DESIGN OF A SINGLE PHASE HIGH VOLTAGE DC POWER SUPPLY AT 15 KV OUTPUT USING VOLTAGE DOUBLER CIRCUIT

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ABSTRACT

This paper describes the design and implementations of a single phase high voltage DC power supply at 15 kV output. This explain the detail description of the simulation, design, development and implementation of the hardware work to build a high voltage DC power supply in the laboratory and its simulation works done by using PSpice software. The designed DC power supply it can be used in industrial applications. Simulation and experimental results are presented in terms of performance and implementation.

I. INTRODUCTION

High voltage testing equipment is generally used in mostly two places, one in the research laboratories and routine testing laboratories. The work carried out in research laboratories varies considerably from one establishment to the other and the type of equipment needed varies accordingly. A general high voltage laboratory may include equipment for all classes of tests. The routing testing is concerned with testing equipment such as transformer, switchgear, bushings as well as cables etc. It sometimes carried out in the factory premises. In the industry, the main application of the DC high voltage is for testing on cables with a relatively large capacitance, which takes a very large current if it is tested with AC voltages [1].

Stefan Mozar has explained how to save the cost for mass production of the voltage doubler circuit for mainly an international market in TV sets. He has proposed an electrolytic capacitor protection circuit using voltage doubler technique [2]. Juichi Tanaka, et al, has explained the new idea to develop the high voltage DC Power supply. They introduce a high frequency switching converter technology as a result its shape becomes smaller. The conventional Cockcroft-Walton (C-W) multiplier circuit ignores the inductance but they have used the inductance as well. They were able to produce 70 kV, 0.15 ampere DC power supply [3]. Joseph M. Beck has presented in his paper the basic operation of voltage multiplier circuits such as half wave voltage doubler and tripler circuits and discusses guidelines for electronic component selection for diode and capacitor [4]. Kenichiro Fujiwara, et al, have discussed about the improvement of the current wave shape for voltage doubler circuit where input voltage is 200 VAC. They used LC filter to improve the line current waveform. Maintaining the same principle of voltage doubler circuit but capacitor of C1 and C2 have been chosen to be reasonably small, so that voltage boosting function is minimized [5]. Richard Red and his group have discussed about the power factor correction based on voltage doubler circuit without switching devices and they used additional inductors and capacitors for power factor correction. In their system, the input current is divided into two periods, where one period charge the small input capacitor and the other charge the large output capacitor. By dividing the input current into different modes, the current conduction period can be widened and harmonics can largely be canceled between the two nodes [6]. Aintablian, et al, have discussed about the single phase harmonic reduction circuit based on voltage doubler circuit using switch operated on line frequency, instead of using switch mode technology. The advantage of this circuit is that low cost, high reliability and simplicity of control. The disadvantages of this circuit are that it cannot completely control the harmonic current [7].

Many research works have been found which offer excellent foundation of this work. The voltage doubler circuit has been mostly used as single phase harmonic reduction circuit [7], this is to save cost for mass production of TV sets [2], for power factor correction [6], for the improvement of the current wave shape where input voltage is 200 VAC [5] and also to build a DC power supply using high frequency switching converter technology [3].

In this paper, the main concept of this work is to study the voltage doubler circuit based on simulation and hardware implementation and finally based on Cockcroft-Walton (C-W) voltage multiplier circuits to fabricate a DC power supply in the laboratory at the output range of 15 kV. The conventional technique is used because the designed multiplier circuit is intended to be applied either for impulse generator charging units or for laser excitation. The main components of the DC power supply are rectifier diodes and capacitors. The simplest unregulated power supply consists of three parts namely, the transformer unit, the rectifiers unit and the capacitors unit.

II. VOLTAGE DOUBLING PRINCIPLE

The design specifications of the voltage doubler circuit are in Table 1.

Table 1 Circuit design specifications

Input voltage	220 volt
Output voltage	15 kV
Single phase transformer	1:1
DC Capacitor voltage level	850 volt
Capacitance value	1 µf
Rect. Diodes max. voltage level	4000 v
Forward current	0.25 A

Figure 1 shows the schematic for a half-wave voltage doubler. In fact, the doubler shown is made up of two half-wave voltage rectifiers. Here C1 and D1 make up one half-wave rectifier and C2 and D2 make up the other rectifier.

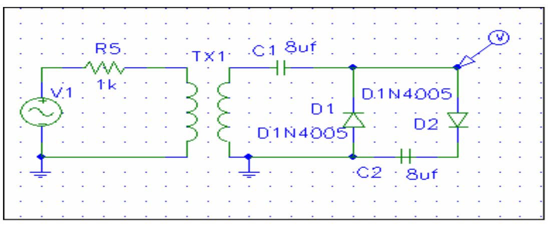

Figure 1 Connection diagram of the half-wave voltage doubler circuit.

The schematic of the first half-wave rectifier is indicated by the arrow lines in Figure 2. The dotted lines and associated components represent the other half-wave rectifier.

Notice that C1 and D1 work exactly like a half-wave rectifier. During the positive alternation of the input cycle in Figure 2, the polarity across the secondary winding of the transformer is as shown. Note that the top of the secondary is negative. At this time D1 is forward biased (cathode negative with respect to the anode).

This forward bias causes D_1 to function like a closed switch and allows current to follow the path indicated by the arrows. At this time, C_1 charges to the peak value of the input voltage or 220 volts, with the polarity shown.

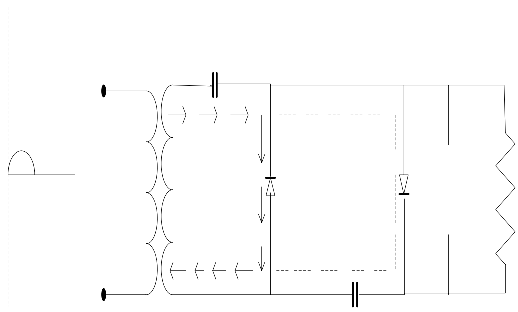

Figure 2 Voltage doubler in positive alternation

During the period when the input cycle is negative, as shown in Figure 3, the polarity across the secondary of the transformer is reversed. Note that the top of the secondary winding is now positive.

At this condition now forward biases D2 and reverse biases D1. A series circuit now exists consisting of C1, D2 and C2and the secondary of the transformer.

The current flow is indicated by the arrows. The secondary voltage of the transformer now aids the voltage on C1. This results in a pulsating dc voltage of 440 volts.

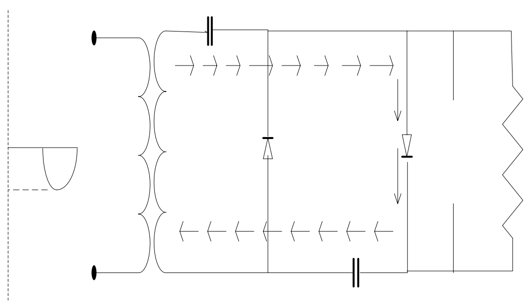

Figure 3 Voltage doubler in negative alternation

III. SIMULATION RESULTS

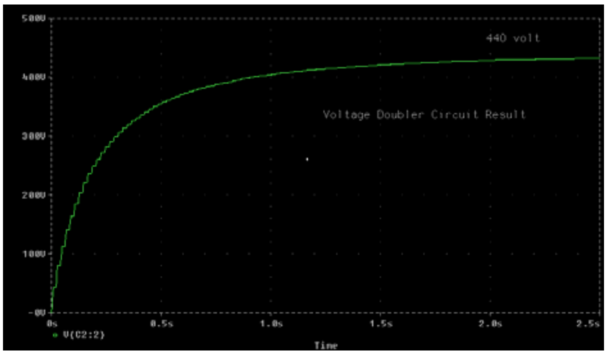

Figure 4 Simulation result voltage doubler circuit

The input voltage of the voltage doubler circuit for the simulation has been set to 220 volt and the output obtained is 440 volt. It shows the voltage doubler circuit functioning as expected in Figure 4.

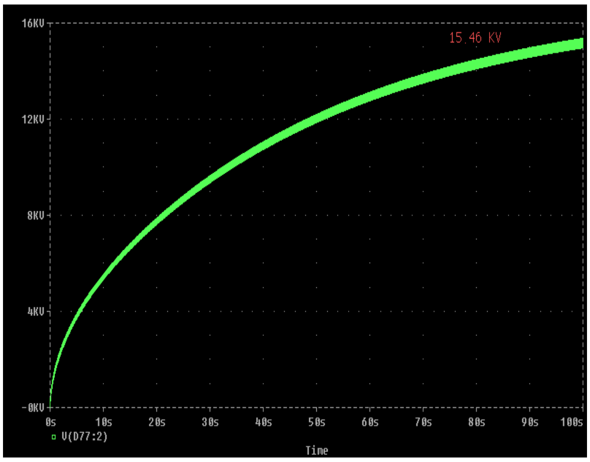

Figure 5 Simulation result 15 kV DC power supply

Figure 5 shows the simulation output voltage and Figure 6 shows the output current of the designed high voltage DC power supply for the proposed 15 kV circuit shown as in Figure 10.

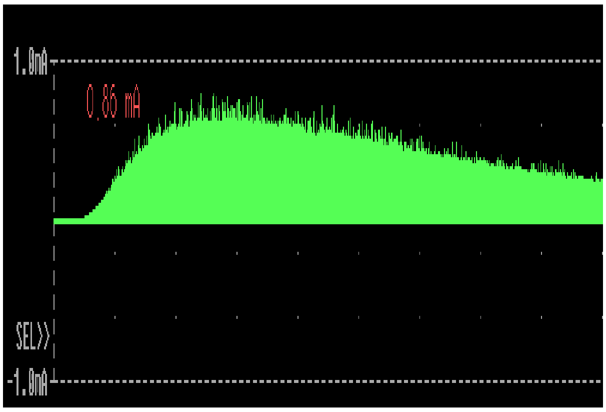

Figure 6 Simulation output current of DC power supply

IV. EXPERIMENTAL RESULTS

The simulation results are corroborated by implementing and testing the circuits in the laboratory. The input voltage was set at 220 volt and the output obtained is 471 volt. So according to the simulation circuit, it should be 440 volt but it has given a higher value than its simulation result as shown in Figure 7.

Figure 7 Experimental output voltage of doubler circuit

Figure 8 shows that the output of the designed DC power supply is 15 kV and it is tested and installed.

Figure 8 Output voltage of the DC power supply

Figure 9 shows the hardware implementation for DC power supply in the laboratory.

Figure 9 Constructed DC power supply in lab.

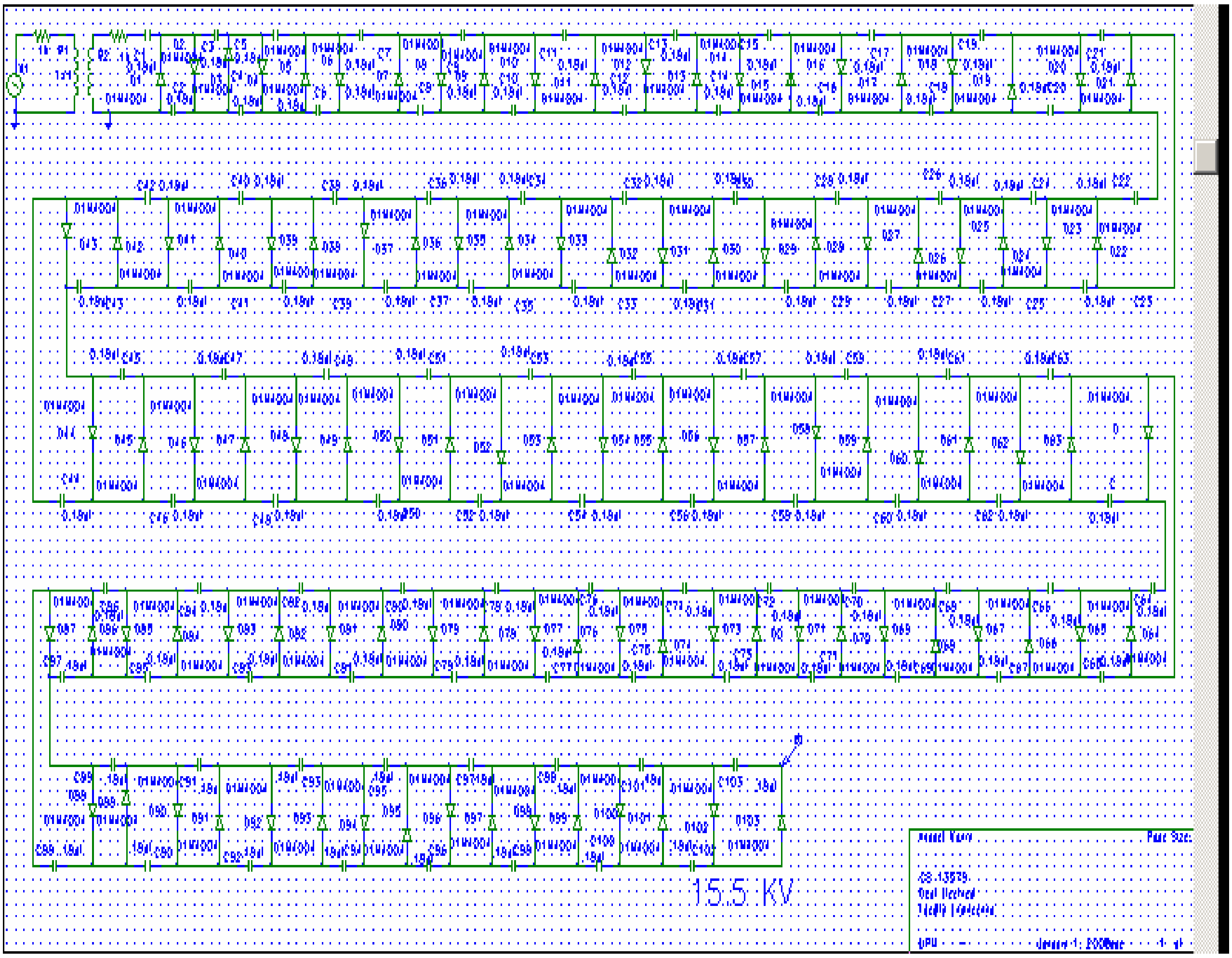

Figure 10 Proposed 15 kV DC power supply simulation circuit

V. DIFFERENCE BETWEEN SIMULATED AND EXPERIMENTAL RESULT

Table 2 Data for voltage doubler circuit

Simulation Result		**Experimental Result**		
Voltage Doubler Circuit		Voltage Doubler Circuit		Remarks
Input	Output	Input	Output	% difference w.r.to simulation result
220 volt	440 volt	220 volt	471 volt	% difference = 471-440/440 *100 =7.04% (Positive)

Table 2 shows the difference between simulated and experimental result based on voltage doubler circuits. It shows that experimental voltage leads to simulation voltage with positive mode.

Table 3 Data for 15 kV Design Circuit

Simulation Result		**Experimental Result**		
15 kV Design Circuit		15 kV Design Circuit		Remarks
Input	Output	Input	Output	% difference w.r.to simulation result
220 volt	15 kV	220 volt	15 kV	% difference = 15-15/15 *100 ** Data analysis

**** Data analysis**

52 and 47 pairs of diodes and capacitors have been used in the 15 kV simulation design circuit and the experimental setup respectively. The output of the voltage multiplier circuit is given by Vo = 2nv – i2n^3/3fc. Since

the higher order terms are ignored, therefore Vo is never equal to 2nv while trying to optimize for calculating no of stages. Usual output is 2/3 or a bit more than 2/3 of the desired/expected output.

VI. CONCLUSION

A PSpice based design for high voltage DC power supply at 15 kV output has been proposed and developed. The system hardware has been implemented and tested in the laboratory. The simulation and experimental results has been observed to be in agreement. The designed DC power supply can be used for multiple purposes such as impulse generator charging units, laser excitation or test on cables in industrial application.

VII. ACKNOWLEDGEMENT

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