RESEARCH ARTICLE OPEN ACCESS

Transformerless DC-DC Converter Using Cockcroft-Walton Voltage Multiplier to Obtain High DC Voltage

Meghana G Naik, CH. Jayavardhana Rao Assoc. Prof., Dr. Venugopal.N Ph.D, Prof& HOD, Y. Damodharamassoc. Prof.
(Department Of Eee, Kuppam Engineering College, Kuppam)
(Department Of Eee, Kuppam Engineering College, Kuppam)
(Department Of Eee, Kuppam Engineering College, Kuppam)
(Department Of Eee, Kuppam Engineering College, Kuppam

ABSTRACT
In the present scenario the use of transformer for high voltages in converter circuit reduces the overall operating efficiency due to leakage inductance and use of transformer also increases the operational cost. . Therefore the proposed system is implemented with transformer less DC-DC converter so as to obtain high DC voltage with the use of nine stage Cockcroft-Walton (CW) voltage multiplier. The proposed converter operates in CCM (continuous conduction mode), so that the converter switch stress, the switching losses are reduced. The DC voltage at the input of the proposed model is low and is boosted up by boost inductor (L_s) in DC-DC converter stage and performs inverter operation. The number of stages in CW-voltage multiplier circuit is applied with low input pulsating DC (AC Voltage) voltage where it is getting converted to high DC output voltage. The proposed **converter** switches operates at two independent frequencies, modulating (f_{sm}) andalternating (f_{sc}) frequency. The f_{sm} operates at higher frequency of the output while the f_{sc} operates at lower frequency of the desired output voltage ripple and the output ripples can be adjusted by the switch S_{c1} and S_{c2}. The regulation of the output voltage is achieved by controlling the Duty ratio.The simulation is carried over by the MATLAB-SIMULINK.

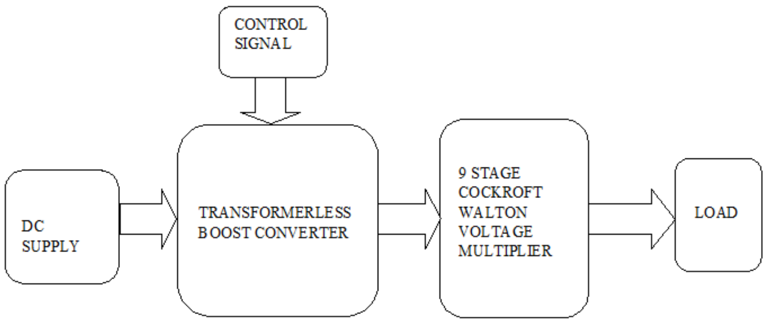
Index terms: Cockcroft Walton Voltage Multiplier, Low duty cycle, High DC voltage, Tranformerless DC-DC converter.

I. INTRODUCTION

Nowadays due to the immense usage of electrical devices there is huge demand for electrical energy. The conventional converters provide high voltage but does so at high duty cycle and the parasitic elements present in the passive elements effects reduces the voltage gain. The high voltages can also be obtained at lower duty cycle by making use of an isolated transformer or coupled inductors but this leads to leakage inductances which results in the voltage spikes across the switches and also increases the design complexities for higher voltages. So to overcome the voltage spikes higher ratings of switches need to be used and this increases cost of device. The step-up dc-dc converters can be obtained without the use of transformer by cascading diode inductor or diode capacitor but this results in the voltage stress on switches and on the passive elements. The voltage stress on switches and passive elements increases with the increase in the number of stages. Moreover these converter operate in Discontinuous conduction mode which leads to higher switching losses, higher switch stress and higher Electromagnetic interference problems.

This paper presents a Transformerless dc-dc converter with the Cockcroft Walton voltage multiplier. The proposed converter with the Cockcroft Walton voltage multiplier operates in Continuous conduction mode and thus reduces the switching losses, switch stress. Thisproposed converter with the Cockcroft Walton voltage multiplier shows that by increasing the number of stages, it obtains high DC voltage across the load without increasing the switch voltage and the diode voltage. This dc-dc converter consists of Tranformerless boost converter, a nine stage Cockcroft Walton voltage multiplier, controller and load to obtain high dc voltage at extremely low duty cycle.

II. PROPOSED SYSTEM MODEL



The block diagram of the proposed system consists of low level dc input supply, thetransformerless boost structure, nine stage CockcroftWalton voltage multiplier to obtain a high dc voltage across the dc load. The low level dc input is boosted by the transformer less boost converter and converts it into alternating voltage (or pulsating DC). The high step up converter with CockcroftWalton voltage multiplier is controlled by using PWM controller which helps the converter to operate in the continuous conduction mode. As the converter is designed to operate in continuous conduction mode hence it reduces the switch stresses, the switching losses as well as EMI noiseis reduced. The nine stage Cockcroft Walton voltage multiplier converts alternating voltage to high dc voltage.

1.1. Boost Converter:

The proposed boost structure consists of low level dc input source, one inductor, four switches namely Sm1, Sm2,Sc1 &Sc2. The four switches are divided onto two sets as (Sm1,Sm2) and (Sc1,Sc2). At any given point of time only two switches are operational and hence are said to operate in complimentary mode. The Sc1,Sc2 are used to generate alternating source which is being fed to stage Cockcroft Walton voltage multiplier .The Sm1,Sm2 are used to determine the flow of inductor energy to the boost converter. The Sm, Sc operate at two different frequencies namely fsm & fsc respectively. The fsm is called as modulation frequency and fsc is called as alternating frequency. The four switches operate at two different frequencies and this helps in providing coordination between output ripple and system efficiency. Though theoretically these two frequencies must be made as high as possible so that smaller range of capacitors and inductors can be used. Whereas in this paper fsm is maintained at much higher frequency than fsm and by controlling the duty cycle Sm1,Sm2 the output voltage is being regulated, whereas the output voltage rippleis adjusted by fsc.

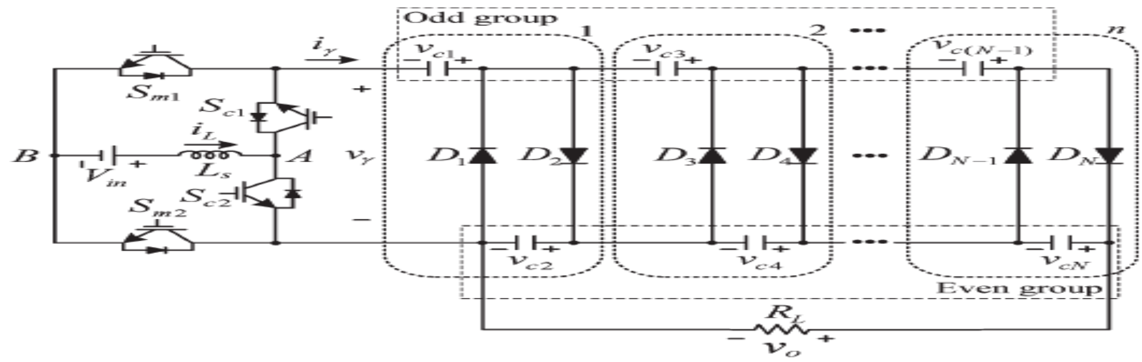


Fig. 2. Proposed converter with n-stage CW voltage multiplier.

1.2. Cockcroft Walton Voltage Multiplier:

The fig 2 shows the Cockcroft Walton voltage multiplier for n stage. The Cockcroft Walton voltage multiplier is basically used to obtain high dc voltage from the low level AC or pulsating DC input. Using Cockcroft Walton voltage multiplier is one of the most simple and cheapest way of developing high DC voltage ranging from several volts to Kilovolts. The Cockcroft Walton voltage multiplier is a voltage multiplier formed by using the ladder network of capacitors and diodes. The n-stage Cockcroft Walton voltage multiplier is obtained by cascading a number of diode–capacitor stages with each stage containing two capacitors and two diodes. The capacitors and the diodes are divided into two groups namely odd group and even groups as per the suffixes.The high-voltage power supplies are widely used for X -ray systems,In Insulation testing on all electrical appliances like cables, lines, Transformers & capacitors,Impulse generator charging units, LCD backlighting, traveling wave tube amplifiers, ion pumps, electrostatic systems, air ionizers, particle accelerators, copy machines, scientific instrumentation, oscilloscopes, TV sets.

III. Circuit Operation Principle:

The proposed converter with 9-stage Cockcroft Walton Voltage Multiplier is shown fig . Each stage of the Cockcroft Walton Voltage Multiplier consists of 2 Diodes and 2 Capacitors. Therefore the 9 stage Cockcroft Walton Voltage Multiplier totally consists of 18 Diodes and 18 Capacitor

The operating principle of the circuit depends on the polarity of the iγ current and hence operation of the proposed converter is divided into two parts: if iγ is greater than or equal to zero then positive conducting interval and if iγ is less than or equal to zero then negative conducting interval. During positive conducting interval only one of the even diodes conduct in a sequence of D18-D16-D14-D12-D10-D8-D6-D4-D2 and has two operating modes under it. During negative conducting interval only one of the odd diodes conduct with a sequence of D17-D15-D13-D11-D9-D7-D5-D3-D1 and has two operating modes under it.During positive conducting interval and the negative conducting the modes of operations are as below.

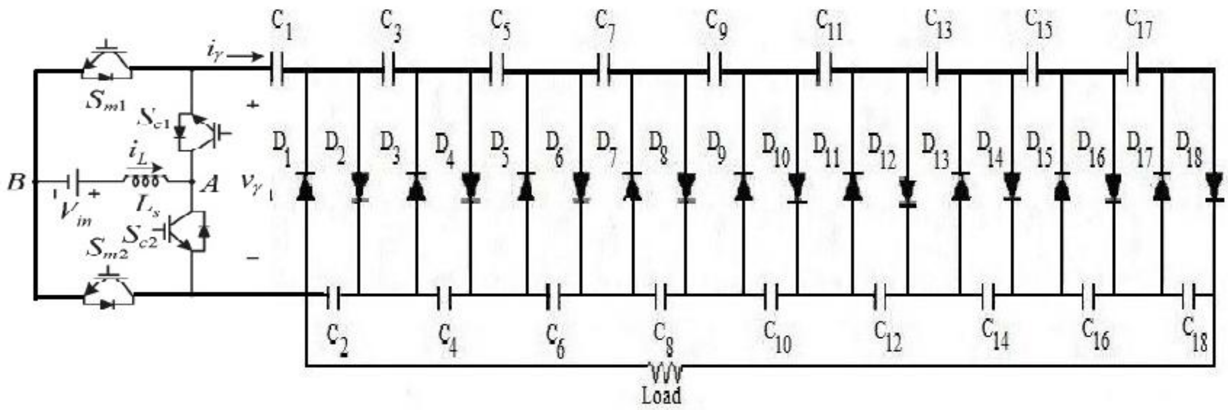


Fig 3. Proposed Transformerless Boost Converter with 9-stage CW Voltage Multiplier

Mode 1: Sm1 and Sc1 are turned on and Sm2and Sc2 are turned off and therefore the iγ is zero and so all the diodes are turned off .The inductor is charged by input DC from , hence the even numbered Capacitors (C18,C16,C14,C12,C10,C8,C6,C4,C2) supply the load and odd numbered capacitors C17,C15,C13,C11,C9,C7,C5,C3,C1) floats.

Mode 2: Sm2 and Sc1 are turned on and Sm1and Sc2 are turned off and the current iγ is positive. The boost inductor and the input DC source transfer the energy to Cockcroft Walton Voltage Multiplier through different even diodes and are explained in the modes 3 to modes 10.

Mode 3: Only diode D 18 conducts and therefore capacitors C18, C16, C14, C12, C10, C8, C6, C4, C2 are charged and the capacitors C17, C15, C13, C11, C9, C7, C5, C3, C1 are discharged byiγ.

Mode 4: Only diode D 16 conducts and therefore capacitors C16, C14, C12, C10, C8, C6, C4, C2 are charged and the capacitors C15, C13, C11, C9, C7, C5, C3, C1 are discharged byiγ,whereas C17 floats & C18 supplies the load.

Mode 5: Only diode D 14 conducts and therefore capacitors C14, C12, C10, C8, C6, C4, C2 are charged and the capacitors C13, C11, C9, C7, C5, C3, C1 are discharged byiγ,whereas C15, C17 floats &C16, C18 supplies the load.

Mode6: Only diode D 12 conducts and therefore capacitors C12, C10, C8, C6, C4, C2 are charged and the capacitors C11, C9, C7, C5, C3, C1 are discharged byiγ,whereasC13, C15, C17 floats &C14,C16, C18 supplies the load

Mode7: Only diode D 10 conducts and therefore capacitors C10, C8, C6, C4, C2 are charged and the capacitors C9, C7, C5, C3, C1 are discharged byiγ,whereasC11, C13, C15, C17 floats &C12,C14, C16, C18 supplies the load

Mode8: Only diode D 8conducts and therefore capacitors C8, C6, C4, C2 are charged and the capacitors C7, C5, C3, C1 are discharged byiγ, whereasC9C11, C13, C15, C17 floats &C10, C12,C14, C16, C18 supplies the load.

Mode 9: Only diode D6 conducts and therefore capacitors C6, C4, C2 are charged and the capacitors C5, C3, C1 are discharged byiγ, whereas C7,C9,C11, C13, C15, C17 floats &C8, C10, C12,C14, C16, C18 supplies the load.

Mode10: Only diode D4 conducts and therefore capacitors C4, C2 are charged and the capacitors C3, C1 are discharged byiγ, whereas C5, C7,C9,C11, C13, C15, C17 floats &C6, C8, C10, C12,C14, C16, C18 supplies the load.

Mode 11: Only diode D2 conducts and therefore capacitors C2 are charged and the capacitors C1 are discharged byiγ, whereas C3, C5, C7,C9,C11, C13, C15, C17 floats &C4, C6, C8, C10, C12,C14, C16, C18 supplies the load.

Mode 12: Sm2 and Sc2are turned on and Sm1and Sc1 are turned off and therefore the iγ is zero and so all the diodes are turned off .The inductor is charged by input DC from , hence the even numbered Capacitors (C18,C16,C14,C12,C10,C8,C6,C4,C2) supply the load and odd numbered capacitors C17,C15,C13,C11,C9,C7,C5,C3,C1) floats.

Mode13: Sm1 and Sc2 are turned on and Sm2and Sc1 are turned off and the current iγ is negative. The boost inductor and the input DC source transfer the energy to Cockcroft Walton Voltage Multiplier through different odd diodes and are explained in the modes 13 to modes 21.
Mode 14: Only diode D 17 conducts and therefore capacitors C17, C15, C13, C11, C9, C7, C5, C3, C1 are charged and the capacitors C16, C14, C12, C10, C8, C6, C4, C2 are discharged byiγ,whereas C18 supplies the load.
Mode115: Only diode D 15 conducts and therefore capacitors C15, C13, C11, C9, C7, C5, C3, C1 are charged and the capacitors C14, C12, C10, C8, C6, C4, C2 are discharged byiγ,whereas C17,floats & C16, C18 supplies the load.
Mode116: Only diode D 13 conducts and therefore capacitors C13, C11, C9, C7, C5, C3, C1 are charged and the capacitors C14, C12, C10, C8, C6, C4, C2 are discharged byiγ,whereasC15, C17,floats &C14, C16, C18 supplies the load.
Mode117: Only diode D 11 conducts and therefore capacitors C11, C9, C7, C5, C3, C1 are charged and the capacitors C10, C8, C6, C4, C2 are discharged byiγ,whereasC13, C15, C17, floats &C12, C14, C16, C18 supplies the load.
Mode118: Only diode D 9 conducts and therefore capacitors C9, C7, C5, C3, C1 are charged and the capacitors C8, C6, C4, C2 are discharged byiγ,whereasC11, C13,C15, C17, floats &C10,C12, C14, C16, C18 supplies the load.
Mode119: Only diode D 7 conducts and therefore capacitors C7, C5, C3, C1 are charged and the capacitors C6, C4, C2 are discharged byiγ,whereasC9, C11, C13, C15, C17, floats & C8, C10, C12, C14, C16, C18 supplies the load.
Mode120: Only diode D5 conducts and therefore capacitors C5, C3, C1 are charged and the capacitors C4, C2 are discharged byiγ,whereas C7, C9, C11, C13, C15, C17, floats & C6, C8, C10, C12, C14, C16, C18 supplies the load
Mode121: Only diode D3 conducts and therefore capacitors C3, C1 are charged and the capacitors C2 are discharged byiγ,whereas C5, C7, C9, C11, C13, C15, C17, floats & C4, C6, C8, C10, C12, C14, C16, C18 supplies the load
Mode122: Only diode D1 conducts and therefore capacitors C1 are charged, capacitorsC3, C5, C7, C9, C11, C13, C15, C17, floats & C2, C4, C6, C8, C10, C12, C14, C16, C18 supplies the load.

IV. Design Consideration for Proposed Converter

In this section, the designing aspects of the capacitor, inductance (Ls), output voltage, output current, output current is presented of the proposed system.

1.3. Inductance:

The input inductance Ls is calculated using the below formula

Ls =Vin (DTsm / Ki Ip)
Where Vin is the supply voltage, Ki is the expecting percentage of the maximum peak to peak current.

1.4. Capacitor voltage:

For the proposed system analyses purpose assumption is made that, whenever a high frequency periodic alternating current is fed into Cockcroft Walton Voltage Multiplier are sufficiently large, the voltage drop and ripple of each capacitor voltage can be ignored under reasonable load condition. Thus, the voltage across all capacitor are equal, except the first capacitor whose voltage is and half of the others. As per this assumption, each capacitor voltage in the Cockcroft Walton Voltage Multiplier can be defined as

$$v_{ck} = \begin{cases} V_o/2n & \text{for } k = 1 \\ V_o/n & \text{for } k = 2, 3, \ldots, N \end{cases}$$

1.5. Output Voltage (V_0):

The output voltage of the Cockcroft Walton Voltage Multiplier can be calculated with the below formula

V_0= nVc

where Vc is the Capacitor voltage

1.6. Output Power (P_0)

The output power can calculated with output voltage and resistive load.

$P_0= V_0^2/R$

1.7. Output current (I_0):

The output current is given by output voltage and output power

$$I_o = \frac{V_o}{R}$$

Table I - Design Values of Proposed Converter

Parameters	**Value**
Supply voltage (Vin)	48V
Modulation frequency, fsm	60KHz
Alternating frequency, fsc	1KHz
Inductance	1.5mH
Number of Stages	9
Output Voltage, Vo	1350V
Output power (Po)	2000W
Output current (Io)	1.48A
Resistive load, RL	1KΩ

V. Simulation circuit:

The simulation of the converter with Cockroft Walton Voltage Multiplier is done using MATLAB software. Thesimulation circuit consists of two parts, one is proposed tranformerless converter with Cockroft Walton Voltage Multiplier and another is the controller. The simulated circuit ofconverter topology is shown as in Fig. 4.

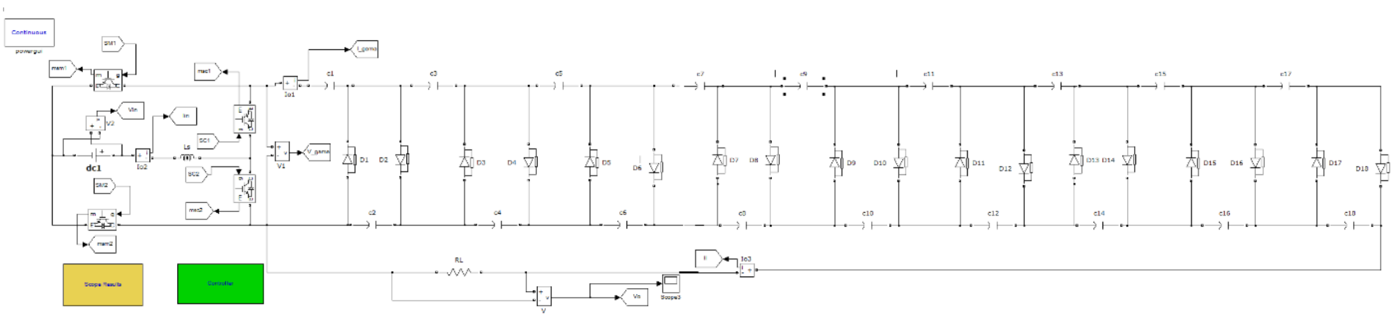


Fig 4. Simulated circuit of Transformerless boost converter with CW Voltage Multiplier

The below fig 5 shows the simulated circuit of controller

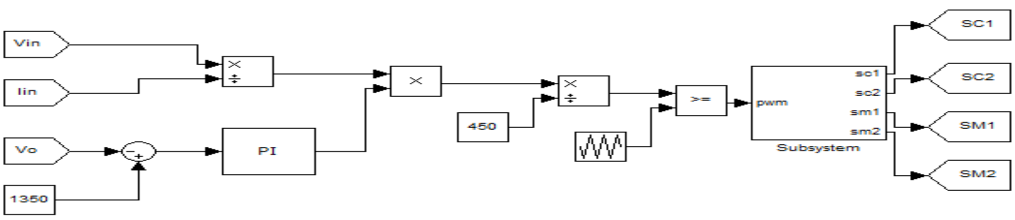


Fig. 5 - Simulated circuit of Controller

VI. Simulation Results

The below fig 6 shows the simulation result of the output voltage of the proposed transformerless boost converter for the nine stage Cockroft Walton Voltage Multiplier.

Fig. 6–Voltage Output

The below fig 7 shows the simulated result of output current of the proposed converter for 9-stage Cockroft Walton Voltage Multiplier

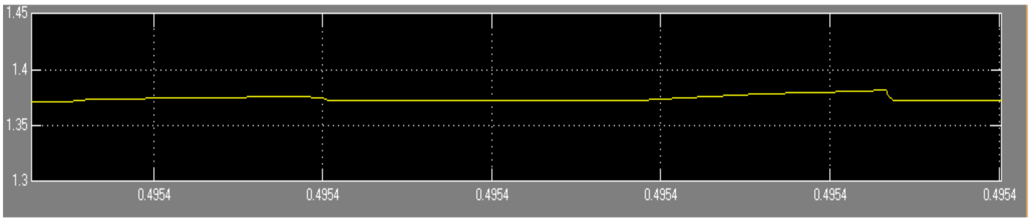


Fig. 7–Current Output

The below fig 8 shows the simulated result of Sm1,Sm2,Sc1&Sc2.

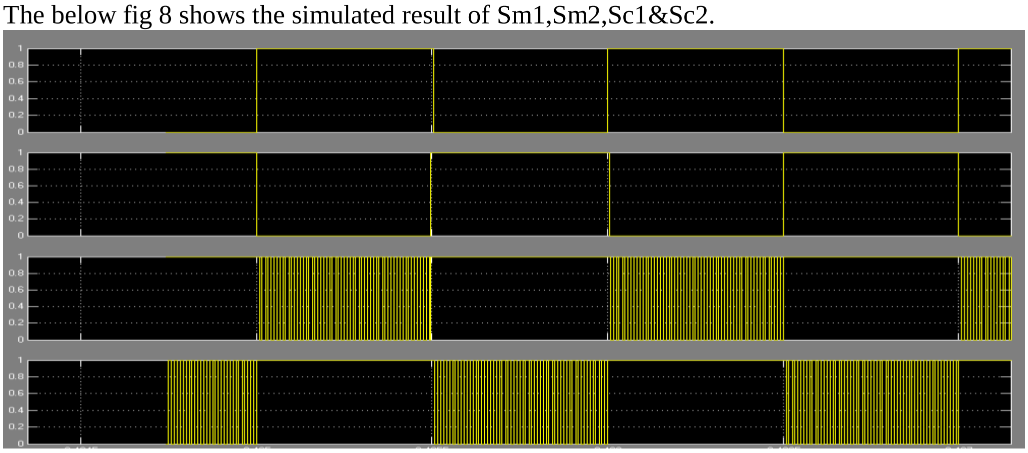
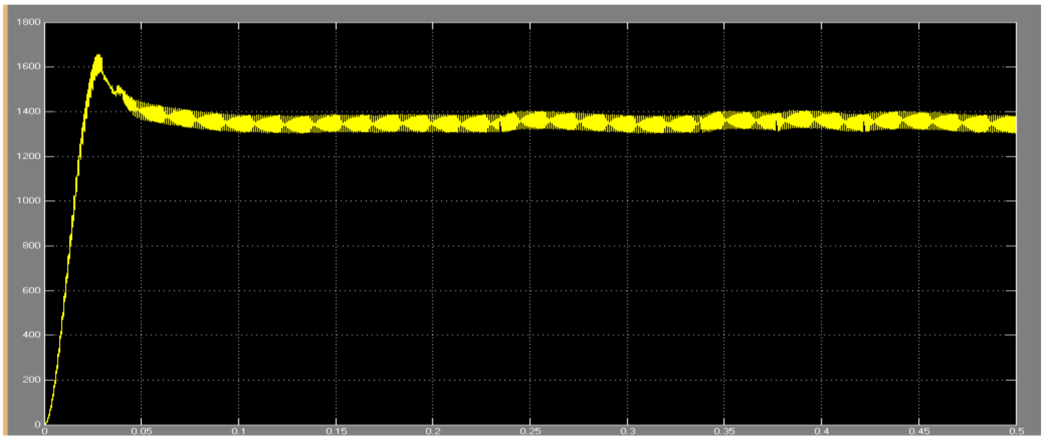


Fig. 8–Pulses of Sm1, Sm2, Sc1 & Sc2



VII. Conclusion

In this paper high DC voltage has been obtained based on Cockcroft Walton Voltage Multiplier without making use of transformer in the circuit. The high Dc voltage is obtained by just increasing the number of stages without increasing the components (Capacitor, Inductance, Diode) ratings .It has also not increased the switch voltage and diode voltage. The regulation of the output voltage is achieved by controlling the Duty ratio.From the simulation results it was observed that, the proposed circuit is suitable for high voltage applications.

References

[1] 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, Aug. 2009.

[2] R. J. Wai, C. Y. Lin, R. Y. Duan, and Y. R. Chang, "High-efficiency dc-dcconverter with high voltage gain and reduced switch stress," *IEEE Trans.Ind. Electron.*, vol. 54, no. 1, pp. 354–364, Feb. 2007.

[3] C. S. Leu, P. Y. Huang, and M. H. Li, "A novel dual-inductor boost converterwith ripple cancellation for high-voltage-gain applications," *IEEETrans. Ind. Electron.*, vol. 58, no. 4, pp. 1268–1273, Apr. 2011.

[4] F. L. Luo and H. Ye, "Positive output cascade boost converters," Proc.Inst. Elect. Eng.—Elect. Power Appl., vol. 151, no. 5, pp. 590–606, Sep. 2004

[5] B. Axelrod, Y. Berkovich, and A. Ioinovici, "Switched-capacitor/switched-inductor structures for getting transformerless hybrid dc-dc PWMconverters," IEEE Trans. Circuits Syst. I, Reg. Papers, vol. 55, no. 2,pp. 687–696, Mar. 2008.

[6] M. Prudente, L. L. Pfitscher, G. Emmendoerfer, E. F. Romaneli, andR. Gules, "Voltage multiplier cells applied to non-isolated dc-dc converters,"*IEEE Trans. Power Electron.*, vol. 23, no. 2, pp. 871–887,Mar. 2008.

[7] M. Prudente, L. L. Pfitscher, G. Emmendoerfer, E. F. Romaneli, andR. Gules, "Voltage multiplier cells applied to non-isolated dc-dc converters,"*IEEE Trans. Power Electron.*, vol. 23, no. 2, pp. 871–887,Mar. 2008.

[8] F. Hwang, Y. Shen, and S. H. Jayaram, "Low-ripple compact high-voltagedc power supply," *IEEE Trans. Ind. Appl.*, vol. 42, no. 5, pp. 1139–1145,Sep./Oct. 2006.

[9] I. C. Kobougias and E. C. Tatakis, "Optimal design of a half-waveCockcroft–Walton voltage multiplier with minimum total capacitance," IEEE Trans. Power Electron., vol. 25, no. 9, pp. 2460–2468, Sep. 2010.

[10] C. M. Young and M. H. Chen, "A novel single-phase ac to high voltagedc converter based on Cockcroft–Walton cascade rectifier," in Proc. IEEEPEDS, 2009, pp. 822–826

[11] 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.[30] E. Kuffel and W. S. Zaengl, *High Voltage Engineering Fundamentals*.New York: Pergamon, 1984, ch. 2.

[12] L. Malesani and R. Piovan, "Theoretical performance of the capacitordiodevoltage multiplier fed by a current source," *IEEE Trans. Power Electron.*, vol. 8, no. 2, pp. 147–155, Apr. 1993.

[13] H. van der Broeck, "Analysis of a current fed voltage multiplier bridge forhigh voltage applications," in *Proc. IEEE PESC*, 2002, pp. 1919–1924.

[14] Infineon Technol., Preliminary datasheet, V1.1 ICE1PCS01-StandalonePower Factor Correction Controller in Continuous Conduction Mode,May 2003.

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

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

CH.Jayavardhana Rao has obtainedhis B.Tech Electrical Engineering fromJNTUH, Hyderabad in the year 2002, M.Techin Power System emphasis on High voltageengineering from JNTUK, Kakinada in theyear 2009. He has 5 years of industrialexperience, 2 years Research experience and 5 years of Teaching experience.Currently working as Associate Professor in Department ofElectrical Engineering at Kuppam Engineering College, Kuppam, Chittoor district, Andhra Pradesh, INDIA his area of researchinclude power systems, power electronics, high voltageengineering, 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, Chittoor Dist. Andhra Pradesh. His research area of interest includes Power electronics, Renewable Energy Systems and Embedded Systems

Y.DAMODHARAM has obtained hisB.Tech in EEE from Kuppam Engineering College affiliated to JNTUH in the year 2006. He completed M.Tech in power system emphasis on High Voltage Engineering from JNTU Kakinada in the year 2010. Currently working as Associate Professor in Kuppam Engineering College in the Department of EEE. His area of research is renewable energy sources, high Voltage engineering, power systems technology.