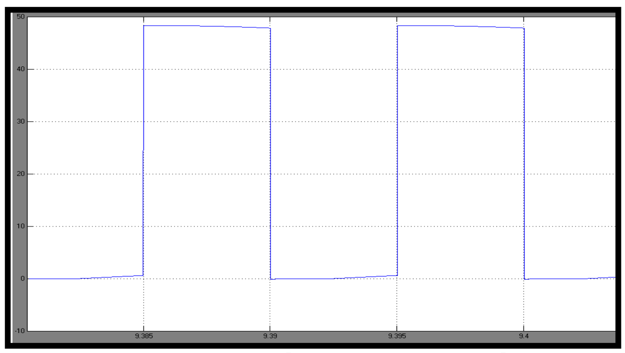

Figure 6.1.5: Voltage across switch S2

Fig. 6.1.4..and Fig..6.1.5 shows the voltage across switch s1 and s2.

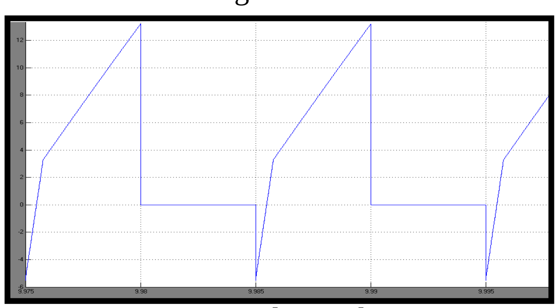

Figure6.1.6: Secondary Side Currents IS1

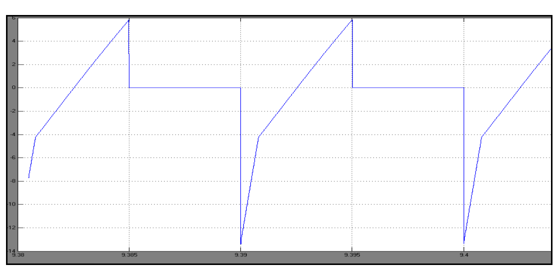

Figure 6.1.7 :Secondary Side Currents IS2

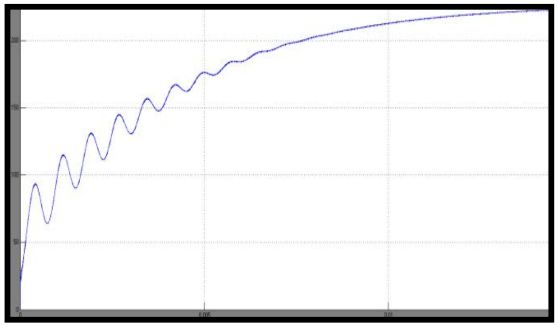

Figure 6.1.8: Capacitor Output Voltage

Fig. 6.1.6.and 6.1.7.shows the secondary side currents of IS1 and IS2 respectively. Fig.6.1.8.shows the capacitor output voltage.

6.2.Case-Interfacing The Boost Converter To Grid By Using Multilevel Inverter With Level Shifted PWM

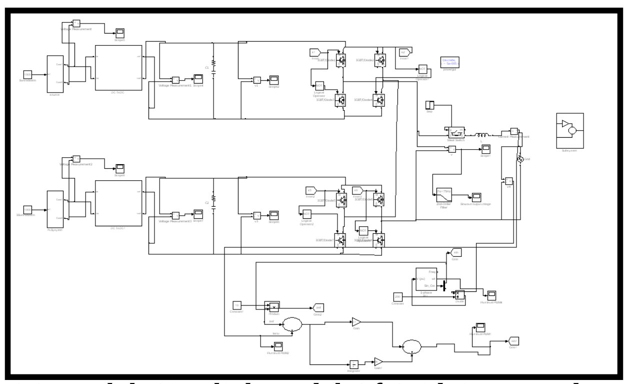

Figure 6.2:Matlab/Simulink Model Of Grid Connected PV System

Figure 6.2. shows the Matlab/Simulink model of Grid Connected PV system interfacing with the help of Five level Multilevel inverter.

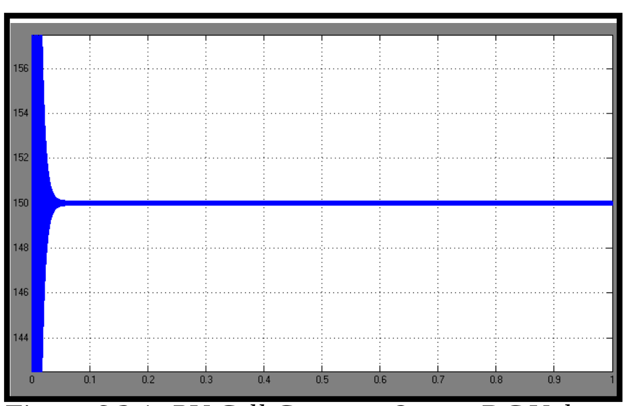

Figure 6.2.1: PV Cell Constant Output DC Voltage

Above Figure 6.2.1. shows the constant Dc coming from the Proposed Boost Converter.

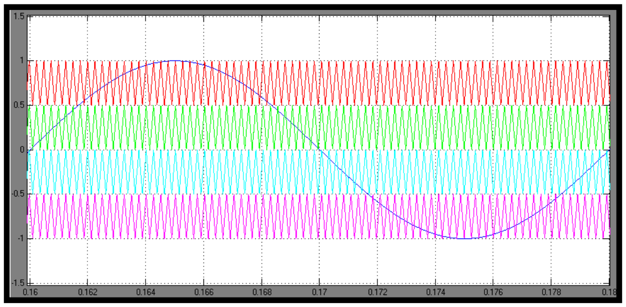

Figure 6.2.2: Carrier And Reference Waves Of Level Shifted Pwm

Fig.6.2.2.shows the Carrier and reference waveforms of the level shifted PWM method

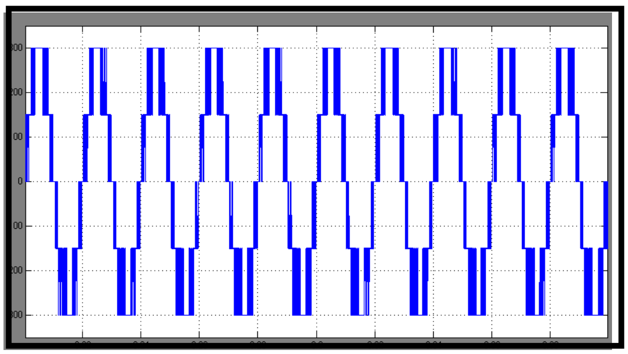

Figure 6.2.3: Five Level Output Voltage

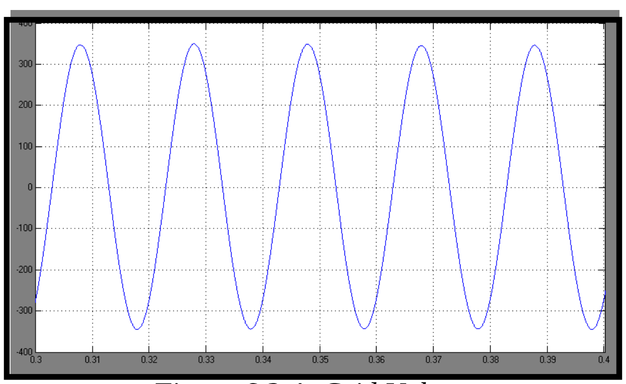

Figure 6.2.4: Grid Voltage

Fig.6.2.3.and 6.2.4.are the output voltage waveforms of the multilevel inverter connected grid without and with filters.

6.3.Case-Interfacing The Boost Converter To Grid By Using Multilevel Inverter With PSCPWM

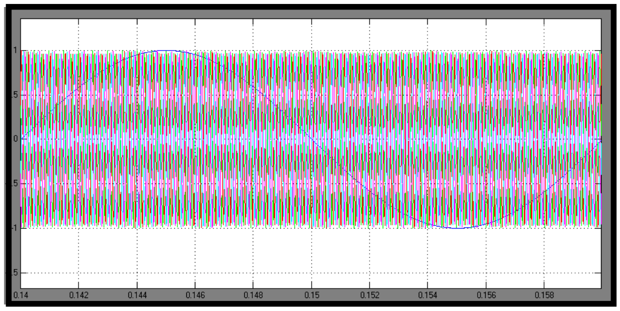

Figure 6.3: Carrier And Reference Waves Of Phase Shifted PWM

Fig.6.3. shows the Carrier and reference waveforms of the level shifted PWM method

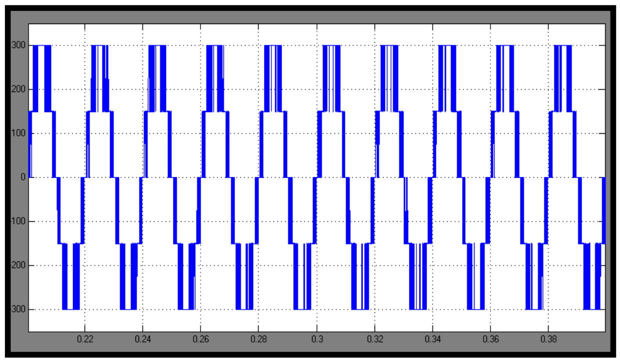

Figure 6.3.1: Five Level Output Voltage

The Above Figure 6.3.1 Shows the Five level Output Voltage, By using some filtering methods, we get Pure sinusoidal voltage and that sinusoidal voltage is directly fed to Grid Connected system as shown in Fig.6.3.2

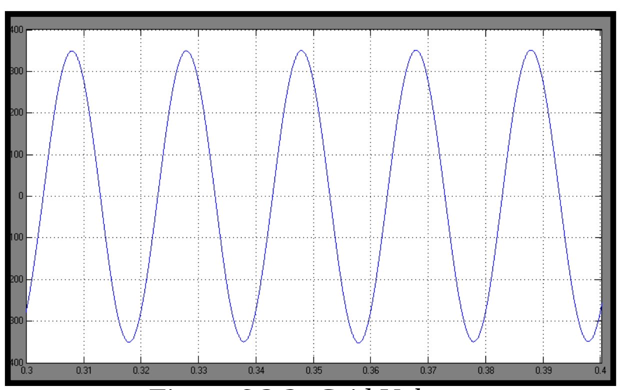

Figure 6.3.2: Grid Voltage

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7.Conclusion

A boost converter with high voltage gain was presented, and its equations, operation principle, and main theoretical waveforms were all detailed. The topology presents, as main feature, a large voltage step-up with reduced voltage stress across the main switches, important when employed in grid connected systems based on battery storage, like renewable energies systems. The voltage gain of the converter even higher by increasing the transformer turns ratio. Finally the proposed boost converter is integrated with multilevel inverter for Grid connected PV application. We get Constant DC output voltage from PV cell, Dc voltage is directly interfaced to Grid with the help of Multilevel Inverter, and here we get pure sinusoidal voltage. In this paper two modulation methods were used and by utilizing this methods multilevel voltage waveforms were obtains. Simulation of these circuits were done by using Matlab/Simulink and simulation results are presented.

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