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Analysis of Impulse Voltage Generator and Effect of Variation In Parameters by Simulation

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Abstract: **In this paper the conventional Marx circuit is analysed mathematically as well as by simulation method. Effect of parameters R_1, R_2 and ratio C_1/C_2 on front time and tail time have been analysed by Simulink. It was found that there is a particular range of ratio C_1/C_2 for the parameters of impulse generator under consideration.**

Keywords: **Analysis of Impulse, Voltage Generator, Effect of Variation.**

LIST OF SYMBOLS

α & β = Time Constant
R_1 = Front Control Resistance
R_2 = Tail Control Resistance
C_1 = Source Capacitance
C_2 = Load Capacitance
t_1 = Front Time
t_2 = Tail Time
V_0 = Charging Voltage
V_{max} = Maximum Output Voltage
η = Efficiency
W = Impulse Energy Transformed During a Discharge

I. INTRODUCTION

A unidirectional voltage which rises rapidly to a maximum value and falls slowly to zero without appreciable oscillations is known as Impulse voltage. In it the maximum value is called the peak value of the impulse and the impulse voltage is specified by this value. In this wave shape small oscillations are tolerated, provided that their amplitude is less than 5% of the peak value of the impulse voltage. In case of oscillations in the wave shape, a mean curve should be considered. If an impulse voltage develops without causing flash over or puncture, it is called a full impulse voltage. If flash over or puncture occurs thus causing a sudden collapse of the impulse voltage, it is called chopped impulse voltage.

A full impulse voltage is characterized by its peak value and its two time intervals, the wave front and wave tail time interval which are defined as:

1. Wave Front Time Interval

The wave front time of an impulse wave is the time taken by the wave to reach to its maximum value starting from zero value.

2. Wave Tail Time Interval

The nominal wave tail time is measured between the nominal starting point and the point on the wave tail where the voltage is 50% of the peak value.

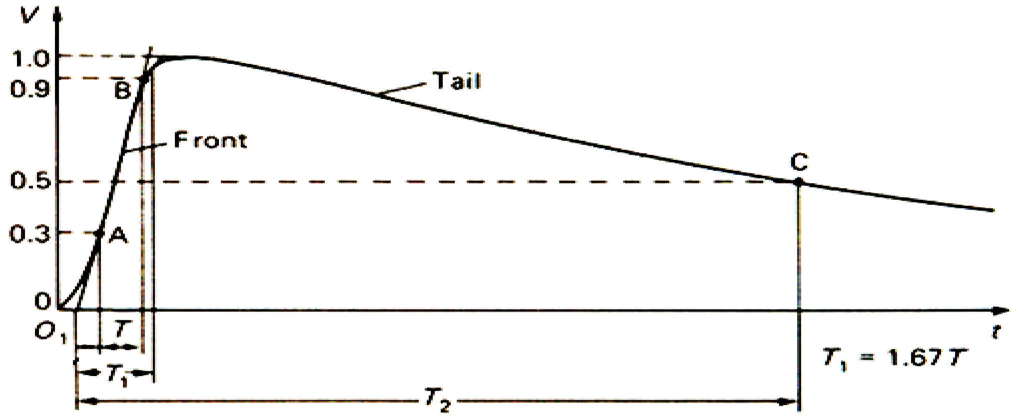

Fig.1. Full impulse voltage wave form with T_1/T_2

Equivalent Circuit Diagrams of Multi Stage Impulse Voltage Generator

Two simplified but more practical forms of impulse voltage generator circuits are shown in Fig. 2(a) & (b) respectively.

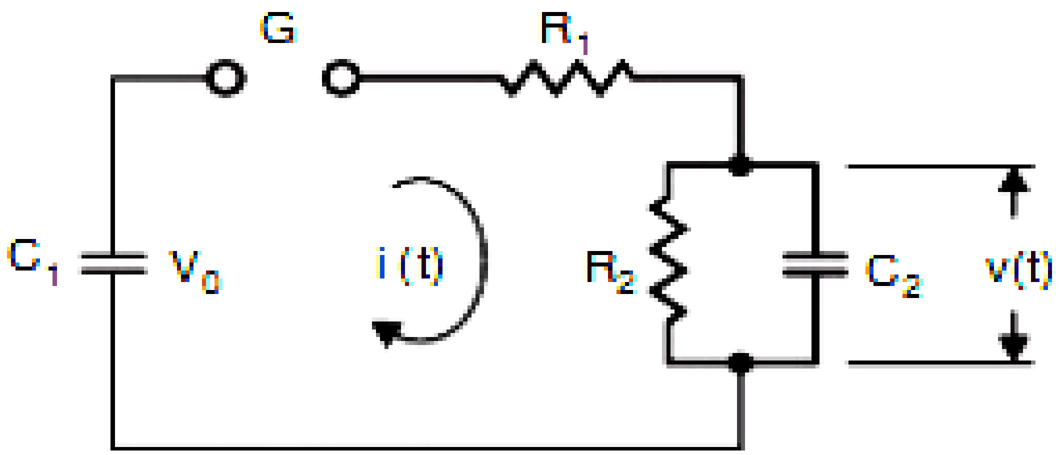

Fig. 2 (a)

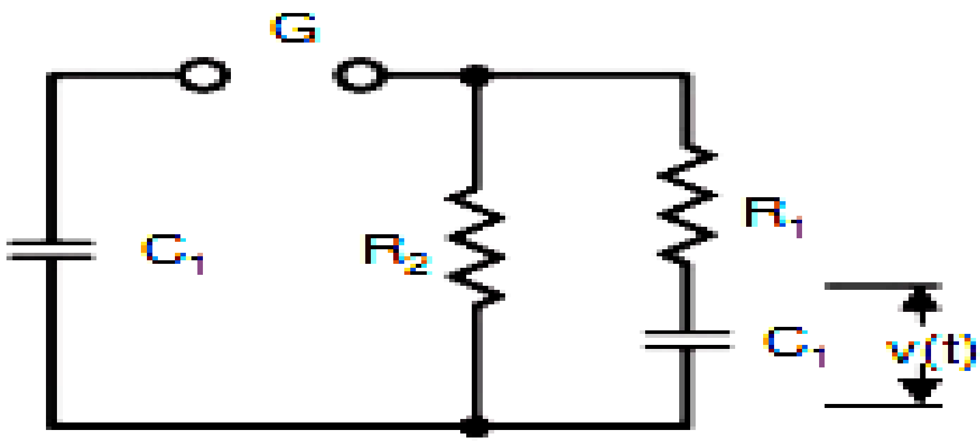

Fig. 2 (b)

Fig.2. Equivalent Circuit Diagram of Impulse Voltage Generator

These two circuits are widely used and differ only in the position of the wave tail control resistance R_2. When R_2 is on the load side of R_1 (Fig. 2 a) the two resistances form a potential divider which reduces the output voltage but when R_2 is on the generator side of R_1, (Fig.2 b) this particular loss of output voltage is absent.

The impulse voltage generator capacitor C_1 is charged through a charging resistance (not shown) to a D.C. voltage V_0 and then discharged by flashing over the switching gap with a pulse of suitable value. The desired impulse voltage appears across the load capacitance C_2. The value of the circuit elements determines the shape of the output impulse voltage. The circuit parameters can be evaluated for achieving a particular wave shape of the impulse voltage by analysis of these circuits.

II. ANALYSIS OF IMPULSE VOLTAGE GENERATOR

Circuit of fig. 2(b) has been considered for analysis purpose because it is the most commonly used circuit. Front time (t_1), tail time (t_2), and output voltage are determined by

1. Analytical Method
2. Simulation Method

The parameters of the circuits are as follows [6]

The generator capacitance, $C_1 = 25nf$

The load capacitance, $C_2 = 2.5nf$

Front resistance, $R_1 = 75\Omega$

Tail resistance, $R_2 = 2600\Omega$

I. Analytical Method

$$Z(s) = R_1 + \frac{1}{C_1 s} + \frac{R_2}{R_2 C_2 s + 1}$$

$$I(s) = \frac{V_0}{sZ_{(s)}} = \frac{V_0}{s}\,\frac{C_1 s[R_2 C_2 s + 1]}{R_1 R_2 C_1 C_2 s^2 + (R_1 C_2 + R_2 C_1 + R_2 C_2)s + 1}$$

And $$v(s) = I(s)\frac{R_2}{R_2 C_2 s+1}$$

$\Rightarrow$ $$\frac{V_0 R_2 C_1}{R_1 R_2 C_1 C_2}\left[\frac{1}{s^2+\left(\frac{1}{R_1 C_1}+\frac{1}{R_2 C_1}+\frac{1}{R_1 C_2}\right)s+\frac{1}{R_1 R_2 C_1 C_2}}\right]$$

The roots of the expression in the denominator are

Suppose $$\alpha = \left(\frac{R_1 C_1 + R_2 C_1 + R_2 C_2}{2R_1 R_2 C_1 C_2}\right) \quad \dots (1)$$

And $$\beta = \frac{1}{2}\left(\sqrt{\left(\frac{R_1 C_1 + R_2 C_1 + R_2 C_2}{R_1 R_2 C_1 C_2}\right)^2 - \frac{4}{R_1 R_2 C_1 C_2}}\right) \quad \dots (2)$$

By taking the inverse Laplace transform of the voltage transform

$$v(t) = \frac{V_0}{R_1 C_2}\frac{1}{2\beta}\left[e^{-(\alpha-\beta)t} - e^{-(\alpha+\beta)t}\right]$$

$\dots (3)$

Let $$V_n = \frac{V_0}{2\beta R_1 C_2}$$

$$\therefore \quad v(t) = V_n\left[e^{-(\alpha-\beta)t} - e^{-(\alpha+\beta)t}\right]$$

Let t_1 = front Time,

And t_2 = Tail Time, then both α and β must have unique value irrespective to the particular circuit used.

At the timet_1, the slope of the wave is zero, therefore t_1 can be obtained from the relation $dv(t)/dt$= 0.

So,

$$\frac{dv(t)}{dt} = V_n\left[-(\alpha-\beta)e^{-(\alpha-\beta)t} - (\alpha+\beta)e^{-(\alpha+\beta)t}\right]$$

$\Rightarrow$ $$e^{2\beta t_1} = ln\frac{\alpha+\beta}{\alpha-\beta}$$

$\Rightarrow$ $$t_1 = \frac{1}{2\beta} ln\frac{\alpha+\beta}{\alpha-\beta}$$

… (4)

If$2\beta t_1 > 4$, then eq. (3.6) will be reduced to

$$\alpha - \beta = \frac{0.7}{t_1(k-1)} \qquad \text{… (5)}$$

With this assumption the result are found to be within 2% error.
Let $\gamma = \frac{C_1}{C_2}$ and working on the similar lines as for the circuit 'a', we have

$$R_1 = \frac{1}{C_1}\left[\frac{1+\gamma}{\alpha \pm \sqrt{\alpha^2 - \frac{1+\gamma}{\gamma}(\alpha^2-\beta^2)}}\right]$$

… (6)

$$R_2 = \frac{1}{C_1}\left[\frac{\alpha \pm \sqrt{-\alpha^2 - \frac{1+\gamma}{\gamma}(\alpha^2-\beta^2)}}{\frac{1+\gamma}{\gamma}(\alpha^2-\beta^2)}\right]$$

… (7)

Corresponding to the wave front time equation becomes

$$V_{max}(t_1) = \frac{V_0}{2\beta R_1 C_2}\left[e^{-(\alpha-\beta)t} - e^{-(\alpha+\beta)t}\right]$$

We define here the voltage efficiency of the generator as the ratio of the peak value of the output voltage $V_{max}(t_1)$ to the charging voltage V_0 and is denoted as

$$\eta = \frac{V_{max}(t_1)}{V_0} = \frac{1}{2\beta R_1 C_2}\left[e^{-(\alpha-\beta)t_1} - e^{-(\alpha+\beta)t_1}\right]$$

The impulse energy transformed during a discharge is given by

$$W = \frac{1}{2}C_1 {V_0}^2$$

With inductive loads the capacitance of generator must be large enough to prevent oscillation on the tail of the impulse wave. The minimum permissible capacitance is given by,

$$C_1 = \frac{8{t_2}^2}{L}$$

Hence wave shape can be determined by the values of the generator capacitance (C_1) and the load capacitance (C_2), and the wave control resistances R_1 and R_2.

By using the equations (1), (2), (3), (4) & (5), the values of $\boldsymbol{\alpha} = \mathbf{2.933 \times 10^6}$,$\boldsymbol{\beta} = \mathbf{2.9189 \times 10^6}$, $\boldsymbol{t_1} = \mathbf{1.03 \times 10^{-6}}\boldsymbol{sec}$., $\boldsymbol{t_2} = \mathbf{50.5 \times 10^{-6}}\boldsymbol{sec}$. and maximum output voltage $\boldsymbol{v(t)} = \mathbf{898.211}\boldsymbol{kv}$ are determined respectively.

II. Simulation Method

MATLAB Simulink is used to simulates the equivalent circuit of fig. 2 (b). Result of two methods are shown in the table

METHODS	Maximum Output Voltage (kv)	T_1 (μs)	T_2 (μs)
ANALYTICAL	898.211	1.03	50.5
SIMULATION	895.45	1.13	50.76

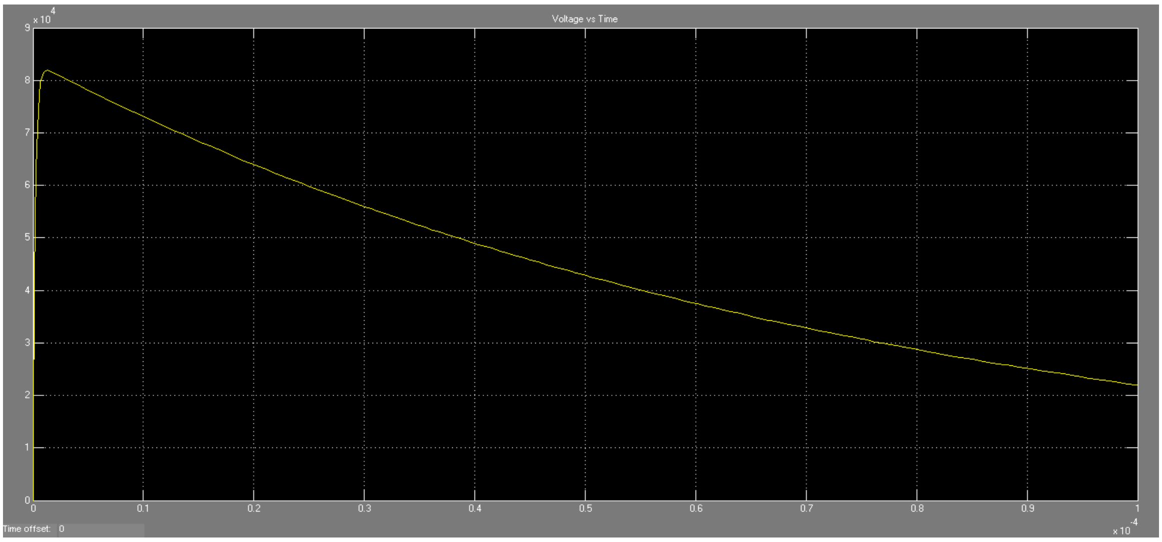

Fig.3. Impulse Voltage Wave Obtained By Simulation Method

Effect of Variation In Front and Tail Resistances

Fig. 4 shows the effect of R_1 on front and tail time.

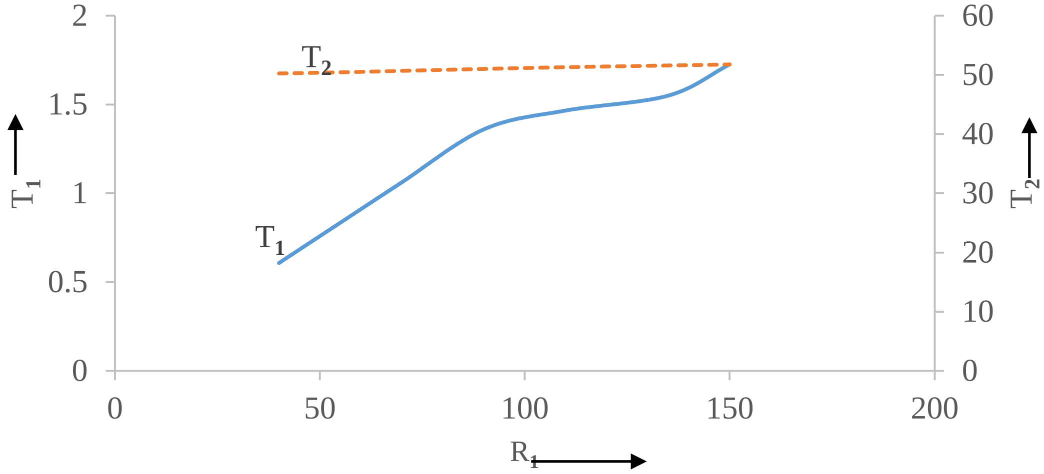

Fig.4. Variation in R_1

In the conventional impulse voltage generator circuit the front resistance R_1 controls the front time and this graph also verifies that the standard front time can be obtained by varying the value of R_1 from 56 to 135. Within this range of R_1, tail time T_2 remains constant.

Fig.5 shows the effect of R_2 on front time and tail time.

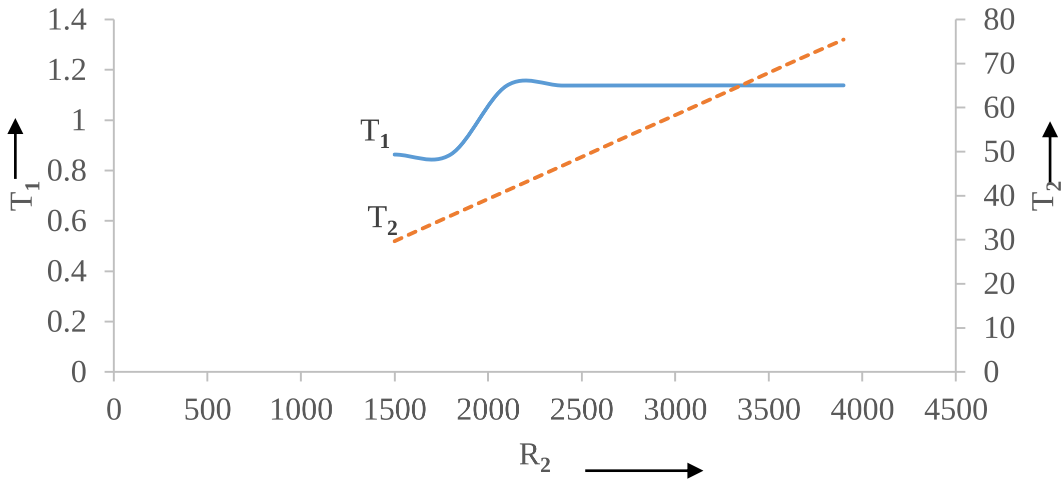

Fig.5. Variation in R_2

According to thumb rule R_2 controls the tail time and the graph also verifies that the standard tail time can be obtained by varying the value of R_2 from 2100 to 3000. Within this range of R_2, front time T_1 remains constant.

Effect of variation in ratio C_1/C_2

For a given wave shape, the choice of R_1, and R_2 to control the wave-front and wave-tail times is not entirely independent but depends on the ratio C_1/C_2.

Variation in ratio C_1/C_2 for Circuit (b)

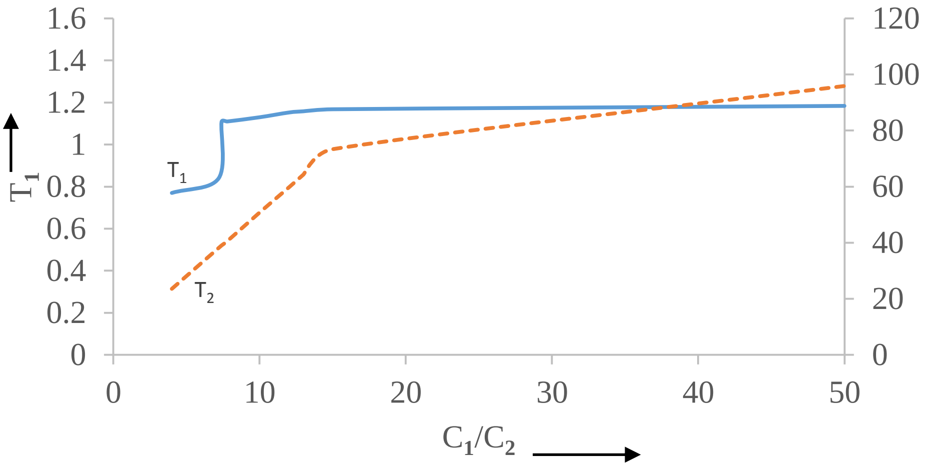

Fig.6. Variation in the ratio of C_1/C_2 for the circuit (b)

The graph in fig.8 shows that the ratio C_1/C_2 , for the considered value of circuit parameters, can be varied from 7.2 to 12 to get the standard front and tail time.

In the conventional impulse voltage generator circuit C_1 is much more effective to tail time as compare to front time. So standard tail time can be obtained by varying the value of C_1/C_2 from 72 to 12 with considered value of circuit parameters. For a fixed ratio C_1/C_2, T_1 and T_2 can be changed with R_1 and R_2 respectively to get the standard wave.

III. CONCLUSION

Both the analytical method and simulation method of the circuit shows that the simulation results are very close to the mathematical analysis. For the object capacitance under consideration the range of generator capacitance can be determined with the help of simulation. It was found that the value of generator capacitance should be between 18nf to 30nf for the considered value of R_1, R_2 and C_2.

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