

Impulse voltage generator modelling using MATLAB

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Abstract. MATLAB is specifically designed for simulating dynamic systems. This paper describes a method of modelling impulse voltage generator using Simulink, an extension of MATLAB. The equations for modelling have been developed and a corresponding Simulink model has been constructed. It shows that Simulink program becomes very useful in studying the effect of parameter changes in the design to obtain the desired impulse voltages and waveshapes from an impulse generator.

Keywords: impulse voltage generator, modelling, MATLAB, simulation

1 Introduction

International Electrotechnical Commission (IEC) has specified that the insulation of transmission line and other equipments should withstand standard lightning impulse voltage of wave shape 1.2/50 s and for higher voltages (220 kV and above) it should withstand standard switching impulse voltage of waveshape 250/2500 μ s^[1].

In the design or use of impulse voltage generators for research or testing, it is required to evaluate the time variation of output voltage, the nominal front and tail times and the voltage efficiency for given circuit parameters. Also, it needs to predict circuit parameters for producing a given waveshape, with a given source and loading conditions. The loading can be inductive or capacitive. The waveshapes to be produced may be standard impulse, steep fronted impulse, short tailed impulse or steep front short tailed impulse.

Expressions and curves have been already developed to predict the parameters of impulse voltage generator circuits required to reproduce the wave forms of required shape for the testing of transformers^[12]. An analysis of standard Marx circuit, with an inductance in series with the tail resistance for the production of short tailed impulses was done by Carrus^[5]. An algorithm workable in a personal computer to evaluate the time variation of the output voltage, nominal front and tail times and voltage efficiency for given circuit parameters or to predict the circuit parameters for given waveshape, source and loading conditions was reported in [6].

After performing an experimental investigation to evaluate the influence of tail resistance and tail inductance in the characteristic parameters of the impulses, provision of an analytical criterion is available for choosing the most suitable inductance value to be combined with a given resistance in order to generate the desired waves^[13]. Methods to be followed to determine parameters and indicate practical criteria which facilitate generation of waveshape of the above type have been also shown in [13]. Studies of transient disturbances on a transmission system have shown that lightning and switching operations are followed by a travelling wave of a steep wave front. This type of impulse may result in the breakdown of the insulation system in power equipments. Generation of impulse voltages in a test laboratory becomes, therefore, one of the standard techniques for testing the breakdown strength of electrical insulation. In high voltage engineering, assembling

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the actual circuit might be very bulky, time consuming and costly, while for the design, calculation technique could be complicated and may involve a lot of simplifications.

The analysis, design and practical implementation of impulse voltage generator without computer simulation is extremely laborious, time consuming and expensive. Various types of software like SPICE (Simulation Program with Integrated Circuit Emphasis) have been used to predict the performance of impulse voltage generator^[8, 10, 11, 14]. Although SPICE can analyse generator circuits, it is less well suited for dynamic analysis and design, which SIMULINK can handle with ease. However SPICE is very slow and is not practical for the design purposes.

In this paper, step-by-step modelling of an impulse voltage generator, used for the testing of high voltage power transmission and distribution equipments, has been carried out and the performance evaluated from the MATLAB package with its SIMULINK tool box suitable for dynamic system simulation. The system is first represented by a set of mathematical equations; the derived equations are modelled with standard blocks available in SIMULINK and the complete system is then simulated^[2-4, 7, 9].

2 Spice versus simulink

SPICE is a user friendly simulator widely used in circuit analysis. SPICE consists of a group of device files, one for each active circuit element, and one executable file, SPICE has a rich library for integrated circuits such as operational amplifiers, comparators etc. The user can create a model for part of a circuit and save it as a sub circuit and then use this sub-circuit later. The SPICE executable file^[8, 10, 11] will read the user circuit file and then execute the simulation. The output is produced either in a graphical or text form which shows the current and voltage of different nodes. Apart from circuit analysis and analogue electronics, SPICE can also be used to study the time - domain steady state behaviour of power electronics circuits. However SPICE cannot handle the dynamic behavior of switching converters because of the inherent switching nature of their circuits^[8, 10].

In contrast, SIMULINK which is an extension of MATLAB is specifically designed for simulating dynamic systems^[2-4, 7, 9]. MATLAB is a well known computer package for high performance matrix computation. As the basic data element of MATLAB is a matrix, it solves numerical problems in a fraction of time compared to other software packages, including SPICE.

Among the other applications, MATLAB and SIMULINK are used to solve problems in automatic control and digital signal processing. The speed and the capability of SIMULINK in simulating dynamic systems were the attraction to choose it for modelling impulse voltage generator circuit in this work.

3 Impulse voltage generator

An impulse generator essentially consists of a capacitor which is charged to the required voltage and discharged through a circuit. The circuit parameters can be adjusted to give an impulse voltage of the desired shape. Basic circuit of a single stage impulse generator is shown in Fig. 1, where the capacitor C_s is charged from a dc source until the spark gap G breaks down. The voltage is then impressed upon the object under test of capacitance C_b . The wave shaping resistors R_d and R_e control the front and tail of the impulse voltage available across C_b respectively. Overall, the waveshape is determined by the values of the generator capacitance (C_s) and the load capacitance (C_b), and the wave control resistances R_d and R_e .

For a multistage generator, a group of capacitors are charged in parallel and discharged in series. The switch over of capacitors from a parallel connection to series connection occurs automatically when the intermediate spark gap breaks down after the capacitors are charged to the required potential V_o . The voltage at the generator terminal is $v(t)$ and is equal to $n V_o$ where 'n' is the number of stages.

Equation for the output voltage is given by

$$v(t) = \frac{V_0}{C_b R_d (\alpha - \beta)} (e^{-\alpha t} - e^{-\beta t}) \quad (1)$$

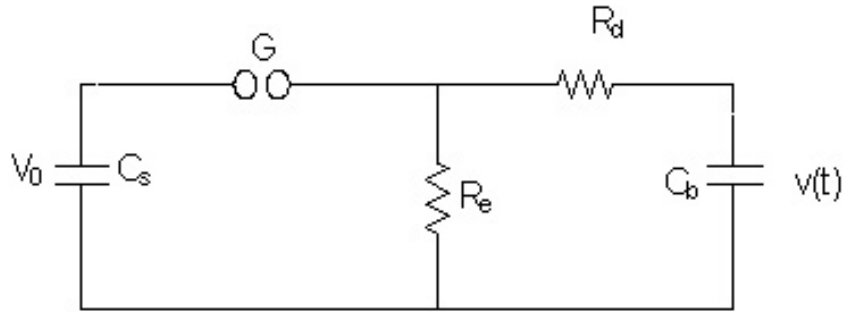


Fig. 1. Basic circuit of single stage impulse generator

Where $v(t)$ - instantaneous output voltage; V_0 - DC charging voltage for the capacitor; α, β - roots of the characteristics equation, which depend on the parameters of the generator.

The exact waveshape, however, will be affected by the line inductance that comes from the physical dimensions of the circuit. Analysis using SIMULINK could become very useful in the proper selection of such components before even assembling them together.

3.1 Numerical analysis of impulse voltage generator

The equivalent circuit of a high voltage multi-stage impulse voltage generator is shown in Fig. 2 and Fig. 3 gives the circuit of a 15 stage impulse voltage generator.

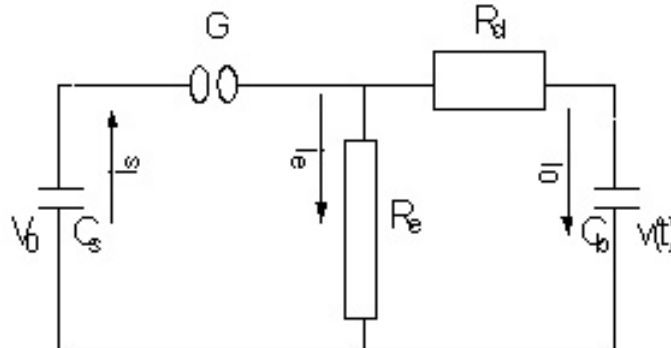


Fig. 2. Equivalent circuit of multi-stage generator

The system equations may be put in the following form.

$$\frac{dV_0}{dt} = \frac{V_0}{C_s R_e} + \frac{i_0}{C_s} \tag{2}$$

$$\frac{dV_0}{dt} = \frac{i_0}{C_b} \tag{3}$$

$$V_0(t_0 + \delta t) = v(t_0) + \delta t \left(\frac{dV_0}{dt} \right)_{t=t_0} \tag{4}$$

$$V_0(t_0 + \delta t) = v(t_0) + \delta t \left(\frac{dv(t)}{dt} \right)_{t=t_0} \tag{5}$$

Values of R_d, R_e, C_s and C_b can be obtained by using the above equations.

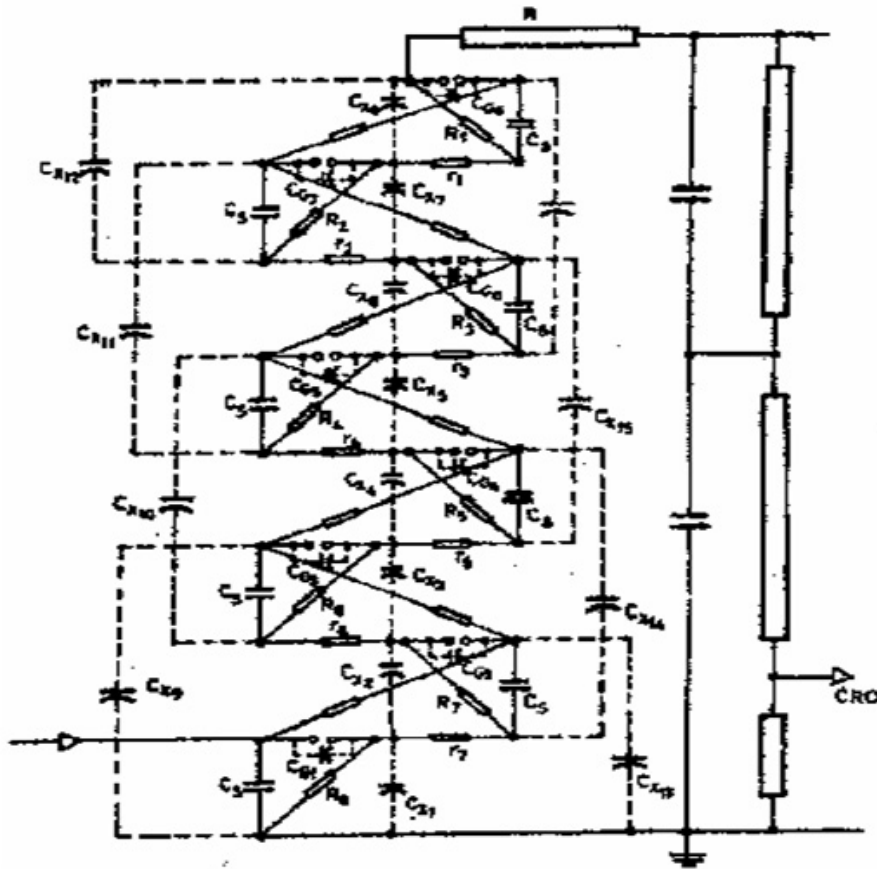


Fig. 3. Multi-stage impulse generator

Fig. 4 shows the developed mathematical model of the impulse generator.

The components of impulse generator can be designed by conventional numerical methods. But it is complicated and time consuming as mentioned earlier. Moreover, the waveforms may not be accurate for the changes in values of components as the conventional solution incorporates a lot of simplification. So it is better to adopt mathematical modelling and computer simulation techniques.

4 Problem associated with impulse generator

In the case of a 15 stages 3MV multi-stage, the capacitors are charged to 200 kV from a regulator and charging supply section. After the capacitors are charged, the first gap G_1 , is triggered from a pulse triggering circuit, which in turn causes a breakdown of all other gaps. To obtain the desired waveform, the choice of R_d and R_e is critical. Changing these high voltage resistors in the laboratory can be inconvenient as the components are too bulky and the processes are too time consuming. Also, the generator has to be triggered each time to obtain the desired output waveform, which at times could become risky for the personnel involved. Hence, modelling of the generator using SIMULINK would be a remedy for the above problems.

5 Modelling and simulation

5.1 Mathematical modelling of impulse generator

The behavior of impulse voltage generator can be represented by differential equations. By simulating the complete system, using its governing equations, the performance can be pre-determined before building the actual system. The following equations represent the system:

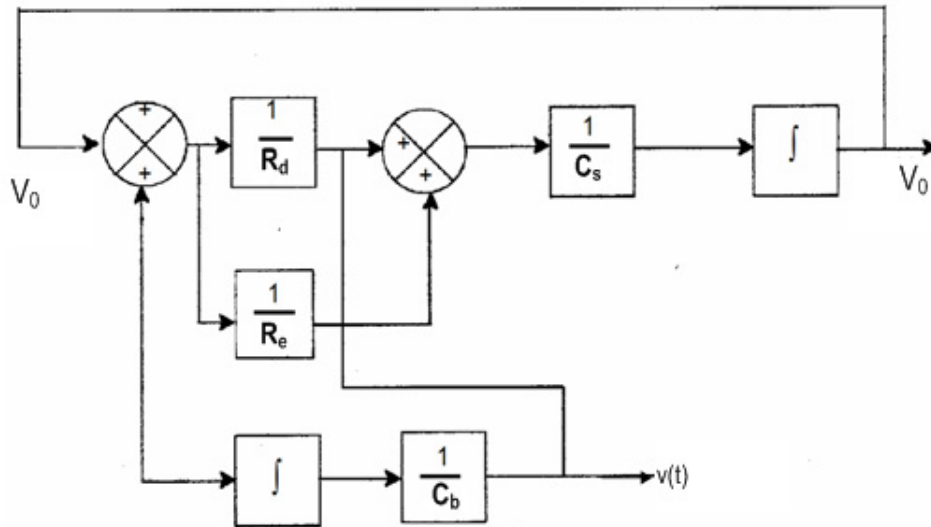


Fig. 4. Block diagram representation of the mathematical model of impulse generator

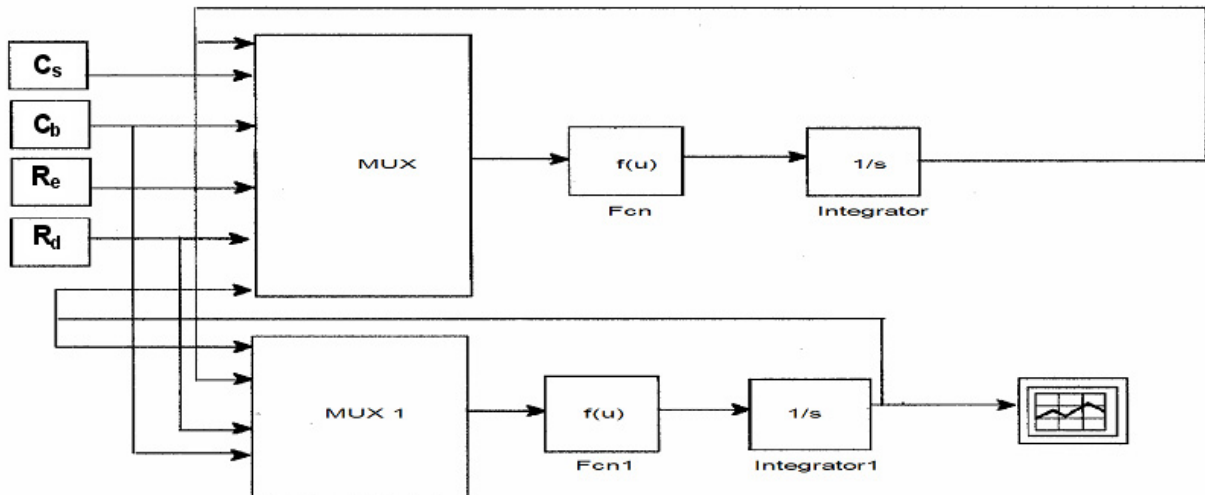


Fig. 5. Simulink model of impulse voltage generator

$$V_0(t) = \frac{1}{C_b R_d} \int (V_0 - v_0(t)) dt + V_0(0) \tag{6}$$

$$i_0(t) = \frac{V_C - V_0(t)}{R_f} \tag{7}$$

To determine the state of the gap, the following variable is defined:

$$A = \begin{cases} 1 & \text{when } G \text{ is conducting} \\ 0 & \text{when } G \text{ is not conducting} \end{cases}$$

The variable *A* stands for the state of active switch (spark gap *G*), and is a binary variable having values either 0 or 1.

5.2 Simulink modelling of the impulse generator

Impulse generator can be modelled by SIMULINK program with standard blocks available in Simulink as shown in Fig. 5. The voltage across the object under test depends on the condition of the active switch

G. When the switch is ON ($A = 1$) the voltage across the test object is given by (6), and when the switch is OFF ($A = 0$) the voltage is zero. The next step in the simulation process is to select the integration step size, t for the simulation. The solution will become more accurate as the step size reduces to small values. However, reduction in solution step size will increase the solution time. In general, the step size will have to be taken much smaller than the natural time periods of the system and the switching time periods employed in the control.

6 Simulation of the model

In a large number of applications, the rise time of the impulse voltage is rather important and therefore, it becomes necessary to determine the effect of wave shaping control elements on the voltage waveform. Different desired outputs can be obtained simply by changing the values of capacitance and resistance. The dependence of the wavefront on the front resistor and load capacitance is observed using SIMULINK.

A word of caution is required about the round-off errors, truncation errors and numerically induced instability due to these errors. However all these problems can be solved by selecting a small step size. Effect of front resistance and load capacitance are studied using SIMULINK and some typical waveforms are shown in Fig. 6.

A comparison between the waveforms obtained using SIMULINK with those derived by methods already reported in literatures [2-9] for the generation of standard, steep front and short tailed impulse waveforms confirmed the validity of the SIMULINK program.

7 Conclusion

A modelling technique has been developed for impulse voltage generator using SIMULINK. Mathematical equations for the elements and the switches of the system are used to construct a SIMULINK dynamic model of the circuit.

In the case of a larger system, it would be possible to break up the overall system into a number of smaller subsystems, simulate and debug each of the subsystems and put together the complete system. This modelling technique could be extended to some other applications in the area of power electronics, power systems, etc.

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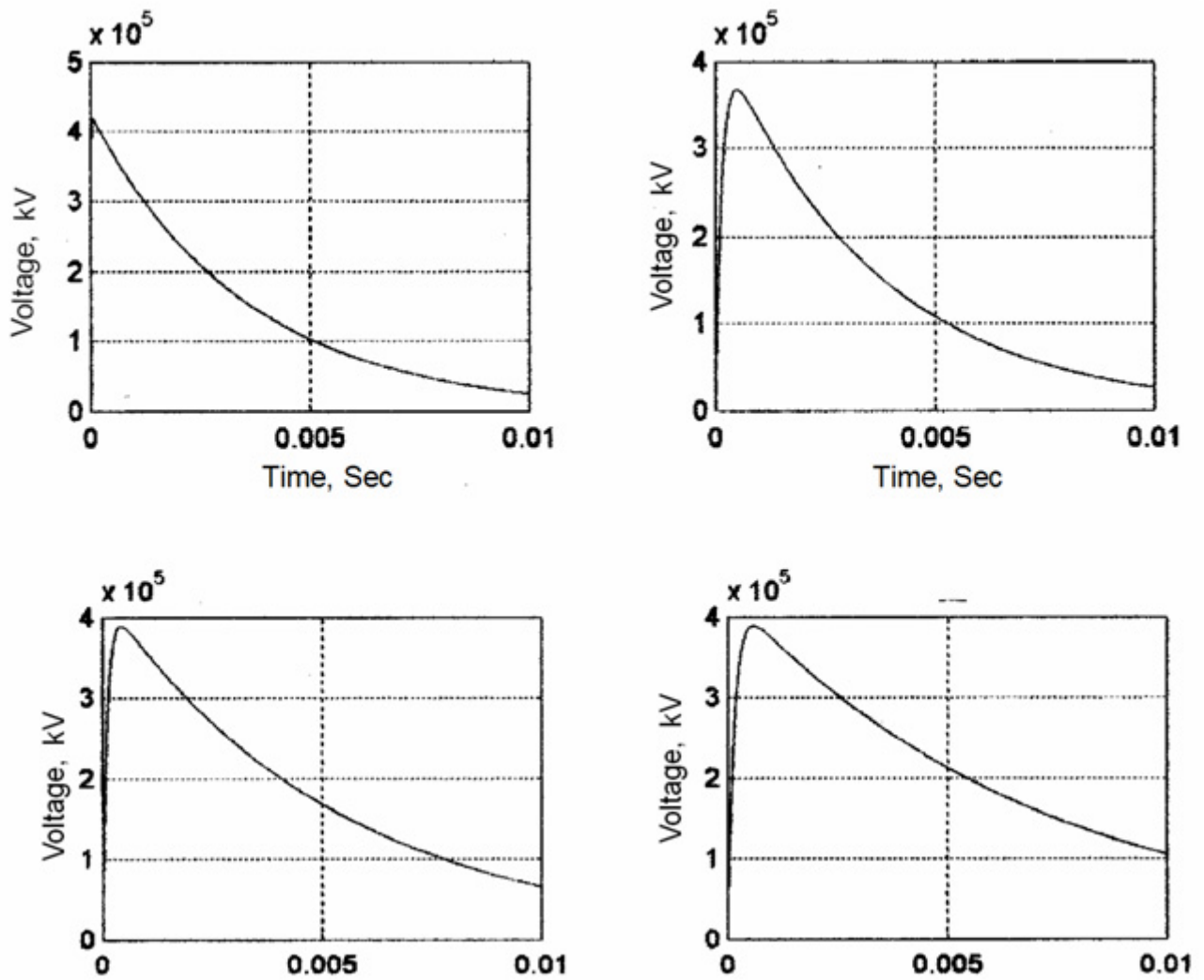


Fig. 6. Simulated impulse waveform

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