THE SIMULATION OF HIGH VOLTAGE TEST EQUIPMENT

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ABSTRACT

This paper presents the simulation of high voltage test equipment. Two major high voltage generation circuits were developed : DC high voltage generation and impulse generation. The simulation of DC high voltage generation includes three types of circuits : half wave, full wave and cascaded circuit. The simulation of HV impulse test equipment was developed in two types of circuits : single and multiple stage circuit. All results were carefully compared with those from real HV test equipment. Simulation of high voltage generation assisted students to understand the relevant concepts clearly. Simulation could also assist engineers to analyze and design the effect of each parameter appropriately.

INTRODUCTION

The high cost of facilities and instruments in high voltage engineering area encouraged people to develop program based on the PSPICE program to simulate high voltage circuit. The intent of the first paper [1] is to show the usefulness of the SPICE software. However, they did not compare with the real experiment. The second paper [2] simulated an impulse current generator as a tool to design and construct an impulse current generator by using MATLAB program .

The intention of this study is to simulate both HV dc generation and HV impulse generation and compare with practical experiments. Three typical DC circuits are performed. The first two circuits are half wave and full wave rectifier, which

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have been analyzed for the output voltage ripple. The last one is the cascade circuit analyzed for ripple and voltage drop. Two principle circuits of HV impulse generator were studies. The first circuit: (single stage impulse circuit) the influence of front resistance, wave tail resistance, circuit inductance and load capacitance on the output wave form were investigated. The second circuit: multi-stage impulse circuit was also simulated to consider the effect of each component. The impulse current and impulse switching voltage were also easy simulated. The simulation followed the specification of waveform given in IEC Standard 60060-1. The results were compared with those from the formula calculation and from the real experiment by using the Haefely impulse generator in Chulalongkorn University.

1. High Voltage DC Generation

1.1 Rectifier Circuit

DC high voltage generated by the rectifier circuit and ripple factor of DC output would be considered. This ripple of direct voltage must be less than 5 percent of mean value (IEC Publication 60060-1 [3]).

A typical circuit of half wave rectifier is shown in Fig. 1.

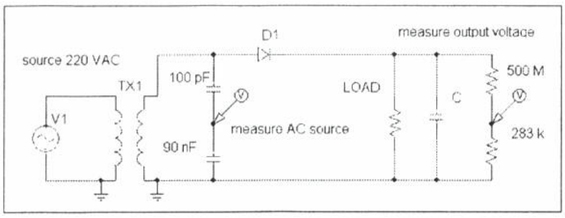

Figure 1 Typical circuit for half wave rectifier

The equation for ripple is

$$\delta v = \frac{IT}{2C} = \frac{I}{2fC} \qquad (1)$$

Where dv is the average ripple.

The simulation results of ripple voltage have been compared with those from realistic experiment. The difference of ripple between the simulation and the experiment is 4.5 %.

The dependence of the ripple amplitude on the capacitor and load resistor is also observed by simulation. Results of changing parameter are plotted in Fig. 2, 3 and 4.

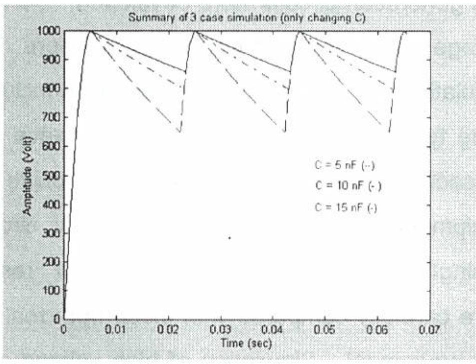

Figure 2. The effect of the capacitance (C) value

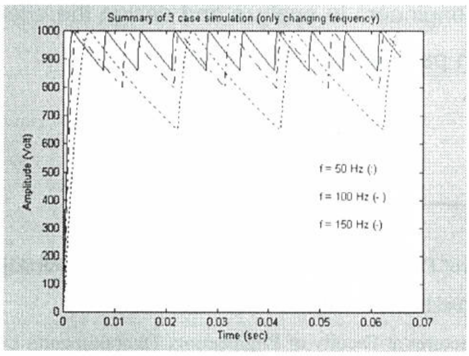

Figure 3. The effect of the frequency(f) value

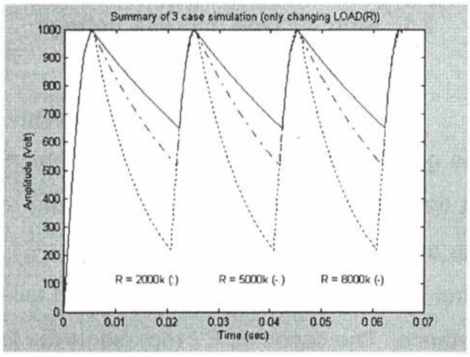

Figure 4. The effect of the load(R) value

The equation of ripple voltage can be clearly visualized from Fig. 2 to Fig. 4. It is clear that the ripple reduced while C, R and f increased.

The influence of each component is very clear and easy to adjust by changing parameters. Therefore, students can easily understand and people can select the appropriate components to obtain the desired ripple amplitude.

A full wave rectifier circuit shown in Fig 5. The ripple amplitude of full wave rectifier is controlled by value of R and C similar to the half wave rectifier.

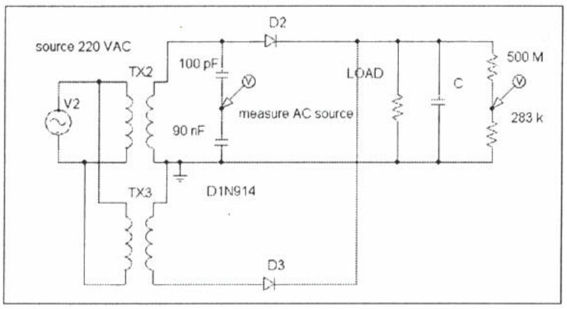

Figure 5. Full wave rectifier circuit

Usually, full wave DC generation has less ripple than that of half wave, which is shown correctly in Fig. 6.

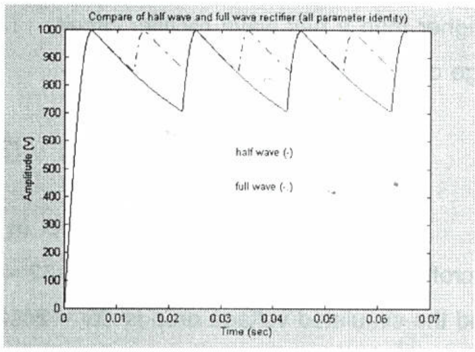

Figure 6. The comparison of full wave with that from half wave.

1.2 Cascaded Circuit

The most adopted method producing high DC voltages in HV laboratory is a cascaded Cockcroft-Walton circuit. Fig. 7 shows the Cockcroft-Walton circuit in double-stage.

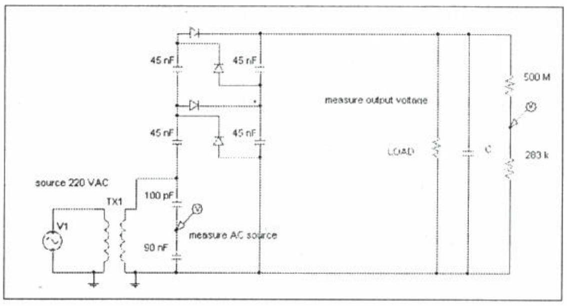

Figure 7. Cockcroft-Walton Circuit

In general, any load at the output will draw some current and will load down the voltage source. It is therefore desirable to have an appropriate value of load, R_{LOAD} connected across the terminals for the generator to deliver the maximum voltage. In addition, the ripple and the output voltage will depend on both the load resistance, R_{LOAD} and the load capacitance C_{LOAD}. The two factors to be considered are ripple amplitude (δv) and voltage drop (Δv). The ripple amplitude is the higher than a half wave rectifier circuit. The voltage drop equation is

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

The calculated voltage drop in a Cockcroft Walton circuit is Δv = 2474 - 2432 =42 V, and the simulated voltage drop is Δv = 2492 - 2443 = 49 V.

The simulation output has been compared with the realistic one. The percentage difference of ripple voltage between practical and simulation is 4.8%. However, the wave form from practice may be effected by some factors(i.e transformer saturated, unexpected characteristic of transformer, stray capacitance).

2. High Voltage Impulse Generator

The lightning impulse voltage defined by IEC standard is shown in Fig. 8. The virtual origin O1 is defined where the line AB cuts the time axis. The virtual front time T1 is 1.2 ± 30% ms , the virtual time to half value T2 is 50 ± 20% ms [3].

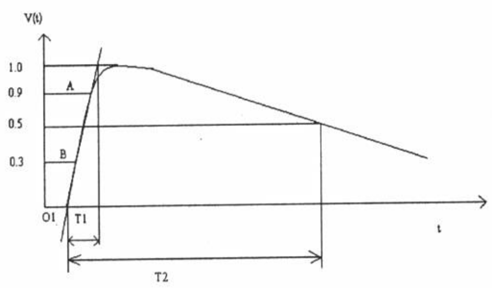

Figure 8 the standard wave form of lightning impulse voltage

2.1 Single Stage Impulse Voltage Generator

The basic circuits for single-stage impulse generators shown in Fig 9. R1 control the front time. Therefore, it is called front time resistance and R2 will discharge the capacitor C1 and control the tail time, Therefore, it is called tail-time resistance. The capacitor C2 represents the load , includes test object, measuring device and other capacitor elements which are parallel to the test object.

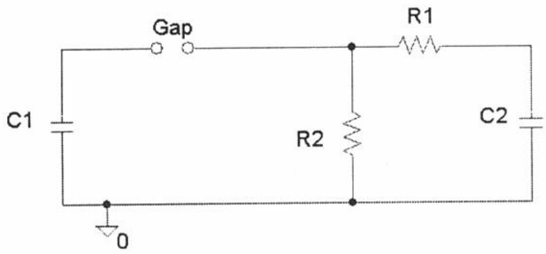

Figure 9. Single-state impulse circuit

The values of all component are shown in Fig. 10.

The value of test object, and the measuring device is assumed to be 1000 pF and 300 pF respectively. Normally the capacitance C1 should be higher than 10 C2, therefore the C1 value of 300 nF was adopted.

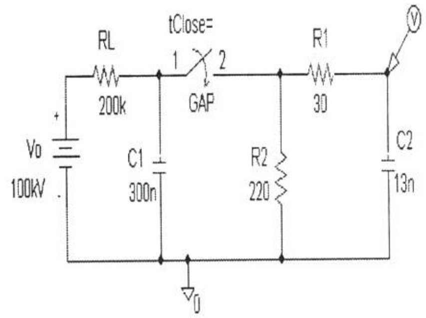

Figure 10. The simulated circuit.

2.1.1 Front time Resistance

The value of front resistance R1 was varied from 10 W to 50 W. (R2 = 220 W, C1 = 300nF, C2 = 13nF)

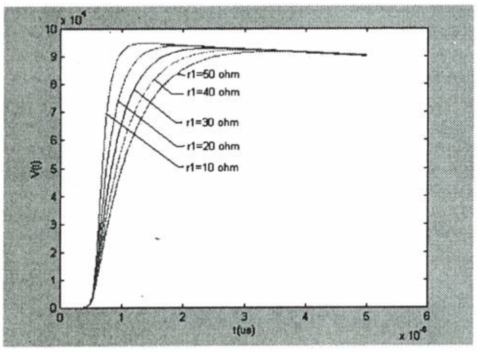

Figure 11 Simulation result shows the effect of R1

2.1.2 Tail Resistance

The tail Resistance was also changed similarly to the front resistance. The results are shown in Fig. 12.

(R1 = 30 Ω, C1 = 300nF, C2 = 13nF)

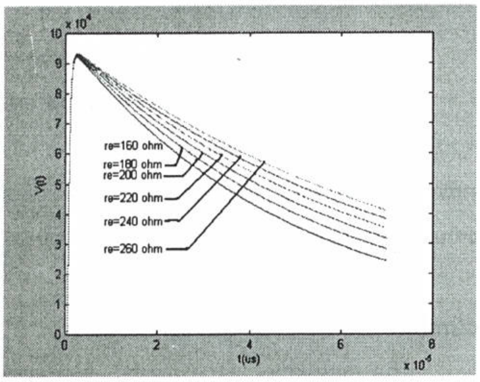

Figure 12. Simulation result shows the effect of R2

2.1.3 Load

The study of the effect of the load magnitude was also done in a similar way and results are shown in Fig.13.

(R1 = 30 Ω, R2 = 220 W, C1 = 300 nF)

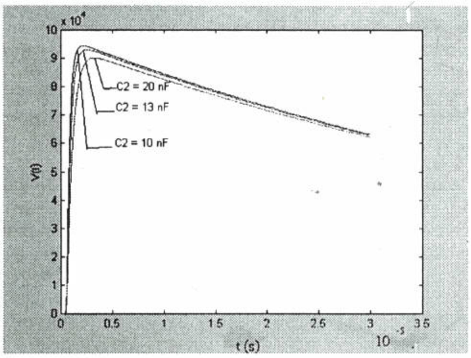

Figure 13. Simulation results showing the effect of load C

2.2 Multistage Impulse Voltage Generator

The multistage impulse voltage generation was simulated by using the circuit of Haefely Trench, series E as shown in Fig. 16. The switches represent gaps. The results are compared with the real experiment in the high voltage laboratory, Chulalongkorn University shown in Table 1.

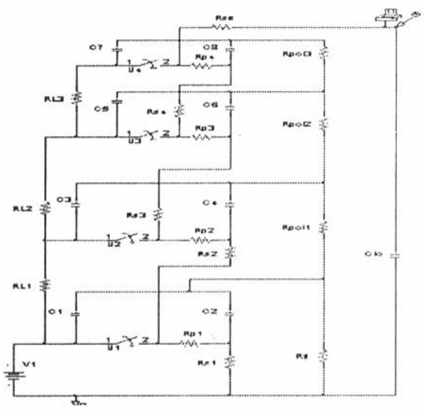

Figure 16. The simulated circuit of multistage impulse generation.

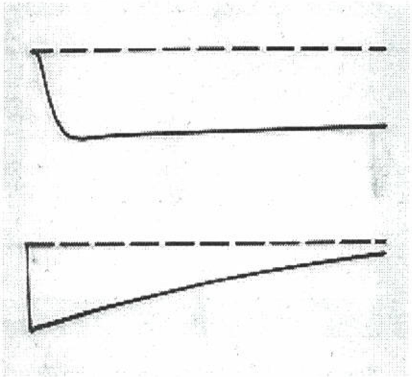

Figure 17. The output wave form from experiment

Table 1 Simulation Results Comparing with the real experiment (impulse voltage generation of Haefely, Series E.) for the multistage impulse circuit.

Simulation			Experiment		
T_1 (μs)	T_2 (μs)	Vp (kV)	T_1 (μs)	T_2 (μs)	Vp (kV)
0.95	60.8	70.2	0.9	55	71

It can be found that the simulation results of single stage impulse generation agree with results of formula calculation very well. Meanwhile, the results between simulation and experiment were only a little different because there was some natural induction in experimental component.

The one who uses the simulation will understand the circuit clearly and can picture the effect of each component so well that he or she can improve the wave form of output voltage as desired.

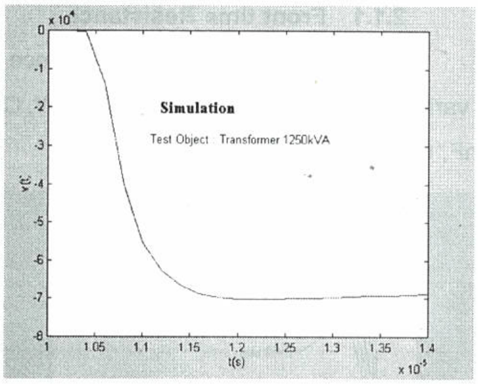

Figure 18a. The simulated front waveform.

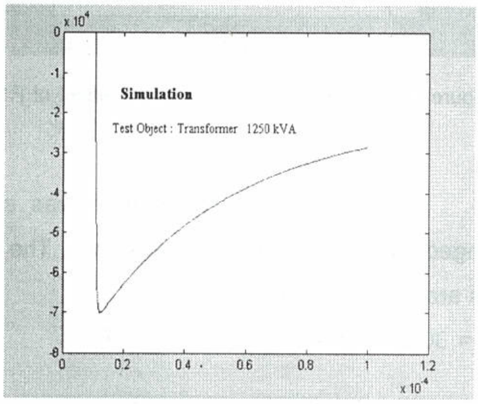

Figure 18b. The simulated tail waveform

The simulation has been adopted in undergraduate student's education. Successful effect indicated it is beneficial for students to understand the relevant concepts.

Conclusion

The simulation is a useful educational tool in the area of high voltage engineering. The advantages of the simulation are better understanding, less time consuming, value-selectable component and safety, while high voltage components and instruments are costly and bulky.

The developed simulation could be used as teaching assistant tool in high voltage engineering subject for undergraduate students.

Good agreement between simulation and real experiment indicated the success of the simulation. ◈◈

REFERENCES

Annop Limsimarat, Samruay Sangkasaad and Podgornov, Dmitry L. "Design and Construction Impulse Current Generatorusing MATLAB" in 20th **Electrical Engineering Conference (EECON-20).**

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