

Simulation and Design of a low-cost Voltage Multiplier Circuit for High Voltage Power Supply

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ABSTRACT: This paper considers the option of providing an alternative and cost effective high voltage power supply for the working of dc energized electrostatic precipitator through the applicative use of voltage multiplier circuits. Simulated results obtained through use of Proteus 8 software gives us the results, which compared well with the calculated data.

KEYWORDS: Text ESP, voltage multiplier circuit, HVDC, Proteus, design, simulation.

I. INTRODUCTION

Voltage multiplier is an AC to DC converter, made up of a network of capacitors and diodes that produce a high voltage DC output from a low voltage AC input when high voltage and low current is required.

Voltage multipliers have different stages. A diode and a capacitor is used in each stage. This arrangement produces a DC output voltage whose peak value is larger than the input AC voltage as per the stages used. Depending on the output to input voltage ratio, voltage multipliers can be classified as voltage doublers, Tripler and Quadrupler. A single transformer with rectifier and filtering circuit can also be used to get high voltage DC output. But in this case as the voltage is stepped up, the level of insulation required for transformer winding increases which increases the size of the transformer and the size of the capacitor used for filtering purposes as a result the circuit arrangement becomes bulky.

To eliminate above problems voltage multipliers can be used.

II. WORKING OF COCKCROFT WALTON MULTIPLIER

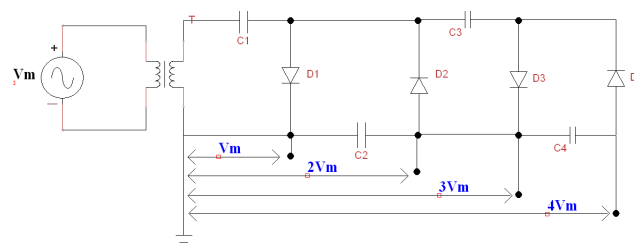


Figure 1 Voltage Quadrupler

The above figure shows the Cockcroft-Walton multiplier made up of a ladder network consisting of capacitor and diodes. Let us consider the operation in two cycles.

A. In the course of first +ve half cycle

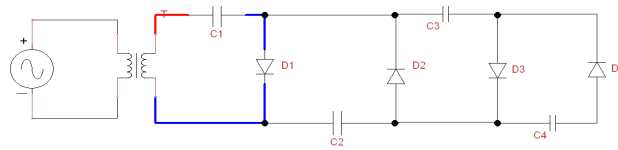


Figure 2

In this period, the diode D₂ and D₄ becomes reverse biased; the diodes D₁ and D₃ are forward biased. The diode D₁ conducts, allowing current to flow through capacitor C₁ and charges the capacitor C₁ to maximum voltage value of the supply (V_m). The polarity of charging is as shown in figure 2.

B. In the course of first -ve half cycle

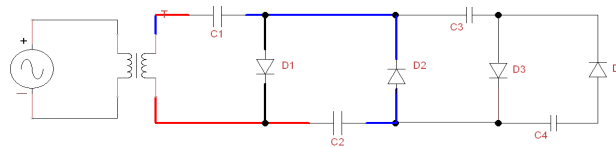


Figure 3

During the first negative half cycle, diodes D₂ and D₄ are forward biased and diodes D₁, D₃ are reverse biased. The diode D₂ conducts and allows electric current through it. The capacitor C₂ is charged to twice the magnitude of the input voltage since the charge (V_m) stored in the capacitor C₁ is connected in series with the transformer which is equal to connecting two voltage sources in series (as shown in figure 3) which causes the capacitor C₂ to charge to twice the supply voltage V_m.

I.e. the capacitor C₁ voltage and the input voltage are added to the capacitor C₂. $V_c + V_i = V_m + V_m = 2V_m$. As a result, the capacitor C₂ charges to 2V_m.

C. In the course of second +ve half cycle

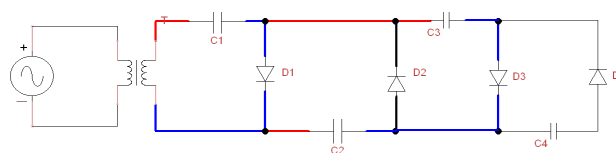


Figure 4

The diodes D₂ and D₄ are reverse biased and diodes D₁ and D₃ are forward biased in the second positive half cycle. Diode D₁ conducts and charges the capacitor C₁ to the voltage V_m. The capacitor C₃ charged to twice the maximum voltage through C₂ - D₃ - C₃ - D₁ since the capacitor C₂ is at 2V_m. The polarity of voltages will be as shown in figure 4.

D. In the course of second -ve half cycle

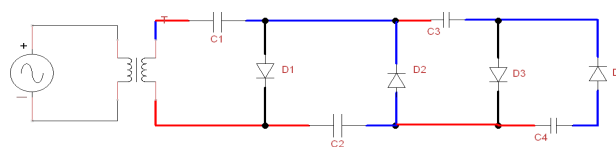


Figure 5



During this cycle diodes D_1 and D_3 are reverse biased whereas diodes D_2 and D_4 are forward biased. This causes the charge ($2V_m$) stored in the capacitor C_3 to be discharged through $C_3 - D_4 - C_4 - D_3$ to charge the capacitor C_4 to the same voltage $2V_m$.

Since the capacitors C_2 and C_4 are connected in series, the output voltage is taken across them. The voltage across capacitor C_4 is $2V_m$ and capacitor C_2 is $2V_m$. So the output voltage is the addition of voltage across the capacitor C_2 and capacitor C_4 i.e. $C_2 + C_4 = 2V_m + 2V_m = 4V_m$. The polarity of charge will be as shown in the figure 5.

III. DESIGN CALCULATIONS

A. Transformer specification

Transformer is mainly used for isolation purposes to isolate the low voltage side and high voltage side of the multiplier. Output of the multiplier is given by

$$2 \times N \times V_m = 60kV$$

Where

N – No. of stages - 5

V_m – Output voltage of transformer (peak)

Hence, $V_m = 6kV$

$$V_{rms} = 6kV \times 0.707 = 4.24kV \quad \dots (i)$$

B. Diode specification

Peak inverse voltage of diode is the maximum voltage that a diode can withstand when it is reverse biased. Generally, PIV of diodes is taken twice that of the supply voltage. Hence, diodes having PIV of $2V_m$ are chosen. I.e. a diode having PIV of 12kV is chosen for simulation.

C. Capacitor specification

Since each capacitor is charged to the voltage twice the supply voltage, the voltage rating of the capacitor should be chosen such that it should be able to withstand twice the supply voltage hence capacitor having voltage rating of 12kV is chosen for simulation.

$$N_{opt} = \sqrt{(V_m \times f \times C)} \div I$$

$$\therefore C = (N_{opt}^2 \times I) \div V_m \times f$$

$$C = \frac{10^2 \times 10 \times 10^{-3}}{50 \times 3.33 \times 10^{-6}}$$

$$\therefore C = 3.3\mu F \quad \dots (ii)$$

D. Output Voltage

$$V_{out} = (2 \times N \times V_m) - \Delta V - \delta V \quad \dots (iii)$$

Where,

ΔV – Voltage drop in multiplier

δV – Ripple in voltage

Voltage drop when load is connected.

$$\Delta V = \frac{I}{f \times C} [\{ (2 \times n^3) \div 3 \} + (n^2 \div 2) - (n \div 6)] \quad \dots (iv)$$

$$\Delta V = \frac{10 \times 10^{-3}}{50 \times 3.33 \times 10^{-6}} [\{ (2 \times 5^3) \} + (5^2 \div 2) - (5 \div 6)]$$

$$\Delta V = 5.7\text{kV}$$

$$\begin{aligned} \text{Therefore, voltage regulation} &= \frac{\Delta V}{2 \times n \times V_m} \quad \dots (v) \\ &= 9.5\% \end{aligned}$$

$$\begin{aligned} \text{Ripple in voltage, } \delta V &= \frac{T}{f \times C} \left[\frac{n(n+1)}{2} \right] \quad \dots (vi) \\ &= \frac{10 \times 10^{-3}}{50 \times 3.33 \times 10^{-6}} \left[\frac{5(5+1)}{2} \right] \\ &= 900 \text{ V} \end{aligned}$$

$$\begin{aligned} \therefore \% \delta V &= \frac{\Delta V}{2 \times V_m} \quad \dots (vii) \\ &= 1.5\% \end{aligned}$$

IV. RESULTS OF SIMULATION

Proteus 8 professional software is used for simulation purposes. A 60kV multiplier consisting of 5 stages is designed, simulated and the results are as shown in the figures below. The circuit has a multiplying factor of 10; hence for a 6kV input, the output is 60kV.

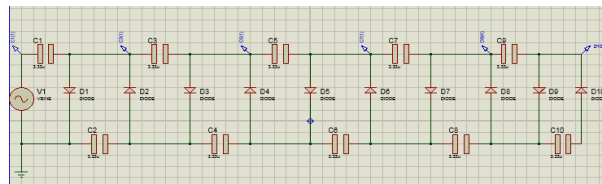


Figure 6 Simulation circuit of 5 stage multiplier

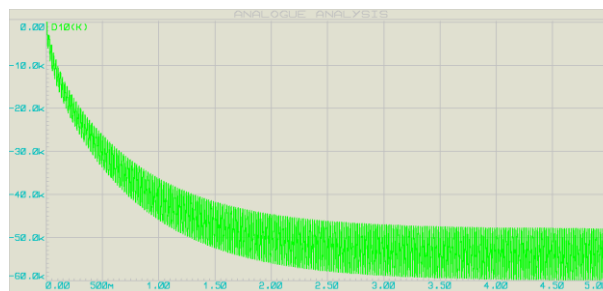


Figure 7 Output voltage

Number of stages	Voltage at each stage node (in kV)
1	12
2	24
3	36
4	48
5	60

Figure 8 Voltage values at each stage

V. ACKNOWLEDGMENT

The authors gratefully acknowledge all the information and useful data which was made available by our faculty and department of Electrical and Electronics Engineering. The constant motivation and help carved the way for our findings.

VI. CONCLUSION

The most common way of improving the performance and working of an electrostatic precipitator are to increase the corona power. The relationship between corona power and collection efficiency is a well understood upgrade. To achieve this, the best option is to choose a power source that can efficiently increase the output of corona power and at the same time, be used at a highly reliable level. However, most of such power supplies come at an expense and hence a large initial investment needs to be made for such an arrangement. This paper gives us an alternative and cheaper solution to the problem and hence, greatly cuts down the initial set-up cost of the whole system. So, looking at alternate sources of power for the necessary requirements helps to strengthen one's position from the monetary point of view. Also, a voltage multiplier circuit is a relatively simple orchestration and all the components are easily replaceable. Thus, such flexibility in operation and maintenance of the power supply is a great asset for any new investment as it will greatly reduce the initial financial burden and at the same time, accomplish the expected purpose of a power sources.

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