TELKOMNIKA, Vol.17, No.4, August 2019, pp.1890~1897
ISSN: 1693-6930, accredited First Grade by Kemenristekdikti, Decree No: 21/E/KPT/2018
DOI: 10.12928/TELKOMNIKA.v17i4.11828

Plasma generator: design of six stage cockcroft-walton voltage multiplier 12 kV for impulse voltage generation

Wijono[*1], Eka Maulana[2], Dony Darmawan Putra[3], Waru Djuriatno[4]
[1,2,4]Electrical Engineering, Brawijaya Universiy, MT. Haryono 167 St, Malang 65145, Indonesia
[3]Master Program in Telecommunication Engineering, National Sun Yat-sen University
[1,2,4]Colaborative Research Center for Advanced System and Material Technology
*Corresponding author, e-mail: wijono@ub.ac.id

Abstract

Cockcroft-Walton (CW) voltage multiplier is a voltage booster circuit with an array of series-connected only diodes and capacitors. In this research, voltage multiplier is designed to generate voltage up to 12 kV that the modified 6-stage constructed generator. It is designed as circuit charger of storage capacitor (CS) to generate combination wave impulse application which following standard those set in IEC (International Electrotecnical Commission) 61000-4-5 class 4. CS should be charged up to 4 kV according this standard. High impulse voltage and current works repeatedly in a short time, so the charging system is expected to reach targeted voltage within a maximum time of 10 seconds. Besides charging is also required to design of circuit discharger for discharging electric charge inside the CS. It is expected to reach 0 kV within a maximum time of 15 seconds with overdamped technique. There are three results of the research projects such as output voltage of CW voltage multiplier before connecting CS, charging time of CS, and discharging time of CS. The result showed that CW voltage multiplier can generate up to 12.01 kV on simulation and 11.9 kV on experiment. CS can be charged up to 4 kV in 9.8 seconds on simulation and 7.9 seconds on experiment. CS can be discharged in 14.2 seconds on simulation and 10 seconds on experiment. These results are in accordance with the expectation.

Keywords*: charging time, cockcroft-walton voltage multiplier, discharging time, storage capacitor voltage*

1. Introduction

Cockcroft-Walton (CW) voltage multiplier is a multilevel voltage multiplier that is often used in many ways due to its components are only from diodes and capacitors [1, 2]. These voltage multiplier convert the alternating current (AC) voltage at the input side to a higher DC current [3]. Some examples of the use of the Cockcroft-Walton voltage multiplier circuit in everyday life are in X-Ray, electron microscope, precipitator, accelerator, insulator tester, nitrogen laser, and so on [4-12]. These applications are successfully made due to they have designed CW voltage multiplier by calculating component values [13, 14]. The design of CW voltage multiplier begins with determining the desired DC output voltage value and knowing the value of AC input voltage available. These values are used for the determination of many levels of CW voltage multiplier. Many of these levels are classified as CW voltage multiplier that the classifications are voltage doublers, triples, quadruplers and so on [15]. After the determination of many levels in the circuit is the determination of the value of diodes and capacitors to be adjusted to the use of CW voltage multiplier [16].

One of the uses of CW voltage multiplier is the charging of storage capacitors (CS) in the impulse voltage current generator or combination wave generator. It is still difficult to obtain on the market, but the need for such equipment to test of protecting equipment against the lightning strike is needed, both at the time of testing and during the design process. It follows the established standards of IEC (International Electrotecnical Commission) 61000-4-5. The CS charging constraint in previous research is a charging device derived from a step up transformer. The step-up transformer has various disadvantages: expensive price, large weight, wide dimension, and various electrical losses [17]. The next constraint is to be rectified AC voltage output from transformer to DC first before through CS. CW voltage multiplier can be the solution of various CS charging problems that are cheap, lightweight, small dimensions, and small losses. It also directly generate DC output which can be directly connected to CS.

Received July 5, 2018; Revised March 2, 2019; Accepted April 5, 2019

In this study, designed CW voltage multipliers for CS charging expected CS has the voltage and energy according to the standard. The voltage and current combination impulse generator works repeatedly in a short time, so it is expected that the duration of charging time is short or only within a few seconds. Capacitor can charge another capacitor faster than other DC supplies that has same voltage [18]. To achieve the duration of the time required a high direct current. When the CS has been overcharge, then there is a problem when removing the charge. The existing grounding tool is a grounding stick, but this tool has many weaknesses such as expensive and generate great power. So need to be designed a tool that can solve the problem. The solution to this discharge problem is to make a damping stick. The damping technique used is the overdamped technique. This technique includes a simple and inexpensive technique, because it only uses resistor and inductor components.

2. Research Method

This research is based on an applicative problem, which is formulated into three main problems, that is how to design Cockcroft-Walton voltage (CW), charge the storage capacitor (CS) load within 10 seconds (Hafely Hipotronics PIM 100 datasheet), and discharge CS in maximum 15 seconds.

2.1. Flowchart of Research

a) Determination of Charging Time of CS

The voltage and current combination impulse generator works repeatedly in a short time, so this charging system is expected to reach that voltage in maximum time such as existing tools and up to standards. It is havely hypotronics 1.2/50μs & 8/20μs Combination Wave Impulse Module.

b) Dete rmination of Targeted Voltage on CS

Determination of expected voltage on CS based on standard combination of voltage and impulse current. The standard is IEC (International Electrotecnical Commission) 61000-4-5. It specifies the impulse voltage waveform is 1.2/50 μs and 8/20μs impulse current waveform. In addition to the waveform is also set value of the components of wave forming. The components are capacitors, inductors and resistors. In this study, the grade 4 is selected. The class chosen is the class that has the largest voltage rating compared to the other class. By designing this class then the charging tool can also be used for charging the other class.

c) Calculation of Output Voltage of CW

From the parameters specified above, the maximum output voltage of the voltage multiplier can also be obtained by ohms and Kirchhoff laws. The use of these laws is used in this study when CS is right after it is connected to a CW voltage multiplier (transition state). The transition state is calculated by a first order differential equation because there are the capacitor and resistor components in the process of charging CS.

d) Determination of Input Voltage of CW

The input voltage used adjusts the availability of the power supply in the laboratory. This power supply consists of PT PLN network sources connected to the AC voltage regulator and microwave transformer. The input voltage supply in the CW voltage multiplier circuit is derived from the AC-current voltage. This AC voltage will be multiplied into a higher direct current (DC) voltage.

e) Calculation of The Number of CW Stages

Based on the input voltage and maximum voltage values above, the number of stages of the CW voltage multiplier circuit can be determined. This determination assumes the ideal constituent component. Ideal component determination due to unavailability of datasheet on component used.

f) Determination of CW Components

The value of the specified component is the multiplier capacitor and the diode. Capacitance of the multipliers capacitor used is the same unit as the CS. It aims to through a sufficiently large current from the multiplier capacitor to the CS. The diode used is a diode capable of blocking the reverse voltage of the capacitor. The diode must also be able to through a sufficiently large current.

g) Determination of Discharging Time of CS

The discharge time is obtained from standard of discharge Capacitor. This standard was adopted by the National Electrical Code (NEC) 1978 on occupational safety standards when the use of a residual charge capacitor. Residual charge capacitors are flammable and cause electrical shock.

h) Calculation of Discharging Stick Components

Calculation of resistance value of resistor, power resistor, inductance inductor and inductor current based on ohm law and Kirchhoff law. The use of these laws is used in this study when CS is right after it is connected to the discharging circuit (transition state). The transition state is calculated by the second order differential equation because there is the capacitor, inductor and resistor components at the discharge process of CS.

i) Measurements of Maximum Voltage of CW, Charging Time of CS, and Discharging Time of CS

Measurements of high voltage parameters can be performed using high damping probes and high voltage isolation resistances. The maximum voltage results at the CW voltage multiplier, the CS charging time and the CS discharging time are obtained from the high-voltage probe connected to the oscilloscope.

2.2. Research Variables

In research there are two variables such as:

a) Controlled variables
- Input power (Pi). The input power is kept steady by using a power source.
- The value R and C of the Cockcroft Walton voltage multiplier components and L and R of discharging circuit of CS. Cockroft-Walton voltage multiplier components that is kept constant is the type of diode, resistor value and capacitor value, whereas the storage capacitor discharging component that is fixed is the value of the resistor and the value of the inductor.
- Input voltage (Vi(t)). The input voltage of the Cockroft-Walton voltage multiplier circuit is kept 1 kV.

b) Dependent variables
- Charging time (t_c). The time interval that will be obtained is the time of charging storage capacitor from the state of initial voltage 0 volts to the final voltage of 4 kV.
- Maximum output voltage (Vo). Maximum output voltage from Cockcrof-Walton circuit before connecting storage capacitor.
- Discharge time (td). The time interval that will be obtained is the time of charging storage capacitor from the state of initial voltage 4 kV to end voltage of 0 volt.

3. Design

3.1. Description of General Design

The first step in the research is the design of a six-stage CW circuit capable of charging CS up to 4 kV working voltage. Charging time is expected to only take a maximum of 10 seconds. In this step we will describe the order of determining the value and type of each component in detail. In this step will also be taken into account the distance of each component so that no breakdown voltage occurs [19]. After designing of the first step, it will be simulated by using Matlab Simulink. The purpose of this simulation to ensure the calculation results when designing. With this simulation will reinforce the hypothesis has been estimated, so that when testing can know the truth of data to be taken.

CW is tested twice that is not connected with CS and connected with CS. The test without the CS connected is to know the maximum voltage of the CW. The second test by connecting CW with CS aims to know the time of charging. The data retrieval in this test uses an oscilloscope and a high voltage probe that has 1000x damping. In this study also designed the discharging stick to discharge the CS charge. The charge on CS is discharged after charging up to the expected voltage. The manufacture of this discharging stick is used to avoid the occurrence of work accidents due to electrical charge shock from CS. It is expected that the discharging time up to 15 seconds [20]. This design will be explained in detail so that the target is implemented. After designing of discharging stick, it will be simulated the discharging circuit by using Matlab listing program. The use of listing program because

Matlab Simulink is not able to move the switch when running. The discharging stick can be used after the charging of CS has been done. This test aims to determine the time of discharging of CS charge. To find out the time then used oscilloscope and high voltage probe that has been used in the testing of charging CS.

3.2. Designing of CW Voltage Multiplier

At the design step, a high-voltage multiplier will be designed to charge the CS that the maximum charging time tc is ten seconds. To achieve these targets then performed calculations and analysis in order to be able to determine the value of CW output voltage, resistors, diodes and capacitors in the CW circuit. The voltage and current combination impulse generator works repeatedly in a short time, then the charging system is expected to reach the voltage within a maximum of 10 seconds. The time is obtained from the existing impulse voltage and current combination wave (havely hypotronics PIM datasheet). Such tools are havely hypotronics PIM 100 1.2/50us & 8/20μs Combination Wave Impulse Module.

Determination of expected final voltage on CS based on standard combination of voltage and impulse current. It is IEC (International Electrotecnical Commission) 61000-4-5. This standard sets the impulse voltage waveform is 1.2/50 μs and the impulse current waveform is 8/20μs. In addition to the waveform is also set value of the components of wave forming. Those are capacitors, inductors and resistors. In this study, the grade 4 standard is selected. The standard in this class sets the CS voltage to be 4 kV. This class is chosen because it has the largest voltage rating compared to the other class. By designing this case, then the charging tool can also be used for charging the other class.

From the parameters specified above, the maximum output voltage of the voltage multiplier can also be obtained by ohms and Kirchhoff laws. The use of these laws is used in this study when CS is right after it is connected to a CW voltage multiplier circuit (transition state). The transition state is calculated by the first order differential equation. Based on (1), the maximum voltage Vmaks of the CW voltage multiplier circuit of 12 kV and final voltage v(t) of 4kV with the voltage ripple of 0 kV can be obtained. The assumption of resistance R in the series of mega ohm due to the absence of datasheet on CS. The calculation of the capacitor C of 25 μF and charging time t to approximately 10 seconds based on (1) as follows:

$$-RC\ln\left(1-\frac{v(t)}{v_{\max}}\right)=t \quad (1)$$

where,

t : time (s)

R : Resistance (ohm)

C : Capacitance (F)

$v(t)$: Final voltage (volt)

v_{max} : Voltage input source (volt)

The determination of stage levels (n) is based on the source of the CW circuit voltage. The source of the supply voltage V_{inmaks} is 1 kV, then to achieve V_{out} of 12 kV it takes six stages n according to the (2).

$$V_{out}=2nV_{\max} \quad (2)$$

where,

V_{out} : Output voltage

n : The number of stages

V_{inmax} : Maximum input voltage

Determination of the first component value is the determination of the multiplier capacitor in the CW circuit that is the first requirement is the *Cn* capacitor capacitor that is serial series greater than 4 kV for the energy of capacitor Cn can move to CS. The second requirement is the potential of Cn capacitors that connect series larger than 12 kV in order to generate 12 kV voltage. The third condition is the minimum multiplier capacitor is worth 0.1 nF in order to avoid voltage stagnation. Therefore, in this study selected capacitor in CW circuit with 0.1 μF capacitance with maximum voltage 3 kV. Selected voltage of 3 kV at each of the multiplier capacitors in addition to meeting the total series voltage above 4 kV, but also because the AC input voltage of 1 kV, then the reverse peak voltage on each capacitor 2√2 kV or 2.8 kV [21]. Determination of the value of the third component is the determination of the diode value in the CW circuit that is with the first condition has the ability to withstand reverse voltage greater than the peak voltage of the capacitor *Cn* of 2.8 kV, the second condition is capable of conducting the transition current originating from the discharging capacitor *Cn'* multiplier capacitor Cn. Therefore, in the study selected diodes in the market but meet the requirements are 2CL72 diodes with a capacity of 10kV / 5mA with a peak of 0.5 A.

To supply the input voltage of a 1 kV CW circuit using a step up transformer with a 220/2000 winding first to raise a voltage of 110 Volts to 1 kV. To set the input voltage of 110 volts then required AC voltage regulator. To avoid the inrush current when starting AC voltage regulator and transformer does not set the input directly to 110 volts, the input voltage should be increased quickly from 0 volts to 110 volts. There are two circuit designs in this study. The first design is the design in Figure 1 (a), the design output is not connected to the CS, aiming to know the maximum voltage. The second design is the design in Figure 1 (b), the output of this design is connected to CS to know t_c. The minimum distance is using an electric field ratios of 357014 V/m at each potentially different electric point, therefore potential 12 kV with 0 volts must be a minimum distance of 4 cm. In addition to using the calculation to design the CW voltage multiplier circuit, Matlab Simulink is used to simulate the charging time and output voltage.

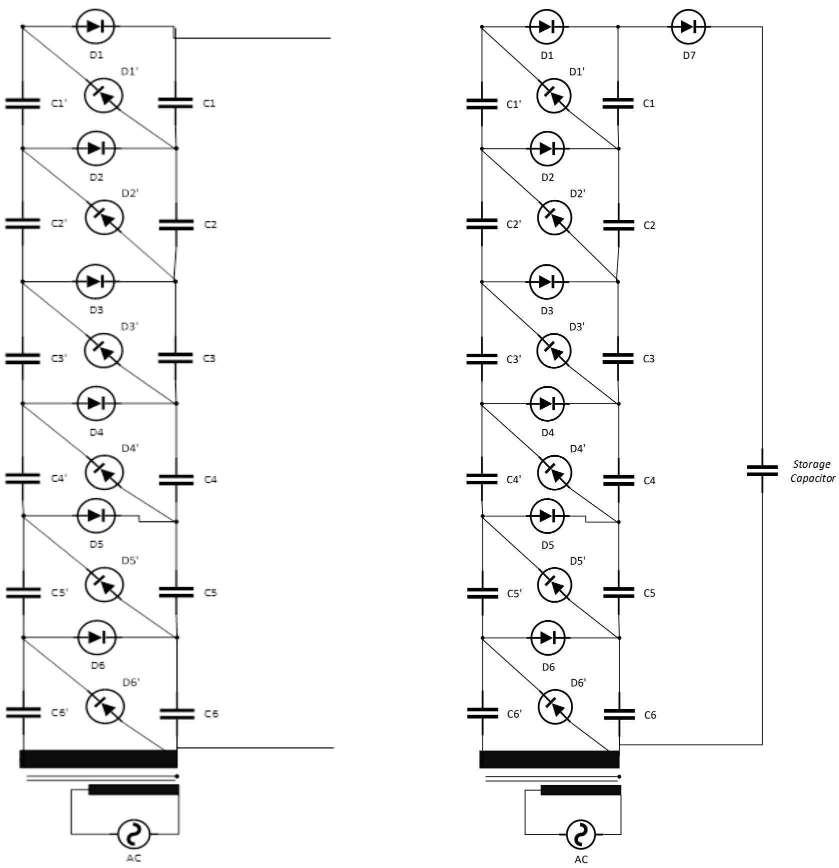

Figure 1. (a) CW with CS (left) and (b) CW without CS

4. Results and Analysis

4.1. Result and Discussion of Experiment

To obtain data of experiment result in this research use high volatge probe with damping 1000x, and also use osiloscope Hantex MSO5074FG.

a) Result and Discussion of CW Output Voltage without CS

Figure 2 shows the results of the Cockcroft-Walton (CW) output voltage output before connecting the storage capacitor (CS). The maximum output voltage reaches 11.9 kV. In addition to the maximum voltage but the results show that the output voltage is not straight without any voltage ripple. It can be seen that there is a voltage ripple of 950 volts. The ripple is caused the charging and discharging of the multiplier capacitor, the amount of the series resistance value inside capacitor. The profile signal shows the input current and input voltage values, to show that the input power is kept fixed, it appears that there is no change in the input power input voltage. Also, the input voltage of a 110 volt transformer in the primary winding raised to 1 kV in the secondary winding can generate a maximum output voltage of 12 kV CW.

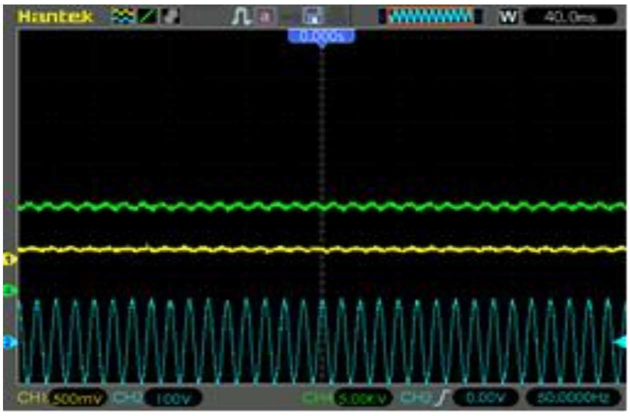

Figure 2. Cockcroft-Walton circuit output voltage before connecting storage capacitor in experiment

b) Result and Discussion Charging of CS

Figure 3 and Figure 4 shows the experimental results of the CS transient voltage condition when it is supplied with a CW voltage multiplier circuit. It represents that the CS is charged to 4 kV in just 7.9 seconds or less than 10 seconds. In the presence of charging it appears, there is a transient waveform not smooth due to the input voltage multiplier circuit is not adjusted directly reach 110 volts, but by rotating the AC voltage regulator quickly. The arrangement is to avoid the inrush current of the transformer which can damage the CW voltage multiplier circuit. After the CS has reached 4 kV then the input is turned off so that the load on the CS can be discharged through discharging stick. The inductor isolator, is only up to 4 kV. Visible when input is off, voltage drop is very slow due to the small resistance in the CS series.

Figure 3. Voltage transient of Cockcroft-Walton output voltage transition after connected storage capacitor

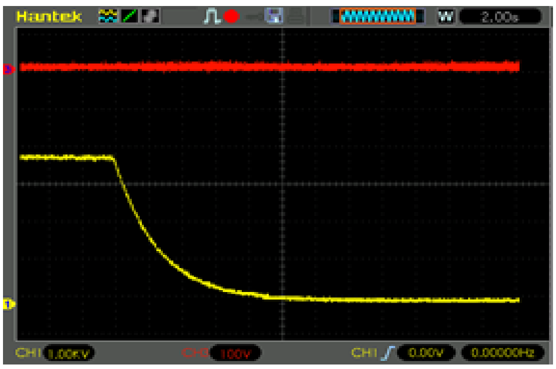

Figure 4. Voltage transient of Cockcroft-Walton output voltage transition during discharging process

c) Result and Discussion Discharging of CS

In Figure 4 shows the result of CS transient voltage change when the discharging stick is connected to CS having initial voltage of 4 kV. It is seen that the voltage of CS vc (t) reaches the point of close to zero volts at 10 second. Thus the energy previously in the capacitor is converted to heat energy in the resistor and the magnetic energy in the inductor.

4.2. Result and Discussion of Simulation

a) Result and Discussion of CW Output Voltage without CS

In the circuit simulation result of the transient transformation of the CW circuit output voltage before being connected to CS occurred. It can be indicated that the voltage rises exponentially then at 5 milliseconds of steady state at a voltage of 12.01kV and when the enlarged transient state differs from the state of the steady state. The difference is that when the transient state occurs oscillations greater than the steady state state. The voltage at steady state is a pure DC line straight where there is little ripple of voltage.

b) Result and Discussion Charging of CS

According to the circuit simulation, the CS transient voltage change when it is supplied with CW voltage multiplier circuit. It can be exhibited that the voltage increases exponentially indicating that the CS charging process is in progress. The charging reaches a voltage of 4 kV at a second to 9.8. After charged 4kV, CS will remain charged, it is in experimental state can not be done due to the grounding stick can only release the charge if the capacitor is filled 4 kV. The consequence if the charging process still done is the damage to CS and grounding stick tool itself. The charging process characteristic can be compared with previous result [22-27].

5. Conclusion

According to this experiment, it can be concluded that the design and manufacture of 12 kV Cockcroft-Walton (CW) voltage multiplier circuit was successfully performed with the difference of output voltage result in relatively small theory, simulation and experiment. In the simulation CW circuit shows the result of maximum output voltage of 12.01 kV which has a voltage ripple of 150 volts. In experiments the CW circuit shows a maximum output voltage output of 11.9 kV which has a voltage ripple of 950 volts. The design of CW 12 kV voltage multiplier circuit can be utilized for storage capacitor (CS) charging up to 4 kV according to IEC 61000 4-5 standard. This charging tool completes the CS in time up to 10 seconds. The voltage and current combination impulse generator works repeatedly in a short time, then this charging system can reach the voltage within a maximum of 10 seconds. CS can be charged up to 4 kV in 9.8 seconds at simulation and 7.9 seconds in experiment. Discharging time (td) on CS when the initial voltage has reached 4 kV until the final voltage of 0 kV is completed in a time faster than the expected time of maximum 15 seconds. CS can be discharged within 14.2 seconds on simulation and 10 seconds on experiment.

References

[1] Shenkman A, Berkovich Y, Axelrod B. Novel AC–DC and DC–DC Converters with a Diode-Capacitor Multiplier. *IEEE Trans. Aerosp. Electron*. Syst. 2004; 40(4): 1286-1293.
[2] Malesani L, Piovan R. Theoretical Performance of the Capacitor-Diode Voltage Multiplier Fed By A Current Source. *IEEE Trans. Power Electron*. 1993; 8: 147-155.
[3] Ramos JAM, Pernia AM, Diaz J, Nuno F, Martinez A. Power Supply for A High-Voltage Application. *IEEE Trans. Power Electron.* 2008; 23 (4): 1608-1619.
[4] Babaji G. Design and Construction of a 12 kV DC Power Supply. *Bayero J. Pure Appl. Sci*. 2009; 2(2): 175–184.
[5] Hino H, Hatakeyama T, Nakaoka M. *Resonant PWM Inverter Linked DC-DC Convertor Using Parasitic Impedances of High-Voltage Transformer and Its Applications to X-Ray Generator.* Proc. IEEE Power Electron. Spec. Conf. 1988; 2: 1212-1219.
[6] Bowles E, Chapelle S, Ferguson G, Furuno D*. A High Power Density High Voltage Power Supply for a Pulsed Radar System.* Proc. IEEE Power Modulator Symp. 1994: 170-173.
[7] Khalifa M. High-Voltage Engineering: Theory and Practice. New York, NY, USA: Marcel Dekker, Mar. 1990.
[8] Katzir L, Shmilovitz D. A Matrix-Like Topology for High-Voltage Generation. *IEEE Trans. Plasma Sci.* 2015; 43(10): 3681-3687.

[9] Iqbal S, Singh GK, Besar R. A Dual-Mode Input Voltage Modulation Control Scheme for Voltage Multiplier Based X-Ray Power Supply. *IEEE Trans. Power Electron.* 2008; 23(2): 1003-1008.
[10] Yan W, Dawson FP. *Design of a Cockcroft-Walton cascade rectifier for triggering flashlamps*. Proceedings of the IEEE Int. Sym on Industrial Electronics. Xian 1992; 2; 715-719.
[11] Bhutange P, Hadke N, Kathane A, Marothiya A, Khergade A. Design, Simulation and Implementation of Generation of High DC Voltage by Using Cockcroft Walton Multiplier. *Int. J. Res. Sci. Eng.* 2017; 6(1): 154–159.
[12] Jang SR, Ryoo HJ, Ahn SH, Kim J, Rim GH. Development and Optimization of High-Voltage Power Supply System for Industrial Magnetron. *IEEE Trans. Ind. Electron.* 2012; 59(3): 1453-1461.
[13] Lamantia A, Maranesi PG, Radrizzani L. Small-Signal Model ff The Cockcroft-Walton Voltage Multiplier. *IEEE Transactions on Power Electronics.* 1994: 9(1); 18-25.
[14] Lamantia A, Maranesi P, Radrizzani L. *The Dynamics of the Cockcroft-Walton Voltage Multiplier.* 21st Annual IEEE Conference on Power Electronics Specialists. San Antonio, 1990: 485-490.
[15] Nikhil M. Waghamare, Rahul P, Argelwar. High Voltage Generation by using CW Multiplier. *Int. J. Sci. Eng. Technol. Res. IJSETR*. 2015; 4(2) 256–259.
[16] Bellar MD, Watanabe EH, Mesquita AC. *Analysis of the Dynamic and Steady-State Performance of Cockcroft-Walton Cascade Rectifiers*, 21st Annual IEEE Conference on Power Electronics Specialists, San Antonio. 1990: 477-484.
[17] Anand SV, Maheshwari M. Analaysis and Design of Closed Loop Cascade Voltage Multiplier Applied to Transformer Less High Step Up DC-DC Converter with PID Controller. *Int. J. Emerg. Technol. Comput. Sci. Electron.* 2014; 11: 101–106.
[18] Kirtiwar A. Ultracapacitor Charging Methods. *Int. Res. J. Eng. Technol*. 2016; 3(2): 1637–1640.
[19] Kiousis KN, Moronis AX, Früh WG. *Analysis of the Electric Field Distribution in A Wire-Cylinder Electrode Configuration.* Proc. 2013 Int. Conf. Appl. Math. Comput. Methods Eng. 2013: 164–170.
[20] Ryk J. Accelerator Division Capacitor Stored Energy Devices. National Electric Code. 1979.
[21] Kuffel E, Zaengl WS, Kuffel J. High Voltage Engineering Fundamental. Great Britain: Butterworth-Heinemann. 2000.
[22] Young C, Chen H, Chen M. A Cockcroft–Walton Voltage Multiplier Fed by a Three-Phase to Single Phase Matrix Converter with PFC. *IEEE Transactions on Industry Applications*. 2014. 50(3): 1994-2004.
[23] Du Y, Wang J, Wang G, Huang AQ. Modeling of the High Frequency Rectifier with 10-KV SiC JBS Diode in High-Voltage Series Resonant Type DC-DC Converters. *IEEE Trans. Power Electron*. 2014; 29(8): 4288-4300.
[24] Mao S, Popović J, Ferreira JA. Diode Reverse Recovery Process and Reduction of a Half-Wave Series Cockcroft–Walton Voltage Multiplier for High-Frequency High-Voltage Generator Applications. *IEEE Transactions on Power Electronics*. 2019; 34(2): 1492-1499.
[25] Zhu Q, Su M, Ning S, Ma A, Zhao Z, Wang C. *A Novel Receiver Topology Based On Cockcroft-Walton Voltage Multiplier for Inductive Power Transfer System*. 2017 IEEE 3rd International Future Energy Electronics Conference and ECCE Asia. Kaohsiung. 2017: 450-455.
[26] Cunha J, Pinto S, Silva JF. Cockcroft-Walton based HVDC System. 2017 IEEE 18th Workshop on Control and Modeling for Power Electronics. Stanford. 2017: 1-6.
[27] Razzak MA, Chakraborty S, Tasneem Z. *Design of a Multistage 0.1/12 kV DC-DC Matrix Converter using Cockcroft-Walton Voltage Multiplier Topology*. IEEE international WIE conference on electrical and computer engineering. 2015: 309-312.