High Performance High Step-Up AC-DC Matrix Converter based on Voltage Multiplier with Improved Power Factor and Stability

A.Mohandoss, G.Radhakrishnan, S.Murugan

Abstract— **This paper proposes a high-performance transformer less single-stage high step-up ac-dc matrix converter using a cascaded Cockcroft-Walton (CW) voltage multiplier with power factor correction circuit. This modified matrix converter consist of eight unidirectional-switch to form four bi-directional switch matrix converters between the input ac source and CW voltage multiplier circuit, the proposed converter topology provides high output voltage gain, adjustable output voltage, and low output ripple. This modified Matrix converter is employed with two independent frequencies. One for power factor correction (PFC) control of the converter and the other one used to put the output frequency of the modified ac to dc matrix converter. The operation principle, control strategy, and design considerations of the modified ac to dc matrix converter are all discussed in this paper. The simulation output illustrates the high performance of the proposed converter topology and the validity for high step-up ac-dc applications.**

Index Terms— **Cascaded Cockcroft-Walton voltage multiplier, one-cycle control, power factor correction (PFC), High step-up ac-dc matrix converter.**

I. INTRODUCTION

The extensive use of electrical equipment has enforced severe demands for electrical energy and this trend is constantly growing till now. Some of the applications of HIGH-VOLTAGE dc power supplies are in industries, science, medicine, military, such as testing equipment, X-ray systems, dust-filtering equipment, testing of insulation, and electrostatic coating .The traditional Cockcroft-Walton voltage multiplier is very popular among high voltage DC applications. By replacing the step-up transformer with the boost type structure for step up process, the proposed converter topology provides higher voltage ratio than that of the traditional CW voltage multiplier based converter. It provides high output gain, high voltage ratio, low voltage stress on the power electronic component such as diodes, capacitors, compactness and cost is considerable. However, the major drawback in traditional converter is that a high ripple voltage appears at the output when a low-frequency (50 or 60 Hz) utility source is used. The Cockcroft-Walton (CW) voltage multiplier is a ac to dc converter which is specially designed by cascading number of diode capacitor stages with each stage containing two capacitors and two diodes. In an n-stage CW voltage multiplier provides dc voltage with the value of 2n times of the magnitude of the input ac voltage source under no-load condition. However, the obtained dc output voltage is practically lesser than that of the theoretic value because of no-ideal characteristics of the circuit elements. But also high output voltage ripple with line frequency of the modified ac to dc matrix converter. However, the use of direct AC-AC converter based on matrix converter topology is restricted due to inherent limitations [1]. One of those limitations is the absence of the natural free- wheeling path afforded in traditional matrix converter topology through the use of diodes. The matrix Converter is a forced commutated converter which uses an array of controlled bidirectional switches as the main power component to develop a variable output voltage system with unrestricted frequency [2]. The SPMC requires 4 bidirectional switches each switch is capable of conducting current in both directions. It requires the use of bidirectional switches which are most capable of blocking voltage and conducting current in both directions. In case of AC-AC matrix converters have attained a massive attention in the Past few decades because of their distinct features such as: direct AC-AC power conversion; the elimination of the DC bus reactive element due to capacitor; ability to feed the energy back to the AC utility source line; the sinusoidal input and output currents and also input current displacement power factor, which is obtained independently of the load type by proper modulation [3]. The intermediate DC-link element can be a critical component, especially in case of high-power or high-voltage Applications, since it is too large and also expensive, and has a narrow lifetime [4]. High expensive, bulk size, heavy weight and energy loss are the major drawbacks of the traditional AC-DC-AC conversion process.

II. COCKCROFT WALTON VOLTAGE MULTIPLIER

A. Conventional Cockcroft Walton voltage Multiplier

A Cockcroft Walton voltage multiplier is a ac to dc converter which constructed by cascading a number of diode-capacitor stages with each stage containing two capacitors and two diodes. In case of theoretical an n-stage CW voltage multiplier provides dc voltage with the value of 2n times of the magnitude of the input ac voltage source under no-load condition. However, the developed dc output voltage

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is practically less than the theoretic value due to no-ideal characteristics of the circuit elements. This CW voltage multiplier is very popular among high voltage DC applications. In this modified converter the step-up transformer is replaced with the boost type structure which provides higher voltage ratio than that of the traditional CW voltage multiplier. In this proposed system four stage Cockcroft Walton voltage multiplier is used. This boost type structure is more compact than step up transformer.it also reduces losses compared to existing system.. In some applications, line frequency transformers with high step-up ratio were generally used to co-operate with the CW voltage multiplier for higher voltage gain. However, sourced by the utility input ac source, the transformers lead to inefficiency because of bulk, cost is expensive and the ripple problem still unsolved. In addition to CW voltage multiplier circuits, some cascaded single-switch step-up dc-dc converters without step-up transformer were also proposed. This system provides high voltage gain with merits of simplicity and cost efficiency.

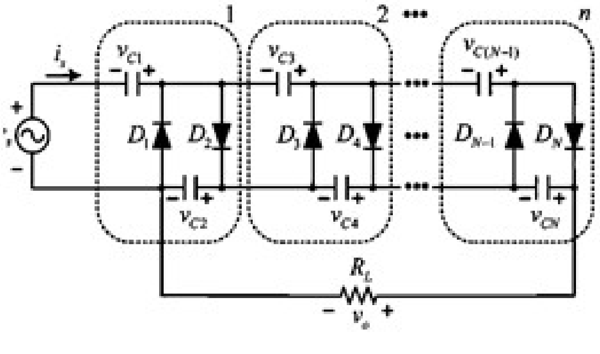

Fig.1. Conventional n-stage CW voltage Multiplier

This project proposes a high step-up dc-dc converter based on the Cockcroft-Walton (CW) voltage multiplier without a step-up transformer or isolation transformer. By supplying continuous input current with high voltage ratio, low current ripple, and low voltage stress on the elements such as switches, diodes, and capacitors. This proposed converter is quite suitable for applying to low-input-level dc generation systems. Based on the n-stage CW voltage multiplier, the proposed converter topology can supply a suitable dc source for an n + 1-level multilevel inverter. In this paper, the presented control strategy consider two independent frequencies; one of them operates at high frequency to reduce the size of the inductor while the other one operates at low frequency according to the desired output voltage and current ripple. Similarly 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 with stability output is required for many industrial applications, such as high discharge lamp ballasts for automobile, headlamps applications and battery backup systems for uninterruptible power supplies system. Taking the advantages of the high-frequency switching technologies, many modified CW circuits have been developed for saving the volume of the transformers, smoothing the output ripple, and regulating the output voltage. Some voltage-fed modified CW topologies, which provide not only high voltage gain but also simplicity of implementation, were proposed. Nevertheless, among these topologies, the high frequency transformer with high turn's ratios causes' large winding capacitance and leakage inductance, which leads to high voltage and current stresses and higher switching losses on the switches? However, many step-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 who consist of a conventional boost converter and an n-stage diode–capacitor multiplier. 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.

B. Proposed Bi-directional Converter with CW Voltage Multiplier Topology

A high step-up dc-dc converter based on the CW voltage multiplier without step up transformer or Isolation transformer has been presented to obtain a high voltage gain. In traditional converter is designed with four unidirectional switches to form the main converter and another two independent switching frequencies were used to operate these switches. In proposed converter, the unidirectional switches are replaced with bidirectional switches and also the step up transformer is replaced by Cockcroft Walton voltage multiplier. The input dc source is replaced by an ac source. By using some replacements the high step-up ac-dc with modified matrix converter is proposed in this paper. The arrangement of the four bidirectional switches can be seen as a single-phase modified matrix converter deployed between the input ac source and the CW voltage multiplier circuit. With the help of the boost type structure, in the proposed converter, not only improve the voltage gain and also the PFC technique can apply to the matrix converter to obtain high performance and dc output voltage regulation. In this proposed paper only continuous conduction mode (CCM) is discussed because of its less stress, low loss, and reduced EMI problems. Moreover, the proposed converter topology a single-phase modified matrix converter, which consider two independent frequencies. One of which is applies to two of the four switches to perform PFC operation, and another one applies to the rest of the two switches to establish the output frequency of the modified matrix converter. The latter frequency establishes the output frequency of the modified matrix converter and it can be applied to smooth the ripple voltage in the dc output. Moreover, by deploying the bidirectional switches, the presented converter achieves PFC control technique of traditional ac-dc boost converters in addition with some modifications. Therefore, some of the commercial control ICs with PFC function can be easily applied to the proposed converter topology with an additional auxiliary circuit which modifies the original switching signal to trigger the four bidirectional switches properly. However, capacitors of these circuit topologies with higher voltage rating are needed when higher number of stages is employed. In this modified converter topology, an integrated multiphase boost converter

ISSN: 2278 – 7798

and voltage multiplier, was proposed for high step-up ac to dc conversion and high-power applications as well. In this converter topology, all capacitors in the voltage multiplier had identical voltage rating. However, dc power sources such as batteries, fuel cells, photovoltaic generators this converter topology needed a front stage for linking to the ac line. Some power factor correction (PFC) techniques have to apply to the front stage.

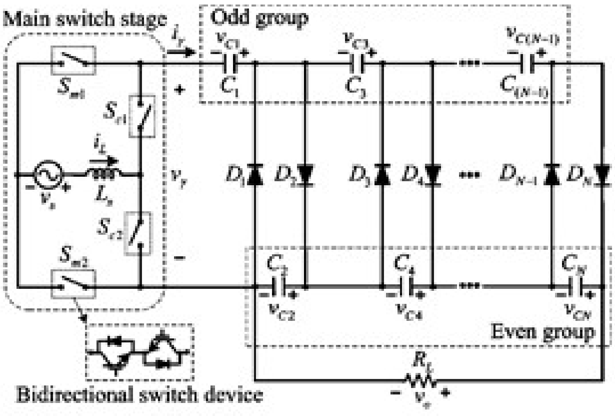

Fig.2. Circuit Configuration of Proposed converter

Otherwise, the proposed converter topology will incur poor line quality and increases power loss The latter frequency establishes the output frequency of the modified matrix converter and this can be used to smooth the ripple voltage in the dc output of the proposed converter. Employing bidirectional switches, the proposed converter can perform PFC control methods of existing ac-dc boost converters topology just with some replacement. Therefore, some commercial control ICs with PFC function can be easily applied to the proposed converter topology with an extra circuit called auxiliary circuit which modifies the original switching signal to trigger the four bidirectional switches in proper manner.

C. Steady state analysis

This proposed converter configuration is mainly composed of a single phase matrix converter cascaded with a traditional n-stage CW voltage multiplier to obtain high dc output. The single-phase matrix converter is formed by four bidirectional switches that are classified into two sets denoted as (S_{c1}, S_{c2}) and (S_{m1}, S_{m2}). The proposed converter topology is energized by a line-frequency input ac source with a series inductor to perform boost operation. Till now, commercial products of bidirectional switches are not available; Here, two anti-series insulated gate bipolar transistors with freewheel diode are used as a bidirectional switch in this paper. The proposed configuration is mainly composed of a single phase matrix converter cascaded with a traditional n-stage CW voltage multiplier, as shown in Fig. 3. The 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, and EMI noise can be reduced as well. New topologies and control strategies that will reduce the leakage current reduce the size, cost and exhibit a high efficiency is proposed, and verified. Moreover, some non-isolated high step-up dc-dc converters with low-voltage dc input were suggested in case of renewable energy applications and also dc based converter system.

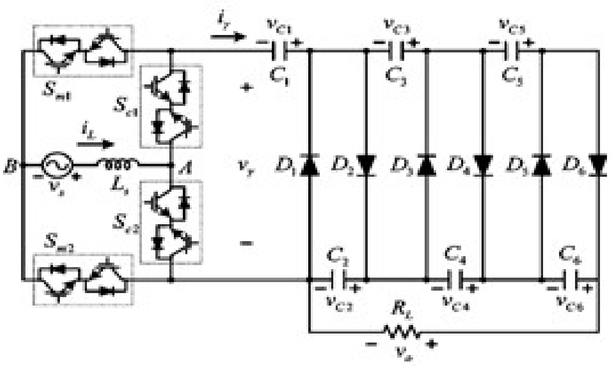

Fig.3. Proposed converter with n-stage CW voltage Multiplier

For convenience, both capacitors and diodes are divided into odd group and even group according to their suffixes. This type of topology gives simplicity to the structure.

In the proposed converter model in order to simplify the analysis of circuit operation, some of the assumptions are made as follows:

1) The circuit elements are ideal and there is no power loss in the system

2) All of the capacitors in the CW voltage multiplier are sufficiently large, and the voltage drop and ripple of each Capacitor can be ignored under a reasonable load condition. Thus, the voltages across all capacitors are equal, except the first capacitor which voltage is one half of the others.

3) The proposed converter topology operates in CCM and under no-load or steady state condition.

4) According to the second assumption, each and every capacitor voltage in the CW voltage multiplier can be defined as

$$v_{Ck} = \begin{cases} V_C, & \text{for } k = 1 \\ 2V_C, & \text{for } k = 2, 3, \ldots, N \end{cases} \quad (1)$$

Where Vck is the voltage of the kth capacitor, VC is the maximum peak value of terminal voltage of the CW voltage multiplier under steady-state condition, and N = 2n.Moreover combining with the boost operation each mode of the circuit has two states.one is during positive half cycle and another one is negative half cycle of the input ac source. Moreover, the proposed converter operates in continuous conduction mode (CCM). It reduces EMI noise as well. For an n-stage CW voltage multiplier, the obtained output voltage is equal to the total voltage of all even capacitors, which can be expressed as

$$\mathbf{V_O = NVC} \quad (2)$$

Where V_O is the no-load or steady-state dc output voltage.

.Moreover, the proposed converter deploys a single-phase improved matrix converter, which considers two independent frequencies. One of which is applied to two of the four switches to perform PFC operation, and the other frequency applied to the rest of the two switches to establish the output frequency of the matrix converter. In this proposed converter topology, all capacitors in the voltage multiplier circuit have identical voltage which is equal to V_O/ (n + 1). However this

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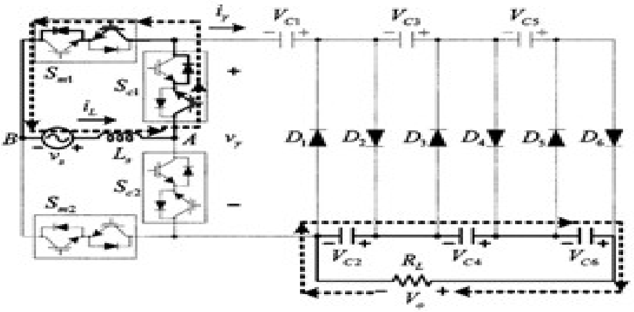
step-up dc-dc converter based on the Cockcroft-Walton (CW) voltage multiplier diminish the Switching frequency losses.

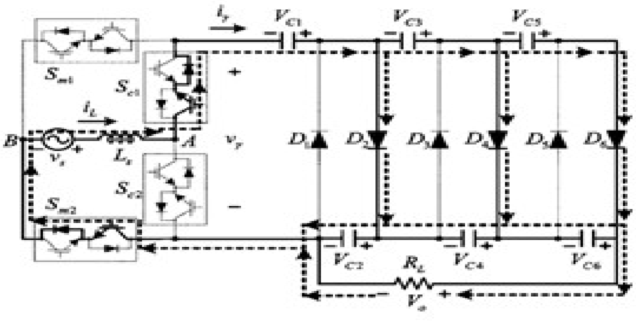
Substituting (2) in (1):

$$v_{Ck} = \begin{cases} V_o/N, & \text{for } k = 1 \\ 2V_o/N, & \text{for } k = 2, 3, \ldots, N. \end{cases} \quad (3)$$

Where Vck is the voltage of the kth capacitor in the circuit. For simplicity, the circuit states of modes III and IV are not presented, and they can be obtained by changing the directions of i_γ and i_L from Fig.4 respectively. Similarly S_{m1} and S_{m2} work as boost converter switches while S_{c1} and S_{c2} control the path of i_γ, i.e., the output frequency of the modified matrix converter. Basically, S_{c1} (S_{m1}) and S_{c2} (S_{m2}) should be operated in complimentary mode and the operating frequencies of Sc1 and S_{m1} are defined as fc and fm, whereas f_c is called alternating frequency and f_m is called modulation frequency. For our convenience, a simple case is used to explain the operation principle of the proposed converter. In this simple case, f_c is twice as large as line frequency and f_m = 60 kHz.



(a)



(b)

Fig.4. Circuit states and conducting paths of the proposed matrix converter at mode-I. Fig(a) State 1. Fig(b) State 2.

However, S_{m1} and S_{m2} work as boost converter switches while S_{c1} and S_{c2} control the current path of i_γ, i.e., the output frequency of the modified matrix converter. Obviously, S_{c1} (S_{m1}) and S_{c2} (S_{m2}) should be operated in complimentary mode and the converter operating frequencies of S_{c1} and S_{m1} are referred as f_c and f_m, respectively, whereas f_c is called alternating frequency and f_m is called modulation frequency of PWM generator. In this paper a simple case is used to define the operation principle of the proposed converter. In this simple case, carrier frequency f_c is twice as large as line frequency and modulation frequency f_m = 60 kHz. This proposed circuit is specially designed for high power rating. This output simulation results clearly explains that the obtained output is more stability with reduced power loss. Moreover the suggested converter reduces cost, switching losses, and voltage stress which are the foremost problem of the conservative ac to dc converter structure.

The circuit behavior in modes I and II will be given in the following:

1) State 1 in mode I [see Fig. 4(a)]: During (D-1)Tm interval, S_{m1} and S_{c1} are turned ON, the boost inductor is charged by the input source, i_γ is zero due to no current path, the even-group capacitors C6, C4, and C2 supply to the load RL , and the odd-group capacitors C5, C3, and C1 are floating.

2) State 2 in mode I [see Fig.4(b)]:During(1-D)Tm interval, S_{m2} and S_{c1} are turned ON, the boost inductor and input source transfer energy to the CW circuit by positive i_γ flowing through one of the even diodes . The ON/OFF states of the diodes and charging behavior of the capacitors can be found as well.

3) State 1 in mode II: During (D-1)Tm interval, S_{m2} and S_{c2} are turned ON, the boost inductor is charged by the input source, i_γ is zero due to no current path, the even-group capacitors C6, C4, and C2 supply to the load RL , and the odd-group capacitors C5, C3 and C1 are floating.

4) State 2 in mode II: During (1-D)Tm interval, S_{m1} and S_{c2} are turned ON, the boost inductor and input source transfer energy to the CW circuit by negative i_γ flowing through one of the odd diodes . The ON/OFF states of the diodes and charging behavior of the capacitors can be found as well.

This step-up dc-dc converter based on the Cockcroft-Walton (CW) voltage multiplier without a step-up transformer reduce the Switching frequency losses there by maintain the system stability. In this paper, the proposed converter is sourced by a sinusoidal voltage source, which can be expressed as

$$Vs = \sqrt{2}Vs \sin \omega s^{t} \quad (4)$$

Where v_s is the line source, and Vs and ω_s are the rms value and angular frequency of v_s , respectively. During state 1 in mode, from Figs. 4(a) and 4(b), it can be seen that the voltage across nodes A and B is zero; thus, the current variation of i_L can be represented as where Ls is the boost inductor, D is the duty cycle of S_{m1} in modes I and III or the duty cycle of S_{m2} in modes II and IV, and Tm = 1/ f_m is the modulation period

$$\Delta i_{L(\text{on})} = \frac{v_s}{L_s} D T_m \quad (5)$$

State 2, the voltage across nodes A and B is equal to V_o /N both in modes I and II. Similarly, the terminal voltage V_{AB} is equal to $-V_o$ /N both in modes III and IV. Thus, the polarities of the terminal voltage V_{AB} in positive- and negative-half cycles have opposite sign. This proposed converter provides ac to dc conversion with reduces switching losses and reduces cost of the converter.

III. SIMULATION STUDY

A Four-stage CW voltage multiplier was connected to the output of the modified matrix converter for the simulation as shown in Fig.8.The input is ac source of 110v given to the modified matrix converter. The output is high voltage dc nearly 450v.MATLAB/SIMULINK is used for simulation. The planned system is designed based on the system specifications.

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However the components as mentioned in the Table I .Output of 450V is obtained with PFC of 0.993. In the conventional converter three-stage Cockcroft Walton with unidirectional switches has low voltage output with increased switching losses. And also in this existing system power factor of the converter is very poor. Because of the higher number of switches the switching losses also increased in the existing converter. In this proposed converter the unidirectional switches are replaced with bi-directional switches. And the four stage Cockcroft Walton voltage multiplier is used in addition with power factor correction circuit. This proposed circuit provides high voltage dc output with reduced switching losses. The major drawback in the conventional unidirectional matrix converter with Cockcroft Walton voltage multiplier are high switching losses, low voltage stress, low efficiency. These all drawbacks are overcome by the proposed bi-directional switch based matrix converter with four-stage Cockcroft Walton voltage multiplier.

TABLE 1

Component list

PARAMETERS	PROPOSED CIRCUIT
Input Line Voltage(Vs)	110v
Output Voltage(Vo)	450v
Output Power(w)	600w
Line Frequency(fs)	60Hz
Alternating Frequency(fc)	960Hz
Modulation Frequency(fm)	60KHz
Capacitor	470µH
Inductor	1.5mH
Resistive Load(R_L)	2.88kΩ

IV. PROPOSED CONVERTER CIRCUIT DIAGRAM

The simulation diagram of the proposed four-stage Cockcroft Walton voltage multiplier with modified matrix converter is explained as follows. The simulation diagram of the proposed four-stage Cockcroft Walton voltage multiplier with modified matrix converter is explained as follows. The simulation output results validated the high performance of the suggested DC-DC step-up converter structure.

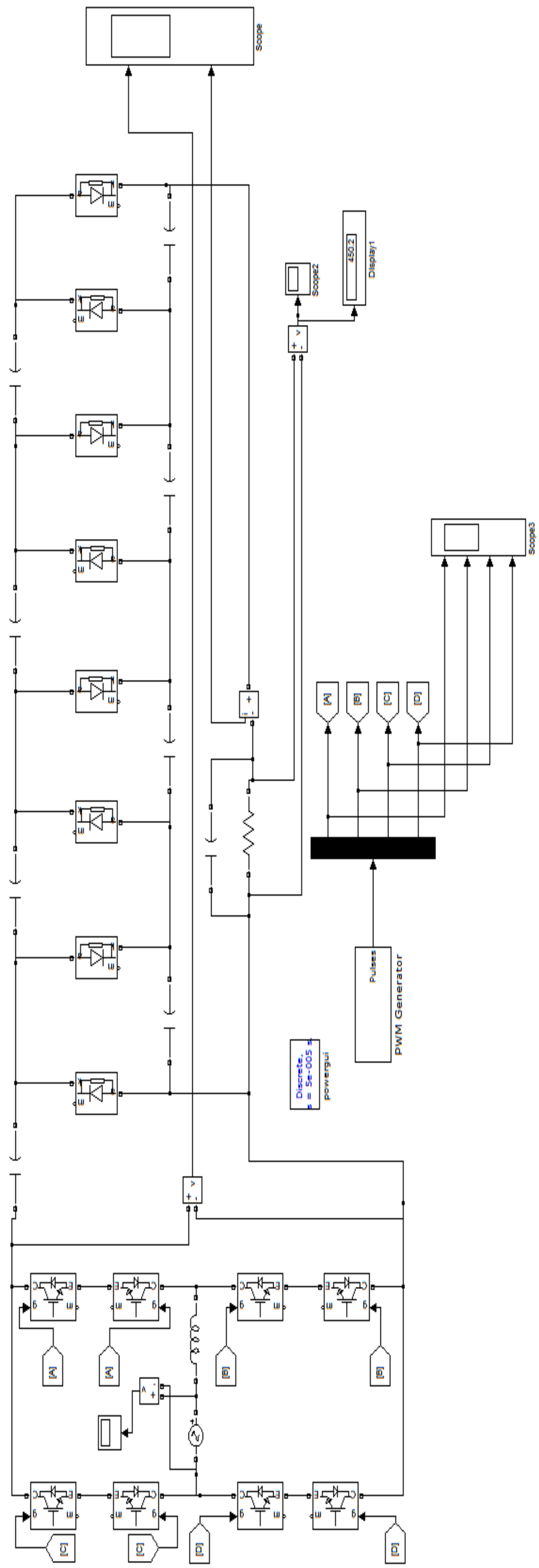

Fig.5. Simulink model of Proposed converter

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V. SIMULATION RESULTS

In this proposed converter ac input of 110v shown in fig.5. The timing pattern of the PWM generator signal is shown in fig.6. In this proposed converter topology high voltage dc output nearly 450v is obtained. The output waveform of the proposed four-stage Cockcroft Walton voltage multiplier with improved matrix converter is shown in fig 8.

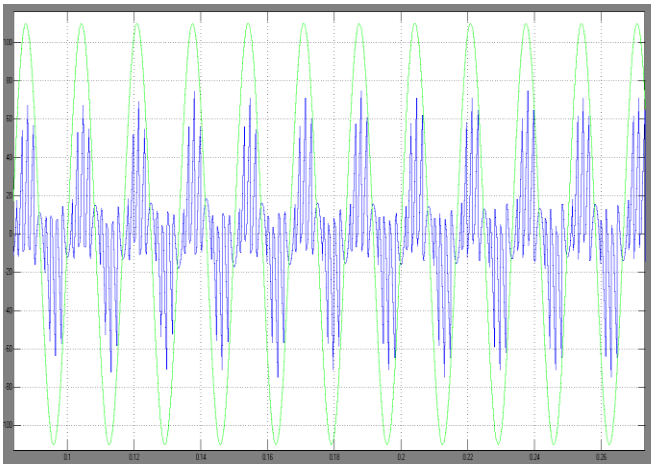

Fig.6. Power factor correction waveform.

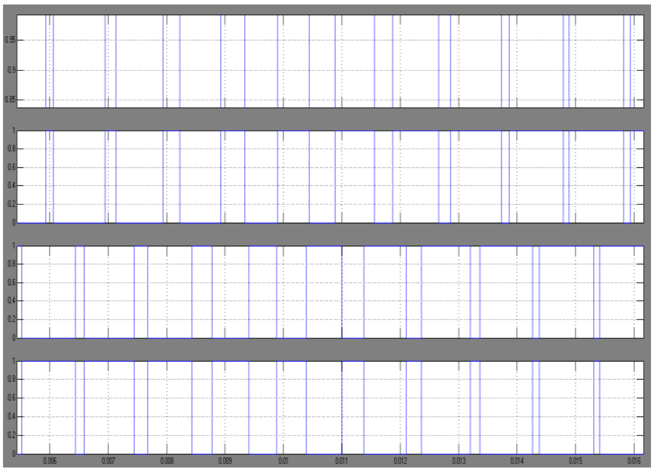

Fig.7. PWM generator timing pattern.

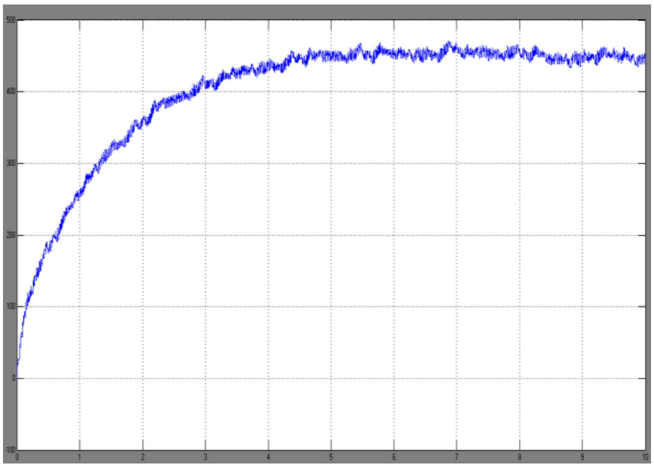

Fig.8. output waveform

VI. CONCLUSION

In this paper, a modified high voltage step-up ac-dc conversion based on bi-directional matrix converter along with four-stage CW voltage multiplier is proposed. In this proposed system former frequency is associated with PFC control technique, while the latter frequency can be used to smooth the converter output ripple. The simulation results demonstrated the high performance of the proposed converter. This proposed circuit is specially designed for high power rating. This output simulation results clearly explains that the obtained output is more stability with reduced power loss. And also the proposed converter reduces cost, switching losses, and voltage stress which are the main drawback of the conventional ac to dc converter topology.

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