ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
(ISRA), Impact Factor: 2.114

IJESRT

INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

SIMULATION OF IMPULSE VOLTAGE TESTING OF POWER TRANSFORMERS USING PSPICE

Lavkesh Patidar *, Hemant Sawarkar
*M. Tech. Scholar Student , Department of Electrical & Electronics Engineering
Assit. Professor , Department of Electrical & Electronics Engineering
J.I.T. Borawan Khargone, India

ABSTRACT

Impulse generator is an indispensible high voltage set. It simulates the voltage due to lightning and switching surges and used for testing of insulation of various electrical equipments like transformer, insulators etc. The standard impulse waveform could be used to test the strength of electrical equipments against the lightning. Lightning characteristics and standard impulse wave form are related to each other. But the lack of realization about relation between them would make the solution to produce better protection against lightning surge becomes harder. Lightning impulse voltage and standard impulse voltage (1.2/50µs) are similar to each other. So, to achieving better protection of high voltage equipment study of impulse voltage waveform is very important. In this paper comparison has been made between standard impulse waveform obtained by simulating Marx impulse generation circuit in Pspice software and practical Marx circuit. This impulse waveform can be used to test the capacity of electrical equipment against the lightning and switching surge voltage.

KEYWORDS: Impulse generator, Pspice software, spark gap, Power transformer, Hardware.

INTRODUCTION

Lightning is an electric discharge that occurs in the atmosphere between clouds or between clouds to ground. Lighting is a natural phenomenon, which generates simple unidirectional double-exponential impulse, which has a significant effect on power transmission system and equipment. Lightning surges induces high voltage of hundreds of kilovolts in the transmission towers and transmission lines. Lighting and switching surges due to transient over voltages cause steep building up of voltage on transmission lines and other electrical apparatus. The voltages are profoundly known as impulse voltage on transmission lines and other electrical apparatus. These voltages/currents are momentary and it is required to test the withstanding strength of the above said power equipments against such conditions. To simulate impulse voltages in the laboratory, we need a test setup for which a marx generator can be used.

STANDARD IMPULSE WAVE SHAPE

Transient over voltages build-up of voltage on transmission line and other electrical investigation showed that these waves have a rising time of 0.5µs to 10 µs and decay time to 50% of the peak value of the order of 30 µs to 200µs. The wave shapes are arbitrary but mostly unidirectional.

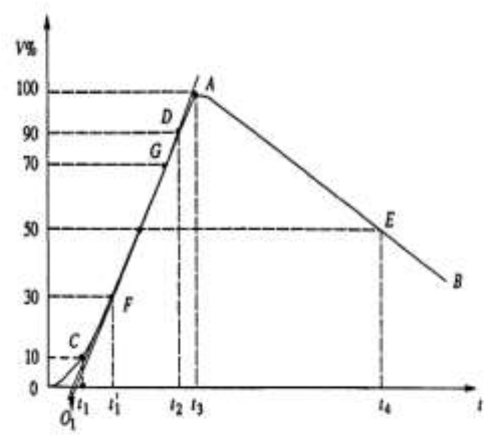

Figure 1: A Standard Impulse Wave

Figure 1 represents a standard impulse wave with T_1 as front or rise time (time taken to reach peak value), T_2 as tail or fall time (time taken to fall 50% of peak value). Indian standard specifications defines

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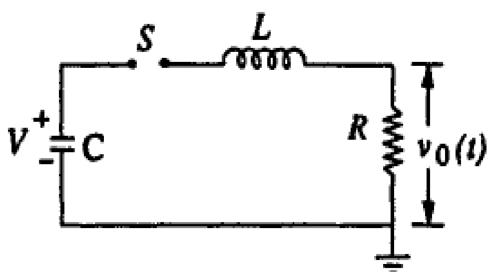
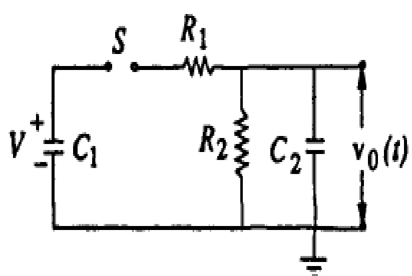
1.2/50μs duration, 1000kV to be standard impulse, Where front time is 1.2 μs with a tolerance of ±30% and a tail time of 50 μs with a tolerance of ±20% for a 1000kV peak value.

CIRCUIT PRODUCE IMPULSE WAVE

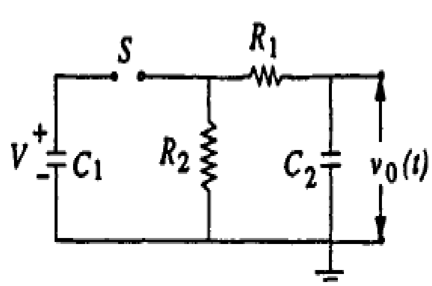
Impulse waves can be produced in the laboratory with a combination of a series R-L-C circuit with over damped conditions or by the combination of two R-C circuits. Various equivalent circuit models that produce impulse waves are shown in Fig. 2(a) to Fig. 2(d). Out of these circuits, the ones shown in Fig. 2(b) and (c) are commonly used experimental purpose. Circuit shown in Fig. 2(a) has some limitations as the front time and tail time over a wide range cannot be varied. Commercial generators circuits shown in Fig. 2(b) to Fig. 2(d).



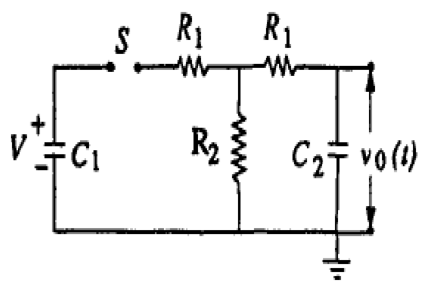
(a)



(b)



(c)



(d)

Figure 2: Circuits for Producing Impulse Waves

A capacitor (C_1 or C) which is previously charged to a constant DC voltage is discharged suddenly into a wave shaping network (LR, $R_1R_2C_2$ or other combination) by turning on switch S. The output voltage V_0(t) gives rise to the desired double exponential impulse wave shape. The impulse generator is designed based on Marx circuit. Fig. 2(b) is a basic single stage Marx generator circuit.

Generally, for a given one stage Marx generator circuit (Fig. 2b) the limiting values of generator capacitance C_1 and load capacitance C_2 varies as depicted in Table1.

Table 1
Limiting Values of C_1/C_2 for Different Standard Wave

T_1/T_2 (μs)	1.2/5	1.2/50	1.2/200	1.2/250
Maximum Ratio (C_1/C_2)	5	40	189.19	6.37

For a lighting impulse voltage wave of 1.2/50 μs, the peak impulse voltage appearing across the test object is higher if the ratios of C_1/C_2 is forty or close to this value. Referring to Fig. 2(b) the desired impulse voltage wave shape of time 1.2/50 μs is obtained by controlling the value of $R_1$and R_2. The following approximate analysis is used to calculate the wave front time T_1 and the wave tail time and T_2. The resistance R_2 is very large. Hence, time taken for charging is approximately three times the time constant of the circuit and is given by the formula given below

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$$T_1 = 3R_1Ce \qquad (1)$$

Here, Ce is given by the following equation:
$Ce = \frac{C1\,C2}{(C1+C2)}$ R_1Ce is the charging time constant in micro-second. For discharging or tail time, the time for 50% discharge is approximately given below.

$$T_2 = 0.7(C_1+C_2)\,(R_1+R_2) \qquad (2)$$

With approximate formulae, the wave front and wave tail can be estimated to within ±20% for the standard impulse waves. Equation (1) can be written as:

$$R_1 = \frac{T1(C1+C2)}{3C1\,C2} \qquad (3)$$

Equation (2) can be written as

$$R_2 = \frac{T2}{0.7(C1+C2)} - R_1 \qquad (4)$$

PRACTICAL SETUP FOR IMPULSE VOLTAGE GENERATOR

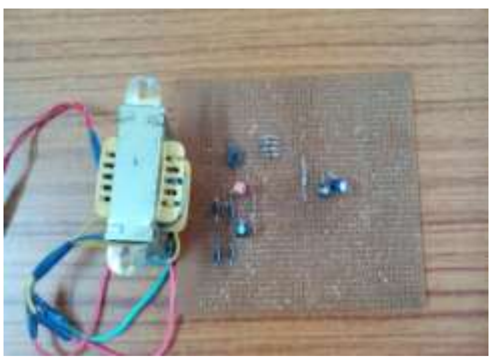

Figure 3: Practical One Stage Marx Generator Circuit

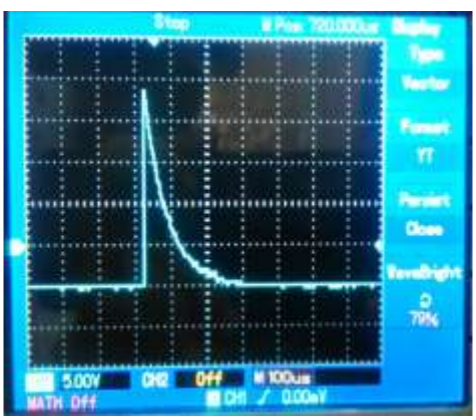

Figure 4: Digital Oscilloscope Output of Practical One Stage Marx Generator

A practical circuit model of one stage Marx Generator circuit is built as shown in Fig.3. The circuit consists of transformer, discharging capacitor C_2 is 1μF, discharging resistor R_2 is 6.3Ω, charging capacitor C_1 is 10μF, damping resistor R_1 is 0.5Ω and switch. Combinations of four 1Ω resistors are connected in parallel and three 2.1Ω resistors connected in series to obtain the resultant 0.5Ω (damping resistor) and 6.3Ω (discharging resistor). Rectifier circuit and wave shaping circuits are indicated by the rectangular portion of the circuit. A 230 V supply is given to the transformer which step downs to 12 V. Then rectifier circuit rectifies 12 V AC (RMS) to 16 V DC which is then supplied to Marx generator circuit. In this circuit sphere gap is replaced by six pin switch which is having two NO contact and two NC contact. Out of these one set of NO and NC contacts are used for simultaneous switching of the circuit.

SIMULATION OF IMPULSE VOLTAGE GENERATOR

In impulse voltage generator circuit, all the components are placed in the Pspice circuit Fig. 4. The capacitor C_1 is charged to 5V DC. To generate a 1.2/50 μs impulse voltage wave, the required parameters are calculated from equation (1). Front time and tail time of the impulse wave are, T_1 is 1.2 μs and T_2 is 50 μs. Hence, maximum value of C_1/C_2 is 40 (From Table 1). Assuming the charging capacitor C_1 to be 10μF and discharging capacitor C_2 as 1μF, such that the ratio of C_1/C_2 will be within the given ratio which is 40. Substituting the value of charging capacitor C_1, discharging capacitor C_2, front time T_1 and tail time T_2 in equation (3) and (4) respectively, the value of damping resistor and discharging resistor are found to be R_1 is 0.44Ω≈ 0.5Ω and R2 is 6.04Ω ≈ 6.2Ω. By simulating the circuit with these parameters the result obtained is as follows.

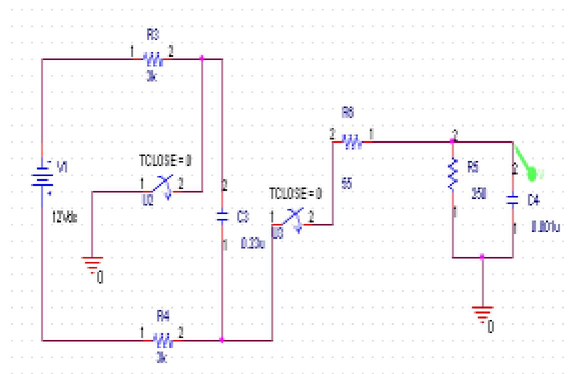

Figure 5: Simulation Circuit for One Stage Marx

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Generator

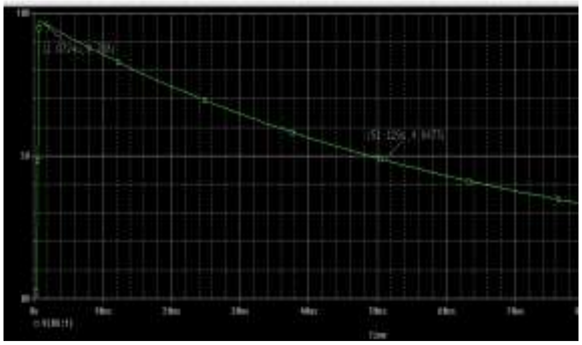

Figure 6: Graph of One Stage Marx Circuit

RESULT

Table 2
Comparison of Results Obtained From Simulated Circuit and Practical Circuit

Simulated data				
Stage	Rise Time (µsec)	Tail Time (µsec)	Peak Voltage (volt)	Efficiency(%)
1	1.072	51.129	9.70	80.8
Experimental data				
1	1	38	9.8	81.6

The data is collected in both the cases and the waveforms are plotted which are shown in Fig. 4 and 6. The values obtained from simulated circuit and practical circuits are different because of the capacitors and resistors used. The tolerances level of resistors used in practical circuit are different from those used in Pspice and the maximum charging voltages in both practical and simulation aren't the same. More over the connection of resistors and capacitors in parallel and series gives an approximate value of what is exactly used in simulation also adds to the errors. Due to these parameters differences have resulted in the two circuits. The ripples produced in the rectifier circuit also contribute in the errors.

In practice all the capacitors are not charged to the same value due to the presence of series resistance in the circuit. In theory any desired output voltage can be obtained simply by increasing the number of stages. But in practice the effect of series resistance between the source and distant capacitor limits the voltage obtainable.

Conclusion

The generation of high impulse voltage is implemented in reduced scale and also in the simulation with the Pspice software environment. It is found that the overall simulated result and the observed impulse voltage result from the experimental setup is close to standard impulse generator 1.2/50µs wave shape for all four stages of Marx generator. The wave shapes are controlled by changing stage front resistor and tail resistor. Rise time is controlled by changing stage front resistor and tail time is controlled by changing tail resistor. The tolerances that is allowed in the front and tail times are respectively ± 30% and ±20 %. Rise time and tail time of impulse voltage wave obtained from simulated data are within tolerance limit, but variation in rise time and fall time of practical Marx circuit is due to following reasons. For obtaining maximum peak voltage the ratio of capacitance of charging capacitor and discharging capacitor is taken 10.

The error in rise time and fall time is because of some tolerance label in damping resistor and discharging resistor. It is also observed that a small change in the resistance value can cause significant change in rise time and fall time of the impulse voltage. In the practical impulse generation circuit model sphere gap is replaced by six pin switch so that all the capacitors are discharged at one instant.

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AUTHOR BIBLOGRAPHY

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J.I.T. Borawan Khargone, India