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A Single Stage High Voltage Gain Boost Converter Stand-Alone PV Applications

Dilip kumar Loya
M. Tech Student Scholar
Department of Electrical and Electronics Engineering, Dadi Institute of Engineering & Technology, A.P, India
K. Sulochana
Senior Assistant Professor
Department of Electrical & Electronics Engineering,
Dadi Institute of Engineering & Technology, A.P, India.

Abstract:

One of the major trends in power electronics is increasing the switching frequencies. The advances in semiconductor fabrication technology have made it possible to significantly improve not only voltage – and current capabilities but also the switching speed. The faster semiconductors working at high frequencies result in the passive components of the converters – capacitors, inductors and transformers – becoming smaller thereby reducing the total size and weight of the equipment and hence to increase the power density. In order to give support to the growing technology demand of renewable energy applications, this paper presents a new converter topology for battery charging feasible to photovoltaic systems. The proposed converter presents in a single stage a large voltage step-up, high efficiency, and reduced voltage stress on switches due to the transformerIn 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.

Key words: *Photo-Voltaic Systems, Soft-Switching, Boost Converter, High Voltage Gain.*

1.Introduction

Energy is the basis of human life. There is hardly any activity or moment that is independent of energy. Every moment of the day we are using energy. Earlier man used muscle power, then fire and animal power. Next, he learned to harness energy, convert it to useful form and put it to various uses. Over the past few decades, energy is the backbone of technology and economic development. In addition to men, machines and money, 'energy' is now the fourth factor of production. Without energy, no machine will run, electricity is needed for every things. Hence, our energy requirements have increased in the years following the industrial revolution. This rapid increase in use of energy has created problems of demand and supply. If this growing world energy demand is to be met with fossil fuels, they will be no more available for producing the energy after few years. It is a need of today's world to concentrate on renewable energy source to satisfy the demand and conserve our finite natural resources for the generation to come. Conventional energy sources based on oil, coal, and natural gas have proven to be highly effective drivers of economic progress, but at the same time damaging to the environment and to human health. Furthermore, they tend to be cyclical in nature, due to the effects of oligopoly in production and distribution. These traditional fossil fuel-based energy sources are facing increasing pressure on a host of environmental fronts. Distributed generators (DG), including renewable sources, within microgrids can help overcome power system limitations, improve efficiency, reduce emissions and manage the variability of renewable sources. A microgrid, a relatively new concept, is a zone within the main grid where a cluster of electrical loads and small micro generation systems such as solar cell, fuel cell, wind turbine and small combined heat and power (CHP) systems exist together under an embedded management and control system with the option of storage devices.

Renewable energy systems using, as main energy source, photovoltaic panels and/or fuel cells have an intrinsic characteristic of producing low voltage levels, requiring a DC converter with large voltage step-up in order to produce a high voltage DC bus which feeds an DC AC converter. Though conventional boost converter can theoretically be used for this purpose, obtaining such high voltage gain implies that it would operate with duty cycles greater than 0.9, which is not feasible due to the great variations on the output voltage caused by small variations on the duty cycle, leading the boost converter to instability.

To overcome this drawback, a large number of large voltage step-up converters have been proposed, as in [1-14].

In [3] and [4], 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 [5], 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 [6-8], 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 hvoltage 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 switchings 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.

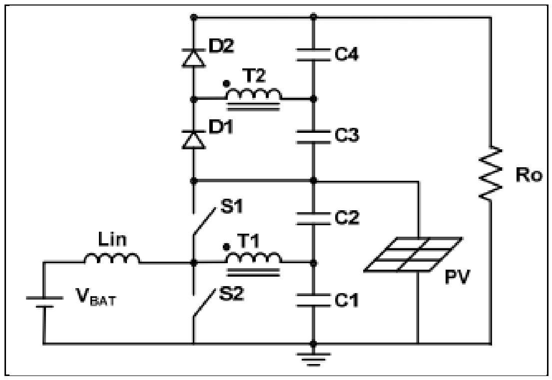

Figure1: A Proposed Topology used in PV Applications

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.

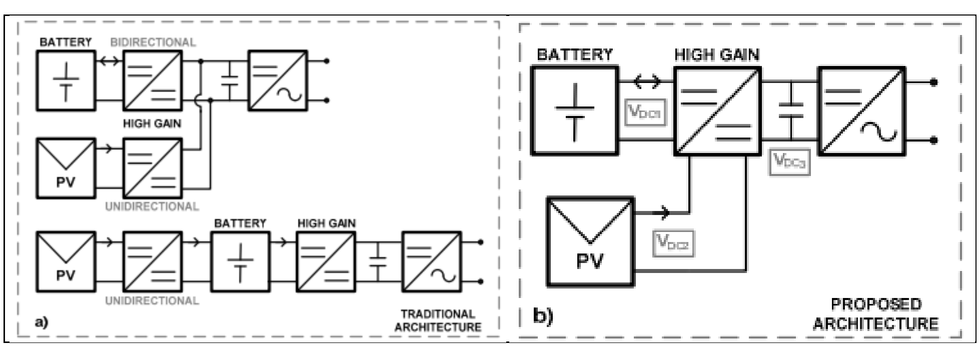

Figure 2: a) Conventional Architecture b)Proposed Architecture

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.

$$V_{C1} = Vin$$
$$V_{C3} = n.Vin \qquad (3) ,(4)$$

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).

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

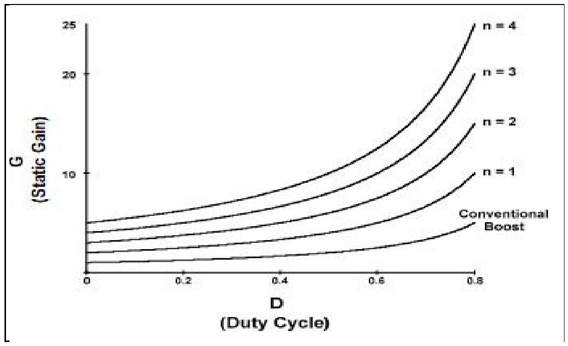

Figure 3: Relation G x D for different values of 'n'

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

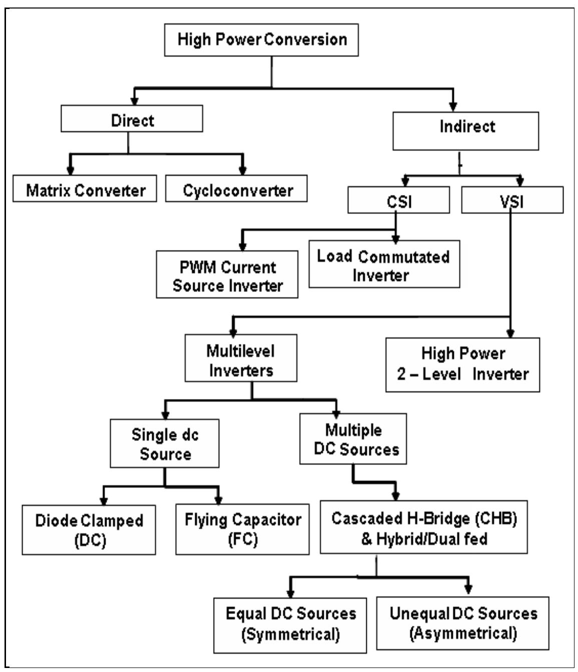

Figure 6: Classification of High power Converters

Fig.6 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

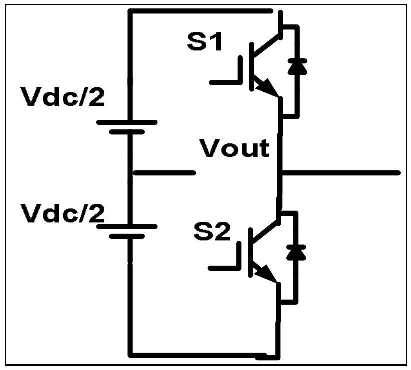

Figure 7: Half Bridge

Fig.7 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

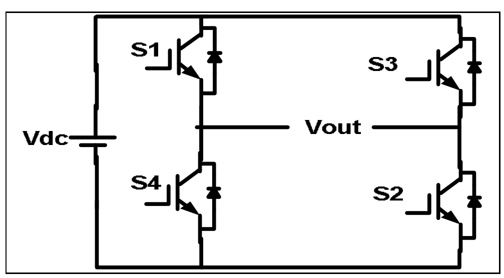

Figure 3 : Full H-Bridge

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.

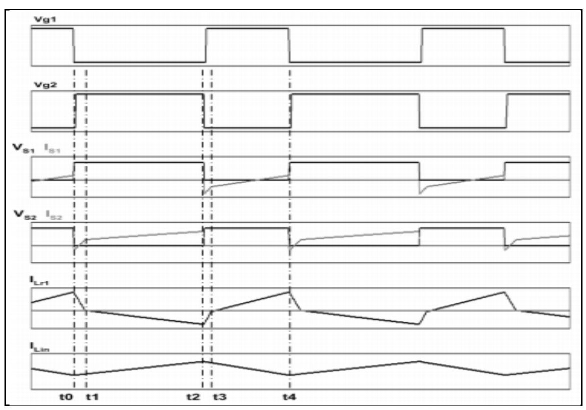

Figure 4: Main theoretical waveforms

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.

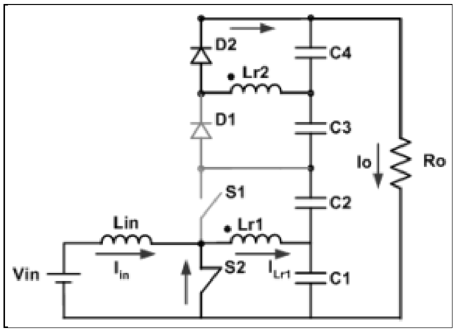

Figure 5: First Stage

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.

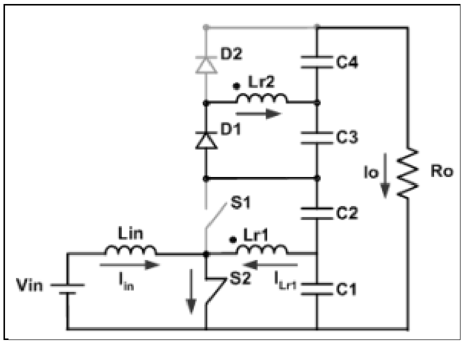

Figure 6: Second Stage

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.

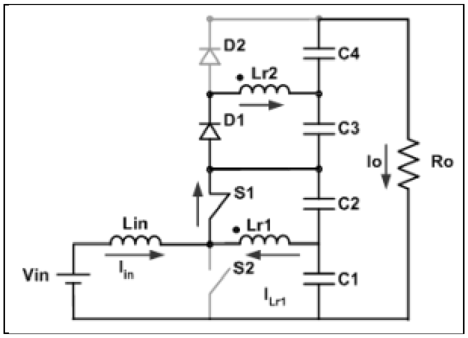

Figure 7: Third Stage

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.

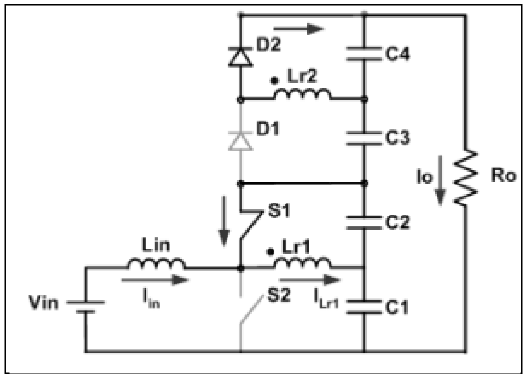

Figure 8: Fourth Stage

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

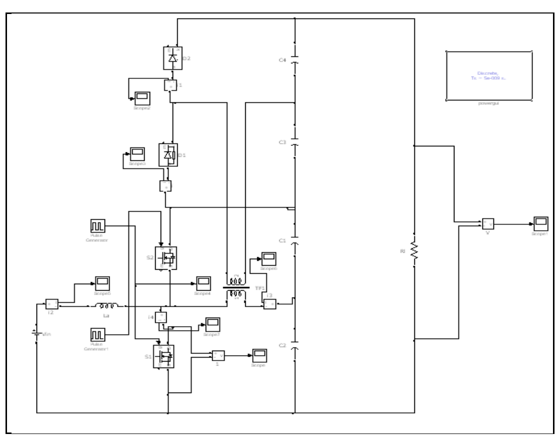

Figure 9: The simulink model of the proposed circuit

The above figure shows the proposed circuit of simulink model

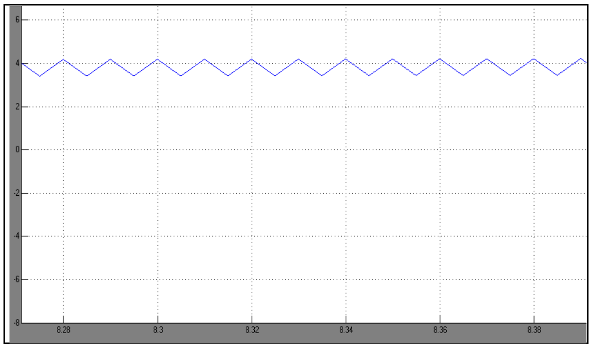

Figure 10: Inductor Current ILB

The above figure shows the inductor current ILB waveform

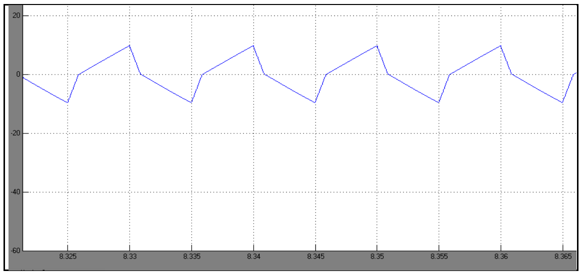

Figure 11: Inductor Current IL

The above figure shows the inductor current IL waveform

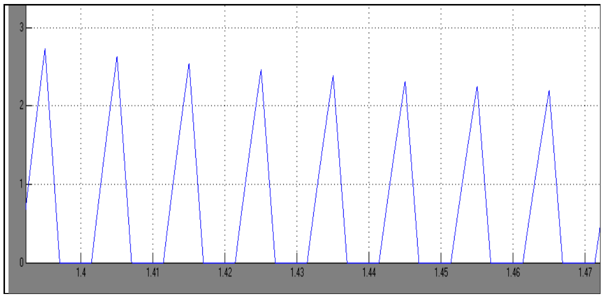

Figure 12: Diode Current ID3

The figure shows above diode current ID3waveform

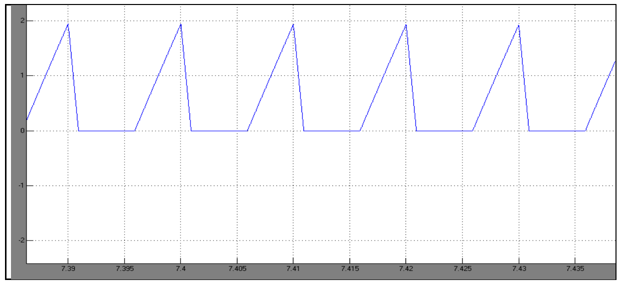

Figure 13: Diode Current ID4

The above figure shows the diode current ID4

Fig. 10 and 11 shows the inductor currents input current ILB and IL. Fig. 12 and 13 shows the diode currents of D3 and D4.

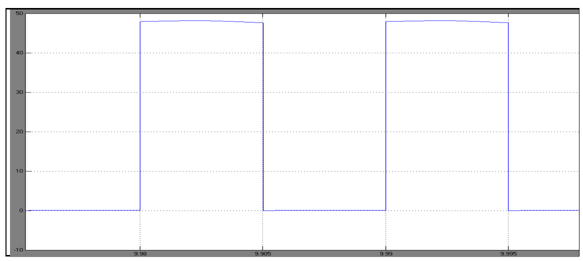

Figure 14: Voltage across switch S1

The above Figure shows the voltage across the switchS1 waveform

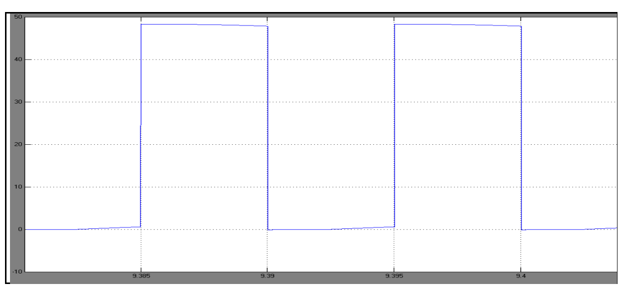

Figure 15: Voltage across switch S2

Fig. 14and Fig.15 shows the voltage across switch s1 and s2.

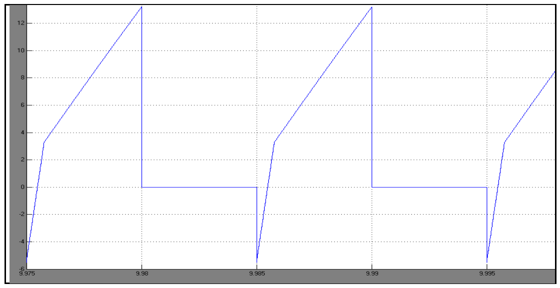

Figure 16: Secondary side currents IS1

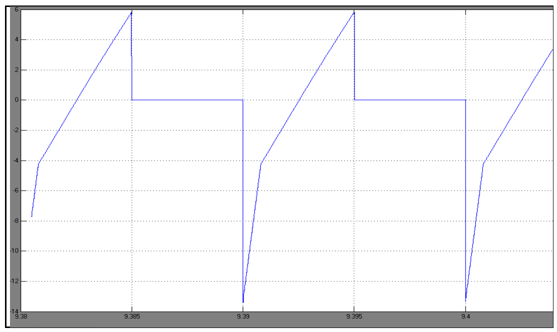

Figure 17: Secondary side currents IS2

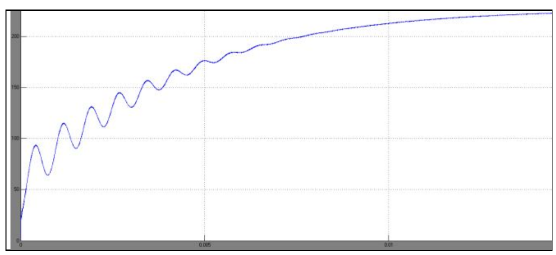

Figure 18: Capacitor output voltage

Fig. 16and 17 shows the secondary side currents of IS1 and IS2 respectively. Fig.18 shows the capacitor output voltage.

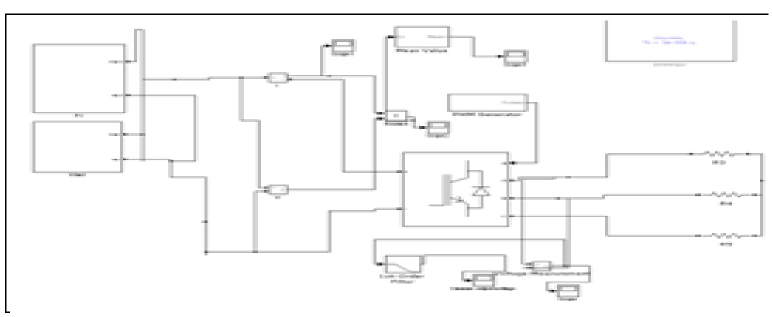

Figure 19: Matlab/Simulink model of Standalone Renewable Energy system

Fig.19 shows the block diagram of standalone renewable energy source.Here we have considered PV, Wind, Hydral.

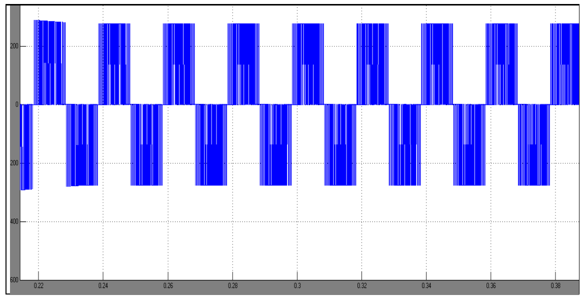

Figure 20: PWM output of inverter

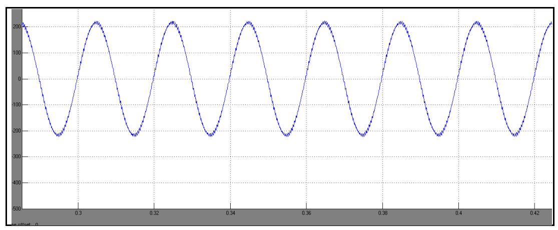

Figure 21: Sinusoidal output

Fig.20 and Fig.21 shows the PWM output of inverter without and with filter.

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 three level inverter for standalone PV application. A Matlab/Simulink model is developed and simulation results are presented.

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