International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2013): 6.14 | Impact Factor (2015): 6.391

# A Transformerless High Step-Up DC-DC Converter Based on Voltage Multiplier

**Shebin Rasheed[1], Soumya Simon[2]**

[1]PG Student [PEPS], Department of EEE, FISAT, Angamaly, Kerala, India

[2]Assistant Professor, Department of EEE, FISAT, Angamaly, Kerala, India

**Abstract:** ***This project deals with a high step-up dc-dc converter based on the Cockcroft-Walton (CW) voltage multiplier without a high frequency transformer. Providing continuous input current with low ripple, high voltage ratio, and low voltage stress on the switches, diodes, and capacitors, this converter is quite suitable for applying to low-input-level dc generation systems. Moreover, based on the n-stage CW voltage multiplier, this converter can provide a suitable dc source for an (n + 1)-level multilevel inverter. In this paper, the control strategy employs two independent frequencies, one of which operates at high frequency to minimize the size of the inductor while the other one operates at relatively low frequency according to the desired output voltage ripple. Simulation results demonstrates the validity of the new converter. The simulation of the converter is done with MATLAB /SIMULINK software.***

**Keywords:** DC-DC Converter, Inverting Mode, Switching Mode, MATLAB/SIMULINK

## 1. Introduction

In recent years, extensive use of electrical equipment has imposed severe demands for electrical energy, and this trend is constantly growing. Consequently, researchers and governments worldwide have made efforts on renewable energy applications for mitigating natural energy consumption and environmental concerns. Among various renewable energy sources, the photovoltaic (PV) cell and fuel cell have been considered attractive choices. However, without extra arrangements, the output voltages generated from both of them are with ratherlow level. Thus, a high step-up dc-dc converter is desired in the power conversion systems corresponding to these two energy sources. In addition to the mentioned applications, a high step-up dc-dc converter is also required by many industrial applications, such as high-intensity discharge lamp ballasts for automobile head- lamps and battery backup systems for uninterruptible power supplies.along with fast recovery diodes in series, which decreases switching losses and poor reverse recovery problem of MOSFETs body diodes is also avoided. The objectives of this project work is to study the new high voltage dc-dc converter based on voltage multiplier and also to make a comparison with the conventional topologies. Then how this topology proves to be more advantageous.

Theoretically, the conventional boost dc-dc converter can provide a very high voltage gain by using an extremely high duty cycle. However, practically, parasitic elements associated with the inductor, capacitor, switch, and diode cannot be ignored, and their effects reduce the theoretical voltage gain. Up to now, manyStep-up dc-dc converters have been proposed to obtain high voltage ratios without extremely high duty cycle by using isolated transformers or coupled inductors. Among these high step-up dc-dc converters, voltage-fed type sustains high input current ripple. Thus, providing low input current ripple and high voltage ratio, current-fed converters are generally superior to their counterparts. A traditional current-fed push pull converter was presented to provide the aforementioned merit. However, in order to achieve high voltage gain, the leakage inductance of the transformer is relatively increased due to the high number of winding turns. Consequently, the switch is burdened with high voltage spikes across the switch at the turn-o_ instant. Thus, higher voltage-rating switches are required.

Some modified current-fed converters integrated step-up transformers or coupled inductors, which focused on improving efficiency and reducing voltage stress, were presented to achieve high voltage gain without extremely high duty cycle. Most of them are associated with soft switching or energy-regeneration techniques. However, the design of the high-frequency transformers, coupled inductors, orresonant components for these converters is relatively complex compared with the conventional boost dc-dc converter.

Some other alternative step-up dc-dc converters without step-up transformersand coupled inductors were presented. By cascading diode capacitor or diode-inductor modules, these kinds of dc-dc converters provide not only high voltage gain but also simple and robust structures. Moreover, the control methods forConventional dc-dc converters can easily adapt to them. However, for most of these cascaded structures, the voltage stress on each individual switch and passive element depends on the number of stages. Figure 1 shows an n-stage cascade boost converter for obtaining a high voltage gain.

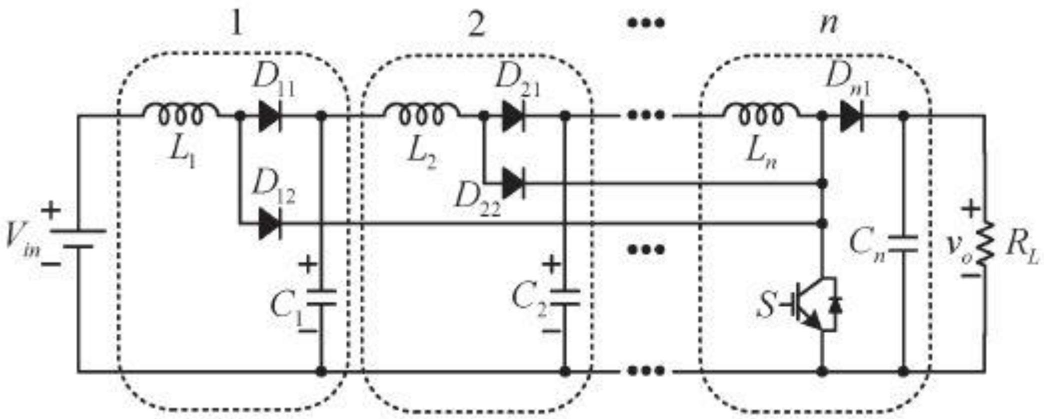


**Figure 1:** Some cascaded dc-dc converters. (a) n cascade boost converter

However, the passive elements and switch sustained high voltage stress in this cascaded converter. Some other structures with switched-capacitor or switched-inductor circuits combined with basic transformer less topologies were proposed. Figure 2 shows one of these topologies in which consists of a conventional boost converter and an n-stage diodecapacitor multiplier.

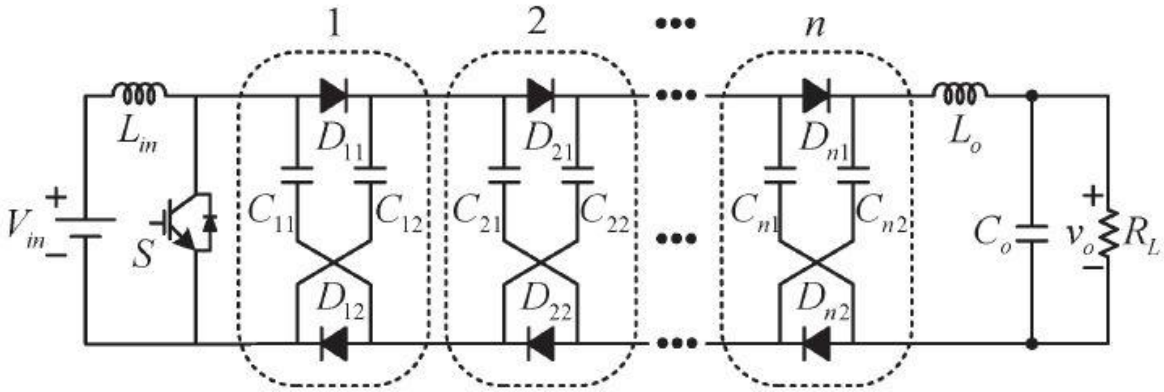


**Figure 2:** Some cascaded dc-dc converters. (b)Diode-capacitor n-stage step-up multiplier converter

The main advantage of this topology is that higher voltage gain can easily be obtained by adding the stages of the diode-capacitor multipliers without modifying the main switch circuit. Nevertheless, the voltage across each capacitor in each switched capacitor stage goes higher when a higher stage converter is used. Figure 3 shows another similar topology which has advantages similar to that of the above mentioned topology.

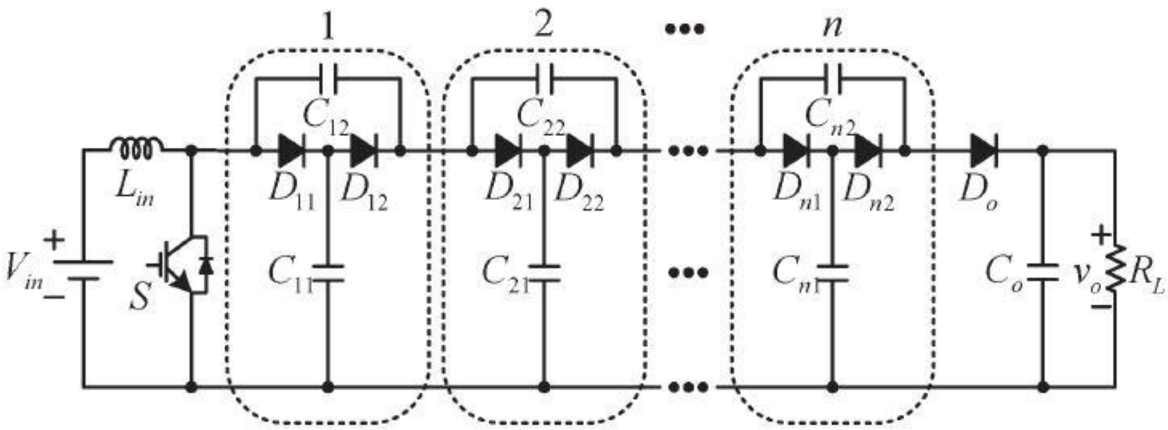


**Figure 3:** Some cascaded dc-dc converters. (c)Boost converter with cascade voltage multiplier cells

However, the voltage stress on the capacitors of higher stage is still rather high. Moreover, a modified topology, with integrated interleaved multiphaseboost converter and voltage multiplier, was proposed for high-power applications as well. In this topology, all capacitors in the voltage multiplier have identical voltage which is equal to Vo/ (n + 1).

In the past few decades, high-voltage dc power supplies have been widely applied to industries, science, medicine, military, and, particularly, in test equipment, such as X-ray systems, dust filtering, insulating test, and electrostatic coating. Providing the advantages of high voltage ratio, low voltage stress on the diodes and capacitors, compactness, and cost efficiency, the conventional Cockcroft-Walton (CW) voltage multiplier is very popular among high-voltage dc applications. However, the major drawback is that a high ripple voltage appears at the output when a low-frequency (50 or 60 Hz) utility source is used.

The concept of voltage multiplying circuit was first introduced by Greinacher in 1921. However, it remained unnoticed for a long period of time and then became known only when Cockcroft and Walton performed their first nuclear disintegration experiment using this circuit in 1932. This original voltage multiplier circuit was of half-wave type, and suffers from several problems such as large output voltage ripple and output voltage drop. To overcome these problems, a symmetrical voltage multiplier (SVM)was developed by Heilpern in 1954by adding an additional oscillating column of capacitors and a stack of rectifiers. It was thought that SVM has a pushpull kind of operation. For this kind of operation, two ac sources, out of phase by 180, were required. Therefore, an HVT with center-tapped secondary was used to operate SVM in push pull manner, as shown in Figure 4.

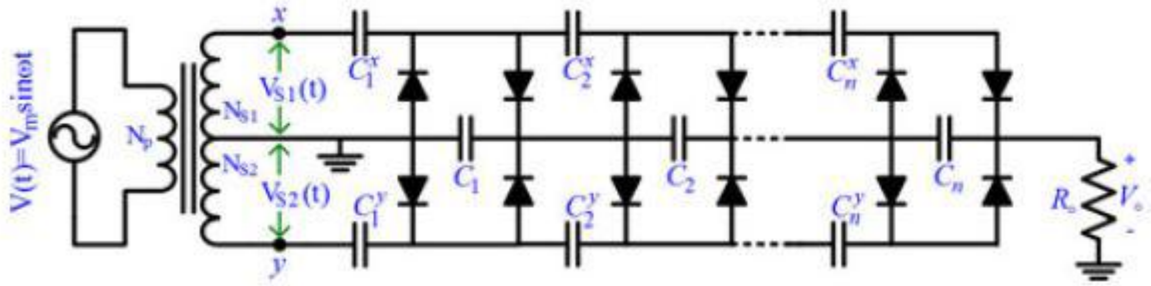


**Figure 4:** Conventional symmetrical voltage multiplier

A fully balanced SVM normally has much better performance, when compared with a half-wave multiplier (i.e., it has significantly smaller voltage ripple, voltage drop, and higher output power).However, the use of HVT with center-tapped secondary windings has two drawbacks. First, it increases the complexity of transformer winding, and second, any asymmetry between the output voltages (driving voltages) of the two secondary windings may give rise to generation of fundamental and higher order odd harmonics in the dc output of SVM. Such harmonics are inversely proportional to load current, and it is difficult to eliminate them. Figure 5 shows a modified topology of symmetrical voltage multiplier.

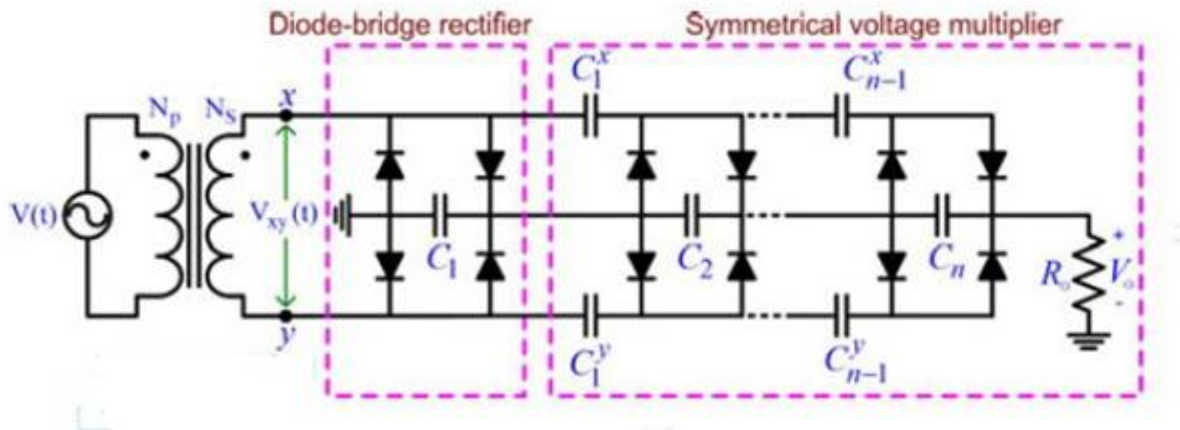


**Figure 5:** Hybrid symmetrical voltage multiplier

It was formed by cascading a diode-bridge rectifier and an SVM thus the name hybrid symmetrical voltage multiplier.The new topology has been foundto have smaller voltage drop, faster dynamic response, lesser component count, and lesser complexity, when compared with the conventional SVM. Thus, the proposed topology may be considered as a better alternative to the conventional SVM., the voltage stress on the capacitors of higher stage is still rather high and the voltage ripple at the dc output were found to be a little higher.

## 2. A Transformer Less High Step-Up Dc-Dc Converter Based on Voltage Multiplier

In this paper, a high step-up converter based on the CW voltage multiplier is discussed. Replacing the step-up transformer with the boost-type structure, the proposed converter provides higher voltage ratio than that of the conventional CW voltage multiplier. Thus, the proposed converter is suitable for power conversion applications where high voltage gains are desired. Moreover, the proposed converter operates in continuous conduction mode (CCM), so the switch stresses, the switching losses can be reduced as well. The new converter deploys four switches, in which Sc1 and Sc2 are used to generate an alternating source to feed into the CW voltage multiplier and Sm1 and Sm2 are used to control the inductor energy to obtain a boost performance. The new converter demonstrates some special features:

1) The four switches operate at two independent frequencies, which provide coordination between the output ripple and system efficiency;

2) With same voltage level, the number of semiconductors in the proposed converter is competing with some cascaded dc-dc converters
3) The dc output formed by series capacitors is suitable for powering multilevel inverters;
4) The proposed converter can adapt to an ac-dc converter with the same topology,

The new converter, which is supplied by a low-level dc source, such as battery, PV module, or fuel cell sources. The proposed converter consists of one boost inductor Ls, four switches (Sm1, Sm2, Sc1, and Sc2), and one n-stage CW voltage multiplier. Sm1 (Sc1) and Sm2 (Sc2) operate in complementary mode, and the operating frequencies of Sm1 and Sc1 are defined as fsm and fsc, respectively. For convenience, fsm is denoted as modulation frequency, and fsc is denoted as alternating frequency. Theoretically, these two frequencies should be as high as possible so that smaller inductor and capacitors can be used in this circuit. In this paper, fsm is set much higher than fsc, and the output voltage is regulated by controlling the duty cycle of Sm1 and Sm2, while the output voltage ripple can be adjusted by fsc. The circuit diagram representing the new dc-dc converter based on voltage multiplier is shown in Figure 6.

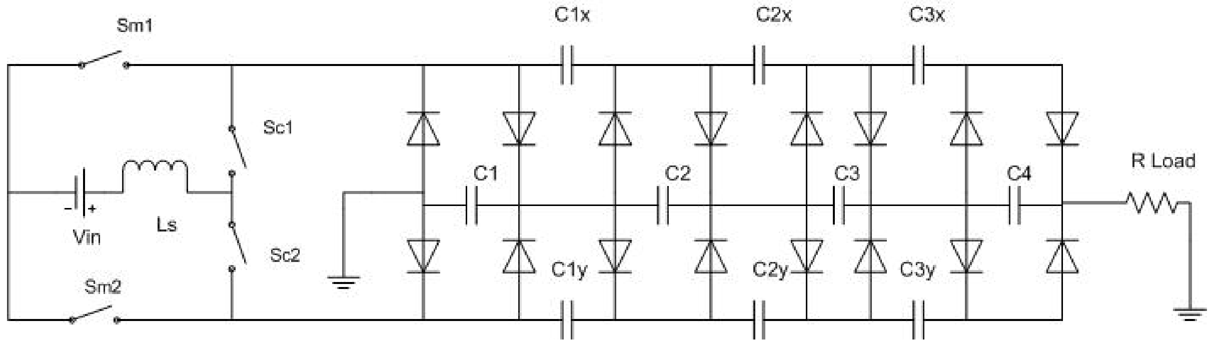


**Figure 6:** dc-dc converter based on voltage multiplier

## 3. Modes of Operation

**Mode-I**

From Figure 7, which is the charging mode for boost inductor, the switches Sm1 and Sc1 are turned ON and switches Sm2 and Sc2 are turned OFF and flows through the boost inductor and charges. During this period the current discharges through smoothing coloumn of capacitors (C1, C2...Cn) to the load. Since there is no path available for the stored current to discharge, it will discharge through the smoothing column of capacitors to the resistive load. This mode of operation is indicated in the Figure 7.Also it is important to note that it is assumed to be, the upper oscillating coloumn of capacitors are charged previously from mode 4.

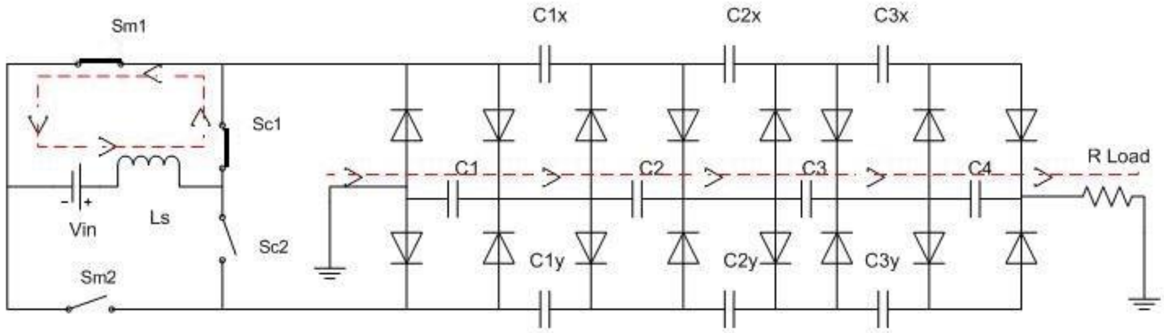


**Figure 7:** Mode I operation

**Mode-II**

From Figure 8, which is the charging mode. The switches Sm2 and Sc1 are turned ON and Sm1 and Sc2 are turned OFF, The boost inductor and input dc source transfer energy to the CW voltage multiplier as shown in Figure 8 i.e. in this mode, the previously charged upper oscillating coloumn of capacitors gets the opportunity to discharge as now the path is in reverse direction thus current flows through the upper oscillating coloumn of capacitors i.e. (Cx1,Cx2....Cxn) from the supply and then further flows through the smoothing coloumn of capacitors (C1,C2...Cn)and lower oscillating capacitors(Cy1,Cy2...Cyn) through the forward biased diodes thus charging smoothning and lower coloumn of capacitors of the multiplier circuit. Now the upper coloumn of capacitors are discharged and are empty which means the other coloumn of capacitors are doubly charged than the previous modes.

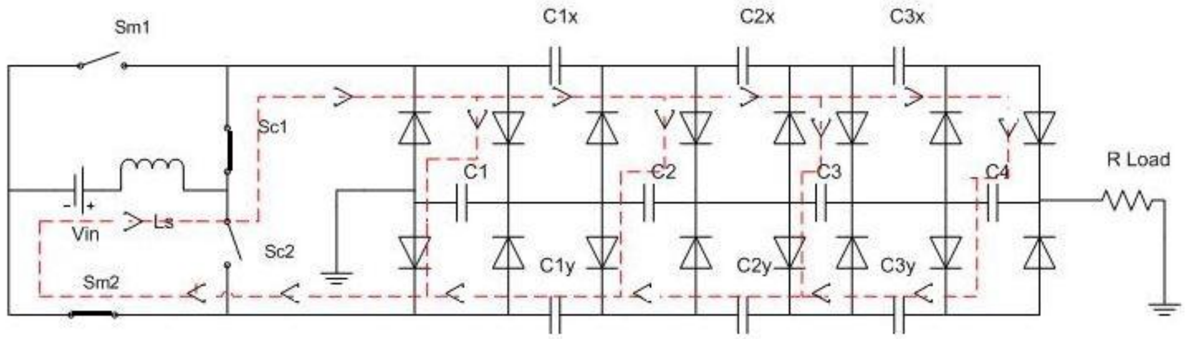


**Figure 8:** mode II operation

**Mode-III**

During this mode Sm2 and Sc2 are turned ON, and Sm1, Sc1, and all CW diodes are turned OFF, the boost inductor is charged by the input dc source in the opposite direction to that of mode 1, the smoothing coloumn of capacitors C1, C2,....Cn supply the load, and the upper oscillating capacitors(Cx1,Cx2....Cxn) and lower oscillating capacitors(Cy1,Cy2...Cyn) are floating while the lower coloumn of capacitors are already charged and waiting for an opportunity to be discharged. This is shown in figure 9.

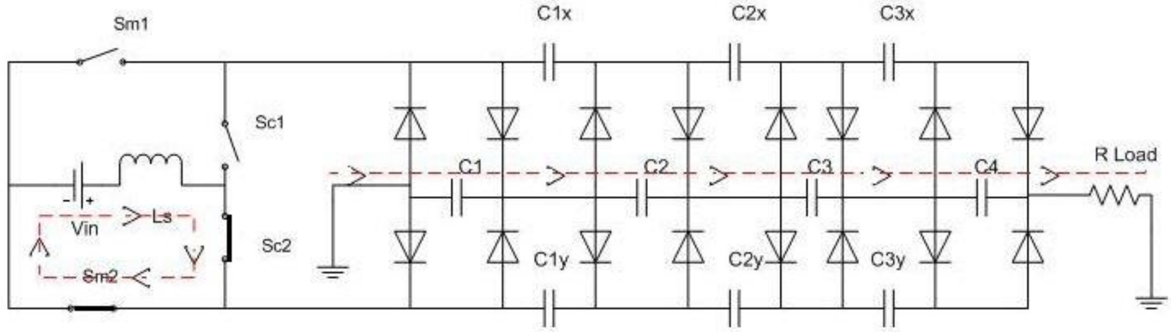


**Figure 9:** mode III operation

**Mode-IV**

During this mode, Sm1and Sc2 are turned ON, Sm2 and Sc1 are turned OFF, and the current is negative. The boost inductor and input dc source transfer energy to the CW voltage multiplier along with lower coloumn of capacitors as the path is in opposite direction thus the capacitors discharges. Here it is important to note that during mode II operation, the lower column of oscillating Capacitors (Cy1,Cy2...Cyn) have been already charged and it didn't find a path to discharge. So in this mode the lower oscillating capacitors gets the opportunity to discharge along with the supply. Thus the upper oscillating capacitors (Cx1, Cx2....Cxn) along with smoothing capacitors (C1, C2...Cn) gets Charged double than the mode II, which is shown in figure 10.

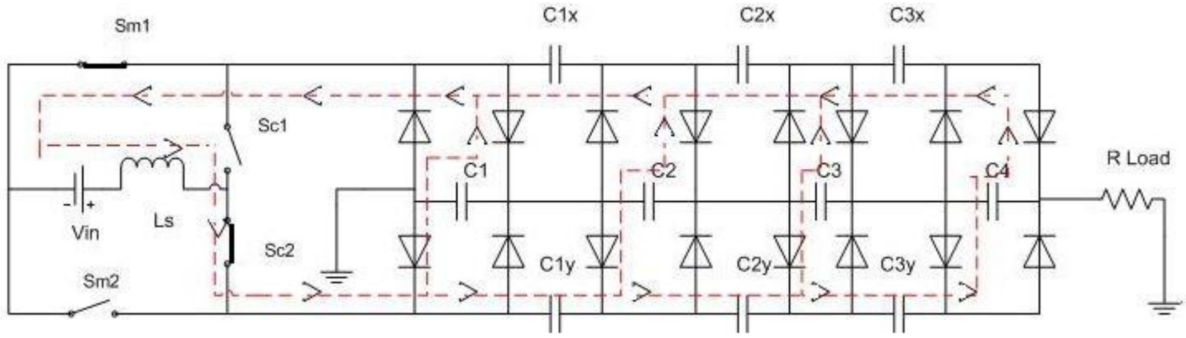


**Figure 10:** mode VI operation

## 4. Simulation Results

The first section describes about the software implementation of the conventional HSVM circuit. The simulation results include simulation model and its corresponding output voltage and current waveforms for R load. And in the second section, description about the software implementation of the conventional transformer less cockroft-walton multiplier circuit is shown. The simulation results include simulation model and its corresponding output voltage and current waveforms for R load. The third and final section includes description about the software implementation of the transformer less high step-up dc-dc converter based on voltage multiplier circuit is shown. The simulation results include simulation model and its corresponding output voltage and current waveforms for R load. The simulation parameters are shown in the table.

**Table 1:** Simulation Parameters

| S.NO. | Parameters | Attributes |
|---|---|---|
| 1 | input voltage Vo | 60 V |
| 2 | Modulation frequency fsm | 60 KHz |
| 3 | Alternating frequency fsc | 1 KHz |
| 4 | Load Resistance R | 4.7 Kohm |
| 5 | Stage number n | 3 |
| 6 | Boost Inductor Ls | 1.5 mH |
| 7 | multiplier capacitors | 10 nF |

The performance of the new dc-dc converter was first evaluated on the basisof computer simulation using MATLAB software. The simulation diagram representing the converter is shown in figure 11 followed by the conventional systems.

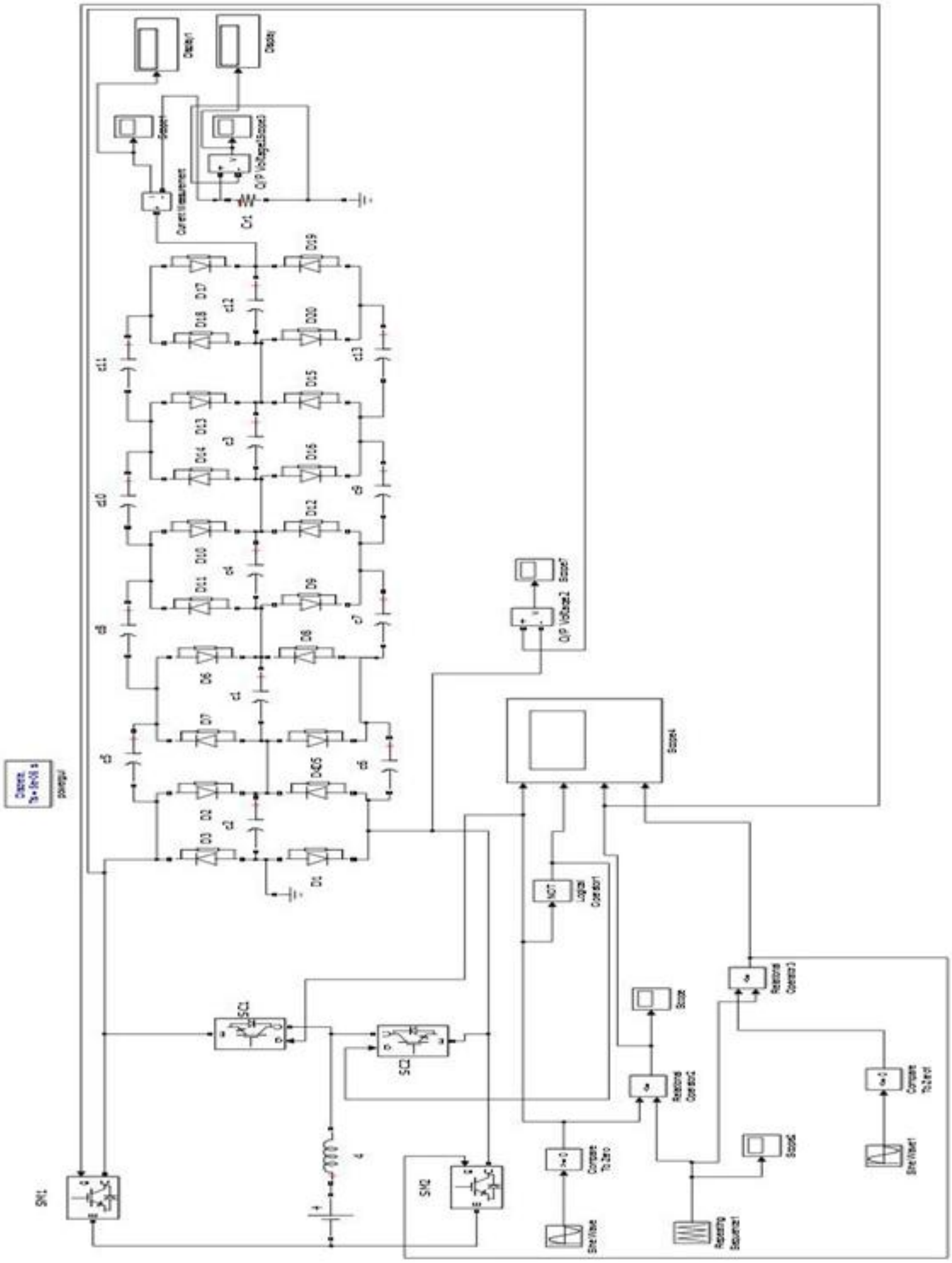

**Figure 11:** Simulation representing dc-dc converter

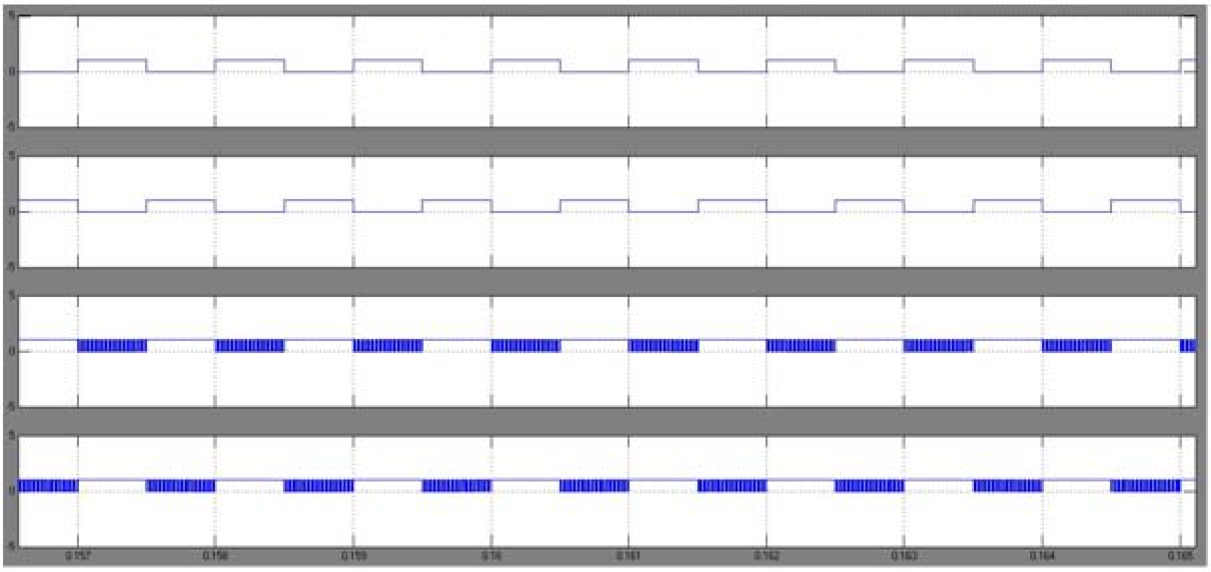

**Figure 12:** Gating pulse for dc-dc converter

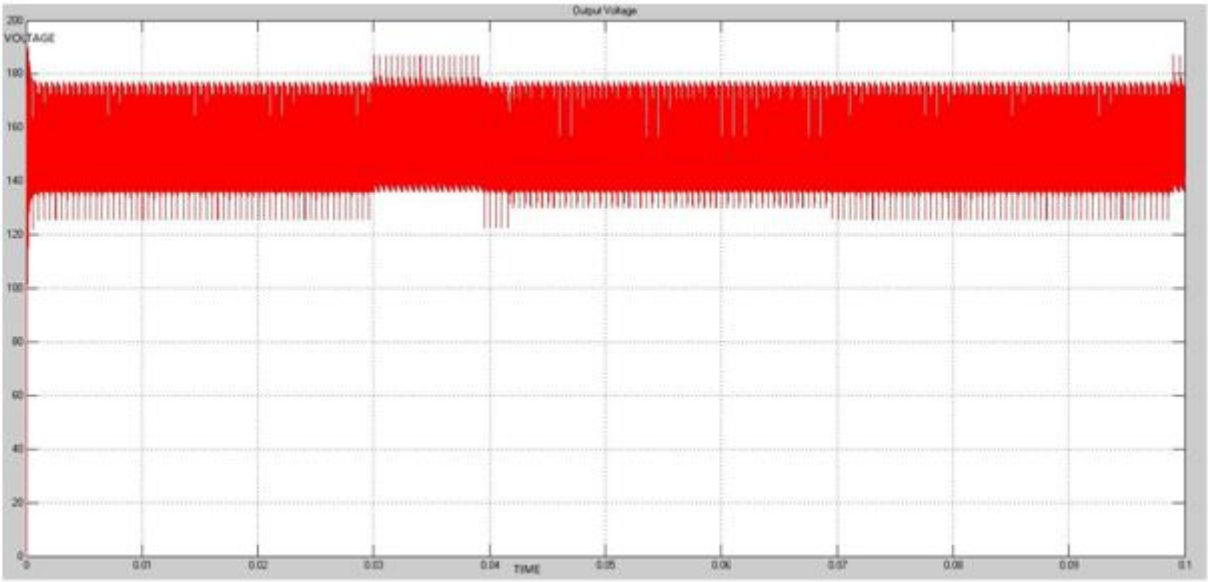


**Figure 13:** Output voltage waveform for new dc-dc converter

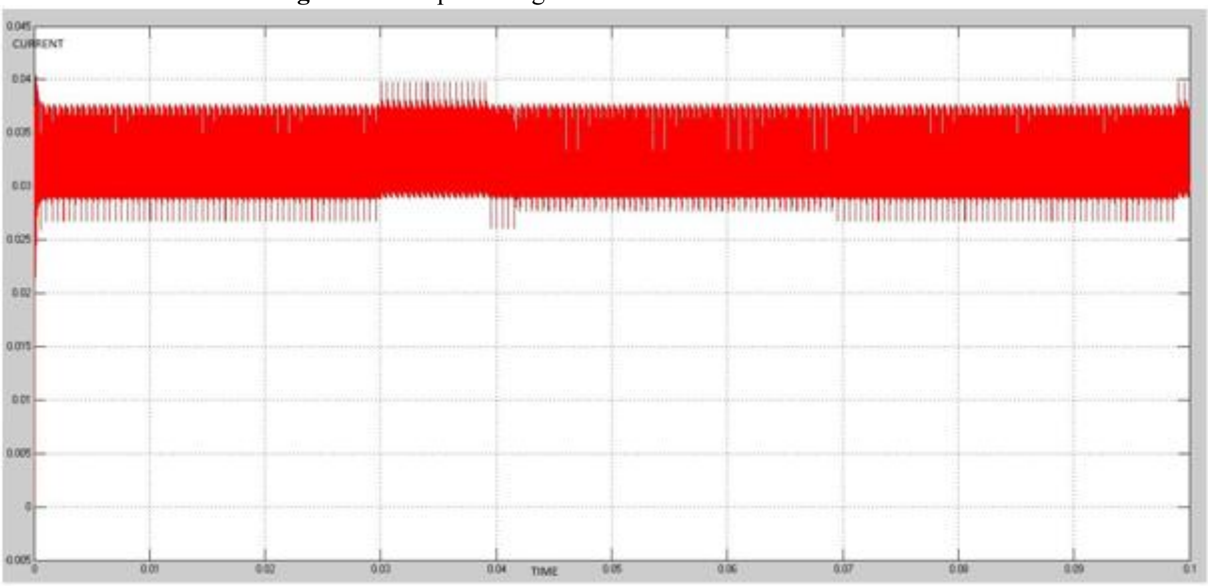


**Figure 14:** output current waveform for the new dc-dc converter

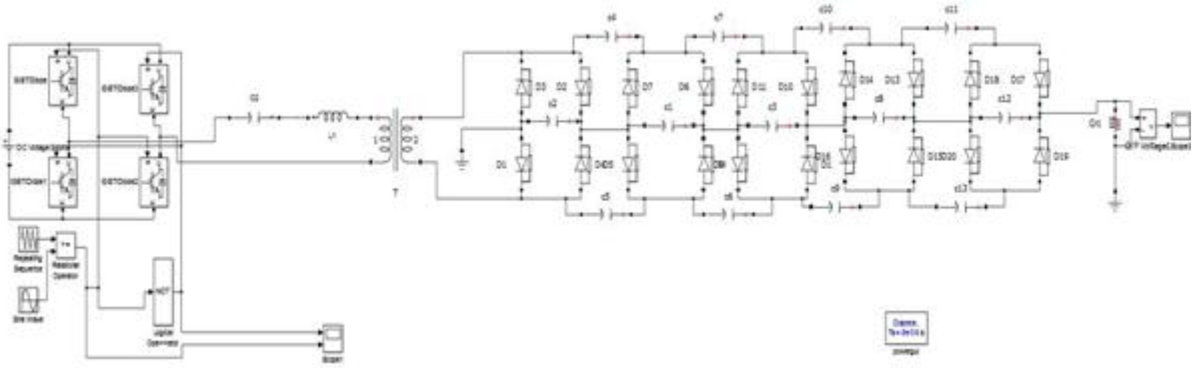

**Figure 15:** Conventional HSVM (Hybrid symmetrical voltage multiplier) circuit

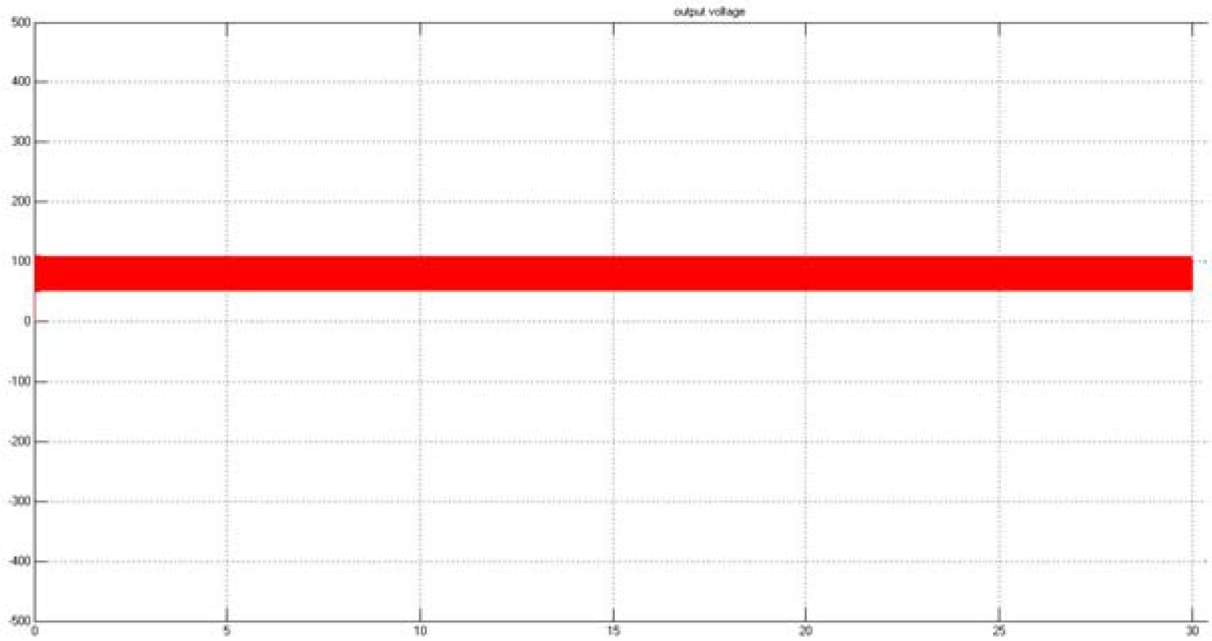


**Figure 16:** Output voltage waveform for conventional HSVM

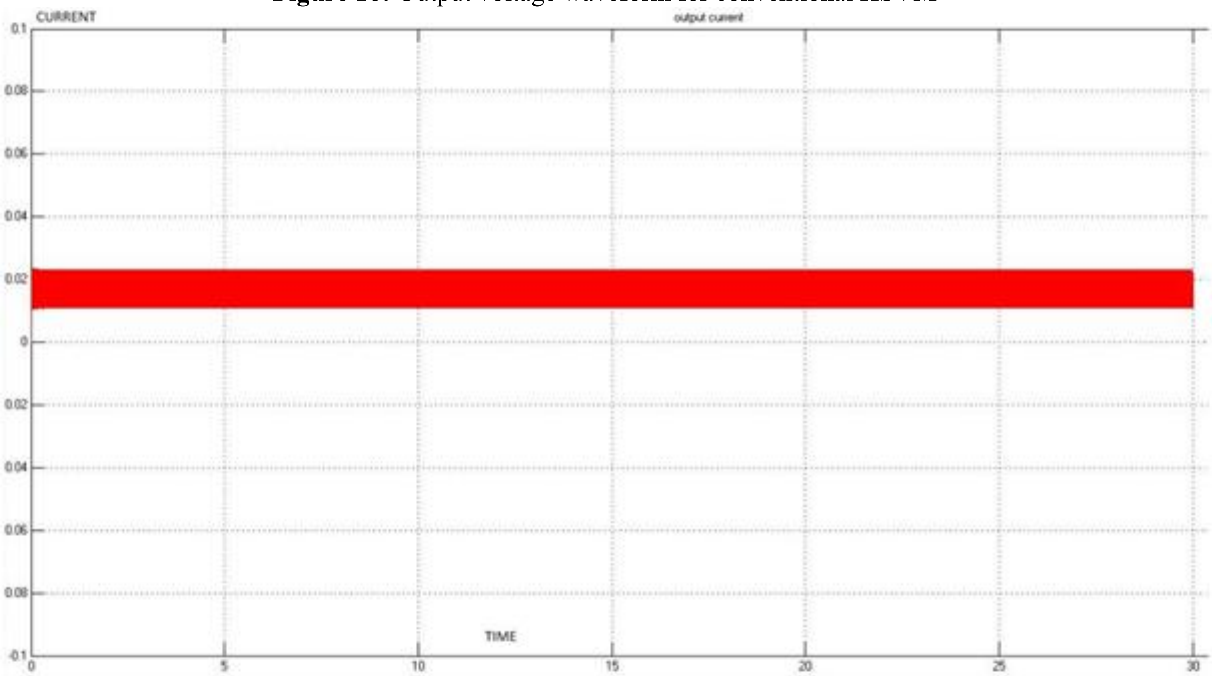


**Figure 17:** Output current waveform for conventional HSVM

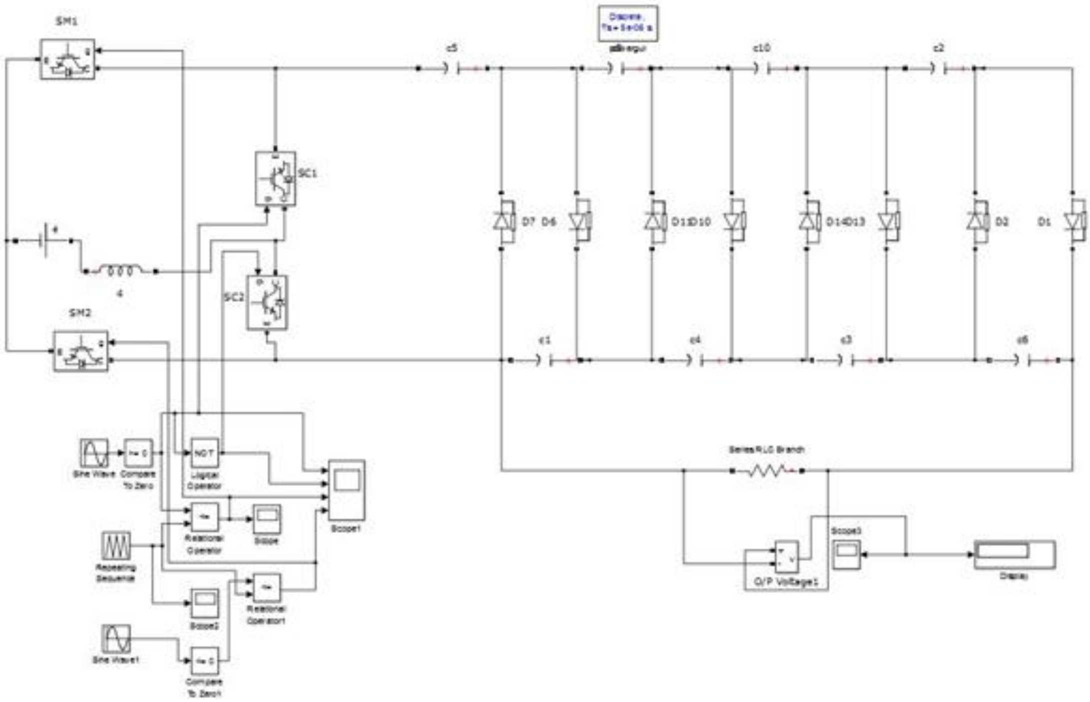


**Figure 18:** Conventional transformerless dc-dc converter


**Figure 19:** Output voltage waveform for conventional transformer less dc-dc converter

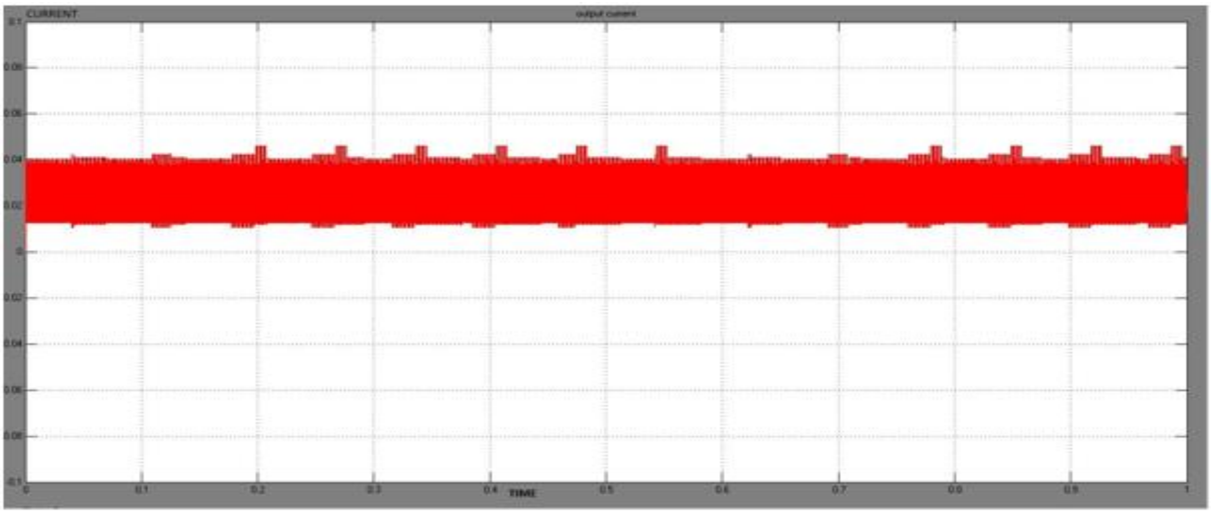


**Figure 20:** Output current waveform for conventional transformerless dc-dc converter

From the above shown simulation diagram, the new topology is simulated upon the prescribed specifications and found results were drawn in the below table. The output voltage and the waveforms representing both current and voltage were also pictured below for further understanding. moreover the comparison between HSVM and the new topology were made in the matlab under the similar conditions and the obtained results are both pictured and the comparison were made below.

**Table 2:** Comparison of different topologies

| S NO. | Topologies | Input Voltage | Output Voltage |
|---|---|---|---|
| 1 | New dc-dc converter | 60 V | 156 V |
| 2 | Conventional HSVM | 60 V | 86 V |
| 3 | Conventional dc-dc converter | 60 V | 109 V |

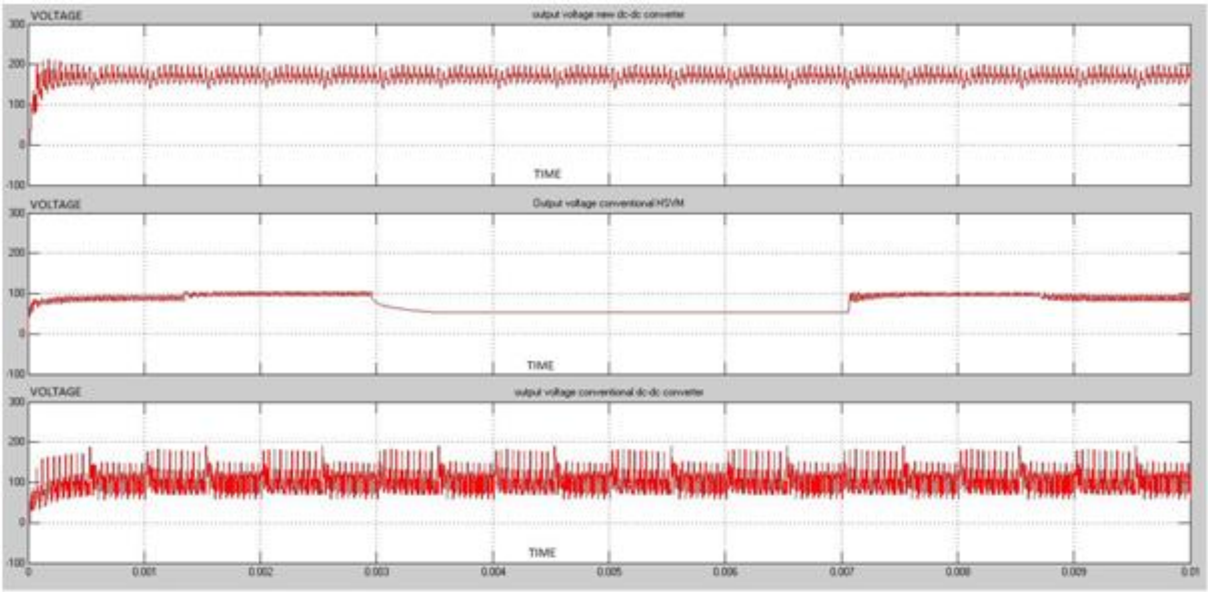


**Figure 21:** Comparison of output current waveform for dc-dc converter, HSVMand conventional dc-dc converter

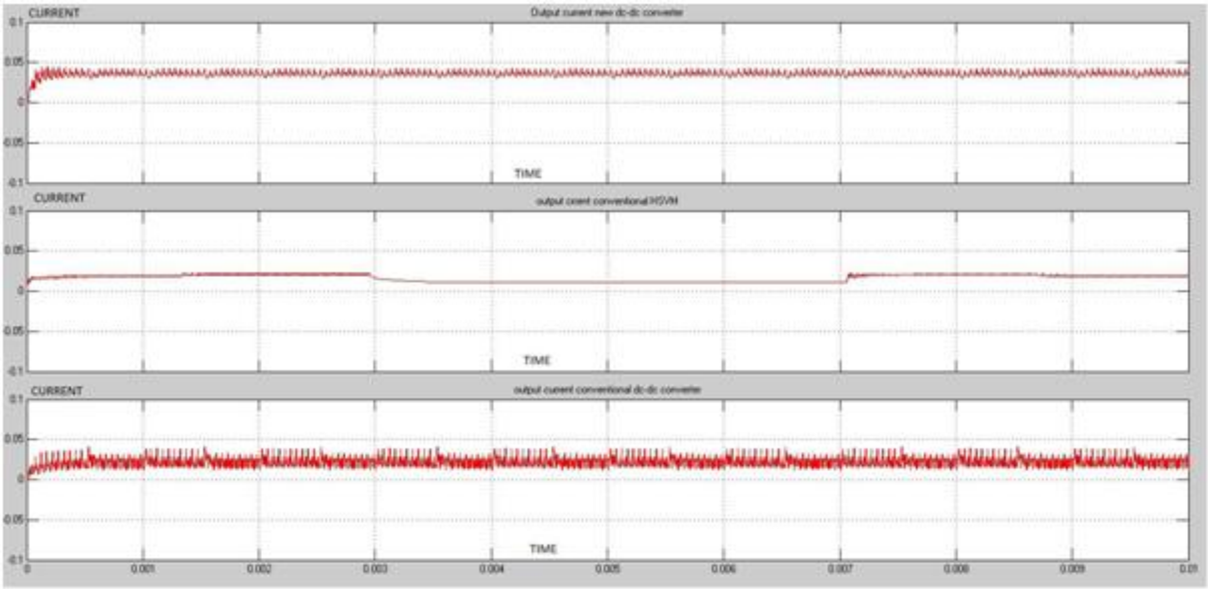


**Figure 22:** Comparison of output voltage waveform for the new dc-dc converter, HSVM and conventional dc-dc converter

## 5. Modulation Scheme

In sinusoidal PWM, also called sine-PWM, the resulting pulse width are varied throughout the half cycle in such a way that they are proportional to the instantaneous value of the reference sine wave at the centre of the pulses. The desired output voltage is achieved by comparing the desired reference waveform (modulating signal) with a high-frequency triangular 'carrier' wave as depicted schematically in figure 23.

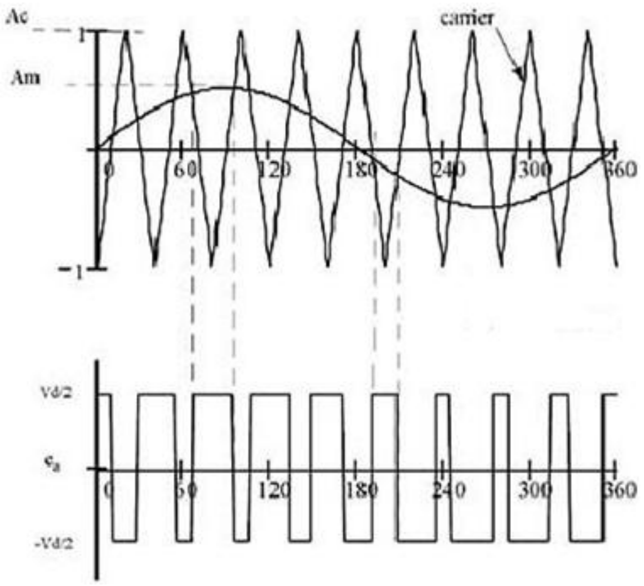


**Figure 23:** Sinusoidal pulse width modulation

Depending on whether the signal voltage is larger or smaller than the carrierwaveform, either the positive or negative dc bus voltage is applied at the output. Note that over the period of one triangular wave, the average voltage applied to the load is proportional to the amplitude of the signal (assumed constant) during this period the triangular signal is called carrier signal. Its frequency is the PWM frequency. These two signals are compared. At the time when the reference signal is larger than the triangular signal, the upper switch is turned ON and the lower switch is turned OFF, otherwise, the upper switch is OFF and the lower switch is ON. A control scheme representing spwm is shown in figure 24.

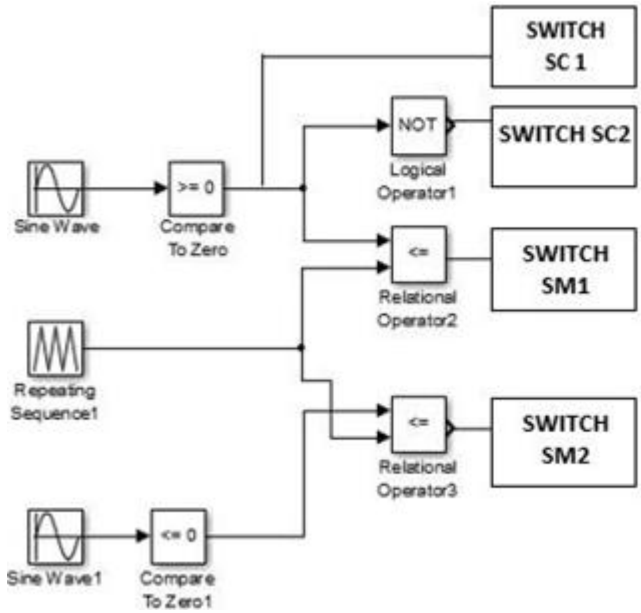


**Figure 24:** control scheme of Sinusoidal pulse width modulation

**Table 3:** Switching Pattern

| S. No. | Switches in the ON state |
|---|---|
| 1 | Sm1 and SC1 |
| 2 | Sm2 and SC1 |
| 3 | Sm2 and SC2 |
| 4 | Sm1 and SC2 |

The switching pulses waveforms are depicted here for better understanding.

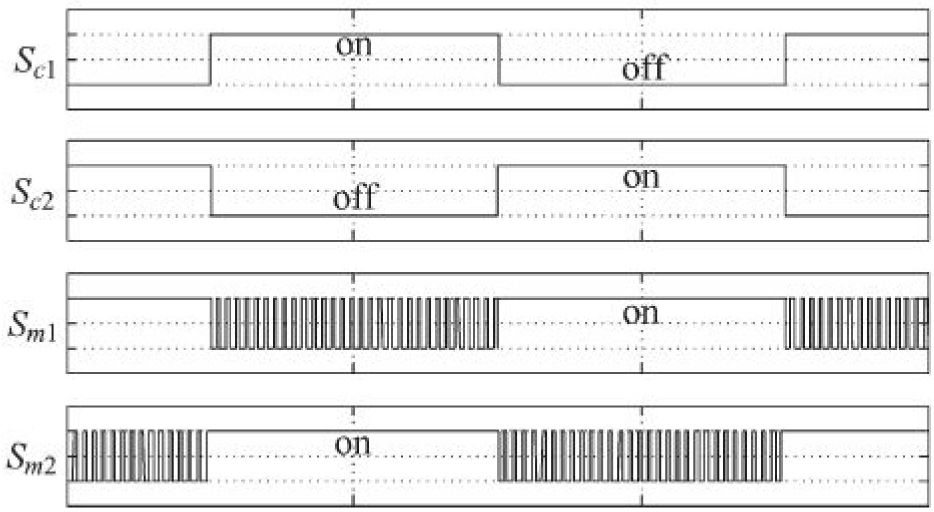


**Figure 25:** Waveform for the desired switching pulses

## 6. Conclusion

In this, a high step-up dc-dc converter based on the CW voltage multiplier without a line- or high-frequency step up transformer has been presented to obtain a high voltage gain. Since the voltage stress on the active switches, diodes, and capacitors is not affected by the number of cascaded stages, power components with the same voltage ratings can be selected. The control strategy employs two independent frequencies, one of which operates at high frequency to minimize the size of the inductor while the other one operates at relatively low frequency according to the desired output voltage ripple. The simulation proved the validity of theoretical analysis and the feasibility of the new converter.

## References


[1] Cascade Cockcroft Walton Voltage Multiplier Applied to Transformer less High Step-Up DC-DC Converter,"IEEE transaction on industrial electronics., vol. 60, no. 2, pp. 523{537, february. 2013.

[2] A Hybrid Symmetrical Voltage Multiplier,"IEEE transaction on power electronics., vol. 29, no. 1, pp. 6{12, january. 2014.

[3] The symmetrical cascade recti_er:An accelerator power supply in the mega-volt and milli-ampere range,"IEEE Trans. Nucl. Sci., vol. NS-12, no. 3, pp.282 {292, January. 1965.

[4] Positive output cascade boost converters,"Proc.Inst. Elect. Eng.Elect. PowerAppl., vol. 151, no. 5, pp. 590{606, september. 2004.

[5] A novel diode-capacitor voltage multiplier for increasing the voltage of photovoltaic cells,"Proc. IEEE COMPEL., pp. 1{5, August. 2008.

[6] Voltage multiplier cells applied to non-isolated dc-dc converters,"IEEETrans. Power Electron. Vol. 23, no. 2 pp. 871{887, Mar. 2008.

[7] Low-ripple compact high-voltage dc power supply,"IEEE Trans. Ind. Appl.,vol. 42, no. 5, pp. 1139{1145,Sep./Oct. 2007.

[8] A three-phase symmetrical multistage voltage multiplier," IEEE PowerElectron. Lett., vol. 3, no. 1, pp. 30{33, Mar. 2005.