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Design of a Cascaded DC High Voltage Generator Based on Cockcroft-Walton Voltage Doubler Circuit

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Abstract— This paper presents a high step-up dc-dc converter based on the Cockcroft-Walton (CW) voltage multiplier without using step-up transformer. The proposed converter is quite suitable for applying low-input dc voltage, to high output dc voltage generation systems. It provides continuous input current to load with low ripple voltage and current. Voltage stress on the all switching device, diodes, and capacitors can be minimised. Moreover, based on the 2-stage Cockcroft-Walton (CW) voltage multiplier, the proposed converter can provide a suitable dc source like solar cells, fuel cell and other type source cascaded for HV generation. In this paper, the control strategy employs two independent frequencies, one operates at high frequency to minimize the size of the inductor and other one operates at relatively low frequency to the desired output voltage ripple. The simulations carried over by the MATLAB-Simulink and Proteus Simulator.

Keywords— Cascaded Circuit , Cockcroft-Walton (CW) Voltage Multiplier, Frequency Multiplier, Ripple Loss.

I. INTRODUCTION

Nowadays due to the wide use of electrical devices there is huge growing demand for electrical energy in both AC and DC form. The conventional sources of AC or DC voltage generator supplied voltage up to a certain limit. The extensive use of electrical equipment has imposed severe demands for electrical energy and this trend is constantly growing for both AC and DC circuit. In modern times, high voltages are used for a wide variety of applications covering the power sector, industry and research laboratories. In context of that, High voltage DC has become an utmost necessity in most of the application sites nowadays. The conventional converter converts AC voltage to DC up to a permissible range. To obtain voltage beyond that range using conventional step up transformer not only increase the complexity due to higher voltages and costing of the system but also reduce the voltage gain of the circuit[1][2]. Moreover these converters operate in discontinuous conduction mode that leads to high switching losses and higher electromagnetic interference [2-4]. The proposed paper represents an idea of a transformer less cascaded circuit for high voltage DC generation using Cockcroft Walton voltage multiplier circuit. This proposed DC-DC converter obtained high voltage with a voltage multiplier cascaded network combining of capacitors and diodes that convert AC or pulsing DC electrical power from a low voltage level to a higher DC voltage level. The proposed cascade circuit delivers a voltage across each level is equal to twice the peak input voltage [5-6]. Voltage multipliers can be used to generate a few volts for electronic appliances, to millions of volts for purposes such as high-energy physics experiments and lightning safety testing.

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II. PRINCIPLE OF HIGH VOLTAGE GENERATION

A voltage multiplier is an electrical circuit that converts AC electrical power from a lower voltage to a higher DC voltage. Each stage is comprised of one diode and one capacitor cascading with each other. The different forms of voltage multiplier circuits are used.

A. Voltage Doubler Circuit

A voltage doubler is an electronic circuit which charges capacitors from the input voltage and shifted these charges in the secondary in such a way that, in the ideal case, exactly twice the voltage is produced at the output[5-6]. The circuit consists of only two diodes, two capacitors and an oscillating AC input voltage. This diode-capacitor circuit gives a DC output voltage equal to the peak value of the sinusoidal input. The circuit diagram for a common voltage doubler circuit is shown in Fig 1.

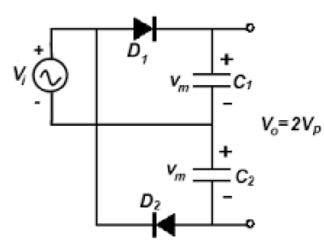

Fig 1. Diagram of a Voltage Doubler Circuit

B. *Villard Circuit*

The Villard circuit consists simply of a capacitor and a diode. (Fig 2)The capacitor is charged on the negative half cycles to the peak AC voltage (V_{pk}). The output is the superposition of the input AC waveform and the steady DC of the capacitor. The effect of the circuit is to shift the DC value of the waveform. The negative peaks of the AC waveform are "clamped" to 0 V by the diode; therefore the positive peaks of the output waveform are $2V_{pk}$.

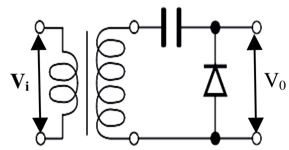

Fig 2. Diagram of a Simple Villiard Circuit

C. *Half Wave Series Multiplier*

The most common type of voltage multiplier is the half-wave series multiplier, which is also called the Villard cascade multiplier. The basic circuit diagram of half-wave multiplier with load is given below (Fig 3)

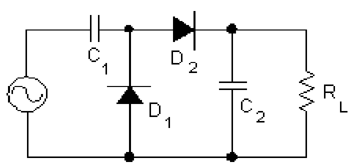

Fig 3. Diagram of Half-wave series multiplier

D. *Cockcroft-Walton Voltage Multiplier*

The Cockcroft-Walton is a voltage multiplier that converts AC or pulsing DC electrical power to a higher DC voltage level. It is basically a ladder network consists of capacitors and diodes to generate high voltages from very low level ac input [7-9]. The input voltage may need to be increased to provide the required output voltage as per requirement. The circuit diagram of a Cockcroft-Walton Voltage Multiplier circuit is shown in Fig 4.

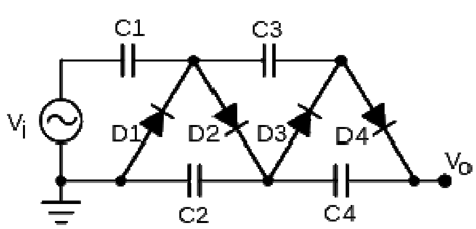

Fig 4. Diagram of a 2 stage Cockcroft-Walton voltage multiplier

By supplying AC input voltage (V_i) having peak value of V_p , current will starts flowing through the circuit. With each change in input polarity, current flows up the "stack" of capacitors through the diodes. Since the capacitors C_2 and C_4 are in series between the output and ground, the total output voltage under no-load conditions is $V_o = 4V_p$ (for 2 stage).

III. Design Consideration

A. *Design Specification*

The operation of this proposes model for high voltage generation is quite simple. We can generate the high voltage DC up to 1kv by using single phase AC supply. The basic criteria for the operation is as follows,

Supply Voltage	: 220V
Input Voltage	: 14.14V
Frequency	: 50Hz
Capacitance	: 2.2µF
Output Voltage	: 51.1V

The functional block diagram representation of the proposed circuit is shown in the Fig 5.

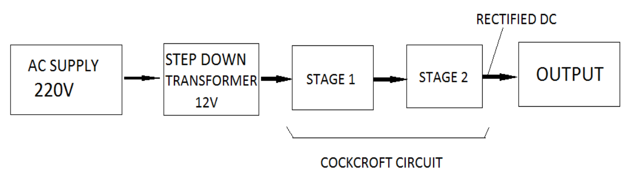

Fig 5. Block Diagram of a Voltage Multiplier circuit

The input voltage is generally the peak or peak-to-peak voltage. The output voltage is equal to the number of stages of the peak input voltage. In most cases, the output voltage will be less than the actual voltage due to the effects of regulation and stray capacitance.

B. *Circuit Diagram*

The equivalent circuit of 2-stage Cockcroft-Walton voltage multiplier is shown in the Fig 6.

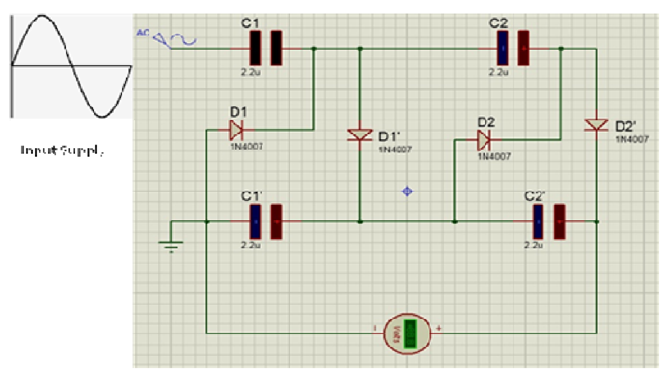

Fig 6. Circuit Diagram representation of 2 stage Cockcroft-Walton Multiplier

C. Operating Principle

The proposed circuit of 2-stage Cockcroft-Walton voltage multiplier is shown Fig 6. Each stage of the Cockcroft-Walton circuit consists of 2 Diodes and 2 Capacitors; hence the proposed multiplier consists of total 4 Diodes and 4 Capacitor. The operation of the proposed two stages Cockcroft-Walton multiplier model in each positive and negative mode is discussed hereunder,

Mode I: When supply is in negative half-cycle, then Capacitor C_1 charges through Diode D_1 to V_{max}. The current flow diagram for this phase is shown in Fig 7(a).

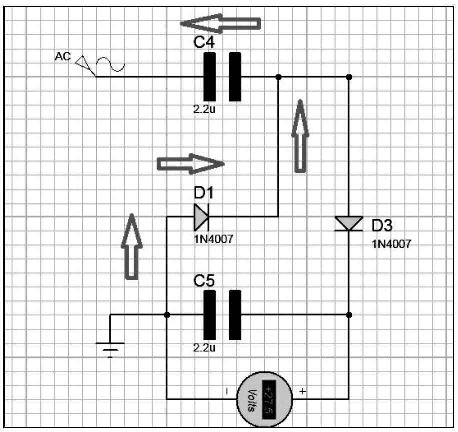

Fig 7a. Circuit Diagram representation of 2 stage Cockcroft-Walton multiplier

Mode II: When supply is in positive half-cycle, then V_{max} add arithmetically to existing potential C_1, thus C_2 charges to $2V_{max}$ through D_2. The current flow diagram for this phase is shown in Fig 7(b).

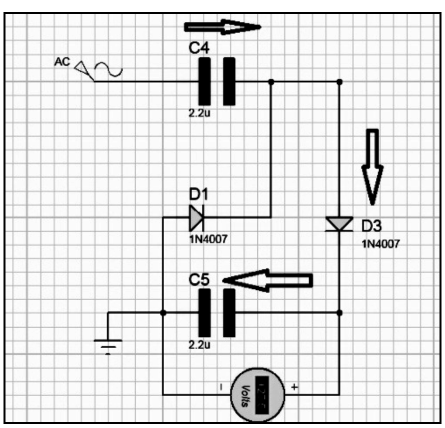

Fig 7b. Circuit Diagram representation of 2 stage Cockcroft-Walton multiplier

D. Mathematical Modelling

For designing a multi stage voltage multiplier, it is essential to calculate the output voltage (V_{out}) of this cascaded circuit.

Theoretically, $V_{out} = 2n * V_m$.

Where V_m = Peak value of supply voltage
n = Number of stages in the circuit.

However, it is seen that theoretical voltage differs from the practical value by a fairly large amount. This voltage drop ΔV which is the difference between the theoretical no load voltage and the on-load voltage across the Capacitor can be expressed as

$$\Delta V = \left(\frac{I}{fC}\right)\left(\frac{2n^3}{3} + \frac{n^2}{2} - \frac{n}{6}\right)$$

Where, I = Load current in Amp
C = Capacitance in Farad
f = Frequency in Hz
n = No. of stages

The ripple loss (peak to peak) can be expressed as

$$\delta V = \left(\frac{I \times n \times (n+1)}{4 \times f \times C}\right)$$

δV = Ripple voltage (peak to peak) in Volt

It is quite obvious that at loaded condition, the output voltage is less due to ripple loss.

IV. MODELLING OF PROPOSED SYSTEM

It has been observed that in a cascaded voltage multiplier circuit, the ripple loss is solely depends on the operating frequency and the capacitance[10-11]. From the High Voltage operational point of view, it is therefore desirable to use high frequency rather applying low frequency under loading condition, which in turn reduce the voltage drop ΔV as well as ripple loss.

A. Block Diagram of Proposed Design

The block diagram of proposed system is shown in the Fig 8.

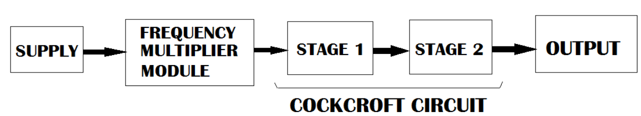

Fig 8. Block diagram of Cascaded Cockcroft-Walton Circuit

B. Circuit Diagram of Proposed Modified Design

In this proposed system, a frequency multiplier circuit is connected earlier to the voltage multiplier circuit. The modified circuit diagram having the frequency multiplier is shown in Fig 9.

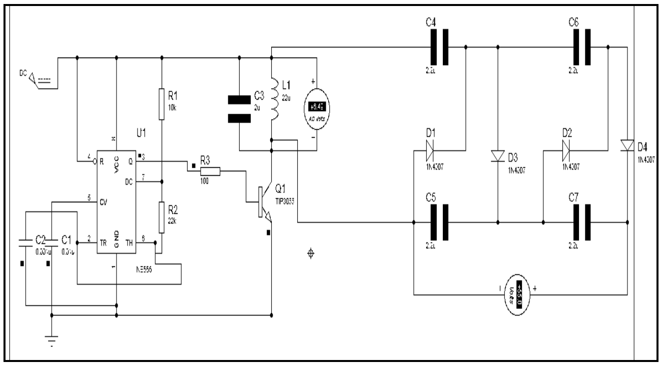

Fig 9. Circuit Diagram of Cascaded Cockcroft-Walton Voltage Multiplier.

V. RESULTS

The model of proposed cascaded voltage multiplier system has been designed by connecting the frequency multiplier using simple NE555 timer along with the cascade Cockcroft-Walton voltage multiplier circuit. This combined circuit is fed power from a normal 220V, 50Hz AC supply which gives a step down AC input of 12V to the input of the frequency multiplier circuit which in turn increase the frequency of the supply voltage upto a higher value of several KHz.

A model of the proposed system was designed, implemented and simulated by using PROTEUS SIMULATION model. The obtained output results are shown in Fig 10.

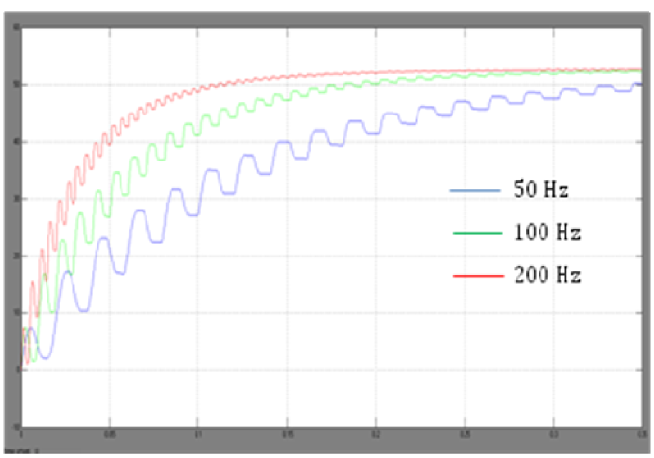

Fig 10. Output voltage waveform at different frequency

VI. CONCLUSION

In this paper we are trying to represent a unique way to obtain High Voltage DC supply using cascaded Cockcroft-Walton Voltage Multiplier circuit. The simulation and experimental results proved the validity of the circuit which is very much feasible. The output voltage ripple loss is minimized by operating the circuit at high frequency. Based upon these observations we can conclude that this voltage multiplier circuit is more economical for particular value of load resistance, capacitance and supply frequency.

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