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Performance of a Multi-Stage Impulse Generator

(Marx Generator)

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***Abstract*- An impulse generator is an electrical apparatus which produces very short high-voltage or high-current surges. Such devices can be classified into two types: impulse voltage generators and impulse current generators. High impulse voltages are used to test the strength of electric power equipment against lightning and switching surges. Also, steep-front impulse voltages are sometimes used in nuclear physics experiments. High impulse currents are needed not only for tests on equipment such as lightning arresters and fuses but also for many other technical applications such as lasers, thermonuclear fusion, and plasma devices. Impulse voltage generators consists of multiple capacitors that are first charged in parallel through charging resistors by a high-voltage, direct-current source and then connected in series and discharged through a test object by a simultaneous spark-over of the spark gaps. In this paper an attempt has been made to evaluate the performance of a practical Eight-stage Impulse Generator with the simulated model. Simulation has been done using SIMPLORER software. The results of simulation have been compared with the hardware and found to be in coincidence.**

1 INTRODUCTION

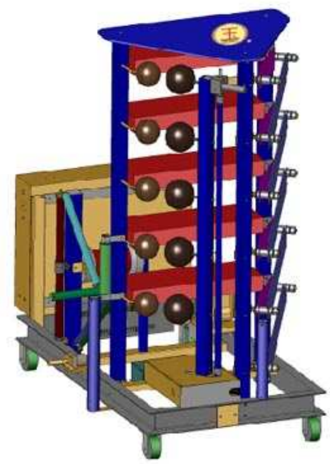
In the fields of electrical engineering, high Voltages are required for several applications. High A.C. voltages at one million volts or even more are required for testing Power apparatus rated for extras high transmission voltages(400KV and above).

High impulse voltages of the order of 2MV and above are required for testing purpose to simulate over voltages that occur in power systems due to lightening and switching action.

Depending upon the duration of the wave, impulses are divided into three types.

- Impulse voltage of short duration such as lightning over voltages
- Impulse voltage of longer duration such as switching surge
- Oscillatory voltages

International Electro technical 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 wave shape 250/2500 µs.



2 STANDARD IMPULSE WAVE SHAPES

Transient over voltages due to lighting and switching surges cause steep build-up of voltage on transmission lines and other electrical apparatus. Experimental investigations showed that these waves have a rise time of 0.5 to 10 us and decay time to 50% of the peak value of the order of 30 to 200 us. The wave shapes are arbitrary, but mostly unidirectional. It is shown that lightning over voltage wave can be represented as double exponential waves defined by the equation.

$$V=V_o\,[\exp(-\alpha t) - \exp(-\beta t)]$$

Where α and β are constants

The above equation represents a unidirectional wave which usually has a rapid rise to the peak value and slowly falls to zero value. The general wave shapes is given in fig.2.1. Impulse waves are specified by defining their rise or front time, fall or tail time to 50% peak value, and the value of the peak voltage.

Peak value (U_{max}): Maximum voltage of the impulse.

Front Time (T_{front} (μs)): Time between Start and the Maximum value of the impulse.

Half-Value Time ($T_{half\ value}$ (μs)): The moment, where the impulse reach 0.5 U_{max} at the decreasing part of the curveT

Thus 1.2/50 us, 1000 KV wave represents an impulse voltage wave with a front time of 1.2 us, fall time to 50% peak value of 50 us, and a peak value of 1000 KV. When impulse wave shapes are recorded, the initial portion of the wave may not be clearly defined or sometimes may be missing. Moreover, due to disturbances it may contain superimposed

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oscillations in the rising portion. Hence, the front and tail times have to be redefined.

3.1 IMPULSE WAVEFORM DEFINITIONS

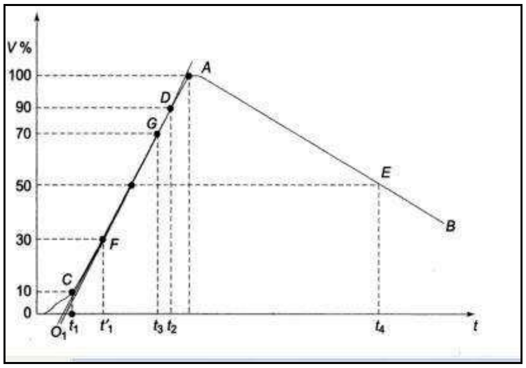

Fig 1: Impulse waveform and its definitions

Referring to the wave shape in Fig 1:

- The peak value A is fixed and referred to as 100% value.
- The points corresponding to 10%(point c) and 90%(point D) of the peak values are located in the front portion. The line joining these points is extended to cut the time axis at O_1. O_1 is taken as the virtual origin.
- 1.25 times the interval between times t_1 and t_2 corresponding to points C and D (Projections on the time axis) is defined as the front time,
- ***Front time=1.25 ($O_1t_2 – O_1t_1$).***
- The point E is located on the wave tail corresponding to 50% of the peak value, and its projection on the time axis is t_4. ***Fall time or Tail Time=O_1 t_4***
- In case the point C is not clear or missing from the wave shape record, the point corresponding to 30% peak value F is taken and its projection t1 is located on time axis. The wave front time in that case will be defined as

1.67$O_1t_3 – O_1t_1$).

Limitations for wave front and tail times:

Front Time : Ts = 1.2us ±30%
Time to Half-value: T r = 50us ±20%
Overshoot : Ü ≤50%
Undershoot: U ≥5%

4 IMPULSE VOLTAGE GENERATORS

An impulse generator essentially consists of a capacitor which is charged to the required voltage and discharged through a circuit. The waveform, Fig.1, is the standard 1.2/50µs duration with the peak voltage reached in 1.2µs(T1) and the tail of the wave decaying to a level of 50 percent of the peak in 50µs(T2). 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.2, where the capacitor Cs 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 Cb. The waveshaping resistors Rd and Re control the front and tail of the impulse voltage available across Cb respectively.

Overall, the wave shape is determined by the values of the generator capacitance(Cs) and the load capacitance (Cb) , and the wave control resistances Rd and Re.

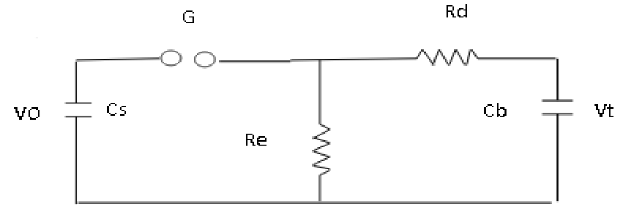

Fig. 2. Basic circuit of single stage impulse generator

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

5 MULTI STAGE IMPULSE GENERATORS

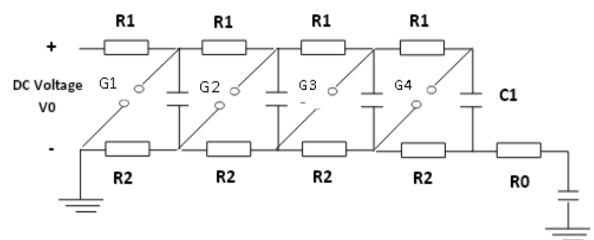

Fig. 3. Equivalent circuit of Multi-stage impulse generator

Fig 3 shows Marx Circuit Arrangement For Multi Stage Impulse Generators. A Marx Generator is a clever way of charging a number of capacitors in parallel, then discharging them in series. Originally described by E. Marx in 1924, Marx generators are probably the most common way of generating high voltage impulses for testing when the voltage level required is higher than available charging supply voltages. Furthermore, above about 200 kV, the discharge capacitor becomes very expensive and bulky.

5.1 WORKING

The charging voltage is applied to the system. The stage capacitors charge through the charging resistors (R_c). When fully charged, either the lowest gap is allowed to breakdown from overvoltage or it is triggered by an external source (if the gap spacing is set greater than the charging voltage breakdown spacing). This effectively puts the bottom two capacitors in series, over voltaging the next gap up, which then puts the bottom three capacitors in series, which over voltages the next gap, and so forth. This process is referred to as "erecting". A common specification is the erected capacitance of the bank, equal to the stage capacitance divided by the number of stages.

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The charging resistors are chosen to provide a typical charging time constant of several seconds. A typical charging current would be in the 50-100 mA range. The charging resistors also provide a current path to keep the arc in the spark gaps alive, and so, should be chosen to provide a current of 5-10 amps through the gap. The resistors are sometimes called "feed forward" resistors for this reason. The discharge through the charging resistors sets an upper bound on the impulse fall time, although usually, the impulse fall time is set by external resistors in parallel with the load .

5.2 EXTENSION

It is often required to test transformer with high energy, for which the existing impulse voltage test generator may not been originally meant. In such cases it is necessary to utilize all reserves of the existing impulse voltage test generator.

- Increasing the effective impulse capacitance.
- Increasing the parallel resistors
- Decreasing the damping of the test circuit

6 COMPUTER SIMULATION

A computer simulation attempts to simulate an abstract model of a particular system. Computer simulations have become a useful part of mathematical modeling of many natural systems.

In the design of multi stage impulse voltage generators, 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 wave shape, with a given source and loading conditions. The loading can be inductive (as in case of transformers) or capacitive (as in case of insulators). The wave shapes to be produced may be standard impulse, steep fronted impulse, short tailed impulse or steep front short tailed impulse.

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.

6.1 CALCULATION OF PARAMETERS FOR EIGHT STAGE IMPULSE GENERATOR

The expression for output voltage is given by:

$V = V_0 (\exp(-at) - \exp(-bt))$

WHILE CHARGING C_2, EFFECT OF R_2 IS NEGLECTED

$T1 = 3.\ R_1.\ C_1C_2/ (C_1+C_2)$

$R1 = T_1.\ (C_1+C_2)/ (3\ C_1C_2)$ ---------(1)

WHILE DISCHARGING C_1, C_2, EFFECT OF R_1 COMBINED WITH R_2

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

$R_2 = T_2 / (0.7\ (C_1+C_2))\ R_1$ ----------(2)

Efficiency of Impulse generator is

$\eta=1 / [1+ [(1+ R_1/R_2)\ (C_2/C_1)]]$

For the 8 stage generator

C_1= Generator Capacitance = 0.128uf

Equivalent Capacitance C_1 =0.016uf

C_2 = Load Capacitance = 1000pf

For 1.2/50uS Wave shape the values of R_1 and R_2 are

Where T_1 = 1.2uS, T_2 = 50uS

Series Resistance

$R_1= [1.2\ \mu * (0.016\ \mu+0.001\ \mu)] / [3*0.016\ \mu*0.001\ \mu]$

$R_1 = 425\Omega$

Shunt resistance

$R_2= \{[50\ \mu] / [0.7*(0.016\ \mu+0.001\ \mu)]\}-425$

$R_2=3775\ \Omega$

For 250/2500uS Wave Shape the values of R_1 and R_2

Where T_1=250uS, T_2=2500uS

Series Resistance

$R_1=[250\ \mu *(0.016\ \mu+0.001\ \mu)] / [3*0.016\ \mu*0.001\ \mu]$

$R_1 = 88540\Omega$

Shunt resistance

$R_2= \{[2500\ \mu] / [0.7*(0.016\ \mu+0.001\ \mu)]\}-88541.66$

$R_2=121550\ \Omega$

6.2 SIMULATION OF EIGHT STAGE IMPULSE GENERATOR:

The impulse generator was simulated using SIMPLORER software. The schematic of the simulated generator is shown in Figure4.9. The stage sphere gaps were simulated by the use of switches, as shown. The output of the generator was also switched. Stage capacitor was given an initial charge voltage value. The values of front and tail resistors were changed in order to get exact value of the impulse wave within less 5% variation.

The equivalent circuit of impulse generator is shown in fig:

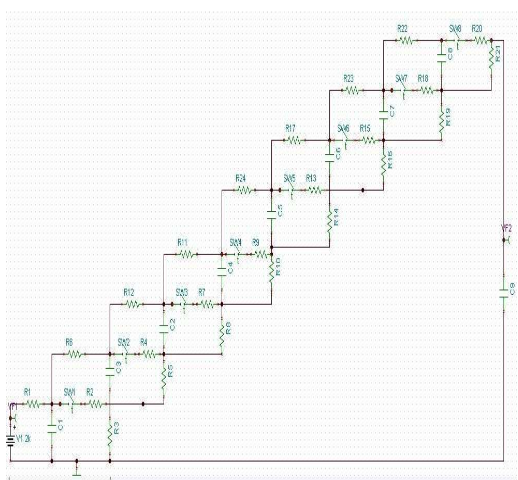

Fig 4: Simulation Model of eight stage impulse generator

6.3 WAVES FORMS OF THE SIMULATED CIRCUIT

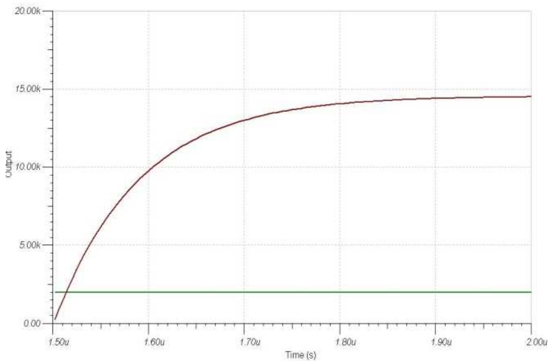

Fig 5 : Front time of 1.2/50uS Wave form

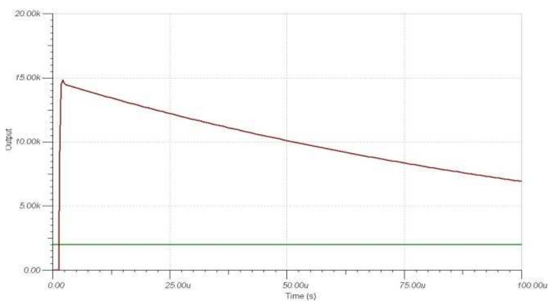

Fig 6 : Tail time of 1.2/50uS Wave form

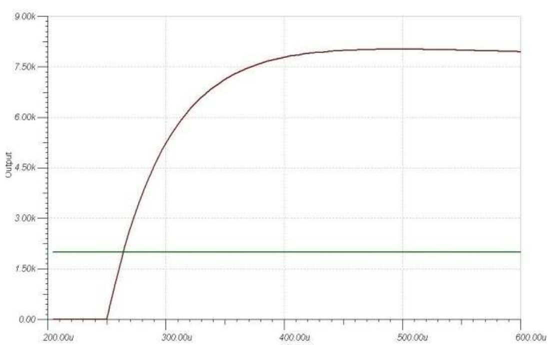

Fig 7: Front time of 250/2500uS Wave form

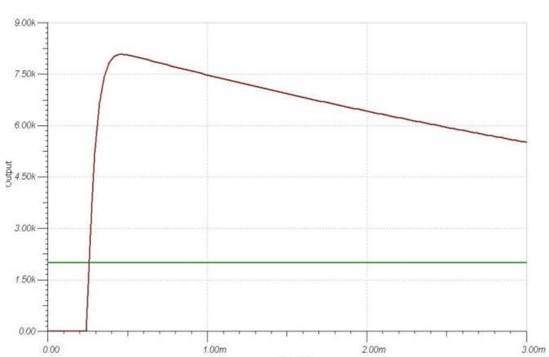

Fig 8: Tail time of 250/2500uS Wave form

6 DESIGN & FABRICATION

An eight stage impulse generator requires several components for flexibility and for the production of the required wave shape. These may be grouped as follows:

DC CHARGING SET:

The charging unit should be capable of giving a variable dc voltage of either polarity to charge the generator capacitors to the required value.

CHARGING RESISTOR:

These are non inductive resistor of about 300 kilo-ohms and 120watts. Each resistor is chosen to have a maximum voltage of 425V to give a time constant of 300mSec and for a maximum charging current of 13.3mA.

GENERATOR CAPACITOR AND SPARKGAP:

The output peak voltage of the impulse generator is typically measured by using sphere gaps. The spheres are of standard dimensions. The most commonly used is a diameter of 25 cm to 100cm. One of the spheres is connected to front and tail resistors, and the other is connected to the high voltage side of the impulse generator. The relative humidity and temperature of the test cell at the time of test determines the required gap for a given voltage level.

Setting the gap of the spheres based on the voltage level and factors of relative humidity and laboratory temperature will produce a breakdown at a known voltage across the gap. In this arrangement, the oscilloscope is utilized with the divider to record the Spark over voltage.

The parameters of the model generator chosen for single stage: C1=1uF and C2=0.065uF.

WAVE SHAPE RESISTORS:

Resistors used are non-inductive wire wound resistors. They are capable of discharging impulse currents of 2A.Modern impulse generators have their wave shaping resistors included internally with a flexibility to add additional resistors outside, when the generators capacitance is changed and are rated for few KA and energy rating of few KWSec (KJ).

Eight stage: C1=0.128uF and C2=0.001uF

VOLTAGE DIVIDER

The voltage divider is used to reduce the level of the voltage to a measurable value and generally consists of two resistances, capacitance or CR combined in series. The two impedances result in a fraction of the total voltage across the lower leg impedance. The lower value impedance normally referred to as the lower leg, will have a voltage that is the input to the measurement instrument.

This divider used has a high voltage resistor value of 2100Ω and a lower leg value of 2Ω. This results in a ratio of 1050:1 with output impedance to the oscilloscope of 75Ω. It is important to match the characteristic impedance of the coaxial cable connection to the scope at both ends. This eliminates

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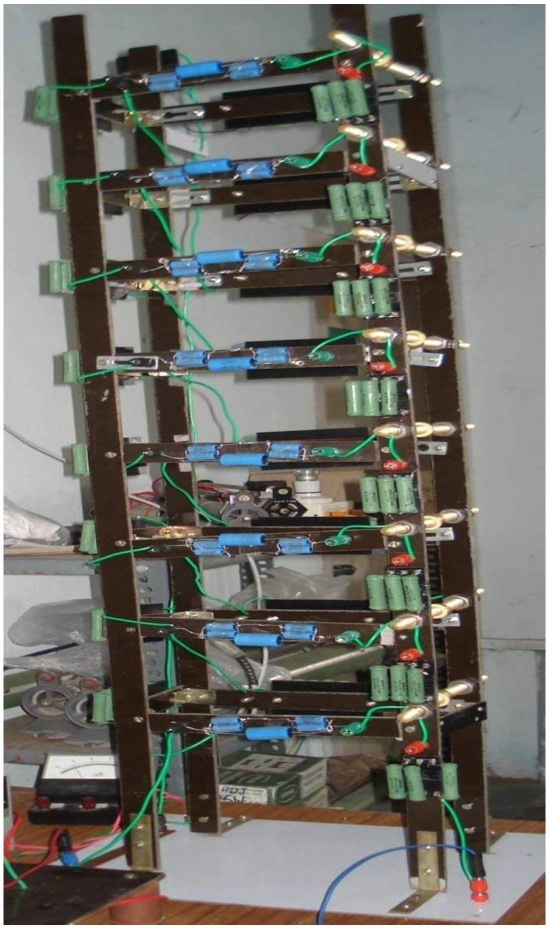
reflection waves and distortion of the signal. To decrease the amount of transmission line distortion, the length of coaxial cable between the divider and the CRO should be kept as short as possible.

For single stage switching generator as such a 2ohm resistor can be used with 2100ohm to give an exact ratio of 1050:1.

6.1 COMPARISON OF RESULTS

FRONT /TAIL TIMES	PRACTICAL RESULTS	SIMULATION RESULTS
1.2/50uS	R1= 6.5Ω	R1=6 Ω
	R2=59Ω	R2=60 Ω
250/2500uS	R1=1360 Ω	R1=1275 Ω
	R2=1915 Ω	R2=1811 Ω



8 REFERENCES

[1] High Voltage Engineering. Fundamentals. Second edition. ... E. Kuffel, W.S. Zaengl and J. Kuffel 2000

[2] MS Naidu and V. Kamaraju, High Voltage Engineering, Tata mcgraw Hill, 2001

[3] CL Wadhwa, High Voltage Engineering, Wiley Eastern Ltd., 1994 .

[4] HAEFELY Circuit design of impulse generators for the lightning impulse voltage testing of transformers by K FESAR

[5] MARX GENERATORS from http://home.earthlink.net/~jimlux/hv/marx.html

[6] Impulse voltage test of power transformers paper submitted by W.SCHRADA , W. SCHUFFT from Chemnitz university of technology, Germany in HV Testing Monitoring Diagnostics Workshop.