DESIGN OF AN IMPULSE GENERATOR

By

Mustakim Refat (1006046)

Anik Das (1006083)

Mehedi Hassan Khan (1006120)

Saiful Islam Sajol (1006187)

Bachelor of Science

In

Electrical and Electronic Engineering

Bangladesh University of Engineering and Technology (BUET)

Dhaka, Bangladesh, 1000

February, 2016

DECLARATION

This thesis titled "**Design of an Impulse Generator**" is a presentation of our original research work. this thesis was done in partial fulfillment of the requirement for the degree of Bachelor of Science in Electrical and Electronic Engineering on February,2016.

The work has been carried out under the supervision of **Dr. Mohammad Jahangir Alam**, Professor, Department of Electrical and Engineering, Bangladesh University of Engineering and Technology (BUET), Dhaka, Bangladesh.

Signature of the Supervisor

____

Dr. Mohammad Jahangir Alam

Professor

Department of Electrical and Engineering

Bangladesh University of Engineering and Technology (BUET)

Dhaka, Bangladesh

Signature of the Authors

____

Mustakim Refat(1006046)

____

Anik Das(1006083)

____

Mehedi Hassan Khan(1006120)

____

Saiful Islam Sajol(1006187)

DEDICATION

To Our Parents and Teachers

ACKNOWLEDGEMENT

We, the authors would like to express our heartiest gratitude to **Dr. Mohammad Jahangir Alam**, Professor, Department of Electrical and Engineering, Bangladesh University of Engineering and Technology (BUET), Dhaka, Bangladesh for his encouragement, guidance and close supervision throughout the work. It was a privilege for us to learn and work under his supervision. Successful accomplishment of our thesis would be impossible without his eagerness to help and provide with valuable suggestions and support. We are also grateful to Mr. Sanaullah of Power Electronics Lab.

The authors also like to appreciate the advice of many friends and others who directly or indirectly helped in performing the work.

ABSTRACT

Lightning strokes and switching operations leave us with a travelling wave of very steep wavefront. They are termed as Impulse Waveshapes. High voltage impulse waveshape causes non-uniform voltage distribution throughout the winding resulting in winding insulation puncture. Hence, before introducing the power instruments (Transformers, Reactors) to the market, they need to be tested in the laboratory whether or not they can withstand the abrupt impulse voltage. In order to generate the specific type of impulse waveshape we need to construct a device named impulse generator. We worked on the construction of a scaled down impulse generator prototype.

CHAPTER 1

INTRODUCTION:

1.1 Lightning

Lightning is a high-frequency electrical phenomenon which causes overvoltage on all conductive items, especially on electrical cabling and equipments like transformers and reactors. Lightning voltage has such a high steep rise they can be compared to impulse voltage.

1.2 Effect on Transmission Line:

A direct lightning strike on a conductor of a power line causes extremely high voltage pulses at the strike point, which are propagated as travelling waves in either direction from the point of strike. This voltage amplitude can be of 2MV and the current amplitude can be of 5000KA.

1.3 Effect on Transformer:

Power transformers are designed for power frequency operation. As lightning is a high frequency phenomenon, the response of transformers will be a different one for voltage with such a high steep rise. Actually the inter turn capacitance and shunt capacitance dominates under impulse voltage applied on a transformer. Voltage distribution within different sections of transformer windings will be non-uniform. Actually 60% of the peak voltage will appear across 10% of the windings. Eventually its insulation will be punctured and winding to winding insulation will be broken down. If the voltage still sustains, the next 10% of the windings will fall down and the following parts will fall down in a similar manner until the lightning voltage diminishes.

1.4 Motivation:

Lightning arrester is used on top of a transformer. Still some lightning can fall on transformer. So we need to test them under such impulse waveshapes. For this purpose, we need to build such instrument which can provide us with such waveshapes, this particular instrument is known as Impulse generator.

We work on building a prototype of impulse generator which will take 12-15V DC voltage as input and delivers a desired steep impulse waveshape.

CHAPTER 2

SOURCES OF IMPULSE WAVESHAPE

2.1 Overvoltage

The voltage stresses on transmission network insulation are found to have a variety of origins. In normal operation AC (or DC) voltages do not stress the insulation severely. Overvoltage stressing a power system can be classified into two main types:

1. External Overvoltage: Generated by atmospheric disturbances. Among these disturbances, lightning is the most common and most severe.

2. Internal Overvoltage: Generated by changes in the operating conditions of the network. Internal overvoltages can be divided into a) Switching Overvoltage b) Temporary Overvoltage

2.2 Lightning Overvoltage

Lightning overvoltage is originated by lightning strokes hitting the phase wires of overhead lines or the busbars of outdoor substations. The amplitudes are very high, usually in the order of 1000kV or more, as every stroke may inject lighning current upto 100kA. Each stroke is then followed by a travelling wave whose amplitude is often limited by the maximum insulation strength of the overhead line. The rate of voltage rise of such a travelling wave is directly proportional to the steepness of the lightning current, which may exceed 100kA/μsec and the voltage levels may simply be calculated by the current multiplied by the effective surge impedence of the line. Too high voltage levels are immediately chopped by the breakdown of insulation and therefore travelling waves with steep wave fronts and even steeper wave tails may stress the insulation of power transformers or other high voltage equipment severely.

2.2.1 Lightning Phenomena

1. Creation of charges in the thunder cloud

Winds inside the cloud are very turbulant. Water droplets are caught in the updraft and lifted to great heights where they are freezed. Meanwhile, downdraft in the cloud pushes the iced droplets down from the top of the cloud. Iced droplets going down meet the water droplets coming up and consequently electrons are stripped off.

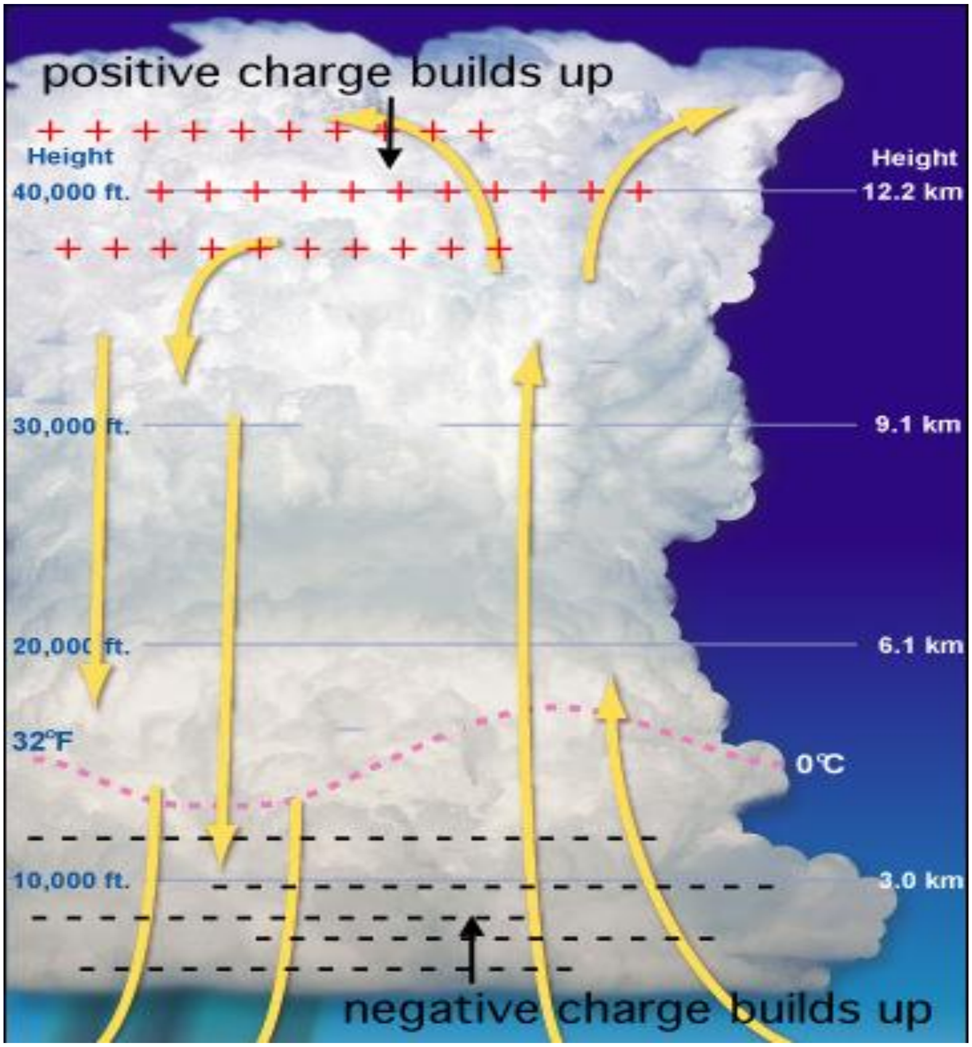


Fig 2.1: Charge seperation in thunder cloud

The frozen portion of the droplets with their negative charge tend to gravitate toward the bottom of the cloud. The upper portion of the cloud is positive. Thus the creation of charged particles are hapened inside the cloud.

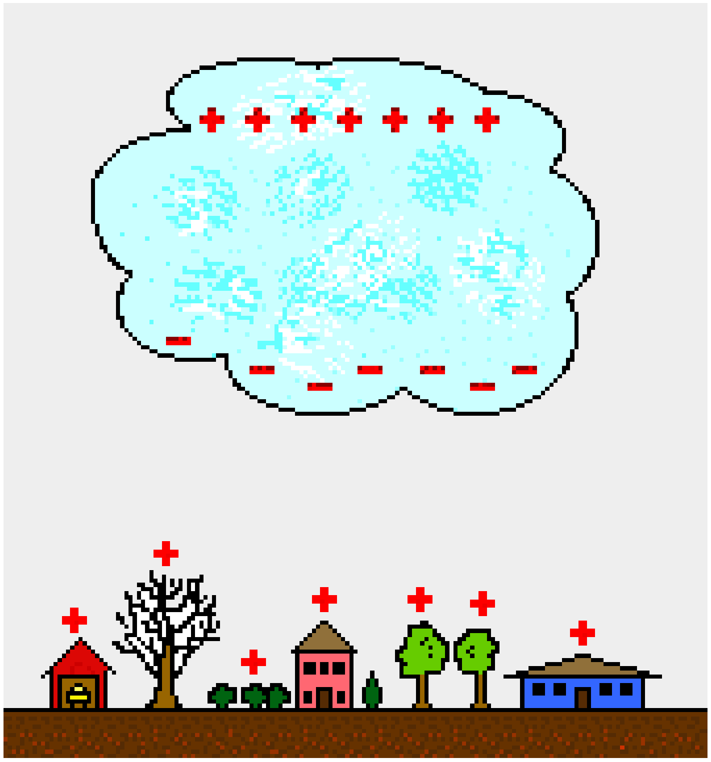


Fig 2.2 : Charge induction in Ground

As more and more negative charges are accumulated in the lower portion of the cloud, they induce positive charges in the upper surface of the ground. The air atmosphere works as an insulation between cloud and ground. Electric field due to built up charges tends to increase gradually until it reaches a breakdown limit for the insulation. Only a part of the total charge (several hundred coulombs) is released to earth by lightning and the rest is consumed in inter-cloud discharges.

2. Channel to Earth

Channel to earth is established by stepped discharge called leader stroke. Leader is first initiated by breakdown between water droplets which is basically discharge between negative charges in the bottom of the cloud and positive charge pocket below it.

Fig 2.3: Stepped Leader

As the downward leader approaches the earth, an upward streamer approaches from the ground before the former reached the earth. There is a point where they meet with each other. This point is called striking point. When the leader stroke and positive charge from the ground meet, a strong electric current carries the positive charge up.

Fig 2.4: Upward Streamer

into the cloud. It is called the return stroke. The current associated with the return stroke is responsible for the known damage of the lightning. The high current causes temperature rise and it leads to rapid air expansion which is known as thunder.

Fig 2.5 : Return Stroke

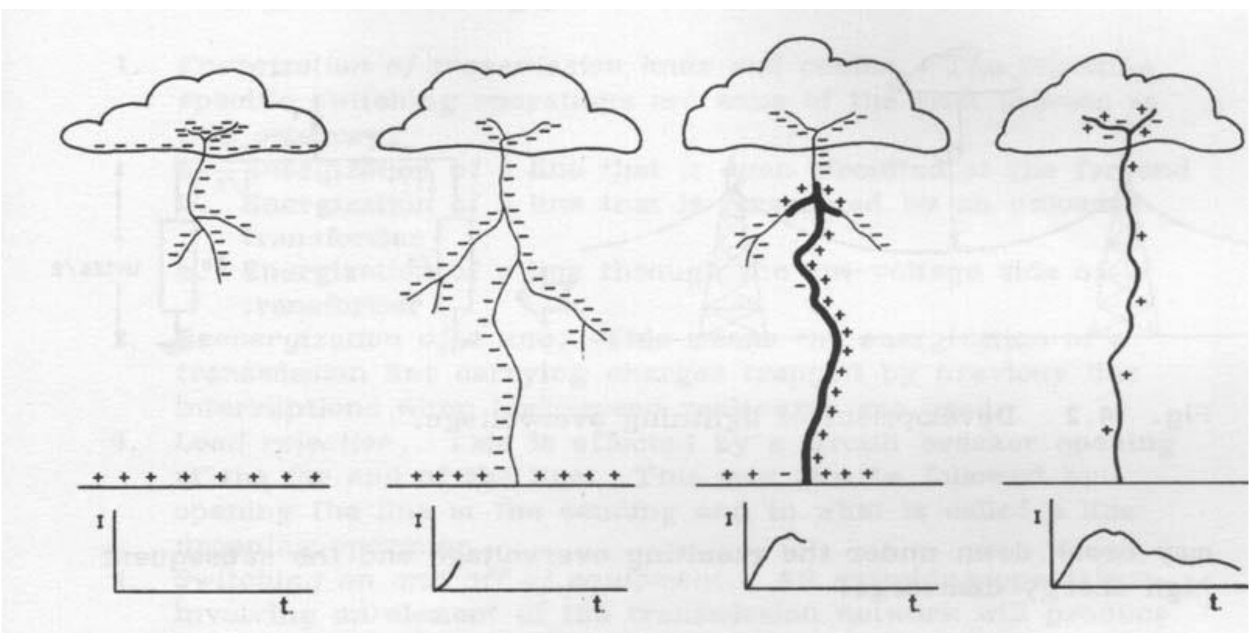


Fig 2.6: Development stages of a lightning flash and the corresponding current surge

2.2.2 Features of Lighning Protection

a. Air Terminal

b. Conductors

c. Ground Termination

d. Surge Protection

2.2.3 Lightning Voltage Surges

The most severe lightning stroke is that which strikes a phase conductor on the transmission line impedence Z, which in this case is half the line surge impedence Z_0 since the current will flow in both directions as shown in Figure 1.6. Therefore the voltage surge magnitude at the striking point is

$V=(1/2)IZ_0$ ....(1)

Lightning surge voltage will probably have a magnitude in excess of 1500kV.

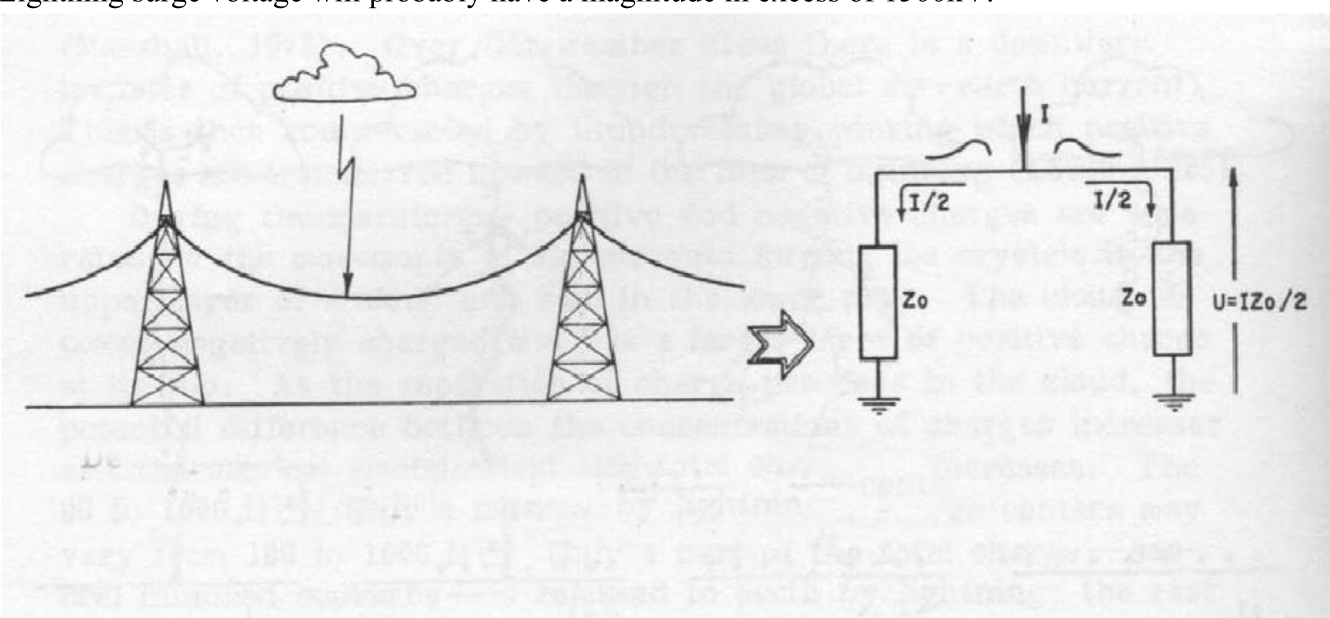


Figure 2.7: Lightning Model Impedence

2.3 Switching Overvoltage

The second kind of overvoltage is switching overvoltage. Their amplitudes are always related to the operating voltage and the shape is influenced by the impedences of the system as well as by the switching condition. The rate of voltage rise is usually slower, but it is well known that the wave shape can also be very dangerous to different insulation systems, especially to atmospheric air insulations in transmission system with voltage levels higher than 245kV.

With the increase in transmission voltage needed to fulfill the required increase in transmitted powers, switching surges have become the governing factor in the design of insulation for EHV and UHV system. In the meantime, lightning overvoltage come as a secondary factor in this networks.

There are two fundamental reasons for this shift in relative importance from lightning to switching surges as higher transmission voltages are called for:

1. Overvoltages produced on transmission lines by lightning strokes are

only slightly dependent on the power system voltage. As a result, their magnitude relative to the system peak voltage decreases as the latter is increased.

2. External insulation has its lowest breakdown strength under surges whose fronts fall in the range 50-500µsec, which is typically for switching surges.

3. According to International Electro-Technical Commission (IEC) recommendations, all equipments designed for operating voltages above 300kV should be tested under switching impulse.

2.3.1 Origin of Switching overvoltages

There is a great variety of events that would initiate a switching surge in a power network. The switching operations of greatest relevance to insulation design can be classified as follows:

1. *Energization of transmission lines and cables:*

The following specific switching operations are some of the most common in this category

a. Energization of a line that is open circuited at the far end

b. Energization of a line that is terminated by an unloaded Transformer

c. Energization of a line through the low voltage side of Transormer

2. *Re-Energization of a line:*

This means the energization of transmission line carrying charges trapped by previous line interruptions when high speed reclosures are used.

3. *Load rejection:*

This is affected by a circuit breaker opening at the far end of the line. This may also be followed by opening the line at the sending end in what is called a line dropping operation.

4. *Switching on and off of equipment:*

All switching operations involving an element of the transmission network will produce a switching surge.

a. Switching of high voltage reactor

b. Switching of transformers that are loaded by a reactor on their tertiary winding

c. Switching of a transformer at no load

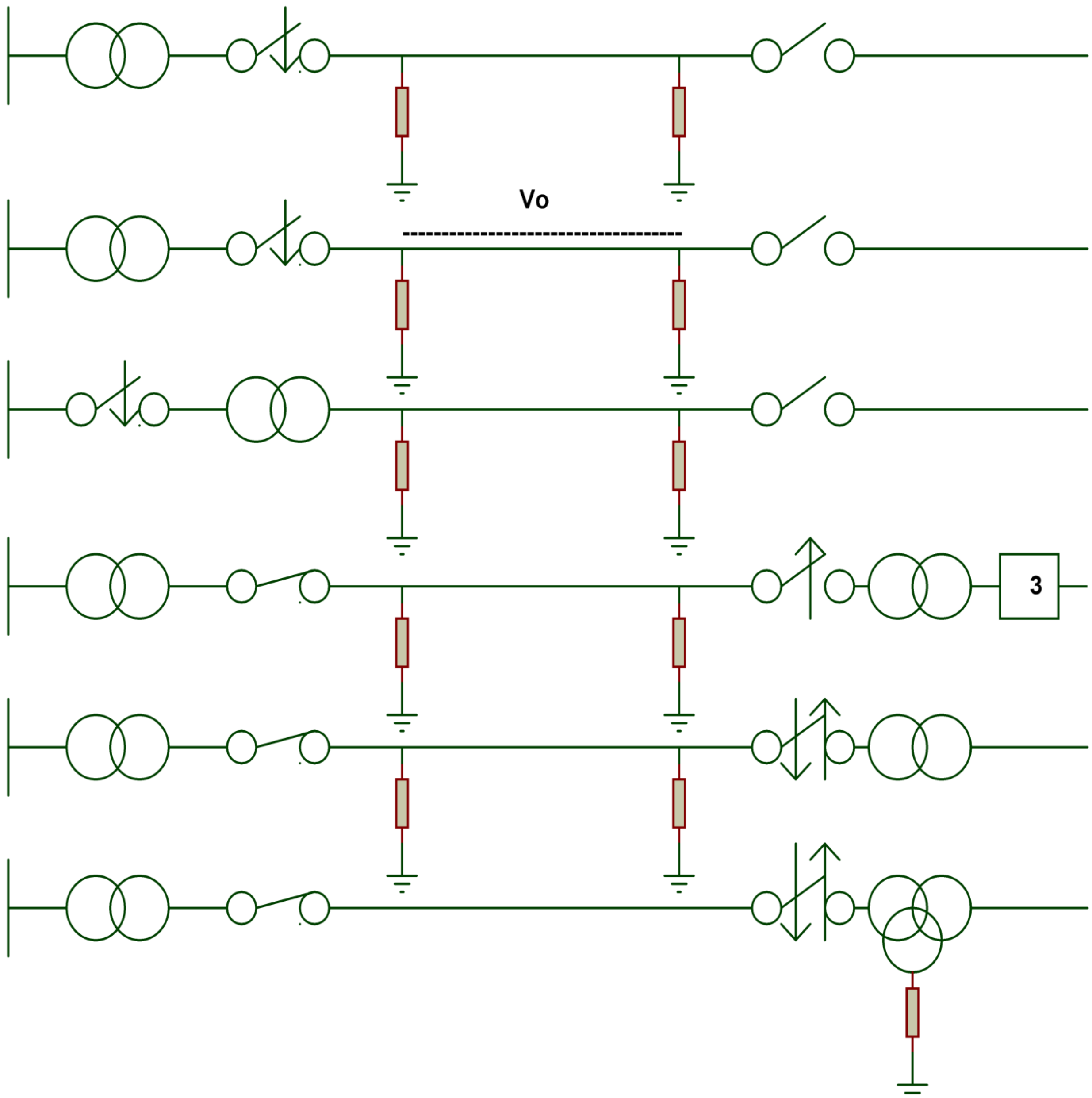


Fig 2.8: Different switching operation responsible for Switching Surge

2.3.2 Energization of an unloaded transmission line

- When an unloaded transmission line is switched on the sinusoidal supply voltage is suddenly applied to it as represented by the following single phase circuit:

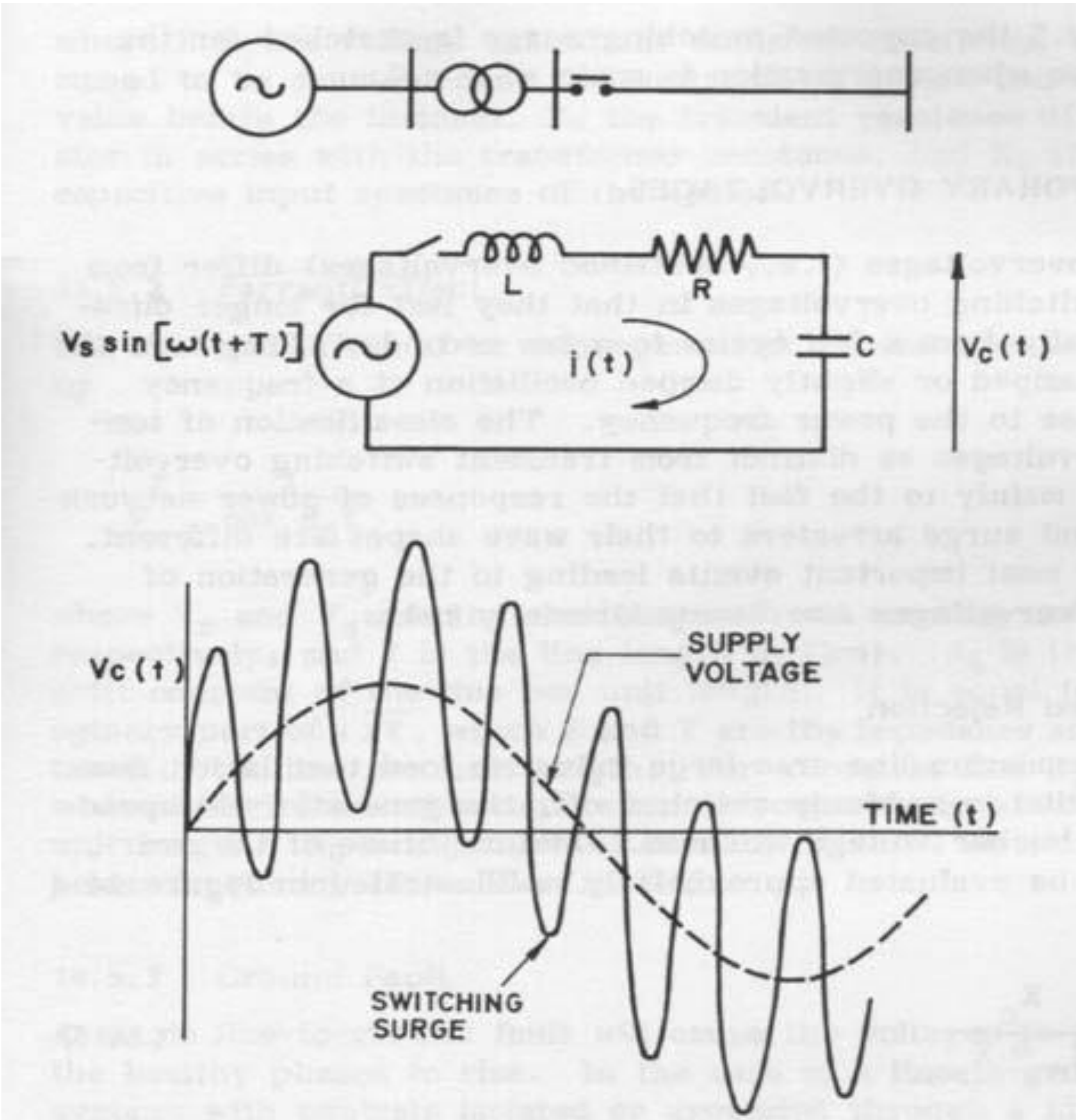


Fig 2.9: Energization switching transient

- The transformer is represented by its leakage inductance and the line by its resistance, inductance and capacitance to ground.
- The switching operation is effected at an instant T seconds beyond that of zero voltage.
- The voltage across the capacitor C is the one under study here, as it represents the voltage at the open circuit end of the line.

- The resistance R includes all series resistances of the line and transformer.
- The circuit performance after swicthing may be expressed by the following equation:

$$v_s(t) = Ri(t) + L\frac{di(t)}{dt} + \frac{1}{C}\int i(t)dt$$

The supply voltage $v_s(t)$ beyond the switching instant is:

$$v_s(t) = V_s \sin(\omega t + \omega T)$$

By using operational calculus the expression for the voltage across the line capacitance takes the form

$$v_c(t) = V_c \sin(\omega t + \omega T - \theta) + Ae^{-\alpha t}\sin(\omega_1 t+\beta)$$

$$\text{Where, } \theta = \tan^{-1}\frac{-R}{\omega L - \frac{1}{\omega C}}$$

$$V_c = \frac{Vs}{\omega C\sqrt{R^2 + (\omega L - \frac{1}{\omega C})^2}}$$

CHAPTER 3

IMPULSE WAVESHAPE AND ITS SPECIFICATION

3.1 Lightning Impulse

It is shown that lightning overvoltage wave can be represented as double exponential waves defined by the equation:

$$V=V_0(e^{-\alpha t}-e^{-\beta t})$$

where α and β are constants of microsecond values.

The above equation represents a unidirectional wave which usually has a rapid rise to the peak value and slowly falls to zero value. Impulse waveshapes are specified by defining their rise of front time, fall or tail time to 50% peak value and the value of the peak voltage. Thus 1.2/50µsec, 1000kV wave represents an impulse voltage wave with a front time of 1.2 µsec, fall time to 50% peak value of 50 µsec and a peak value of 1000kV. When impulse waveshapes are recorded, the initial portion of the wave may not be clearly defined or sometimes may be missing. Due to stray capacitances and inductances, there may be oscillations. Hence the front time and tail time are redefined. The points corrsponding to 30% and 90% of the peak values are located in the front portion (points A and B). The line joining this points is extended to cut the time axis at O_1. O_1 is taken as the virtual origin. 1.67 times the interval between times t1 and t2 corresponding to points A and B (projection on the time axis) is defined as the front time.

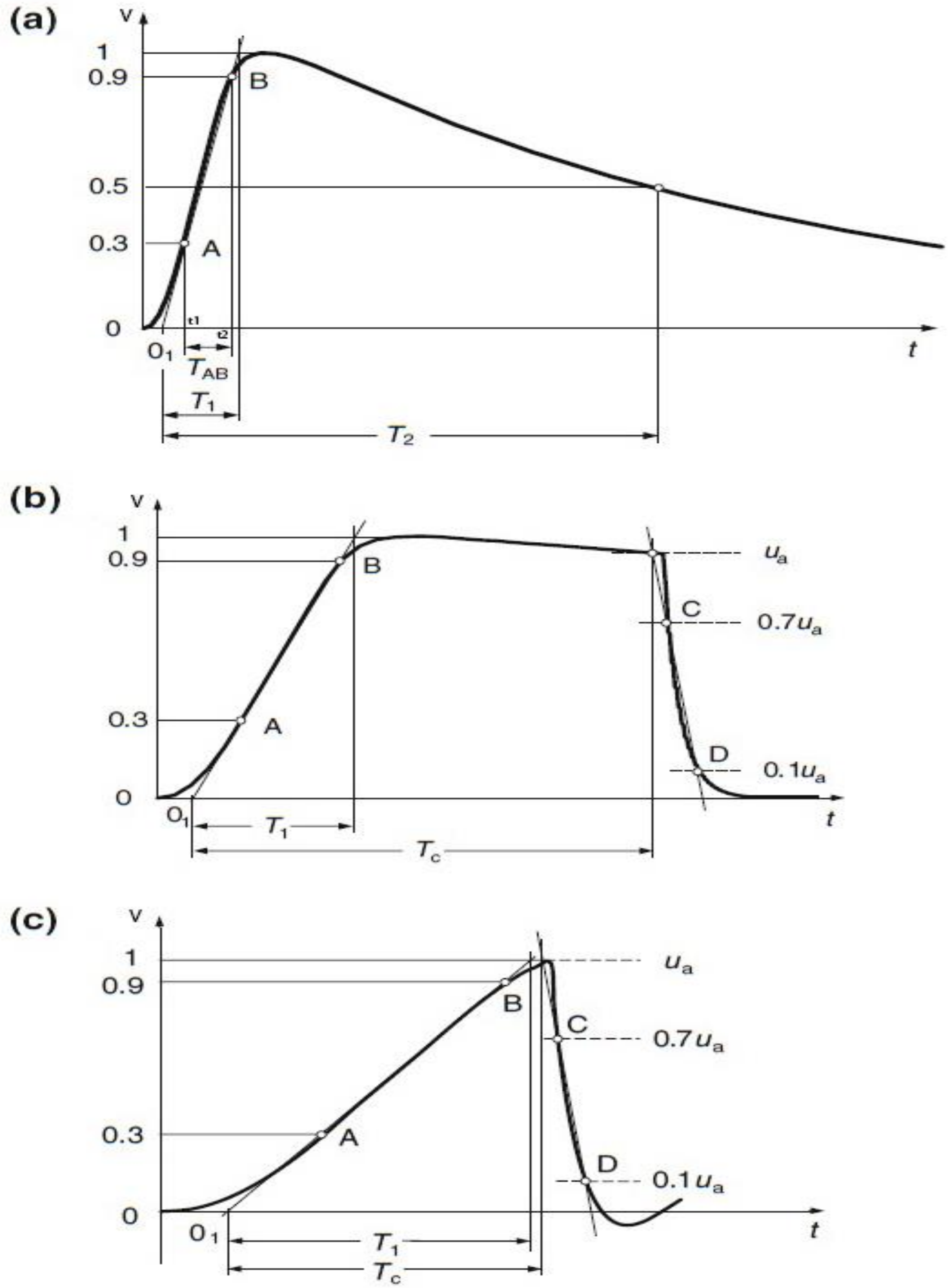


Fig 3.1: Lightning impulse voltage. a) Full wave b) Wave chopped at tail c) Wave chopped at front. T_1: virtual front time, T_2: virtual time to half value, T_c: time to chopping

So, $T1=1.67(O_1t2-O_1t1)$

The tolerance that can be allowed in the front time and tail time are respectively ±30% and ±20%. The tolerance allowed in the peak value is ±3%

Lightning impulses are therefore of very short duration, mainly when they are chopped on front. Due to inherent measurement errors and uncertainty in the calculation, T_1 and T_2 can hardly be quantified with high accuracy.

3.2 Standards

1.2/50 (Indian Standard)

1/50 (British Standard)

1.5/40 (American Standard)

3.3 Switching Impulse

The amplitude of switching impulse wave is dependent on the operating voltage and the shape is influenced by the impedances of the system as well as by the switching conditions. Fig 1.10 illustrates the slope of a switching impulse. Whereas the virtual time to half value T_2 is defined similarly as before, the time to crest T_{cr} is the real time interval between the actual origin and the instant when the voltage has reached its maximum value. An additional parameter is the time T_d, the time at 90% of crest value. The standard switching impulse has time values of

$$T_{cr} = 250\mu sec \pm 20\%$$

$$T_2 = 2500\mu sec \pm 60\%$$

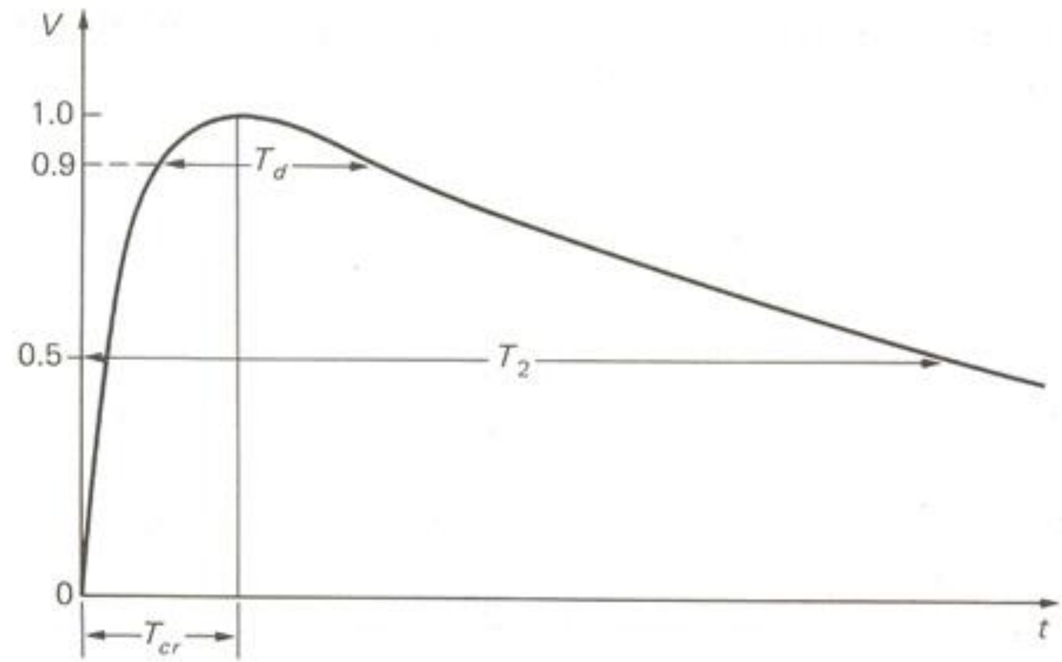


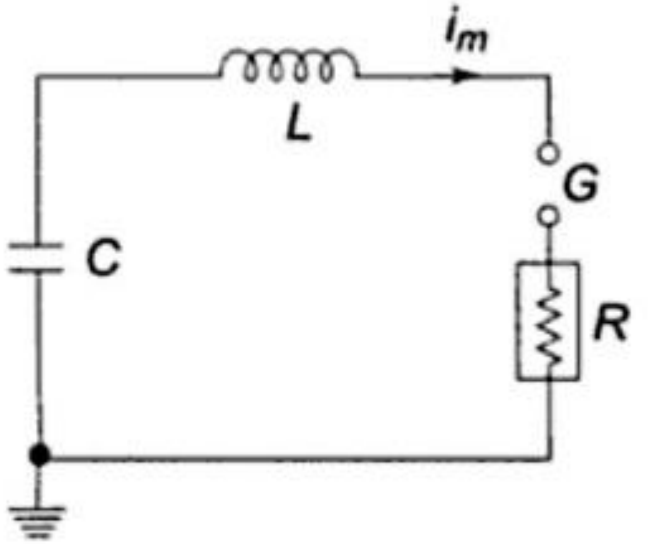
Fig 3.2: General shape of switching impulse voltages. T_{cr}: time to crest. T2: virtual time to half value, T_d: time above 90%

3.4 Generation of Impulse Current

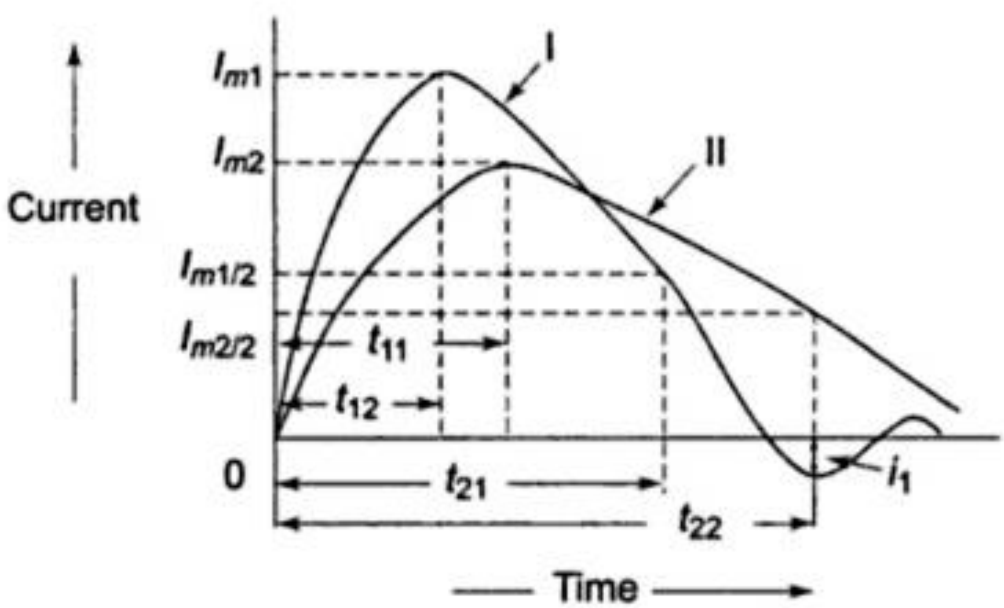
Lightning discharges involve both high voltage impulses and high current impulses on transmission lines. Protective gear like surge diverters have to discharge the lightning currents without damage. Therefore, generation of impulse current waveforms of high magnitude (100kA peak) find application in test work as well as in basic research on non-linear resistors, electric arc studies and studies relating to electric plasmas in high current discharges.

3.4.1 Definition of Impulse Current Waveforms

The waveshapes used in testing surge diverters are 4/10 and 8/20 µsec. The tolerance allowed on these are ±10% only. Apart from the standard impulse current waves, rectangual waves of long duration are also used for testing. The waveshapes should be nominally rectangualr in shape. The rectangular waves generally have duration of the order of 0.5 to 5 ms, with rise and fall times waves being less than ±10% of their total duration. The duration of the wave is defined as the total time of the wave during which the current is at least 10% of its peak value.



(a) Basic circuit of an Impulse Current Generator



(b) Types of impulse current waveforms

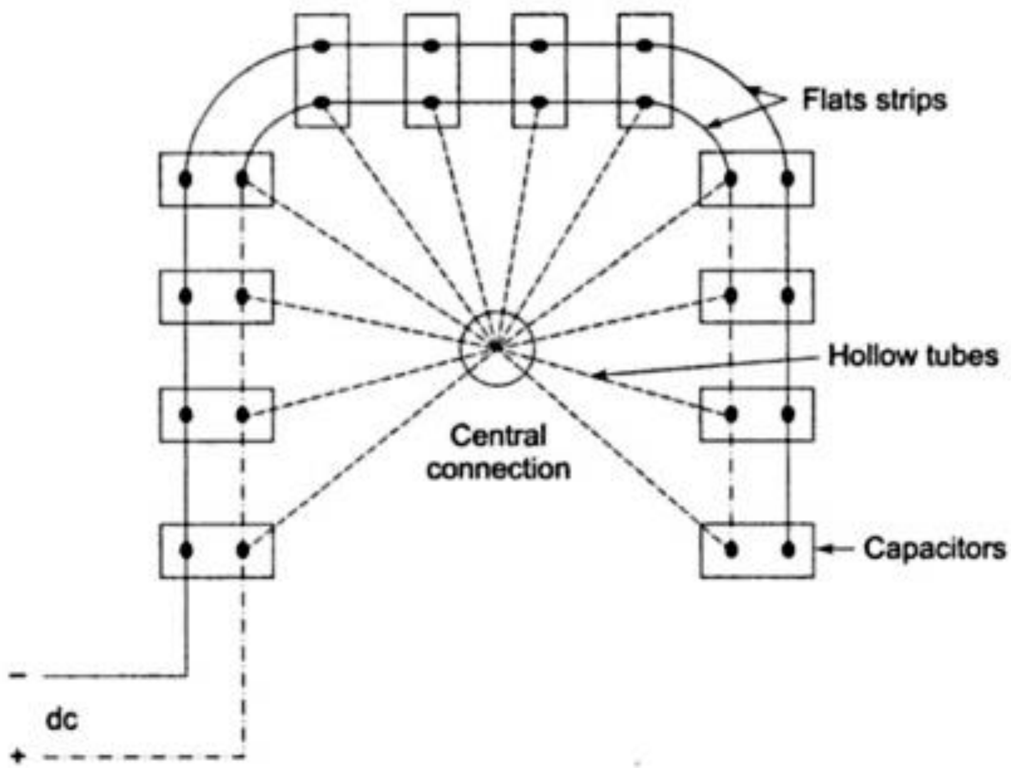
t11 and t12 = time to front of waves I and II

t21 and t22 = time to tail of wave I and II

I --- damped oscillatory wave

II ---overdamped wave

i1 ---overshoot



(c) Arrangement of capacitors for high impulse current generation

Fig 3.3: Basic Circuit and Waveform of Impulse Current Generation

3.5 Application of Impulse Current Generator

Impulse current generators are designed mainly to inspect and test the withstand capacity of electric equipment to strong impact current. These are widely used in lightning arresters and the oscillatory wave immunity tests of electric and electronic equipment under their running conditions.

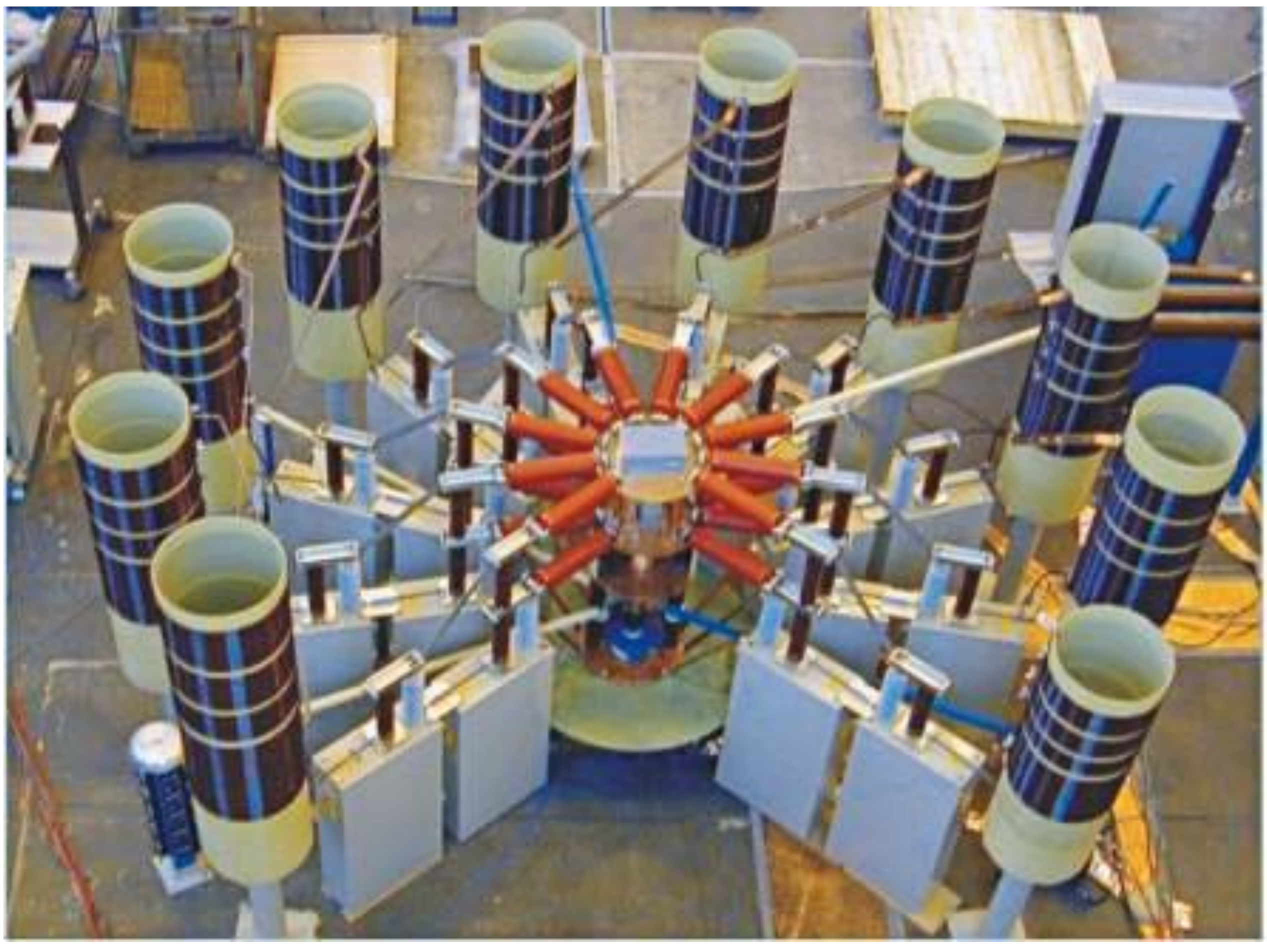


Fig 3.4: Impulse Current Generator

CHAPTER 4

DESIGN OF AN IMPULSE GENERATOR

4.1 How To Create Impulse Using Electrical Circuits:

We can produce impulse wave using a combination L-R-C circuit in overdamped condition or by combination of two R-C circuits. Circuits shown in figure (b,c,d) is used in commercial generator. By closing switch s we can get the desired double exponential output curve.

4.1.1 Principle of operation:

The mathematical representation of impulse waveshape is $V=V_0(e^{-\alpha t}-e^{-\beta t})$

We can achieve such waveshapes by an R-C circuit but the problem is the time constant is different during charging and discharging period. Either we have to change capacitance or we have to change resistance producing different time constant during charging and discharging.That’s why we have to switch the resistance.

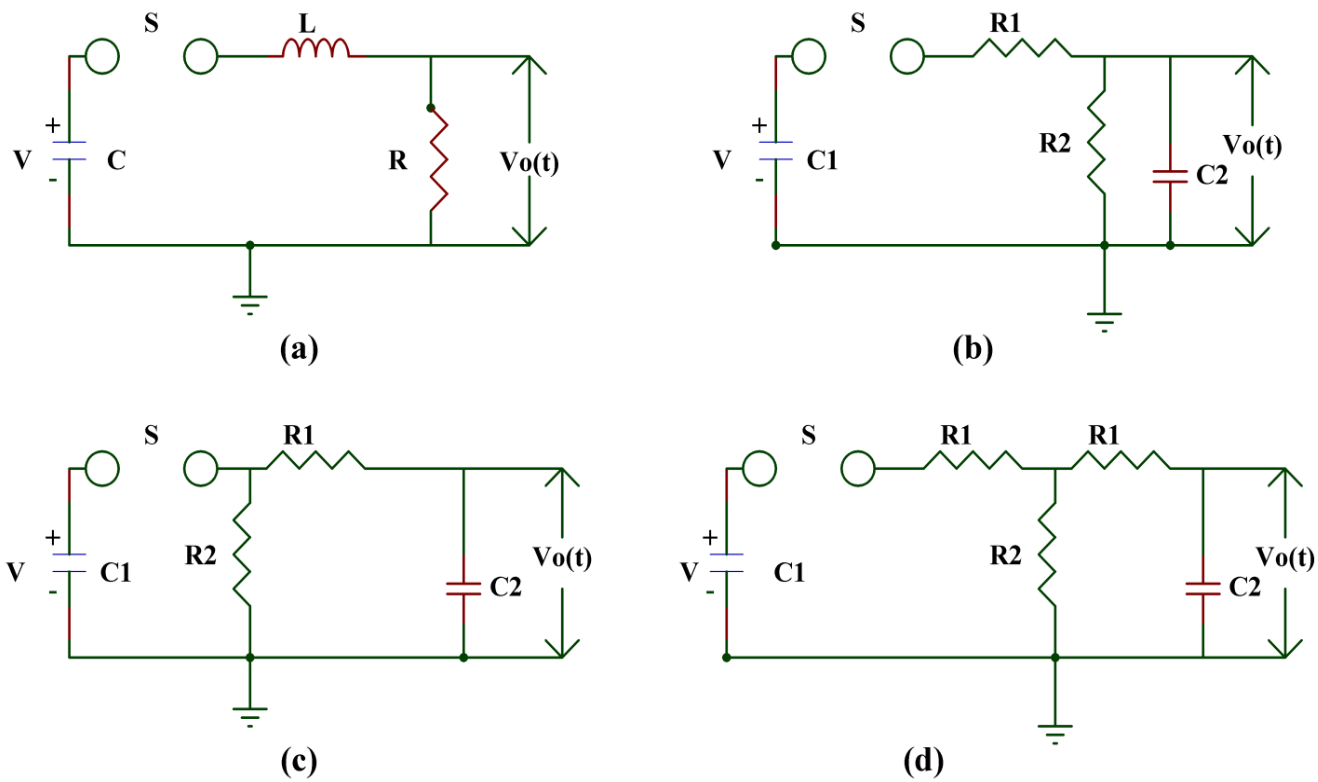


Figure 4.1 : Impulse waveshape producing circuit

4.1.2 Mathematical Analysis

Here,

C1= Generator capacitance, it will be charged and discharged in a controlled manner to get the impulse shape

R1, R2= Waveshaping Resistor

C2= Load Capacitance

Front time= 3.0*R1(C1*C2)/(C1+C2)

Tail time= 0.7*(R1+R2)(C1+C2)

For the configuration b,

Wave front and tail is controlled by R1 and R2. Test object is C2 which is considered as capacitive only

Output voltage across C2 is given by,

$$v_0(t)=\frac{1}{C2}\int_0^t i_2\mathrm{dt}$$

Performing Laplace transformation, $\frac{1}{C2s}I_2(\mathrm{s}) = v_0 s$

Where i_2 is the current through C2

Taking the current through C1 as i_1 and its Fourier transformed value as $I_1(s)$,

$$I_2(s) = [\frac{R_2}{R_2+\frac{1}{C_2\mathrm{s}}}]I_1(s)$$

$$I_1(s) = [\frac{\mathrm{V}}{\mathrm{s}}\frac{1}{\frac{1}{C_1\mathrm{s}}+R_2+\frac{R_2\cdot\frac{1}{C_2\mathrm{s}}}{R_2+C_2\mathrm{s}}}]I_1(s)$$

Substitution of I1(s) gives

$$v_0(\mathrm{s}) = [\frac{R_2}{R_2+\frac{1}{C_2\mathrm{s}}}][\frac{\mathrm{V}}{\mathrm{s}}\frac{1}{\frac{1}{C_1\mathrm{s}}+R_2+\frac{R_2\cdot\frac{1}{C_2\mathrm{s}}}{R_2+C_2\mathrm{s}}}]$$

After simplification and rearrangement,

$$v_0(\mathrm{s}) = [\frac{\mathrm{V}}{R_1C_2}][\frac{1}{s^2+(\frac{1}{C_1R_1}+\frac{1}{C_2R_2}+\frac{1}{C_2R_1})s \quad +\frac{1}{C_1C_2R_1R_2}}]$$

If the roots of the equation are α and β then,

$$\alpha+\beta=(\frac{1}{C_1R_1}+\frac{1}{C_2R_2}+\frac{1}{C_2R_1})$$

$$\alpha.\ \beta=\frac{1}{C_1C_2R_1R_2}$$

taking inverse transform of $v_0(s)$ gives

$$v_0(t)=\frac{V}{R_1 C_2(\alpha-\beta)}[\exp(-\alpha t)-\exp(-\beta t)]$$

The roots may be approximated as

$\alpha = \frac{1}{R_1 C_2}$ and

$\beta = \frac{1}{R_2 C_1}$

4.1.3 Restrictions

The ratio C1/C2 must be more than 0.01 otherwise we can’t fetch the desired output.

Sometimes several stray series inductance are added to the circuit which cause oscillations in front and tail portion

4.2 Marx Circuit

For building above 200kv impulse we need a single charging capacitor whose cost would be much large.

To prevent the capacitor being more costly Marx proposed a bank of capacitors should be charged in parallel and discharged in series to reduce the size and complexity of building large capacitors.

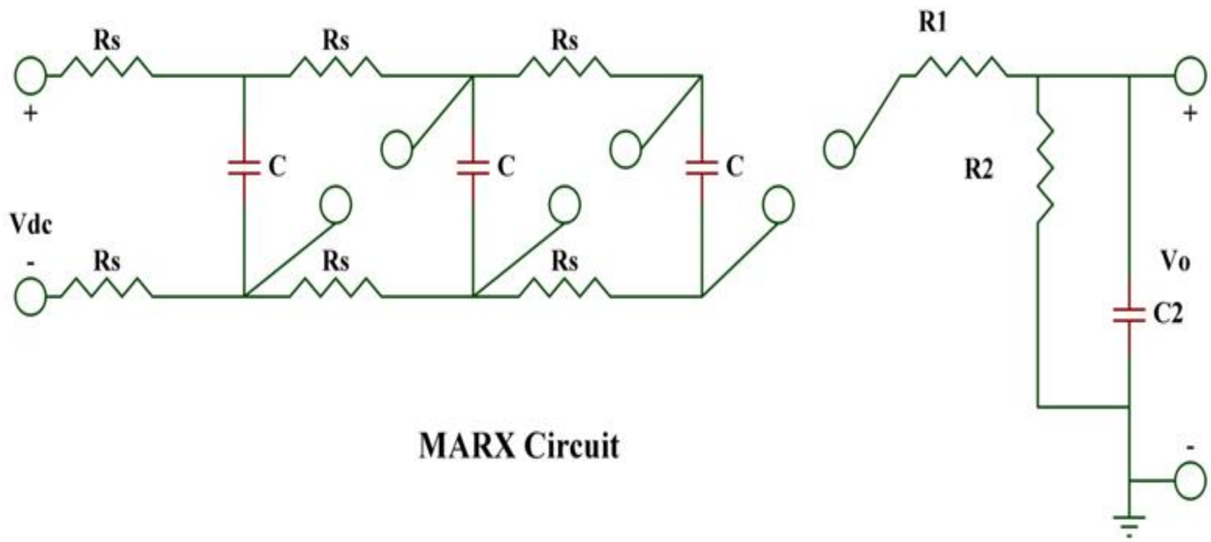


Fig: 4.2: Marx Circuit

Usually the charging resistor Rs is chosen to limit the charging current to about 50 to 100mA. And the generator capacitance Cs is chosen such that the product CRs is about 10s to 1min. The breakdown voltage of spark gap is higher than the charging voltage V. Thus all the capacitances are charged to the voltage V in about 1min. While discharging the spark gaps are made to breakdown simultaneously by external circuitry. The discharge time constant CR1/n will be very small (microsecond) compared to the charging time constant CRs (seconds). Hence, no discharge will take place through the charging resistor Rs.

4.2.1 Modified Marx Circuit

Wave shaping resistors R1 & R2 are incorporated inside the unit so that the size is reduced significantly

R1/n is connected in series with the spark gap and R2/n is connected across each capacitance unit

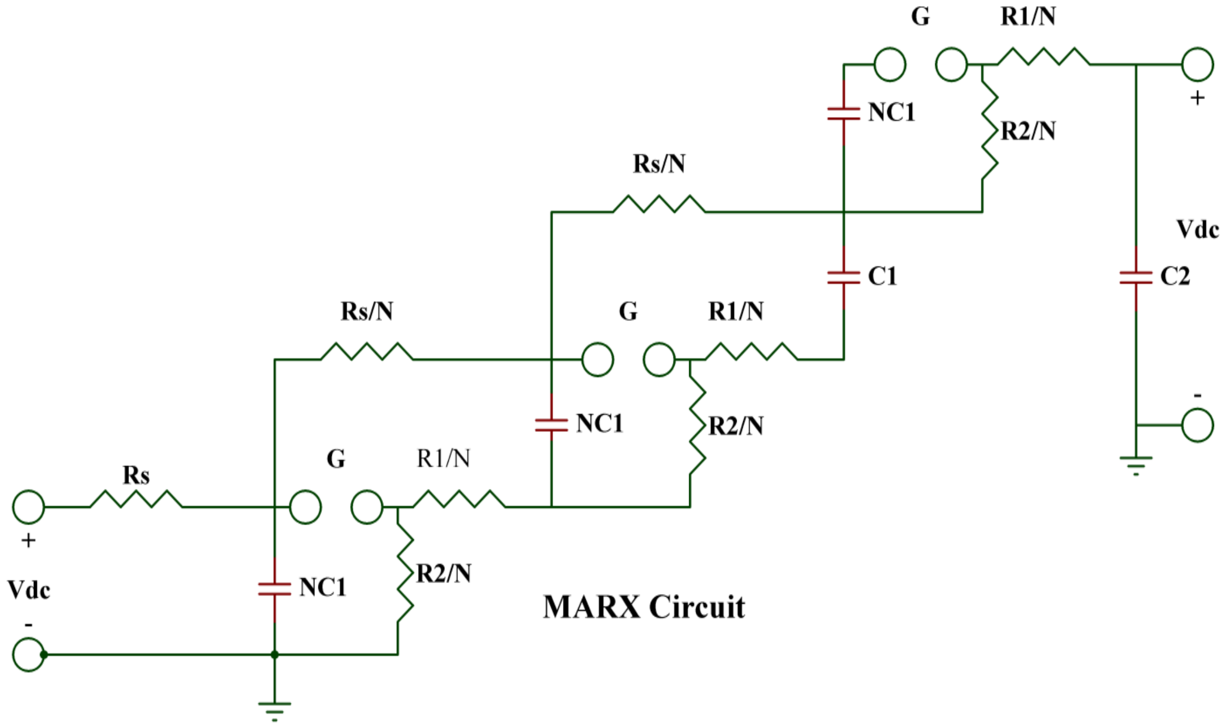


Figure 4.3: Modified Marx Circuit

4.2.2 Problems regarding Marx:

Spark gap has been used in real operation. The control signal for the spark gap must be synchronized otherwise result wouldn't be up to the mark.

All the resistances need to be changed if we want to control front or tail time as in every stage charging and discharging resistor exists.

CHAPTER 5

OBSERVATION UNDER DIFFERENT TEST OBJECTS :

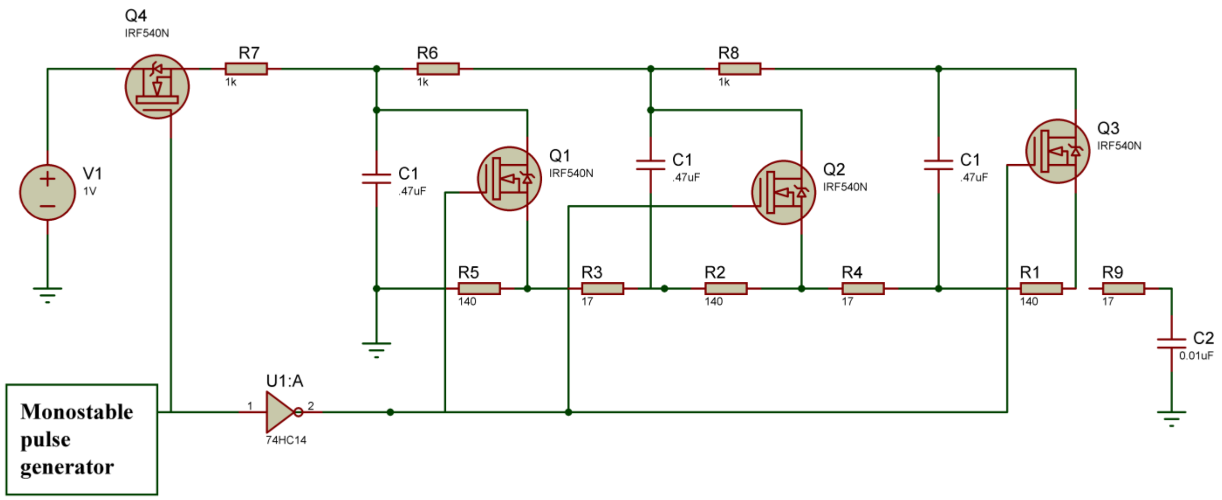


Figure: 5 stage Marx circuit used for Simulation

5.1 Observations under No Load:

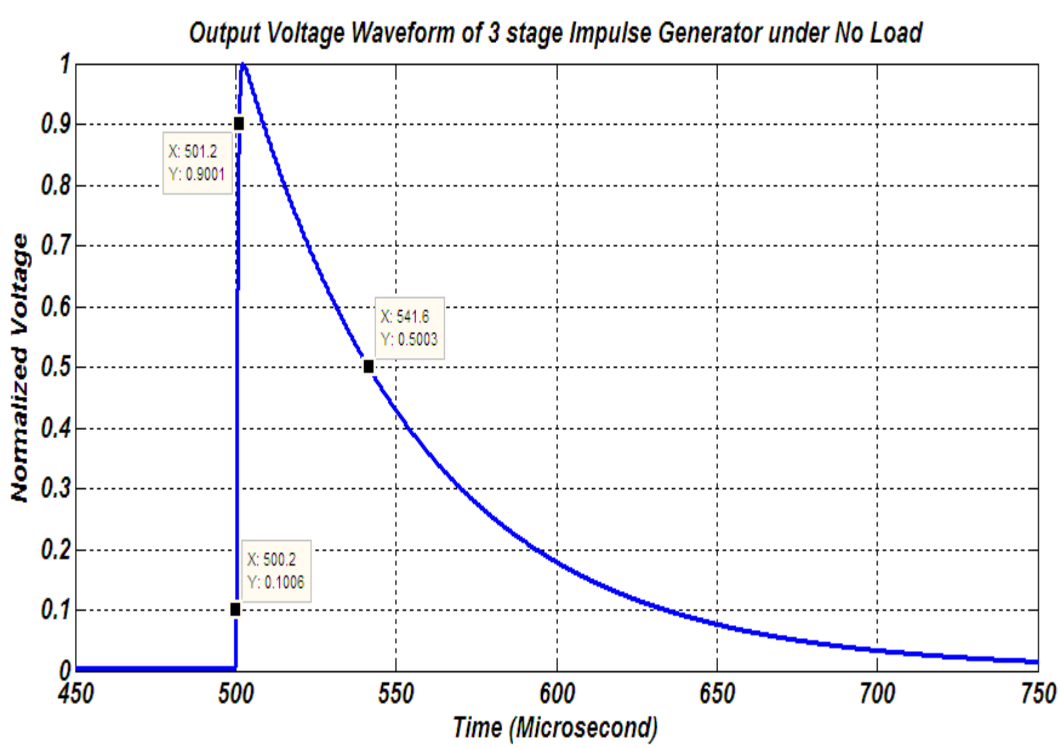


Figure 5.1 Observation under no load

Front time under No load is 1.25us

Tail time under No load is 41.6us

Overshoot is negligible.

5.1.1 Effect of Circuit Inductances and Series Resistance

The equivalent circuits in practice comprise several stray series inductances. Further, the circuits occupy considerable space and will be spread over several meters in a testing laboratory. Each component has some residual inductance and the circuit loop itself contributes for further inductance. The actual value of the inductance may vary from 10 µH to several hundreds of micro henries. The effect of the inductance is to cause oscillations in the wave front and in the wave tail portions. Inductances of several components and the loop inductance are shown in.The effect of the variation of inductance on the wave shape is shown. If the series resistance Rs increased, the wave front oscillations are damped, but the peak value of the voltage is also reduced. Sometimes, in order to control the front time a small inductance is added.

5.2 Observations of Test Object with capacitive load :

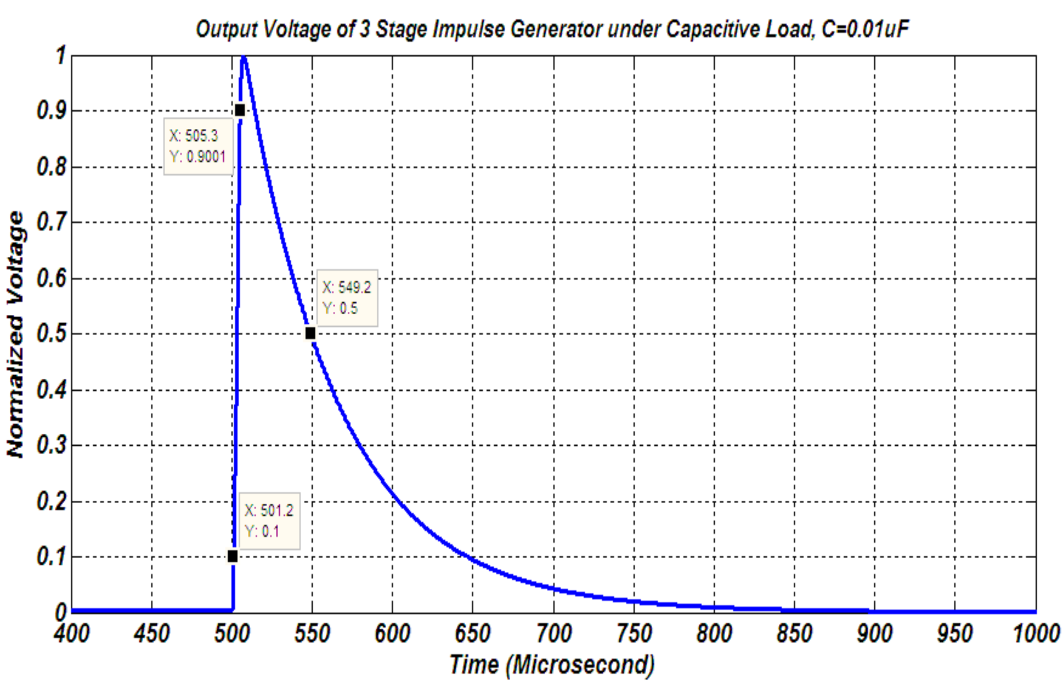


Figure 5.2 : Observations of Test Object with capacitive load

Front time under capacitive load is 8.375us which deviates largely from standard 1.2/50 lightning Impulse wave shape.

Tail time under capacitive load is 49.2us which remains within the tolerance limit of stand curve.

5.2.1 Testing Objects having Large Capacitance

When test objects with large capacitances are to be tested (C > 5 nF), it is difficult to generate standard impulses with front time within the specified tolerance of ± 30% and the specified less than 5% tolerance in the overshoot This is mainly because of the effect of the inductance of the impulse generator and the front resistors. Normally the inductance of the impulse generator will be about 3 to 5 μH per stage and that of the leads about 1 μH/m. Also the front resistor which is usually of bifilar type has inductance of about 2 μH/unit. An overshoot in the voltage wave of more than 5% will occur if R/ (SL/c) < 1.38, where R is the front resistance, L is the generator inductance and C is the equivalent capacitance of the generator given by

C = C1. C2/ (C1 + C2).

5.2.2 Problems and Solutions :

For purely capacitive loading, keeping the time to half-value within permissible limits poses no problem. Discharge capacitance Rp is chosen according to the capacitances. Generator capacitances Cs and load capacitance Cb where by Tr ≈ Rp (Cb+Cs), and thus Rp allows keeping the time within the specified limits for a corresponding range of Cb. In practice, Impulse capacitance is known. The discharge resistance Rp is chosen such that time to half value is kept within the tolerance limit for capacitive load. Time to half-value can be kept within permissible tolerances for practically any capacitive load by means of additional parallel resistors.

Maintaining Front time however poses a problem with purely capacitive test objects (Ts ≈ Rs. Cb). Beyond a certain range of capacitive load, the value of the resistance Rs has to be so small that the resulting overshoot at the peak of the impulse would exceed 5%. This means that the range of values of capacitive loads for which it is possible to obtain a permissible wave shape is limited by the stray inductance Ls, which depends on the construction of the generator. In practical operation, the problem is solved by connecting resistors in series and parallel and therefore the impulse generator should be designed so that series resistance connections can be changed quickly and easily.

5.3 Observations under Inductive Load :

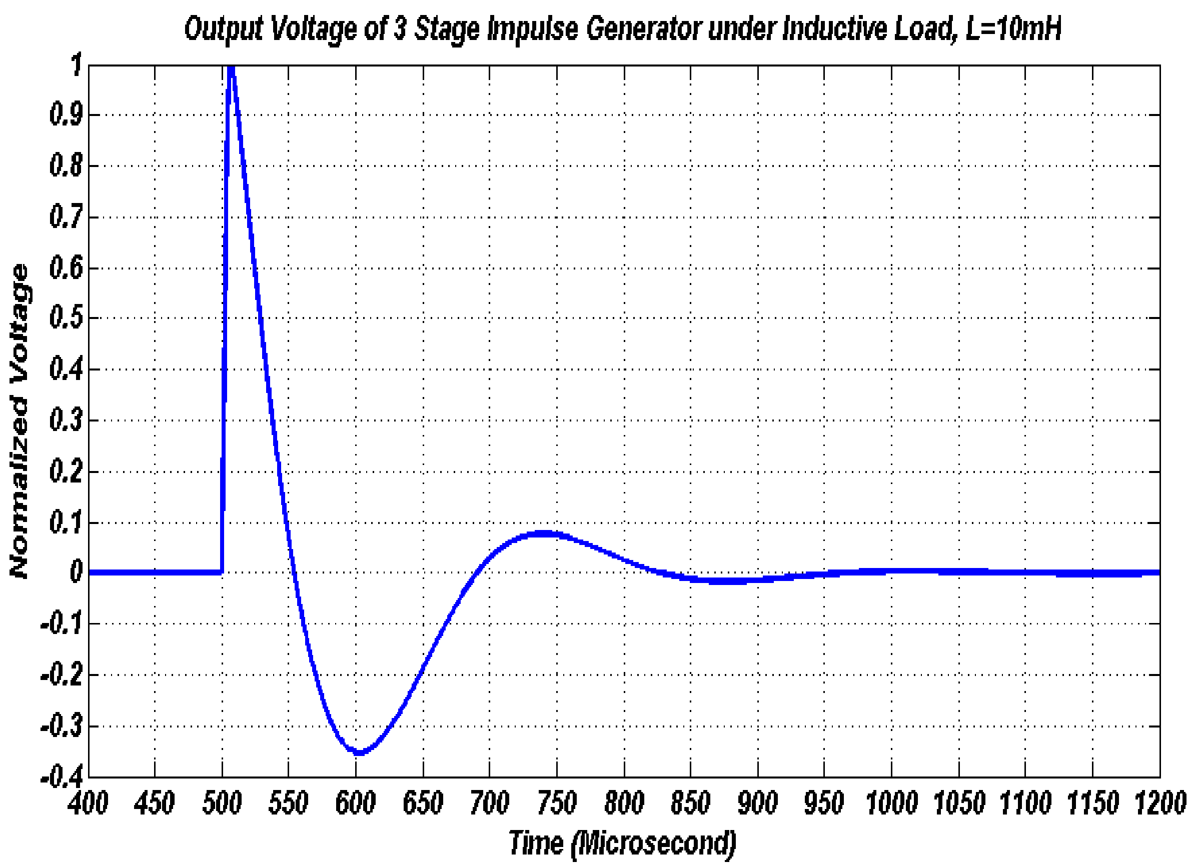


Figure 5.3 : Testing Objects with Inductance

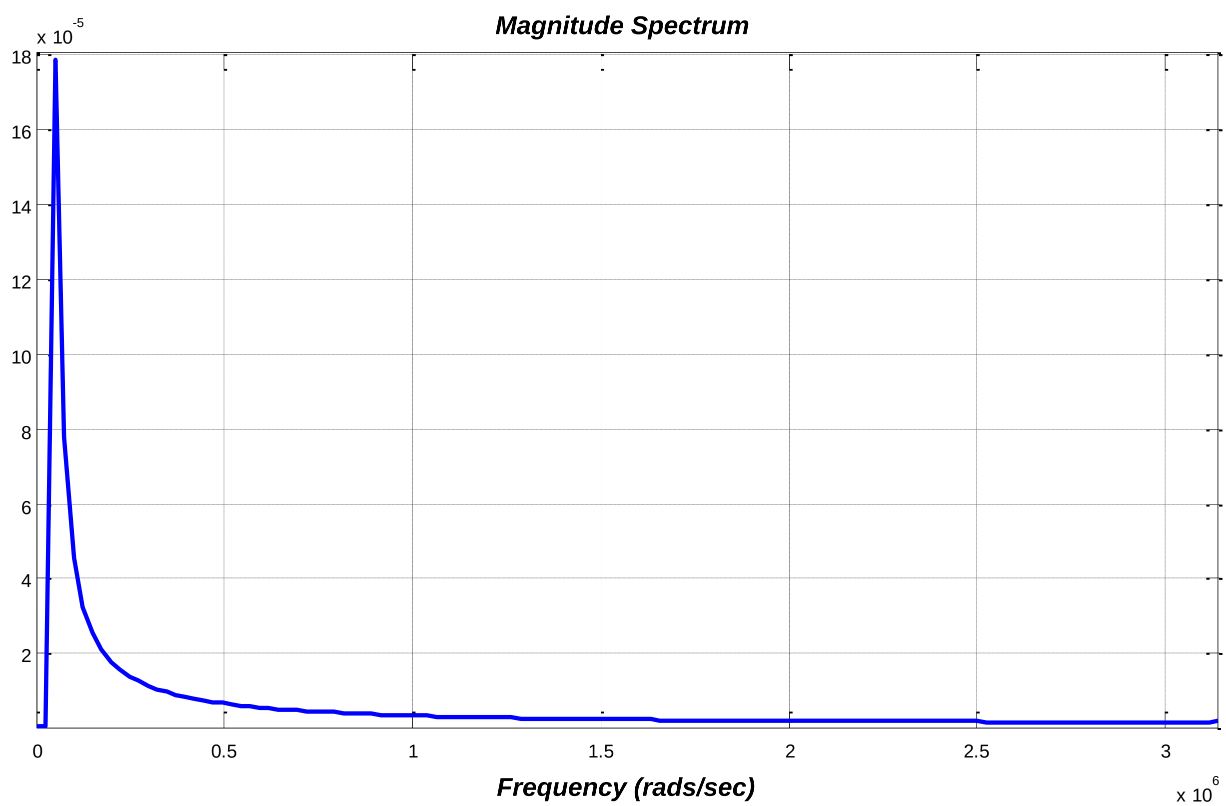
Often impulse generators are required to test equipment with large inductance, such as power transformers and reactors. Usually, generating the impulse voltage wave of proper time-to-front and obtaining good voltage efficiency are easy, but obtaining the required time-to-tail as per the standards will be very difficult..For the calculation of time-to-tail the circuit can still be approximated as a series C-R-L circuit As the value $R/\sqrt{(L/C)}$ decreases, the overshoot and the swing of the wave to the opposite polarity increases thereby deviating from the standard wave shape. Therefore, it is necessary to keep the value of the effective resistance R in the circuit large. One method of doing this is to connect a large resistance, R_2 in parallel with the test object or to connect the untested winding of the transformer (load) with a suitable resistance. Another method that can be used is to increase the generator capacitance with which the time-to-tail also increases, but without altering the time-to-front and the overshoot.

Test voltage actually appearing in a test circuit can contain oscillations at the peak as well as oscillations on the front. Reasons for such oscillations are the inductances and capacitances of the impulse voltage generator and those of the test and measuring circuits including high voltage. It may be recognized that the real limitation is from the damping resistance R_d which has to have a specific value in order to damp the oscillations as well as to obtain a time to front according to standards. By increasing the impulse capacitance C_s through parallel connection of stages, one can conduct practical tests on inductances $L_b > 4mH$ with standard lightning impulse voltage. But still lower inductances are encountered while testing the low voltage winding of 3 phase transformers. Obtaining time to half value of 40 us cannot be obtained.

5.4 Voltage Distribution under Impulse Voltage :

Impulse tests are made with wave shapes which simulate conditions that are encountered in service. From the data compiled about natural lightning, it has been concluded that system disturbances from lightning can be represented by three basic waveshapes- full waves, chopped waves and front of waves. If a lightning disturbance travels some distance along the line before it reaches a transformer, its wave shape approaches that of full wave generally referred to as 1.2/50 wave. If the travelling wave causes flashover across insulator it is simulated by chopped wave. The impulse voltage can rise steeply until it is relieved by a flashover, causing sudden collapse in voltage. It is simulated by wave chopped at front. The full wave causes major oscillations to develop in the winding and consequently produce not only in turn to turn and section to section insulation throughout the winding, but also develop relatively high voltages compared to power frequency stresses. The chopped wave, because of its shorter duration does not allow major oscillations to develop fully and generally does not produce as high voltages across the large portions of the windings. The front of wave is still shorter in duration and produces still lower winding to ground voltage within the winding. The rapid change of voltage on the front followed by a flashover produces high turn to turn and section to section voltages very near line end of the winding.

It is well known that lightning phenomenon produces impulse travelling wave in the transmission line. The spectrum of waveform is in MHz range normally less than 5 MHz. It can exceed 50 MHz in certain cases. Distribution of these transient over voltages in transformer winding is highly non uniform. It has been observed that 60 percent of these voltages appears across first 10 percent length of the winding. The non uniform voltage distribution can damage the transformer insulation.



5.4.1 Capacitance effect

The winding of a transformer can be represented as a distributed capacitance to steep-fronted waves. As the steep-fronted surge up travels down the winding it can be shown that the voltage U at any point in the winding is given by

Where Co = capacitance to earth

C   = interturn capacitance

The presence of capacitance to earth causes a non-uniform distribution of voltage in the winding and greater the value of $\sqrt{Co/C}$ greater will be the concentration of voltage at the line end of the winding and the larger interturn insulation stress on the first few turns of the transformer winding. Such a phenomenon has been responsible for many unprotected distribution transformer insulation failures. After the surge has travelled down the winding the picture becomes complicated by multiple reflections and natural frequency oscillations in the winding. In high voltage transformer design, the value of interturn capacitance can be artificially increased by screening and by winding interconnections. These measures improve the transformer surge response and reduce the stressing of the line end turns.

Another factor to bear in mind is the near voltage doubling effect that occurs when a surge travelling down a line encounters the high surge impedence of a transformer. This effect can be virtually eliminated by the presence of a short length of cable of low surge impedence between the transformer and overhead line. However, because of improvements in transformer insulation and high cost of such cable and fixings this practice is diminishing.

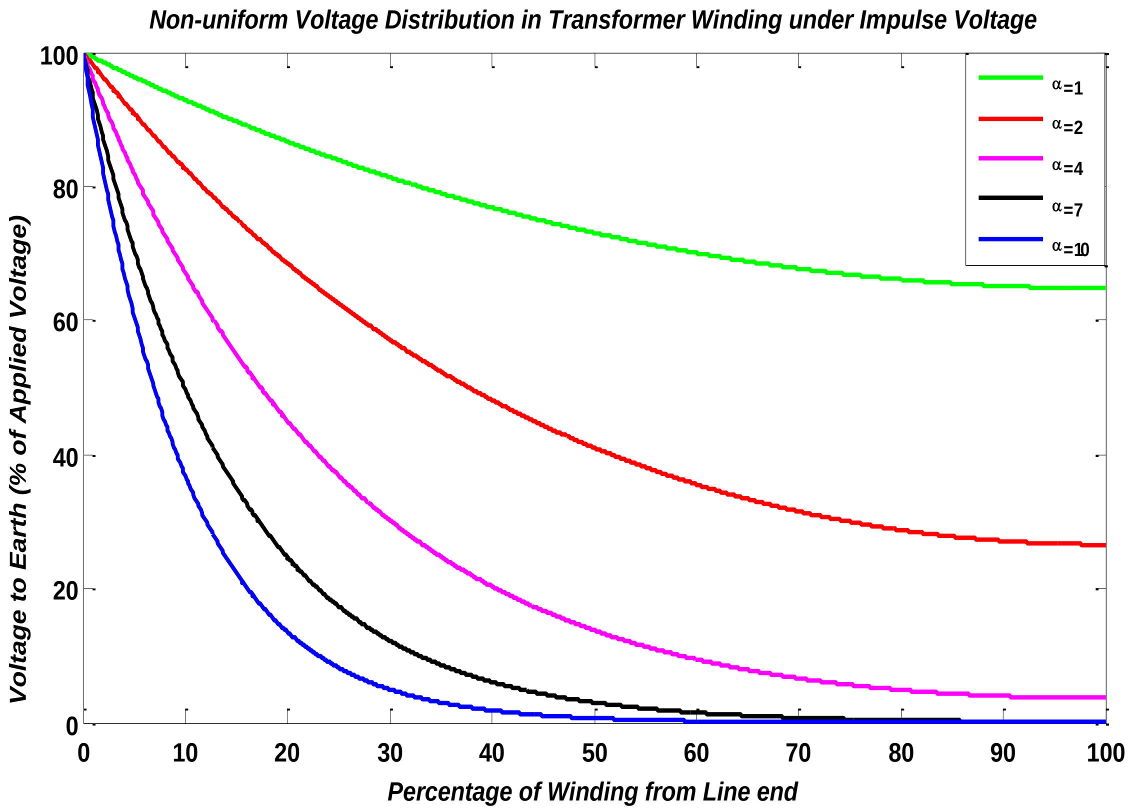
Waves in one part of a circuit can be transferred to other circuits by inductive and capacitive coupling. As indicated above a transformer appears to a steep fronted wave as a distributed capacitance which can be crudely represented by a simple pi network. Cp and Cs are the lumped capacitance so that the transferred wave Us is given by

$Us=Up.Ct/Ct+Cs$

The values of these capacitances are not easily obtainable so IEC 60071-2 and identical EN 60071-2 give various formulae for transferred waves. It is considered that the initial voltage on the secondary side of the transformer is given by

Us=s.p.Up

Where s can range from 0 to 0.4 and is typically 0.2 and p for a a star/delta or delta/star transformer is typically about 1.05



CHAPTER 6

CIRCUIT IMPLEMENTED IN THE LABORATORY

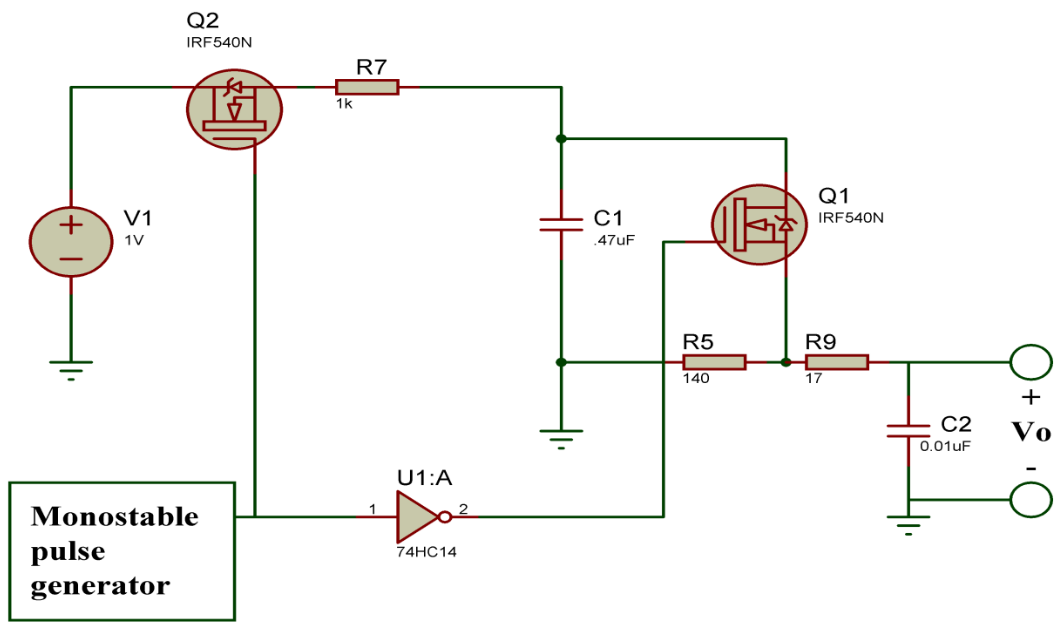


Figure 6: block diagram for practical circuit

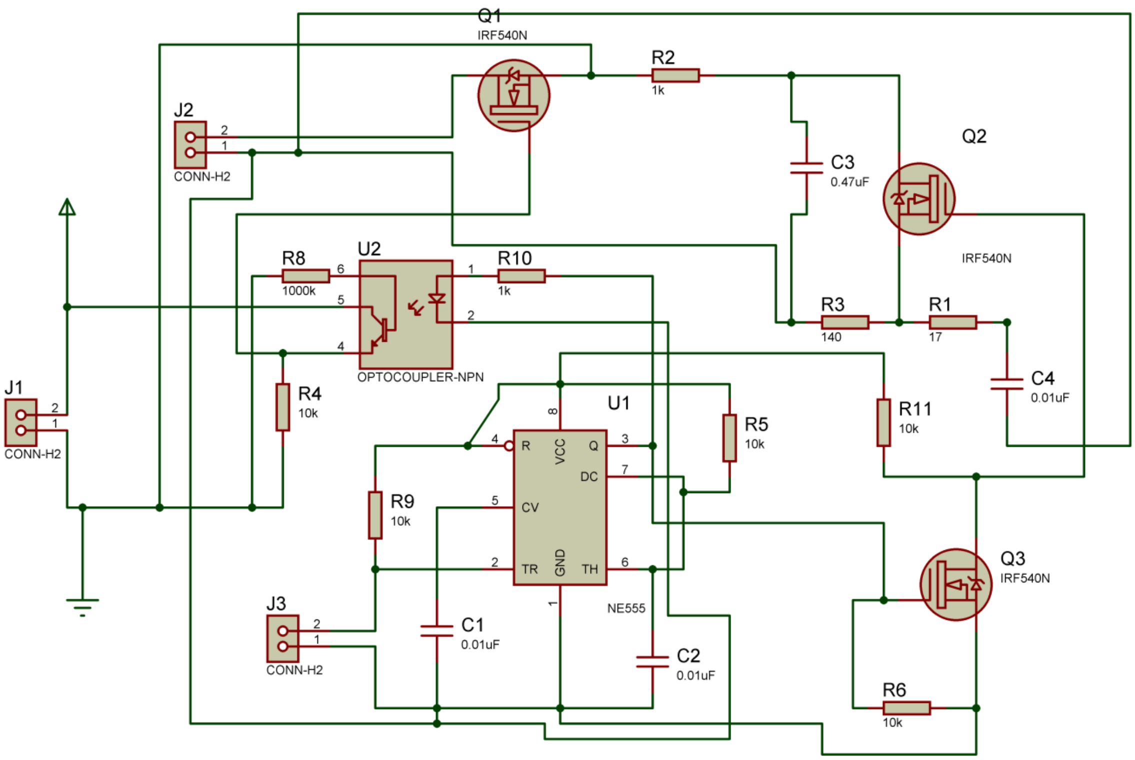


Figure6.1 : physical circuit implemented in laboratory. Both 1 and 2 stages have been performed but 1 stage is shown here**.**

6.1 Components used in the circuit

6.1.1 MOSFET as switch- as we need very high speed switching (within µs range). We have used IRF 540 enhancement type n-MOSFET. We must consider whether the load attached to the MOSFET is pure resistive. If not and inductive load exists, we must use a fly wheel diode or snubber circuit to protect the MOSFET devices.

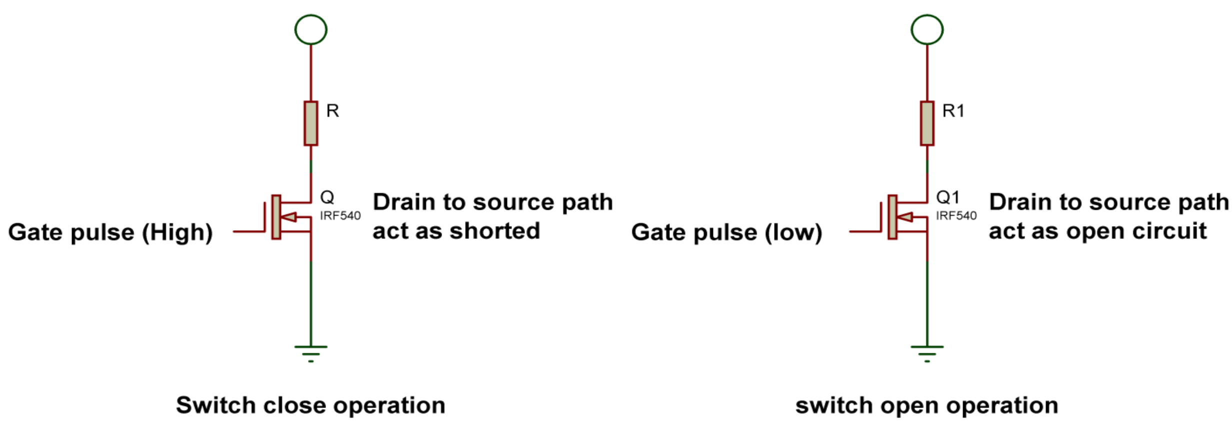


Figure 6.1.1: MOSFET in switching operation

Resistors, capacitors, inductors as required.

6.1.2 MOSFET as NOT gate. We can't find any other suitable alternative ic which can provide 15V inverted output.

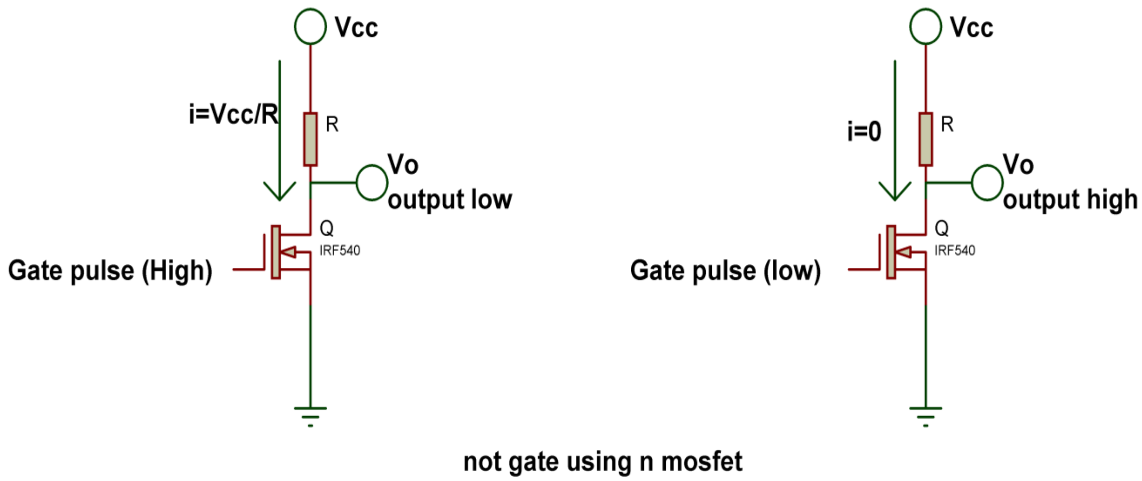


FIGURE 6.1.2 MOSFET as NOT gate

6.1.3 OPTOCOUPLER(4n25) for creating virtual ground. Otherwise voltage difference between gate and source of MOSFET Q1 does not exceed its cut off value.

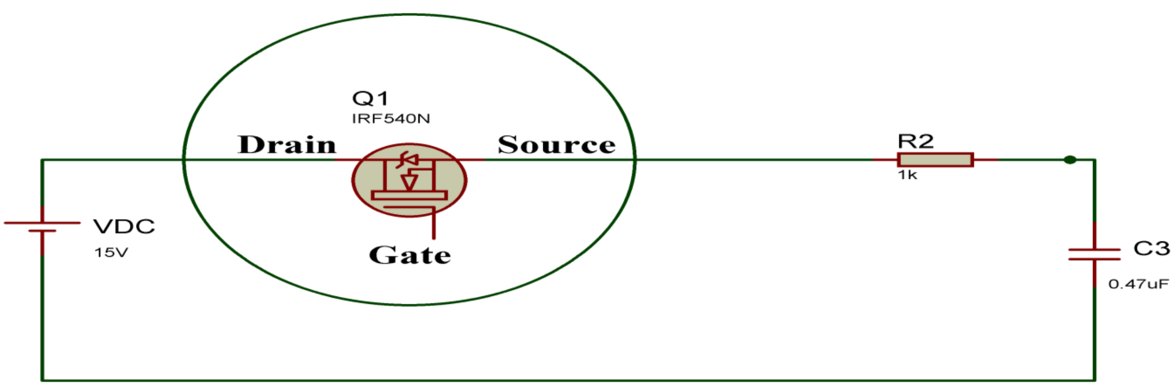


Figure 6.1.3 (a): the reason for creating virtual ground

From the above picture it is clearly evident that voltage of gate is not greater than voltage of source if we use same voltage source for cell and signal. So MOSFET couldn't be turned on.

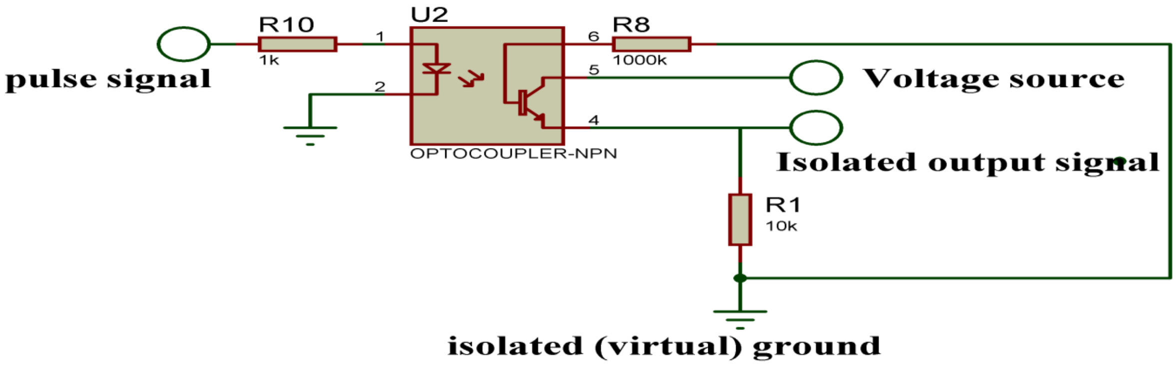


Figure 6.1.3 (b): Optopcoupler creating a virtual ground for MOSFET Q1 if we connect the gate at 4 and the source to the isolated ground

6.1.4 Timer ne555 ic in monostable mode is used to create a single pulse to distinguish between charge and discharge.

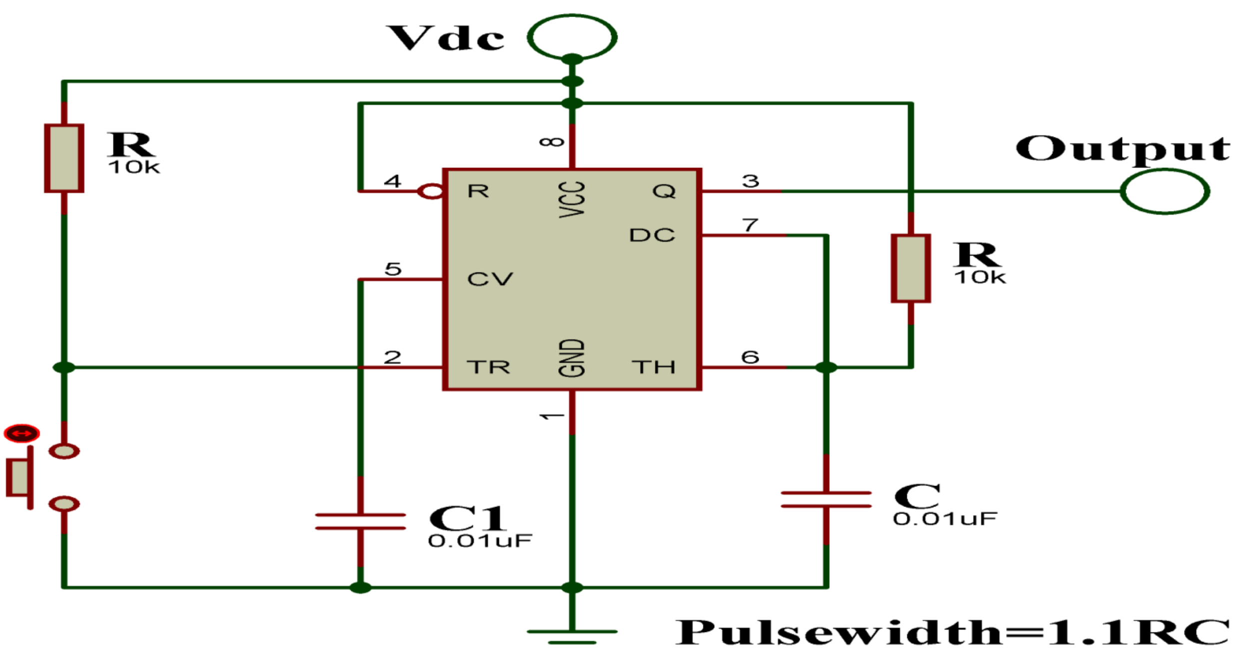
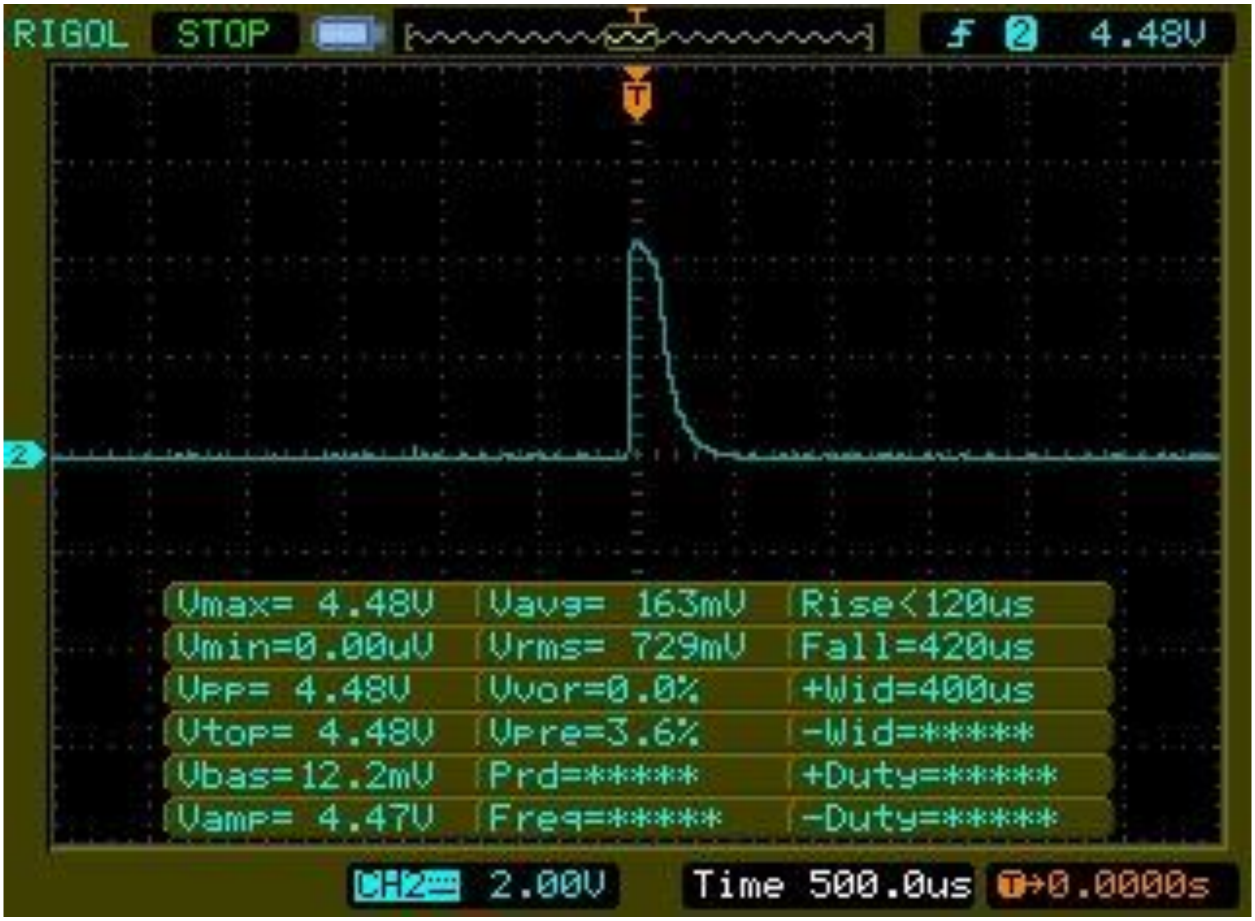


Figure 6.1.4 : ne555 timer monostable connection. Output pulse width=1.1RC

6.2 Output:



From the output wave shape front time is measured approximately as 20 µs and tail time as 200 µs

6.3 Comparison:

The output differs from the Indian standard 1.2/50 µs standard which is hard to achieve using normal speed MOSFETs available in the market. E.g the irf540-n used by us has a response at best of 2.3 µs. Moreover time delay in different ics' cause some deviation which is vital for working in µs range.

6.4 Components of a Multistage Impulse Generator

A multistage impulse generator requires several components pans for flexibility and for the production of the required waveshape. These may be grouped as follows:

DC. Charging Set

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

Charging Resistors

These will be non-inductive high value resistors of about 10 to 100 kilo-ohms. Each resistor will be designed to have a maximum voltage between 50 and 100 kV.

Generator Capacitors and Spark Gaps

These are arranged vertically one over the other with all the spark gaps aligned. The capacitors are designed for several charging and discharging operations. On dead short circuit, the capacitors will be capable of giving 10 kA of current. The spark gaps will be usually spheres or hemispheres of 10 to 25 cm diameter. Sometimes spherical ended cylinders with a central support may also be used.

Wave-shaping Resistors and Capacitors

Resistors will be non-inductive wound type and should be capable of discharging impulse currents of 1000 A or more. Each resistor will be designed for a maximum voltage of SO to 100 kV. The resistances are bifilar wound or non-inductive thin flat insulating sheets. In some cases, they are wound on thin cylindrical formers and are completely enclosed. The load capacitor may be of compressed gas or oil filled with a capacitance of 1 to 10 nF.

Modern impulse generators have their wave-shaping resistors included internally with a flexibility to add additional resistors outside, when the generator capacitance is changed (with series parallel connection to get the desired energy rating at a given test voltage). Such generators optimize the set of resistors. A commercial impulse voltage generator uses six sets of resistors ranging from 1.0 ohm to about 160 ohms with different combinations (with a maximum of two resistors at a time) such that a resistance value varying from 0.7 ohm to 235 ohms per stage is obtained, covering a very large range of energy and test voltages. The resistors used are usually resin cast with voltage and energy ratings of 200 to 250 kV and 2.0 to 5.0 kWsec. The entire range of lightning and switching impulse voltages can be covered using these resistors either in series or in parallel combination.

Triggering System

This consists of trigger spark gaps to cause spark breakdown of the gaps

Voltage Dividers

Voltage dividers of either damped capacitor or resistor type and an oscilloscope with recording arrangement are provided for measurement of the voltages across the test object. Sometimes a sphere gap is also provided for calibration purposes

Gas Insulated Impulse Generators

Impulse generators rated for 4MW or above will be very tall and required large space. As such they are usually located in open space and housed in an insulated enclosure. The height of a 4.8MV unit may be around 30m. To make the unit compact, a compressed gas, such as Nitrogen or Sulphur hexaflouoride may be used as the insulation.

6.5 Tripping and Control of Impulse Generator

In large impulse generators, the spark gaps are generally sphere gaps or gaps formed by hemispherical electrodes. The gaps are arranged such that sparking of one gap results in automatic sparking of other gaps as overvoltage is impressed on the other. In order to have consistency in sparking, irradiation from an ultra-violet lamp is provided from the bottom to all the gaps

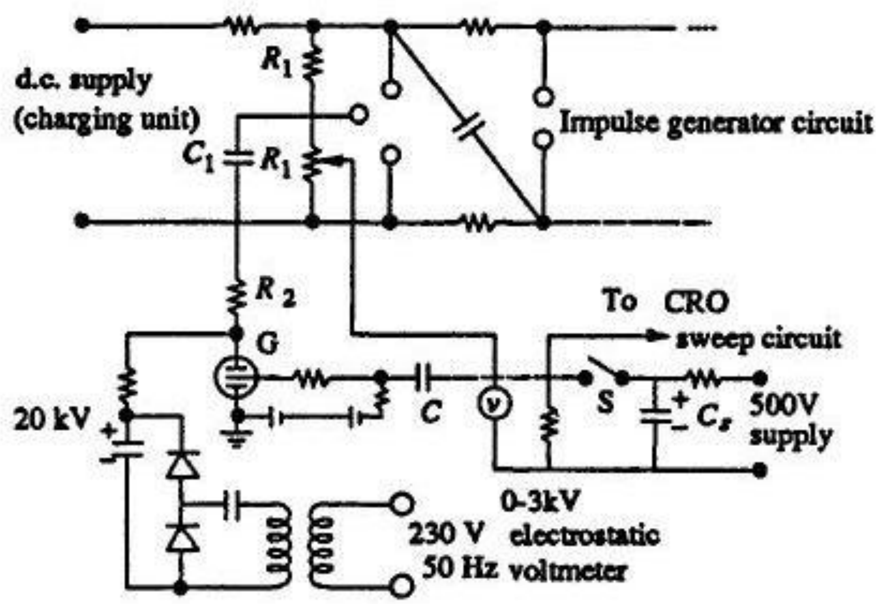


FIGURE 6.5 : Tripping of an impulse generator with a three electrode gap

movable frame, and the gap distance is reduced by moving the movable electrodes closer. This method is difficult and does not assure consistent and controlled tripping A simple method of controlled tripping consists of making the first gap a three electrode gap and firing it from a controlled source. Figure 6.5 gives the schematic arrangement of a three electrode gap. The first stage of the impulse generator is fitted with a three electrode gap, and the central electrode is maintained at a potential in between that of the top and the bottom electrodes with the resistors *R* and *RL*. The tripping is initiated by applying a pulse to the thyratron G by closing the switch S. The capacitor *C* produces an exponentially decaying pulse of positive polarity. The pulse goes and initiates the oscillograph time base. The thyratron conducts on receiving the pulse from the switch S and produces a negative pulse through the capacitance Ci at the central electrode of the three electrode gap. Hence, the voltage between the central electrode and the top electrode of the three electrode gap goes above its sparking potential and thus the gap conducts. The time lag required for the thyratron firing and breakdown of the three electrode gap ensures that the sweep circuit of the oscillography begins before the start of the impulse generator voltage. The resistance *R* ensures decoupling of voltage oscillations produced at the spark gap entering the oscilloscope through the common trip circuit.

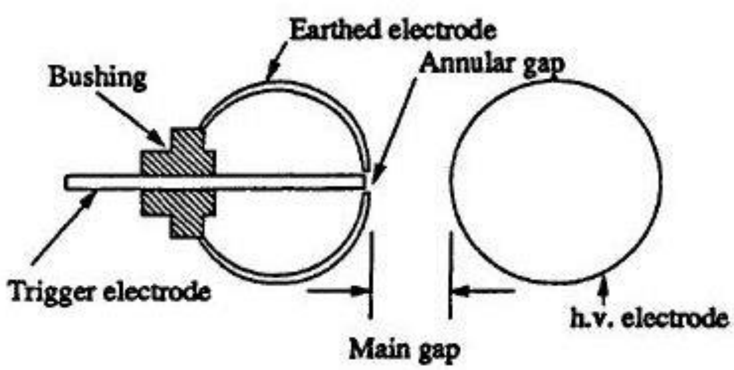


FIGURE : 6.5 (a) Trigatron gap

The three electrode gap requires larger space and an elaborate construction. Now-a -days a trigatron gap shown in Fig. 6,5(a) is used, and this requires much smaller voltage for operation compared to the three electrode gap. A trigatron gap consists of a high voltage spherical electrode of suitable size, an earthed main electrode of spherical shape, and a trigger electrode through the main electrode. The trigger electrode is a metal rod with an annular clearance of about 1 mm fitted into the main electrode through a bushing. The trigatron is connected to a pulse circuit as shown in Fig. 6.5(b).

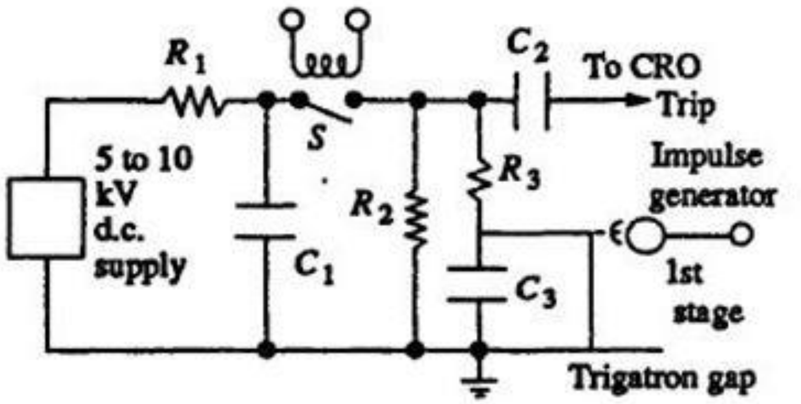


FIGURE 6.5(B) : Tripping circuit using a trigatron

Tripping of the impulse generator is effected by a trip pulse which produces a spark between the trigger electrode and the earthed sphere. Due to space charge effects and distortion of the field in the main gap, spark over of the main gap occurs. The trigatron gap is polarity sensitive and a proper polarity pulse should be applied for correct operation

6.6Some suggestions for the successors:

Use an inductance in series with the resistor to get a better front and tail time.

Use more faster responding MOSFET to get a better result.

Check the response of the circuit with additional load capacitance and inductance.