

# Boost Converter with Multistage Cockcroft Walton Voltage Multiplier

Meghana G Naik<sup>1</sup>, CH. Jayavardhana Rao<sup>2</sup>, Dr. Venugopal .N<sup>3</sup> (Ph.D)

<sup>1</sup>PG-Scholar, Department of Electrical and Electronics Engineering, KEC Kuppam, JNTU Ananthapur, AP, India

<sup>2</sup>Associate Professor, Department of Electrical and Electronics Engineering, KEC Kuppam, JNTU Ananthapur, AP, India

<sup>3</sup>Profesoor & HOD, Department of Electrical and Electronics Engineering, KEC Kuppam, JNTU Ananthapur, AP, India

**Abstract:** *In this modern era due to various application running on high voltage, the requirement to fulfil this demand at lower operational cost is very essential. In this paper, high dc voltage is obtained by implementing step –up converter (boost converter) with multistage Cockcroft Walton voltage multiplier. This step-up converter operates in the continuous conduction mode, due to this the voltage stress across the switches are reduced and there by improves the performance of the converter with reduced ripples. The boost converter consists of four IGBT switches and operated at two different independent frequencies. The high DC voltage is obtained at lower duty cycle. The proposed topology is validated by Matlab simulation.*

**Keywords:** Boost converter, Cockcroft Walton Voltage Multiplier, Continuous Conduction Mode, High DC Voltage, average current control method

## 1. Introduction

The high voltage DC power supplies are in huge demand in the areas of science, medicine for example X-ray machine, military, and, specially, in test equipment, insulation testing, cable testing. To fulfill the demand of high dc voltage many attempts have been made to discover new ways to generate high voltage, which is higher than the supply voltage. In earlier days the demand for high voltage was fulfilled mainly by the usage of the transformer. However, the usage of transformer hinders the development for a compact converter. The use of transformer for high voltages in converter circuit reduces the overall operating efficiency due to leakage inductance as it results in high voltage stress which increases the losses in case of higher dc voltages and also increases the operational cost. The difficulties of the transformer can be overcome by replacing the transformer with the step up converter to obtain the high dc voltage as this removes the leakage inductance problem, requirement of heavy core, bulk insulation and reduces operational cost. Implementation of step up converter is critical part for the high output voltage with minimum voltage stress. Many non –isolated dc-dc converter has already been employed to obtain high step –up voltage but at the cost of higher duty cycle, high voltage stress and high current stress on the switches. The integration of boost converter with CW voltage multiplier has tremendous advantage as it is possible to obtain higher dc voltage supplies with the low input source and small scale circuit. In this paper, the Cockcroft Walton voltage multiplier has been cascaded for nine stage and integrated with boost converter so as obtain higher dc voltage at lower duty cycle with low input dc source.

## 2. Cockcroft Walton Voltage Multiplier

The Cockcroft Walton voltage multiplier is basically a device used for the generation of high DC voltage. It consists of

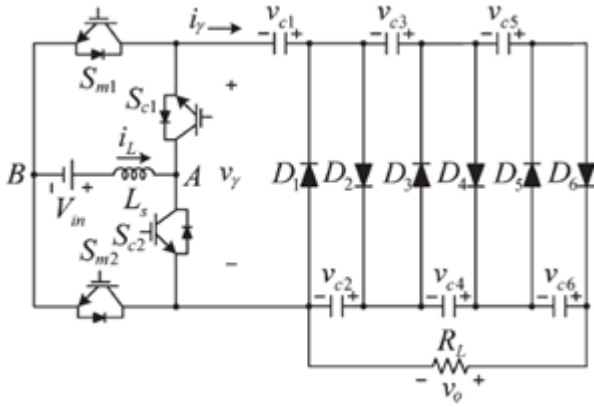
networks of diodes and capacitors connected in form of ladder network and these converts the input pulsating ac into dc.

### 2.1 Conventional Cockcroft Walton voltage multiplier

In earlier days the input supply to Cockcroft Walton voltage multiplier was provided by the transformer. Now it has been replaced by the boost converter which acts as the input supply.

The boost converter is supplied by the low input dc and here the battery is used for this purpose. The boost converter consists of boost inductor and the four switches. The boost inductor is used to boost the input supply voltage. The two switches are made to operate at lower frequency known as the alternating frequency. The other two switches are made operate at higher frequency known as the modulating frequency. These switches work in complimentary mode. The advantage of these two frequencies is that it helps to provide the coordination between the output ripple of the system and its efficiency. The higher frequency helps to maintain the flow of the energy through the inductor. The lower frequency is used to provide the flow of the alternating or the pulsating alternating current to the voltage multiplier circuit. The boost voltage of the boost converter is available across a converter as the terminal voltage. The circuit of the conventional circuit is shown in the Figure 1.

The circuit shows the arrangement of the boost inductor, four IGBT switches, ladder network of diode and capacitor with the voltage being obtained across the load.



**Figure 1:** Conventional Cockcroft Walton Voltage Multiplier

### 3. Proposed circuit Diagram

The conventional Cockcroft Walton Voltage multiplier consists of three stages and the output voltage is obtained across the load. The circuit diagram of the proposed boost converter with the multistage Cockcroft Walton voltage multiplier is shown in the Figure 2. The Proposed boost converter with multistage Cockcroft Walton voltage multiplier has nine number of stages. The proposed circuit has low input dc source, boost inductor, four IGBT switches, eighteen capacitors and eighteen diodes, one resistive load.

The  $V_{in}$  provides the low input dc supply to the boost inductor, which boosts the input voltage. As soon as the IGBT switches receives the gate pulses from controller the switches turn on. Due to the operation of IGBT switches with independent frequencies the terminal voltage obtained from converter is step – up voltage. The current  $i_y$  obtained from the boost converter is of pulsating a.c form which is fed then through the Cockcroft Walton voltage multiplier. The Cockcroft Walton voltage multiplier thus multiplies the voltage to obtain high DC voltage.

#### 3.1 Static voltage gain

The boost structure is expressed in two modes with switches ( $S_{m1}$  &  $S_{m2}$ ) in on (closed) & off (open) modes. The  $S_{m1}$  is on during positive conducting interval and switch  $S_{m2}$  is on during negative conducting interval.

Mode 1:

In this mode the switch  $S_{m1}$  is turned on during positive half cycle and  $S_{m2}$  is turned on during negative half cycle, the inductor current increases from  $i_1$  to  $i_2$  and the inductor voltage  $V_L = V_{in}$ . The voltage-current relation for the inductor  $L_s$  is

$$V_{in} = L_s \frac{di}{dt} \quad (1)$$

$$V_{in} = L_s \frac{i_2 - i_1}{T_{on}} = L_s \frac{\Delta I}{T_{on}}$$

The inductor current variation during the interval  $0 \leq t \leq DT_{sm}$  is

$$\Delta I = \frac{V_{in}}{L_s} DT_{sm} \quad (2)$$

Mode 2:

The switch  $S_{m1}$  is turned off during the positive conducting interval and the switch  $S_{m2}$  is off during negative conducting interval. The inductor  $L_s$  supplies the load and the inductor current falls from  $i_2$  to  $i_1$  at  $(1-D)T_{sm}$  as  $S_{m1}$  or  $S_{m2}$  are off. Hence the inductor voltage is

$$V_{in} - \frac{V_o}{2n} = -L_s \frac{\Delta I}{(1-D)T_{sm}} \quad (3)$$

$$\Delta I = \frac{V_o / 2n - V_{in}}{L_s} (1-D)T_{sm} \quad (4)$$

From the above two equations, the gain is derived as

$$\Delta I = \frac{V_{in} DT_{sm}}{L_s} = \frac{V_o / 2n - V_{in}}{L_s} (1-D)T_{sm} \quad (5)$$

By simplifying the above equation (5), the voltage gain of the proposed converter is obtained as

$$M_v = \frac{V_o}{V_{in}} = \frac{2n}{(1-D)} \quad (6)$$

With  $n$  representing the number of stages.

#### 3.2 Working principle

There are certain assumptions for the simple analysis of the proposed circuit. The assumption are as follows

- All the components used in the circuit are assumed to be ideal.
- The capacitors used in the circuit are assumed to be very large and hence the voltage drop and the ripple across each capacitor can be ignored under reasonable condition.
- Assume to operate in the continuous conduction mode for no load condition.
- At a time only one diode conducts

Based on the second assumption, the voltage across each capacitor can be expressed as

$$V_{cp} = \begin{cases} V_c & \text{for } p = 1 \\ \frac{V_c}{2n} & \text{for } p = 2, 3, \dots, N \end{cases} \quad (7)$$

$$V_{cp} = \begin{cases} V_c & \text{for } p = 2, 3, \dots, N \end{cases}$$

Where  $V_{cp}$  is the voltage of the  $p^{\text{th}}$  capacitor and  $V_c$  is the steady state voltage  $V_{C2} - V_{CN}$

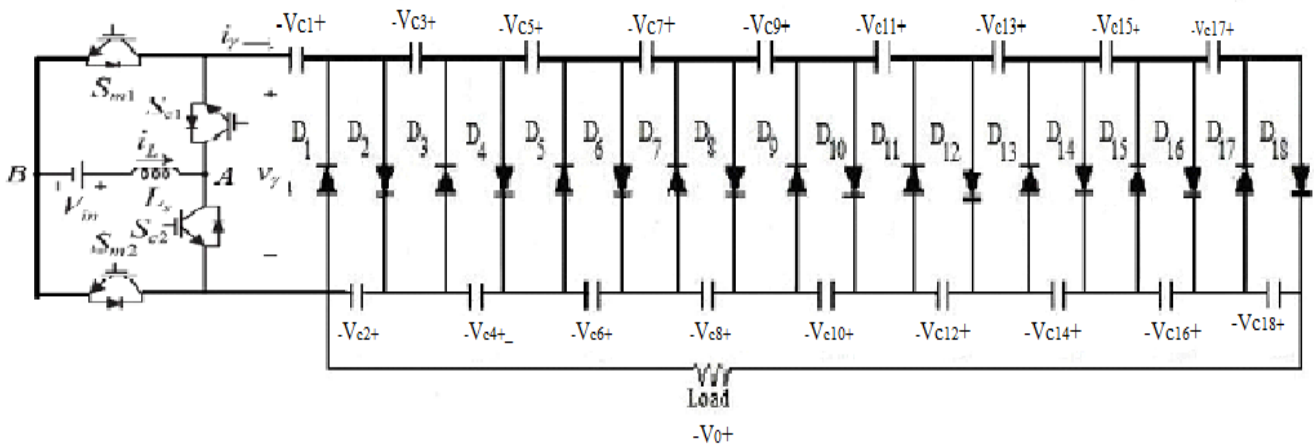
The output voltage across the load is given by sum of all the voltages across the even capacitors

$$V_o = nV_c \quad (8)$$

Each capacitor voltage can also be expressed as

$$V_{cp} = \begin{cases} \frac{V_o}{2n} & \text{for } p = 1 \\ \frac{V_o}{n} & \text{for } p = 2, 3, \dots, N \end{cases} \quad (9)$$

$$V_{cp} = \begin{cases} \frac{V_o}{n} & \text{for } p = 2, 3, \dots, N \end{cases}$$



**Figure 2:** Proposed boost converter with nine stage Cockcroft Walton voltage multiplier

The working condition mainly depends on the polarity of the Current. The condition for the polarity of the current  $i_\gamma$  depends on the switching condition of the four IGBT switches. Therefore depending on the polarity of the current the circuit operation is mainly divided into two major states of operation. They are Positive conducting interval: In this interval, the current is greater than zero and only one of the even diodes conduct at a time beginning with right most diode in a sequence of  $D_{18}, D_{16}, D_{14}, D_{12}, D_{10}, D_8, D_6, D_4, D_2$  and the even capacitors are charged and the odd capacitors through the conducting diodes.

Negative conducting interval: In this interval, the current is lesser than zero and only one of the odd diodes conduct at a time with the sequence  $D_{17}, D_{15}, D_{13}, D_{11}, D_9, D_7, D_5, D_3, D_1$  and the odd capacitors are charged and the even capacitors are discharged through the conducting diodes.

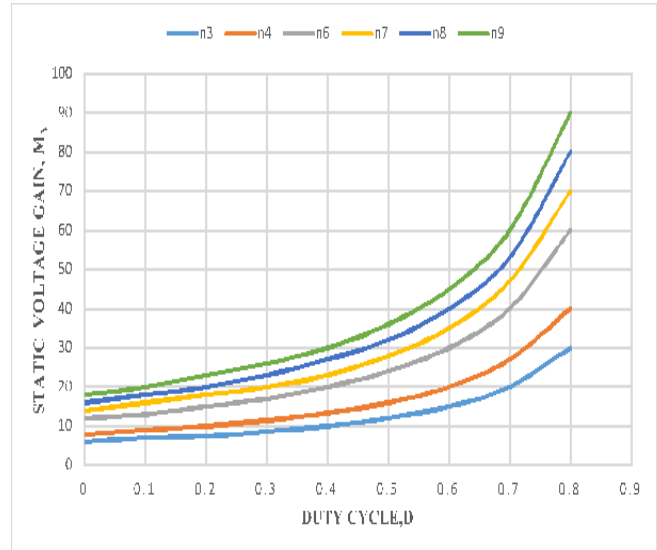
#### 4. Control Strategy

The controller used in this paper follows the average current mode control so as to design the PWM process in order to obtain the proposed converter in Continuous conduction mode (CCM) and the modulated voltage is obtained by PI Controller. The  $V_{ref}$  which is the desired output (it is 1350V in this case) is compared with the actual obtained ( $V_0$ ) from the proposed system. The difference between the desired output and the actual output is termed as the Verror. If there Verror is present then the PI Controller regulates the output. This regulated output is then multiplied with the resistance  $[R_s(V_0)]$ . This product is then divided by the modulated voltage ( $V_m$ ) which here is given by the error command between reference value and the actual output voltage. So with this the objective to regulate the average inductor current such that it is proportional to the input voltage is obtained. The averaged waveform is now compared with the ramp generator. The PWM is performed by the intersection of a ramp signal with the averaged inductor current thus the signal for  $Sc_1$  is generated. The  $Sc_2$  signal is obtained by  $180^\circ$  phase shift delay. The  $Sm_1$  and  $Sm_2$  signal is obtained by using the OR operator with PWM signal as their inputs. The PWM signal of the  $Sc_1$  is given as the input for and the other input to this given by pulse generator, with these two inputs the logic operator provides the triggering pulse for the

$Sm_1$  switch. Similarly for the  $Sc_2$  signal acts as one of input for the second logic OR operator and the other input is given by the pulse generator, with these two inputs the logic OR operator provides the triggering pulse for the  $Sm_2$  Switch.

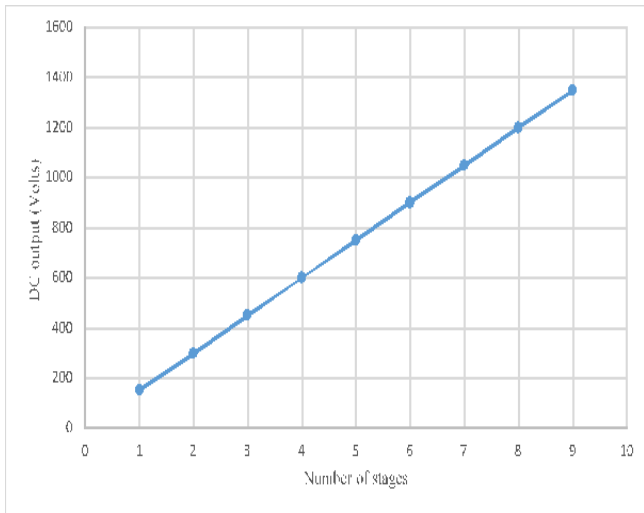
#### 5. Analysis

The proposed converter is said to provide to a high voltage at low duty cycle. By using the equation (6), it can be shown that by increasing the number of stages the voltage gain also correspondingly increases and provides higher voltage gain at lower duty cycle. The Figure 3 shows the variation of the voltage gain with the increase in the number of stages.

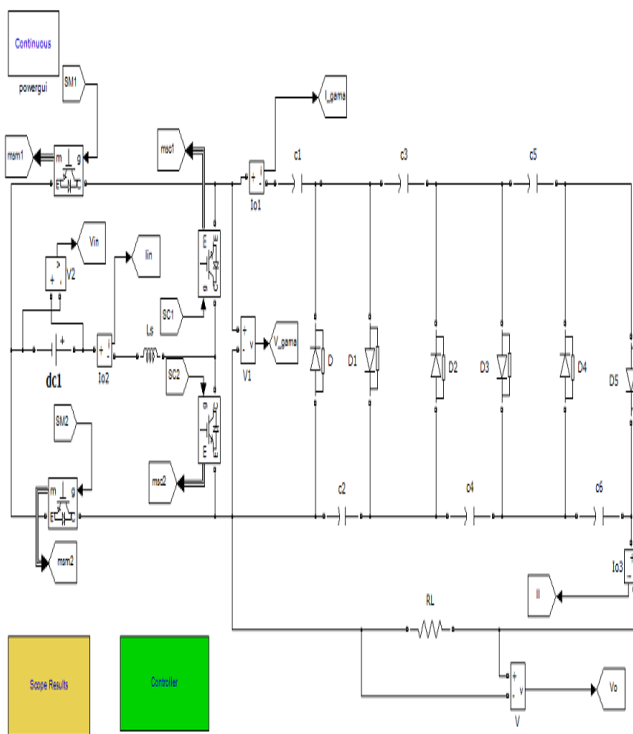


**Figure 3:** Voltage gain v/s duty cycle

By using the equation (8) it can be seen that by increasing the number of stages the high DC Voltage can be obtained, this is clearly indicated in the Figure 4



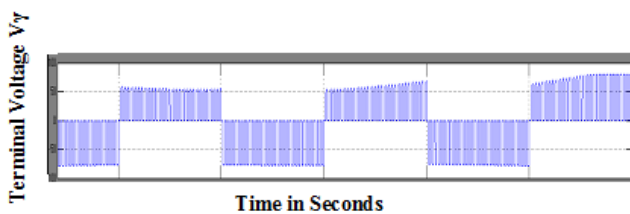
**Figure 4:** DC Output voltage v/s Number of stages



**Figure 5:** Simulink Model of Conventional Circuit with three stages of Cockcroft Walton Voltage Multiplier

**6.1.1 Simulation results**

The simulation results for terminal voltage is as shown in the Figure 6. The terminal voltage waveform indicates the step up voltage due to the boost converter.



**Figure 6:** Terminal voltage  $V_{\gamma}$

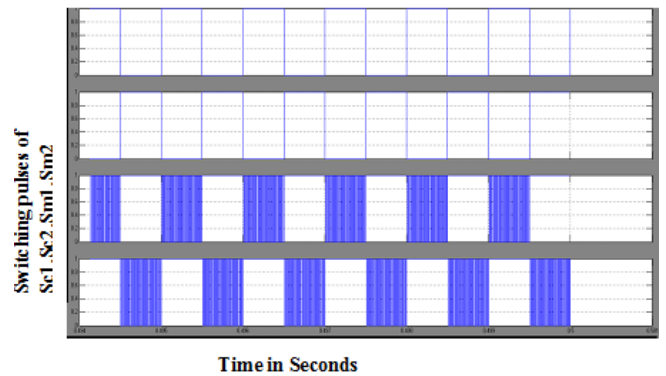
The simulation results for the switching pulses for the four

IGBT switches are shown in Figure 7. The first two switching pulses waveform are of  $Sc_1, Sc_2$  which operates at lower alternating frequency 1 KHz and the other two switching pulses waveform are of  $Sm1, Sm2$  which operates at higher frequency 60 KHz.

**6. Simulation Models and Results**

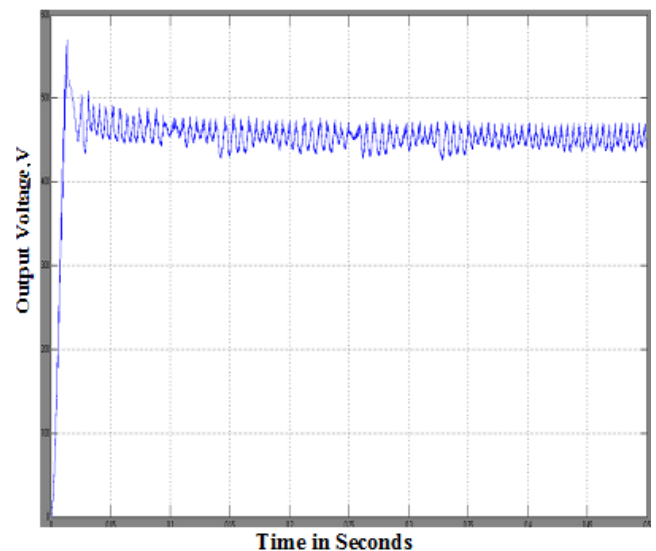
**6.1 Conventional circuit.**

The simulation for the conventional circuit has been built using Mat lab –Simulink and shown in the Figure.5. The conventional circuit consist of three stages of Cockcroft Walton circuit. The input voltage provided for the circuit is 48V and the load R is 1K $\Omega$ .

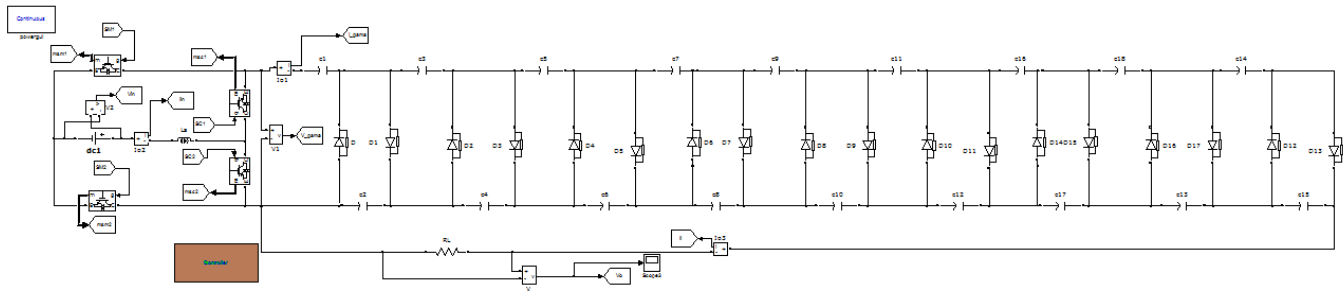


**Figure 7:** Switching pulses of IGBT switches

The output voltage for the conventional circuit consisting of three stages of Cockcroft Walton voltage multiplier circuit is shown in the Figure 8. With the equation (8) the output for the conventional circuit for three stage Cockcroft Walton voltage multiplier is 450V. The waveform is shown in the Figure 8. proves that output voltage is 450V



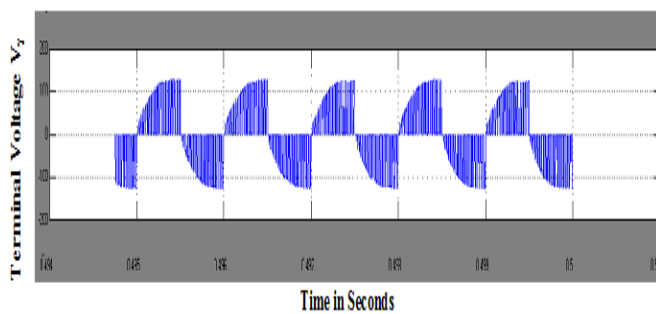
**Figure 8:** Output voltage of the three stage Cockcroft Walton voltage multiplier



**Figure 9:** Simulation model of proposed boost converter with nine stage Cockcroft Walton Voltage multiplier

### 6.2.1 Simulation results

The Terminal voltage for the proposed converter is shown in the Figure 10. It is very clear from the figure that terminal Voltage has increased.

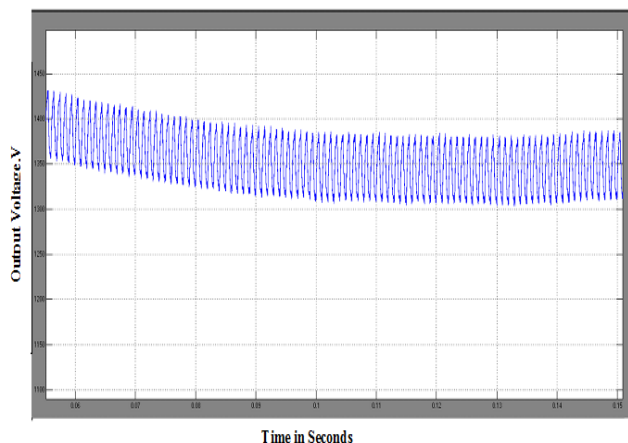


**Figure 10:** Terminal voltage

The output voltage of the proposed circuit for nine stages of Cockcroft Walton voltage multiplier is 1350V by using equation(8).The output voltage waveform of proposed circuit for 9 stages shows that the as number of stages is increased the corresponding output voltage can also be increased. The simulation results of the proposed circuit is shown in the Figure.11

### 6.2 Proposed circuit

The simulation model for the proposed circuit for nine stages is shown in the Figure 9.The proposed circuit consist of nine stages of Cockcroft Walton voltage multiplier with input supply voltage of 48V and the load R of 1K $\Omega$ .



**Figure 11:** Simulation results for the proposed circuit with nine stages representing output voltage.

## 7. Conclusion

This is a unique and compact circuit with low operational cost with the ability to provide the high DC Voltage. Both conventional circuit and proposed circuit are built using Simulink and their simulation outputs are compared and verified. This paper establishes the fact that by increasing the number of the stages to the conventional Cockcroft Walton voltage multiplier the required high voltage DC can be obtained without making any major changes in the conventional circuit. This circuit can be used for the high voltage DC applications for insulation testing, in medical field.

## References

- [1] J.Wang, F. Z. Peng, J. Anderson, A. Joseph, and R. Buffenbarger, "Low cost fuel cell converter system for residential power generation," *IEEETrans. Power Electron.* vol. 19, no. 5, pp. 1315–1322, Sep. 2004.
- [2] L. S. Yang, T. J. Liang, and J. F. Chen, "Transformerless dc-dc converters with high step-up voltage gain," *IEEE Trans. Ind. Electron.*, vol. 56, no.8,pp.3144–3152, 2009.
- [3] N. Mohan, T. M. Undeland, and W. P. Robbins, *Power Electronics*, 2nd New York: Wiley, 1995, pp.172–178.
- [4] R. J. Wai, C. Y. Lin, R. Y. Duan, and Y. R. Chang, "High-efficiency dc-dc converter with high voltage gain and reduced switch stress," *IEEE Trans.Ind. Electron.* vol. 54, no. 1, pp. 354–364, Feb. 2007.
- [5] T. F. Wu, Y. S. Lai, J. C. Hung, and Y. M. Chen, "Boost converter with coupled inductors and buck-boost type of active clamp," *IEEE Trans. Ind.Electron.*, vol. 55, no. 1, pp. 154–162, Jan. 2008.
- [6] C. S. Leu, P. Y. Huang, and M. H. Li, "A novel dual-inductor boost converter with ripple cancellation for high-voltage-gain applications," *IEEE Trans. Ind. Electron.*, vol. 58, no. 4, pp. 1268–1273, Apr. 2011.
- [7] M. D. Bellar, E. H. Watanabe, and A. C. Mesquita, "Analysis of the dynamic and steady-state performance of Cockcroft–Walton cascade rectifiers," *IEEE Trans. Power Electron.*, vol. 7, no. 3, pp. 526–534,Jul. 1992
- [8] M. M.Weiner, "Analysis of Cockcroft–Walton voltage multipliers with anarbitrary number of stages," *Rev. Sci. Instrum.*, vol. 40, no. 2, pp. 300–333,Feb. 1969
- [9] E. Kuffel and W. S. Zaengl, *High Voltage Engineering Fundamentals*.New York: Pergamon, 1984, ch. 2.
- [10] L. Malesani and R. Piovon, "Theoretical performance of the capacitor diode voltage multiplier fed by a current

source,” IEEE Trans. Power Electron., vol. 8, no. 2, pp. 147–155, Apr. 1993.

- [11] Z. Lai and K. M. Smedley, “A family of continuous-conduction-mode power-factor-correction controllers based on the general pulse-width modulator,” IEEE Trans. Power Electron., vol. 13, no. 3, pp. 501–510, May 1998.

## Author Profile



**Meghana G Naik** has received the B.E degree in EEE from Sri Taralabalu Jagadguru Institute of Technology in the year of 2004. Presently she is pursuing M.Tech in Power Electronics in Kuppam Engineering College, Kuppam.



**CH. Jayavardhana Rao** has obtained his B.Tech Electrical Engineering from JNTUH, Hyderabad in the year 2002, M.Tech in Power System emphasis on High voltage engineering from JNTUK, Kakinada in the year 2009. He has 5 years of industrial experience, 2 years Research experience and 5 years of teaching experience. Currently working as Associate Professor in Department of Electrical Engineering at Kuppam Engineering College, Kuppam, Chittoor district, Andhra Pradesh, INDIA his area of research include power systems, power electronics, high voltage engineering, renewable energy sources, industrial drives, HVDC & Facts technology.



**Dr. Venugopal.N** has obtained his doctoral degree from Dr. MGR. University Chennai. B.E. degree from and M.E. Degree both from Bangalore University. He has 17 years of teaching experience. His research area is Digital Image Processing & Video sequence separation. Currently working as an HOD of EEE Department & Director, R & D in Kuppam Engineering College, Kuppam, and Chittoor Dist. Andhra Pradesh. His research area of interest includes Power electronics, Renewable Energy Systems and Embedded Systems.