

ZVS Circuit based – Cockcroft Walton High Voltage DC Generator

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Abstract - The primary use of high voltage D.C. power supplies is at the industrial level and in research activities, particularly in the field of applied physics. When tested with an A.C. high voltage power frequency of sinusoidal waveform rather than d.c. voltage, Kuffel et al. discovered that the power supply draws a significant amount of current due to the comparatively large capacitive load in the proven design of high voltage cables (2000). High voltages are produced at power frequency A.C./D.C. switching surge voltages and lightning impulse voltages for dielectric testing of high voltage equipment. Voltages are raised to several million volts for dielectric testing of high voltage equipment, but currents are lowered to a few milliamps and a maximum of one ampere for A.C./D.C. high voltage tests. D.C. high voltage is used in a variety of electrical engineering and applied physics applications, including electron microscopes, X-ray machines, electrostatic precipitators, nuclear physics particle accelerators, dielectric testing, and more. The dielectric behaviors under all conditions that the equipment/apparatus are expected to experience are studied using high voltage equipment. To determine the safety aspects of the working conditions and to make sure that the working margin is neither too high nor too low, tests are carried out at voltages higher than the typical working voltage.

Key Words: High voltage, Cockcroft Walton voltage multiplier, High frequency, Ripple, High voltage, Flyback Transformer

1.INTRODUCTION

Today, there are many devices and instruments requiring high voltages. Typically, a High voltage DC output is often required in various facets of research areas in the field of applied physics and for testing purposes in industries. High voltage is used for dielectric and insulation testing of electrical equipment at power frequency. There are many applications of High voltage DC power in electrical engineering such as electron microscope, x-ray, electrostatic precipitators, particle accelerators, etc. Dielectric behavior of electrical equipment can be tested by giving high voltage DC supply as an input to them, where the surviving capacity of equipment can be tested at all conditions. The voltage given to the equipment should be greater than the normal DC voltage to find out the equipment's sustaining capability of voltage and decide the voltage margin for the particular equipment.

The system A circuit that creates DC power at a high voltage is known as a voltage multiplier or Cockcroft Walton generator. Heinrich Greinacher, in 1919, made a considerably earlier discovery of this circuit. The British and Irish physicists Jhon Douglas Walton and Earnest Thomsan Walton, who originally utilised this circuit to power their particle accelerator in 1932, are honoured by the circuit's name. With a greater number of stages, CW multipliers are also utilised in laser systems, high-voltage power supplies, X-ray systems, LCD backlighting, traveling-wave tube amplifiers, ion pumps, electrostatic systems, air ionisers, particle accelerators, copy machines, scientific instrumentation, oscilloscopes, television sets, cathode-ray tubes, electroshock weapons, bug zappers, and numerous other high-voltage DC applications. The CW has a number of shortcomings in actual use. The electrical resistance of the capacitors in the lower stages is the main cause of the voltages of the upper stages starting to "sag" as the number of stages is raised. Additionally, as the number of steps is increased while supplying an output current, the voltage ripple quickly grows. The output voltage's ripple content, voltage drop, and voltage regulation are the three main performance indicators of the Cockcroft Walton generator. Both the source voltage, or generator input voltage, and the frequency of the AC supply given to the generator's input determine these performance factors.

In this project, we've tried to increase these performance criteria by adding two components that feed the primary Cockcroft-Walton generating circuit with a high voltage, high frequency AC supply. The flyback transformer and the zero-voltage switching (ZVS) driver are these two parts. The ZVS driver is an electronic circuit that produces high frequency, high voltage ac output and is supplied by a low voltage DC power supply. Additionally, the output's high frequency can be customised by using a variable capacitor at the ZVS driver's output. The flyback transformer raises low voltage, high frequency ac input to high frequency, high voltage. It is a specific kind of transformer capable of handling high frequency ac.

Additionally, in addition to enhancing performance, the suggested approach focuses on creating an economical. The pricey high voltage capacitors and diodes employed in the CW generator's ladder network account for the majority of the generator's cost. The price of the generator rises as the number of steps grows. However, by using fewer stages to provide high voltage output at the output side, this cost can be decreased. This is made possible by the addition of a flyback transformer, which supplies high voltage to the CW

generator's input, allowing for the generation of high voltage DC with fewer steps.

The proposed model is therefore cost-effective. Since the ZVS is supplied by a low voltage DC supply, this variant can be run on a small battery. This makes the model easy to use, lightweight, and portable. Because of this, the model is very practical and helpful in field experiments.

Advantages and Applications

Advantages of ZVS Circuit Based Cockcroft Walton Generator

Some of the key blessings of ZVS driver-based Cockcroft-Walton Generator are as follows-

- **Performance:** The Performance parameter of generator dependent of input power frequency i.e. ripple voltage and voltage regulation ar improved by victimization high frequency AC.
- **Economical:** The implementation of flyback electrical device among the model makes it attainable to feed high voltage AC input to the generator circuit that helps in getting high voltage DC output in less range of stages, reducing the elements (Capacitor & Diode) resulting in reduction of value.
- **Flexibility:** The high frequency output of the ZVS driver depends upon the value of output aspect electrical device condenser reverberant circuit, by variable that, we are going to simply vary the worth of the high frequency ac output of ZVS, therefore the performance parameters ar usually varied as desired.
- **Handiness:** The ZVS circuit of the planned model used low voltage DC power supply of 12V which can be simply supercharged employing a battery, creating the model handy and simple to hold.

Applications

- The planned model ar usually used for testing of insulating cables, the quality and compactness of the model makes it terribly simple to need it from one place to a different, which can be terribly advantageous in insulation cable testing.
- It are usually used as charging unit for Impulse generators, Particle accelerators.
- Medical applications (X-Ray).

- High voltage military application (very low frequency radio communication).

2. Review of Components

2.1 ZVS DRIVER:

The ZVS (zero voltage switching) Driver circuit shown in Fig-1 is a Royer-type push-pull generator with a resonated primary that's enforced with FETs. It's normally Used for top Voltage generation or In Induction Heaters to drive High current air core.

In Our circuit the Role of Our ZVS Driver is to need Input as Low Voltage DC and provides Output as Low Voltage AC at Higher Frequency (in KHz).

The Output of this ZVS Driver is then fed to the Flyback electrical device that Converts this Low Voltage High Frequency AC to High Voltage High Frequency AC.

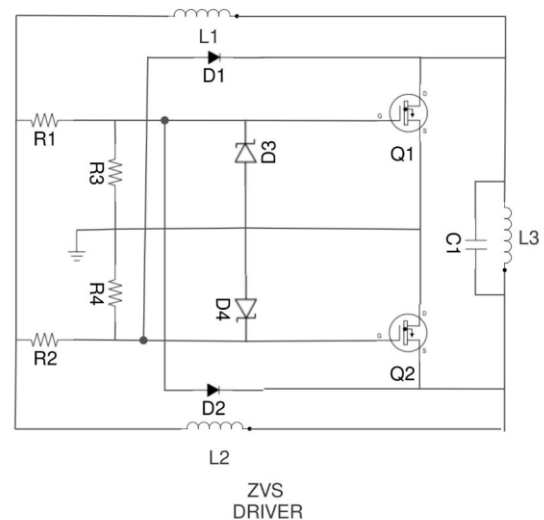


Fig -1: ZVS DRIVER CIRCUIT

2.2 FLYBACK TRANSFORMER

A unique reasonably Electrical device may be a flyback transformer (FBT), conjointly noted as a line output Transformer (LOPT), as shown in Fig-2. It had been ab initio meant to provide comparatively high frequency, high voltage serration signals. It's wide utilized in switched-mode power offer for each low voltage (below 3 KV) and high voltage (over 10 KV) provides in modern application.

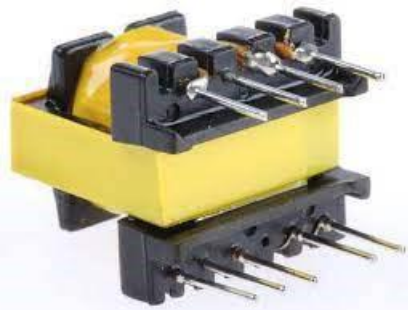


Fig -2: FLYBACK TRANSFORMER

The primary winding of the flyback electrical device is driven by a switch from a DC offer (usually a transistor). Once the switch is switched on, the primary inductance causes the present to make up in an exceedingly ramp. AN integral diode connected serial with the secondary prevents the formation of secondary current that may eventually oppose the primary current ramp.

When the switch is turned off, the current within the primary falls to zero. The energy keep within the core is free to the secondary because the field within the core collapses. The voltage among the output winding rises terribly quickly (usually but a microsecond) till it's restricted by the load conditions. Once the voltage reaches such level on enable secondary current, the charge flow is among the shape of a downhill ramp.

The cycle will then be continual. If the secondary current is allowed to discharge fully to zero (no energy keep among the core), then it's aforementioned that the electrical device works in discontinuous mode (DCM). Once some energy is sometimes keep within the core (and the present waveforms look quadrangle instead of triangular), then (this is usually) often continuous mode (CCM). This nomenclature is utilized particularly in power offer transformers.

The primary is wound first around a primary solid solution rod, then the secondary is wound round the primary. This arrangement minimizes the run inductance of the primary. Finally, a primary solid solution frame is wrapped around the primary/secondary assembly, closing the magnetic flux lines. Between the rod and thus the frame is AN air gap, that will increase the reluctance. The secondary is wound layer by layer with enamelled wire, and Mylar film between the layers. Throughout this manner components of the wire with higher voltage between them have additional nonconductor material between them.

The operation of CRT-display equipment, such as television sets and CRT computer displays, uses a flyback transformer. Depending on the gadget, voltage and frequency can both vary widely. With a horizontal scan rate of 15.734 kHz for NTSC devices and 15.625 kHz for PAL devices, for instance, a large colour TV CRT may need 20 to 50 kV. A flyback transformer normally operates with

switched currents at much higher frequencies in the range of 15 kHz to 50 kHz, in contrast to a power (or "mains") transformer, which utilises an alternating current of 50 or 60 hertz.

2.3 COCKCROFT WALTON GENERATOR

By converting AC or pulsing DC electrical power, the CW generator is a voltage multiplier that increases the level of DC voltage from low to high. It comprises of a capacitor and diode voltage multiplier ladder network to generate high voltages. This method, in contrast to transformers, does not necessitate a substantial core, insulation, or potting. These voltage multipliers can step up very low voltages to extremely high values using only capacitors and diodes, and they are significantly lighter and less expensive than transformers. The fundamental advantage of such circuits is that the voltage across each stage of the cascade is only double the peak input voltage of a half-wave rectifier. This voltage is three times the input voltage in a full-wave rectifier. It benefits from needing comparatively inexpensive components and being simple to insulate. Additionally, like with a multitapped transformer, the output from any stage can be tapped.

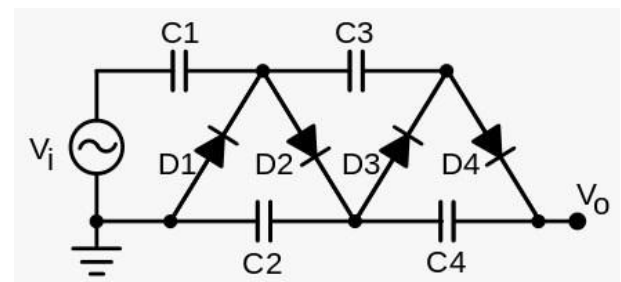


Fig -3: CLASSIC COCKCROFT WALTON VOLTAGE MULTIPLIER CIRCUIT

3. DESIGN OF COCKCROFT WALTON VOLTAGE MULTIPLIER

3.1 DESIGN CRITERIA

1. Capacitor selection: -

The frequency of the input signal is directly proportional to the size of the capacitors employed in the multiplier circuit. The type of multiplier circuit determines the capacitor's voltage rating. The maximum voltage that the capacitor can withstand depends on how many stages are being employed. As a general guideline, choose a capacitor whose voltage rating is roughly twice as high as the actual peak applied voltage.

$$\% \text{ Reg} = (\Delta V / 2nV_{\text{max}}) * 100$$

For 5% Reg. at $V_{\text{max}} = (\sqrt{3}) * 2.2 \text{ kV}, n=3$

$$\Delta V = (5 * 2 * 3 * (\sqrt{3}) * 2.2) / 100$$

$$\Delta V = 1.14 \text{ KV}$$

$$\Delta V = (1/fC) * \{(2/3)m^3 + (n^2/2) - (n/6)\}$$

Therefore,

$$C = (1/f \Delta V) * \{(2/3)m^3 + (n^2/2) - (n/6)\}$$

$$\text{At } \Delta V = 1.14 \text{ KV, } f = 10 \text{ KHz, } n = 3$$

$$C = [1/(10*10^3*1.14*10^3)] * \{(2/3)*3^3 + (3^2/2) - (3/6)\}$$

$$C = 1.9 \text{ uF}$$

$$C \approx 2 \text{ uF}$$

3.2 DIODE SELECTION: -

3.2.1 Repetitive peak reverse voltage: -

The repeated peak inverse voltage is the maximum instantaneous value of the reverse voltage across the diode. As a result of the device's ability to conduct enough leakage current, applied reverse voltage above this maximum value can cause circuit malfunction and even irreparable component damage. Conversely, applied reverse voltage below this maximum value will only cause minimal leakage current to flow through the device. In a multiplier circuit, each diode detects a reverse voltage of $2E_m$. As a result, the device needs to have a reverse voltage (VRRM) value of at least $2E_m$.

3.2.2 Frequency of input signal: -

When selecting the rectifier diode, the frequency of the input signal to the multiplier circuit must be taken into account. The gadget of choice must be able to flip faster than symmetric input signals' rise and fall timings. If the reverse recovery time is too long, the device's effectiveness and control will suffer. In the worst situation, prolonged device heating will result from slow recovery times. And in this case, the equipment will suffer permanent damage. The reverse recovery time is significantly influenced by the circuit and the measuring condition. Backward recovery Time specifications should only be utilised for qualitative, not quantitative, purposes because the conditions given for the measurement rarely match those seen in actual real-life circuit functioning.

When utilising a multiplier circuit, a higher input frequency is achievable due to the lower current flow. A spike in current flow has been the opposite outcome. The network load on the multiplier must be totally current-free.

3.3.3 Peak forward surge current (Ifsm): -

A peak forward surge current rating is given for most rectifier diodes. When the device's rated load current is added, this rating is the highest peak value of a single half

sine wave that can be produced without damaging the rectifier. This rating takes relevance when the considerable capacitance associated to multiplier networks is taken into account.

An n-stage voltage multiplier circuit Surge currents may appear in rectifier circuits as a result of the effects of capacitive loading. Due to the significant step-up turn ratio between the primary and secondary in most high voltage transformers, the first multiplier capacitor C1 (on the secondary side) is reflected as a much bigger capacitance into the primary. The following is a general formula to calculate this:

$$C'1 = NC1,$$

Where, C1 = first multiplier circuit capacitance

C'1 = Referred capacitance on primary side

K = turns ratio of HV transformer $N2/N1$

As the circuit turns on, a significant amount of current will be produced in the primary side, charging the effective capacitance. A significant surge current may flow through the secondary side rectifiers during the initial capacitor charging during turn-on. The installation of a series resistance R_s can greatly reduce both these current surges and those in the core circuitry.

$$R_s = V_{\text{peak}} / I_{\text{fsm}}$$

If, maximum secondary voltage, $V_{\text{rms}} = 240$ volts, then $V_{\text{peak}} = 1.414 \times 240 \text{ V}$.

$$R_s = 1.414 \times 240 / 16 = 21.21 \text{ Ohm}$$

I_{fsm} = Forward surge current rating of diode = 16 Amp.

3.3.4 Forward current (IO): -

As was said before, in an ideal multiplier circuit, the load won't draw any current. Ideal high current flow across the rectifier while the capacitor is charging. Use HT/MV cables with equipment that can only withstand 100 mA of current. Utilizing microamperes is a possibility. It is important to understand the connection between forward current and forward surge current rating.

Given that both are dependent on the silicon chip region. High forward current IO rated devices will also have high surge current IO rated devices, and vice versa.

3.3.5 Forward voltage (Vf): -

The overall performance of multiplier networks is essentially unaffected in practice by the forward voltage loss V_f of the rectifier. As an example, let's say that when measured at 100 mA of current, the rectifier diodes had a forward drop of 2.0 volts. A half wave doubler multiplier with an 8 kV output will lose 0.05% ($2/8 \text{ kV}$) of its

efficiency because of forward voltage drop. The calculation above is founded on a rule of thumb that

Voltage drop is equal to the number of stages * Vf / the output voltage in kV.

4. SIMULATION MODEL & RESULT

4.1 INTRODUCTION TO NI MULTISIM SOFTWARE

MULTISIM 14.2

The NI Multisim 14.2 (formerly MultiSIM) electronic schematic capture and simulation software is part of a set of circuit design tools, coupled with the NI Ultiboard. Multisim is one of the few circuit design software programmes that continues to use the original Berkeley SPICE-based software simulation. Multisim was initially created by Electronics Workbench Group, a company that is now a division of National Instruments. In addition to microcontroller simulation, Multisim provides integrated import and export features for the suite's printed circuit board layout software, NI Ultiboard (formerly known as MultiMCU).

4.1.1 SIMULATION MODEL:-

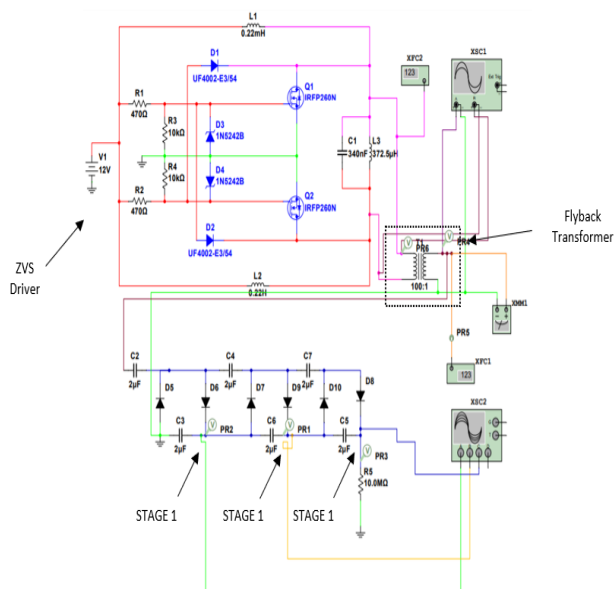


Fig-4: Simulation Model of ZVS circuit-based Cockcroft Walton Voltage Multiplier

The Fig 4 illustrates the simulation model of ZVS circuit-based Cockcroft Walton Voltage Multiplier. The given model consists of ZVS circuit powered by 12V DC power source, feeding out high frequency AC to the primary of the flyback transformer, the secondary of which gives output of high voltage AC which is then fed to the Cockcroft Walton multiplier Circuit.

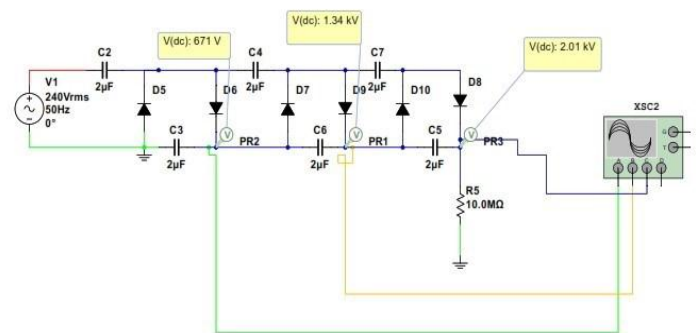


Fig -5: Simulation Model of Classic Cockcroft Walton Voltage Multiplier

The figure 5 is the simulation model of the Cockcroft Walton multiplier circuit. It consists of a multiplier circuit of a ladder circuit which is powered by 230V at 50Hz

4.2 RESULTS:-

The results in this project were based on comparison between the ZVS-based CWG and the classic CWG. The parameters for consideration were the transient response and the ripple content of the systems at each stage.

4.2.1 TRANSIENT RESPONSE :-

The Transient Response for the 3 stages in the ZVS circuit based Cockcroft Walton voltage multiplier and a classic Cockcroft Walton voltage multiplier are given below

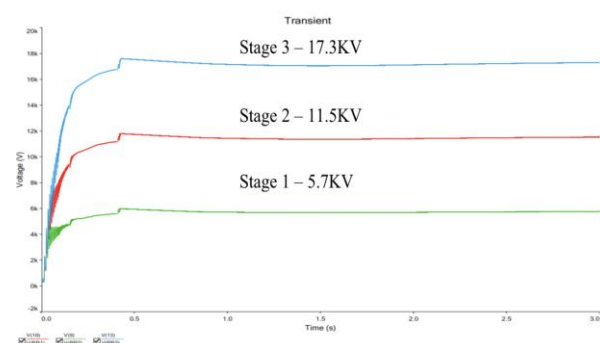


Fig-6: Transient Response of ZVS circuit-based Cockcroft Walton Voltage Multiplier.

The Fig-6 shows the Transient response for the model shown in Fig-4. The Green line shows the transient response for the 1st stage. The Red line shows the transient response for the 2nd stage and the blue line shows the transient response for the 3rd stage

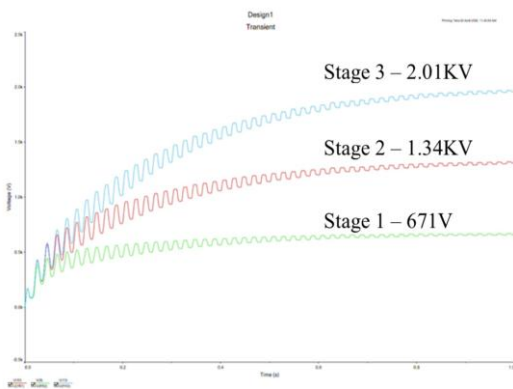


Fig-7:-Transient Response Classic Cockcroft Walton Voltage Multiplier

The Fig-7 shows the Transient response for the model shown in Fig-5. The green Line shows the transient response for the 1st stage. The Red line shows the transient response for the 2nd stage and the blue line shows the transient response for the 3rd stage.

4.2.2 RIPPLE VOLTAGE: -

The Ripple voltages and voltage drop for all the 3 stages in both the circuits have been recorded and compared as under for ZVS circuit based Cockcroft Walton voltage multiplier and a classic Cockcroft Walton voltage multiplier for different frequencies of 5KHz and 10KHz

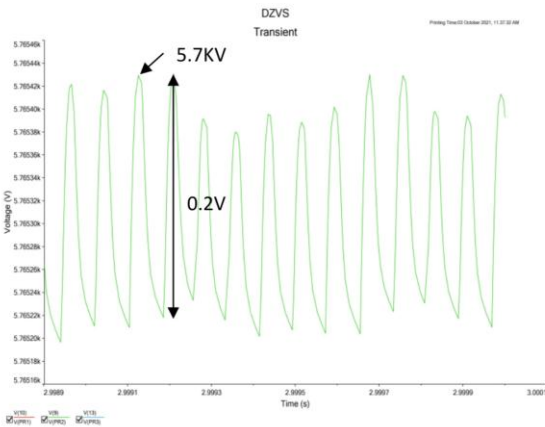


Fig-7 Ripple voltage ZVS circuit-based Cockcroft Walton Voltage Multiplier – Stage 1

The Fig-7 shows the Ripple voltage for the 1st stage which is found out to be 0.2V for a Peak voltage of 5.7 KV

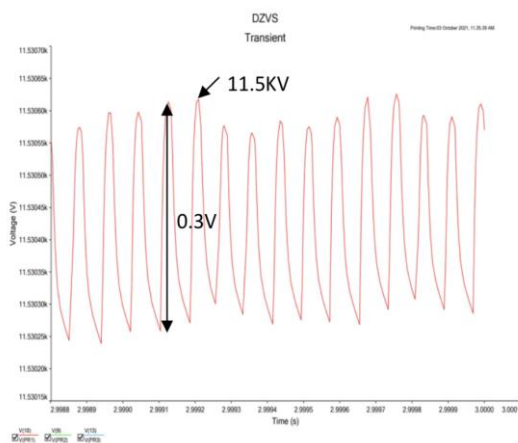


Fig-8 Ripple voltage ZVS circuit-based Cockcroft Walton Voltage Multiplier – Stage 2

The Fig-8 shows the Ripple voltage for the 2nd stage which is found out to be 0.3V for a Peak voltage of 11.5 KV.

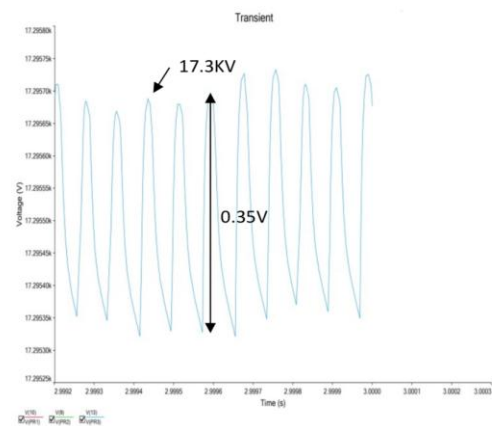


Fig-9 Ripple voltage ZVS circuit-based Cockcroft Walton Voltage Multiplier – Stage 3

The Fig-9 shows the Ripple voltage for the 3rd stage which is found out to be 0.35V for a Peak voltage of 17.3 KV.

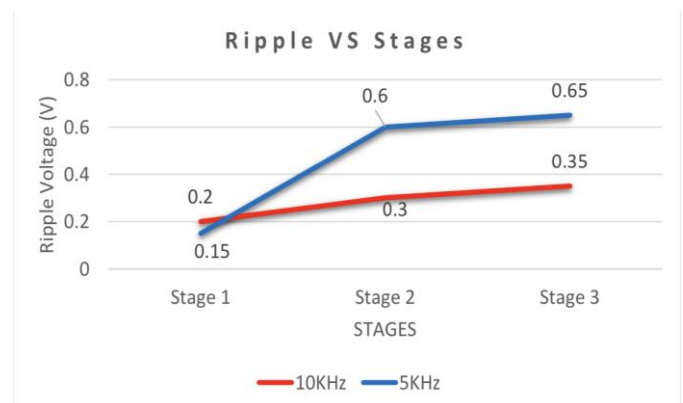


Fig-10 Ripple Voltage v/s Stage

The Fig-10 shows the Ripple voltage vs stages for the 3 stages for frequencies of 5KHz and 10Khz.

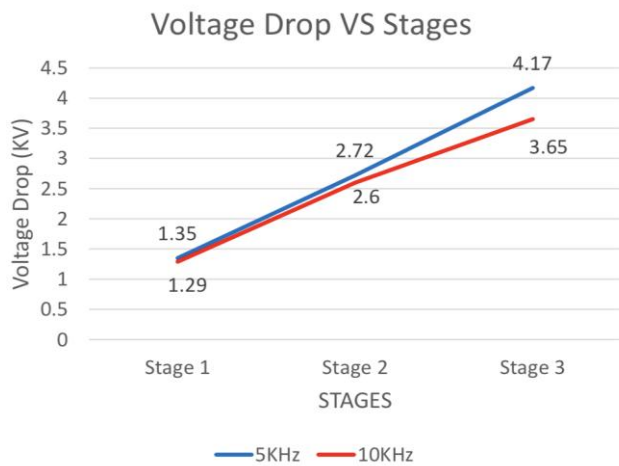


Fig-11 Voltage Drop v/s Stage

The Fig-11 shows the Voltage Drop vs stages for the 3 stages for frequencies of 5KHz and 10Khz.

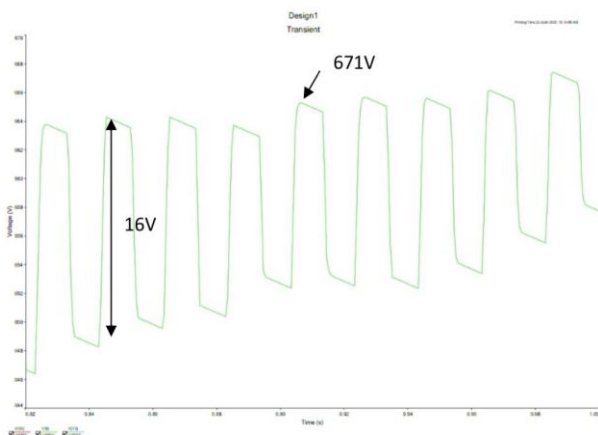


Fig-12 Ripple voltage Classic Cockcroft Walton Voltage Multiplier – Stage 1

The Fig-12 shows the Ripple voltage for the 1st stage which is found out to be 16V for a Peak voltage of 671 V.

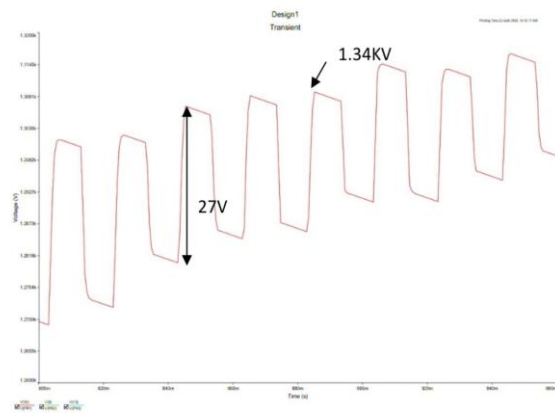


Fig-13 Ripple voltage Classic Cockcroft Walton Voltage Multiplier – Stage 2

The Fig-13 shows the Ripple voltage for the 2nd stage which is found out to be 27V for a Peak voltage of 1.34 KV

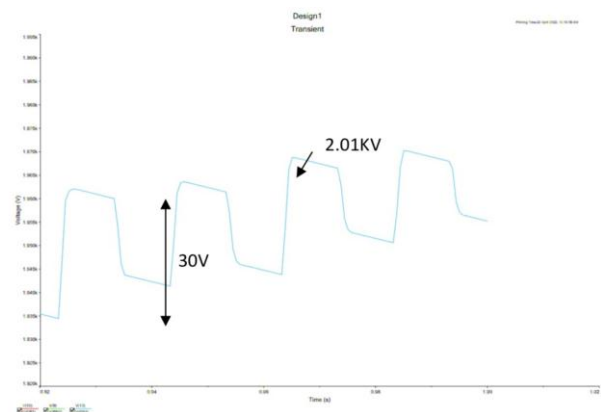


Fig-14 Ripple voltage Classic Cockcroft Walton Voltage Multiplier – Stage 3

The Fig-14 shows the Ripple voltage for the 3rd stage which is found out to be 30V for a Peak voltage of 5.7 KV

4.3 ANALYSIS OF RESULT

From the Fig-6 & Fig-7 it is observed that as compared to the classic model of Cockcroft Walton Generator the modified version of Cockcroft Walton generator driven by ZVS circuit has shown better performance in terms of ripple voltage and output voltages.

The ripple voltages of classic model are comparatively higher as compared to the modified version. For Stage 1, the ripple voltage for classic model is found out to be 16V, where as in modified version it is found out to be 0.2V. Similarly, for the 2nd and 3rd stage the value of ripple voltages for classic model and our modified model 27V and 0.3V, 30V and 0.35V respectively.

Fig-10 Ripple Voltage v/s Stage, is the graphical analysis of the ripple voltage of the output the stage at various frequencies corresponding to the stage number. It can be observed that at higher frequency the ripple is lower as compared to the lower frequency operation. For the 10KHz frequency of operation, the ripple voltage observed for the stage 1, stage 2, stage 3 are 0.2V, 0.3V and 0.35V respectively. Similarly, the ripple voltage for 5KHz frequency of operation for stage 1,2 and 3 are found out to be 0.15V, 0.6V and 0.65V.

Fig-11 Voltage Drop v/s Stage, shows the graphical analysis of the voltage drop of the stages of multiplier corresponding to the stage number for different frequency of operation. The analysis shows that at higher frequency, the voltage drop is found out to be less as compared to lower frequency. The 10KHz frequency of operation shows the voltage drop for the stage 1, stage 2 and stage 3 as 1.29KV, 2.6KV and 3.65KV. Similarly for the 5KHz frequency of operation, the corresponding value of voltage drop for stage 1,2 and 3 are 1.35KV, 2.72KV and 4.17KV

CONCLUSIONS

Years after its creation, the Cockcroft-Walton voltage multiplier is still in use and unrivalled in a wide range of high voltage and ac to dc conversion applications. The design is a combination of three separate systems, a ZVS circuit that supplies high frequency AC power at resonance, a step-up transformer to increase voltage and voltage multiplier (CW generator) to convert medium voltage AC to high voltage DC. The proposed model is expected to improve the performance of the CW generator in comparison to the classical model of CW generator. The simulations of the proposed models are carried out using Multisim software. Through this simulation, the circuit is tested. The results of the simulation are thoroughly analysed and the performance parameters are measured. The simulation results are found out to show a considerable level of improvement in the performance of the generator circuit. This kind of high voltage DC power supply test set is of simple to control, low cost, portable due to its light weight, robust and high reliability. Without changing the input voltage, different stages can produce outputs of varying high voltage DC. This developed equipment will be very useful for field testing of HV cables of different voltage grade, as a prime DC source for VLF and charging unit of impulse generators.

The hardware designing and implementation of the prototype based on the proposed model is to be done. It is expected to be show high performance and to be cost effective. The actual prototype is to be tested and the results are to be compared with those found in the simulation. Since, size of the complete high voltage circuit is small and the developed system is cost effective, therefore it is User friendly as well as construction wise this circuit is easy to implement and is also reliable.

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