DEVELOPMENT OF PORTABLE 1O STAGES MARX GENERATOR

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ABSTRACT

High voltage equipments are often placed in open air and they are often exposed to lightning strike as well as surge voltage. They are sustaining high surge voltage during the lightning phenomena. To achieve better protection of all such power equipments and quality power supply, these voltages should be simulated and test the above said equipments in laboratories, Marx generator is the commonly used. This generator produces lightning impulse voltages of 1.2/50 μs duration. This project describes the development of a cost effective and easily portable compact 10 stages Marx Generator capable of producing lightning impulses voltage up to 25kV. In addition, three different experimental circuits of HV DC supplies have been made. The highest output was 2.5 kV DC which was taken as the main supply for the experimental and simulated Marx generator circuit. This generator can be used by small scale industries and academic institutions to demonstrate impulse voltages and also to perform testing on insulators of lower rating in laboratory. A total of 10 stages of both simulated, experimental Marx impulse generator circuit was designed and the impulse waves were recorded. The simulated recorded impulse waveform was compared with the standard impulse wave with front time of 1.2 μ seconds and tail time of 50 μ seconds. Both of circuits, the efficiency of each stages was calculated and the percentage of error in the front and tail time was also found out as well as the effects of the circuit parameters on the impulse waveform characteristics were also studied. The simulation was done with the help of Pspice Software Simulation. In this work, the comparison in terms of magnitude of the experimental and simulated 10 stages Marx generator circuit has been carried out as well as its illustrative curve has been drawn. These results have confirmed the validity of the proposed method and they were in close agreement.

ABSTRAK

Peralatan voltan tinggi sering diletakkan di udara terbuka dan peralatan tersebut sering terdedah kepada serangan kilat dan voltan lonjakan. Peralatan voltan tinggi mengekalkan voltan lonjakan tinggi dalam fenomena kilat. Untuk mencapai perlindungan yang lebih baik bagi semua peralatan kuasa dan kualiti bekalan kuasa, voltan, simulasi dan menguji perlu dibuat di atas peralatan yang dinyatakan di dalam makmal, penjana Marx ini adalah biasa digunakan. Penjana ini menghasilkan tempoh voltan impuls kilat pada 1.2 / 50 μs. Projek ini menggambarkan pembangunan kos padat 10 peringkat berkesan dan mudah alih penjana Marx mampu menghasilkan impuls kilat sehingga 25kV. Di samping itu, tiga litar uji kaji yang berbeza bekalan HV DC telah dibuat. Keluaran tertinggi ialah 2.5 kV DC yang diambil sebagai bekalan utama bagi eksperimen dan simulasi litar penjana Marx. Penjana ini boleh digunakan oleh industri kecil dan institusi akademik untuk menunjukkan voltan impuls dan juga untuk melakukan ujian ke atas penebat penarafan yang lebih rendah di dalam makmal. Sebanyak sepuluh peringkat bagi kedua-duanya simulasi ini, eksperimen impuls litar penajan Marx telah direka dan gelombang telah direkodkan. Gelombang impuls merekodkan simulasi dan dibandingkan dengan gelombang impuls standard dengan masa depan 1.2 μ saat dan masa ekor 50 μ saat. Bagi kedua-dua litar, kecekapan setiap peringkat telah dikira dan peratusan kesilapan di depan dan ekor masa itu juga mendapati serta kesan parameter litar kepada ciri-ciri gelombang juga dikaji. Simulasi ini dijalankan dengan bantuan Pspice Perisian Simulasi. Dalam kajian ini, perbandingan dari segi eksperimen magnitud dan simulasi sepuluh peringkat litar penjana Marx telah dijalankan serta lengkung ilustrasi telah disediakan. Keputusan ini telah mengesahkan tempohnya pada kaedah yang dicadangkan dan telah menjadi perjanjian dekat.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Most of the high voltage equipments such as power transformers, surge arresters, circuit breakers, isolators and high tension transmission line towers are placed in transmission substations. As these equipments are very costly and important for maintaining continuity of power supply, there safety should be the major priority for an electrical engineer. These equipment must tolerate not only the rated voltage which corresponds to the highest voltage of a particular system, but also over voltages. Accordingly, it is mandatory to test high voltage (HV) apparatus during its development stage. Protection of power system is an important aspect for the continued service of the electrical power system [1-4]. Mostly the protection of electrical power depends on the performance of insulation systems under transient over voltage conditions arises due to lightning and switching applications. Transient over voltages along with the abrupt changes in the state of power systems, e.g. switching operations or faults are known as switching impulse voltages and that due to lightning are known as lightning impulse voltages. It has become generally identified that switching impulse voltages are usually the prevalent factor affecting the design of insulation in HV power systems for rated voltages of about 300 kV and above [5-6]. Hence attention is required for these two types of over voltages. So in order to protect these equipments a prototype of the same can be used to test against lightning strikes.

A Marx Impulse generator is used to generate lightning impulse voltage. The magnitude and nature of test voltage varies with the rated voltage of particular equipment. It was originally described by E. Marx in 1924 and is primarily used because of its ability to repetitively provide high bursts of voltages especially when the available voltage sources cannot provide the desired voltage levels [1]. This generator 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 concurrent spark-over between the sphere gaps. The generated voltage from impulse generator must satisfy the standard values of voltage defined by the International Electro techno Commission in order to qualify as a standard impulse voltage that can be used for testing purposes [7]. The standard methods of measurement of high-voltage and the basic methods for application to all types of apparatus for alternating voltages, direct voltages, switching impulse voltages and lightning impulse voltages are laid down in the important national and international standards. Although the wave shapes of impulse voltages occurring in the system may vary extensively.

International Electro technical commission IEC60060 specifies that the insulation of transmission line and other equipments should withstand standard lightning impulse voltage of wave shape 1.2/50 μs and for higher voltages (220 kV and above) it should withstand standard switching impulse voltage of wave shape 250/2500μs. The tolerances [3-4] that can be allowed for the impulse wave are given by ±30% for time to front and ±20% for time to tail. [5-7].

In this work, an attempt has been made to develop a compact, inexpensive, portable 10 stages Marx impulse generator circuit for demonstration of lightning impulses in academic institutions. This 10 stages Marx generator circuit, was simulated by using PSpice software and the same circuit was made practically. In addition, three different sorts of HV DC supply were made to test the practical circuit as well as to provide HV DC supply in laboratory. Finally, the simulated and experimental results were compared in terms of their magnitudes.

1.2 Project Objectives

Over voltages on power lines create a great danger for the equipment, continuity of supply and more specifically the safety of personnel. Hence research in this area specifically the study of Impulse waves, its generation, its nature and characteristics is desired. As the power lines and equipments are exposed to the atmosphere, hence lightning strike is a common phenomenon. The main complication in high voltage engineering is the construction of proper high voltage insulation with minimum dimension at low cost. The only way to protect the power systems is to test the equipment's insulation strength by subjecting them to high impulse voltages and accordingly design the insulation of these equipments. Therefore, prediction of impulse withstands voltage for power equipments are very much essential which can only be achieved if we closely monitor the generation and characteristics of impulse waves. This motivates the need for practical high voltage impulse generation using Marx Impulse generator. Marx generators are used to provide very high voltage pulses for the examining the strength of insulation of electrical equipments such as large power transformers, or insulators used for aiding power transmission lines. The main objective of the thesis is:

i. To know characteristics of lightning voltage strikes.
ii. To develop 10 stages Marx Generator circuit using PSpice software to generate a waveform impulse voltage.
iii. To develop a practical 10 stages circuit model of Marx generator and to produce an impulse voltage.
iv. To provide three different kinds of high voltage DC supply in UTHM laboratory.
v. The final goal is to compare the theoretical values of peak lightning voltage obtained in simulation with those recorded in practical circuit.

1.3 Scope Of Project

The reason in writing the scope of this project is to make sure the project could be work regularly and not out of target. Thus, the research is more focus on :

i. Construct circuit of impulse generator using OrCAD PSpice version 9.1 software simulations.
ii. Collect the information about Marx impulse generator and how to design it properly.
iii. The lightning voltage's characteristics which can be a reference to design lightning protection and detection.
iv. 10 stages of Marx generator circuit will be constructed and designed using a prototype model on a reduced scale (1.2/50 μs), and 2.5 kV DC as input .
v. Collect the information about high voltage DC and construct three different circuits to be provided in the laboratory.
vi. Network analyzer is used to measure experimental result and measurements will be compared with simulated result.

1.4 Problem Statement

Each of the projects has their own problem to be discussing before starting the project. By stating the problem statement it easy to know the purpose of doing this project and what are the problem to be solved. Below are the problem statements for this project.

i. Lack of portable impulse generator mainly for research and education purpose.
ii. There are applications where they are needed for low magnitudes of impulse voltage(less than 5 kV).
iii. To provide an alternative for studying the generator impulse voltage in such a way that modification can be made easily.

iv. To provide portable HV supplies in the laboratory for education purpose.

v. To provide hands-on experience to the students in developing HV related stuff, for example; HV resistive divider.

1.5 Organization of Thesis.

This project report consists of five chapters, chapter one is introduction, chapter two is impulse generation for HV review, chapter three is implementation of simulation and experiment of HV impulse Generator, chapter four is development of portable 10 stages Marx generator and chapter five is conclusion and future recommendation.

Chapter one will be explain about the high voltage definition, history and standard. This chapter also states the problem for the project, objective and scope of the project report.

Chapter two will discuss about the theory of impulse voltage, there are five parts in this chapter to be discuss. First part about the theory of impulse voltage, second part types of impulse testing, third part impulse voltage circuit, fourth and five are about equipment and component that are use in this project.

Chapter three is the methodologies for the whole processes of project. In project methodology will explain the whole project procedure from starting finding and research the topic until choose the best circuit. For simulation method will explain the step of simulation project circuit. Lastly experiment methods are explaining the step in the experiment project.

In chapter four is discussing about the project result, this chapter consist of simulation and experimental result. In simulation part will discuss the result of output waveform and experiment part will discuss the output lightning voltage from the Multimeter and oscilloscope by using resistive voltage divider.

Finally, the last chapter five is the conclusion of the whole project report and suggestions.

CHAPTER 2

IMPULSE GENERATION FOR HV: REVIEW

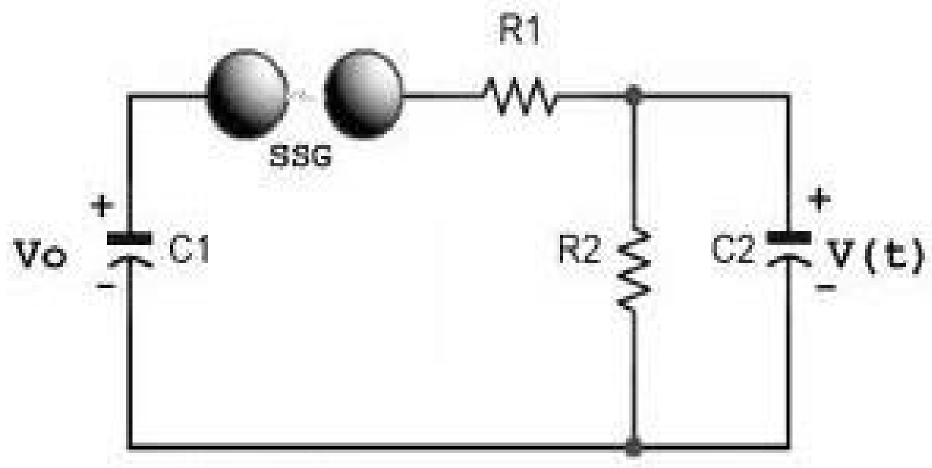
2.1 Background

High voltage technology was introduced at the beginning of the last century for electrical power generation and transmission systems. Long before that efforts have been made to study the lightening characteristics inside laboratory to carry out the tests on power system equipment in order to protect them from hazardous of lightning strike. A number of theories on lightening formation and generation have been presented [5]. Since the exploration on lightening started, efforts have been made to realise the lightening phenomenon inside laboratory so that the characteristics of the lightening can be studied more accurately and tests on power system equipment can be carried out. Many authors have presented their work about the generation of lightening impulse inside laboratory [3-15]. Marx has been the important guiding principle in generating lightening impulse voltage [8-13]. Almost in every paper Marx theory has been used but some paper have modelled the same principle differently for different application. Modified Marx generator has also been studied extensively [13-14]. In almost all the papers discussed so far has employed capacitive loading for getting the impulse responses. Marx circuit has been widely used in the generation of high repetition voltage pulses, high power microwaves where rise time ranges in the ns region. For accurate measurement of high voltage pulses through measuring instruments, measurement techniques and procedures have also been proposed [4], [9].

2.2 Single Stage Marx impulse Circuit

2.2.1 Standard

The energy storage capacitor C_1 is charged from the high voltage direct current (HVDC) power supply. The output waveform is controlled by the interaction of the front resistor R_1 and the tail resistor R_2 with the energy storage capacitor C_1 and the load C_2. The sphere gap in the circuit is a voltage limiting or voltage sensitive switch. Capacitor C_1 charges from a dc source until the sphere gap breaks down. The time of breaking down of sphere gap is very short.



Figurer 2.1: Single Stage Impulse Generator Circuit (Standard Marx circuit)

Charging voltage in large impulse generator can be of the order of mega volt (MV). The wave shaping network in the impulse generator consists of R_1, R_2 and C_1. Resistor R_1 basically damps the circuit and regulates the front time while R_2 is the discharging resistor through which C_1 will discharge. C_2 is the load which represents the capacitance of the load itself and capacitance of other elements parallel with the load. Capacitor C_1 discharges into the circuit comprising of R_1, R_2 and C_2, when break down of the sphere gap takes place [5].

Usually the impulse generator incorporates a load capacitance which is adequately large that the output waveform shape does not change considerably with changes in sample capacitance. The resistors R_1, R_2 and the capacitance C_2 form the wave shaping network. R_1 will primarily damp the circuit and control the front time T_1. R_2 will discharge the capacitors and therefore essentially control the wave tail. The capacitance C_2 represents the full load, i.e. the object under test as well as all other capacitive elements which are in parallel to the test object [1], [2].

Fast impulse or slower impulses can be generated if switching modifications are applied in the impulse generating circuits. One probable way of generating longer pulse is to add an inductance in series with R_1 [5], [7]. The difference in circuit arrangement will have different efficiency for the impulse generator. The dc voltage can be generated by the use of rectifier circuits. The rectifier used in the simulation is full wave rectifier circuit. The smoothness of dc value is not much of concern as it has to only charge the capacitor to peak. A sphere gap is a switch and the voltage across the sphere gap builds up as a voltage building up across capacitor takes place. Normally the sphere gaps are allowed to fire naturally or for smooth operation it can be fired through control methods.

2.2.1.1 Circuits For Producing Impulse Wave

Impulse waves can be produced in a 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 Figure 2.2(a) to 2.2(d). Out of these circuits, the ones shown in Figure 2.2(b) and (c) are commonly used for experimental purpose. Circuit is shown in Figure 2.2(a) has some limitations as the front time and tail time over a wide range cannot be varied. Commercial generators implement circuits is shown in Figure 2.2(b) to 2.2(d) [l-4].

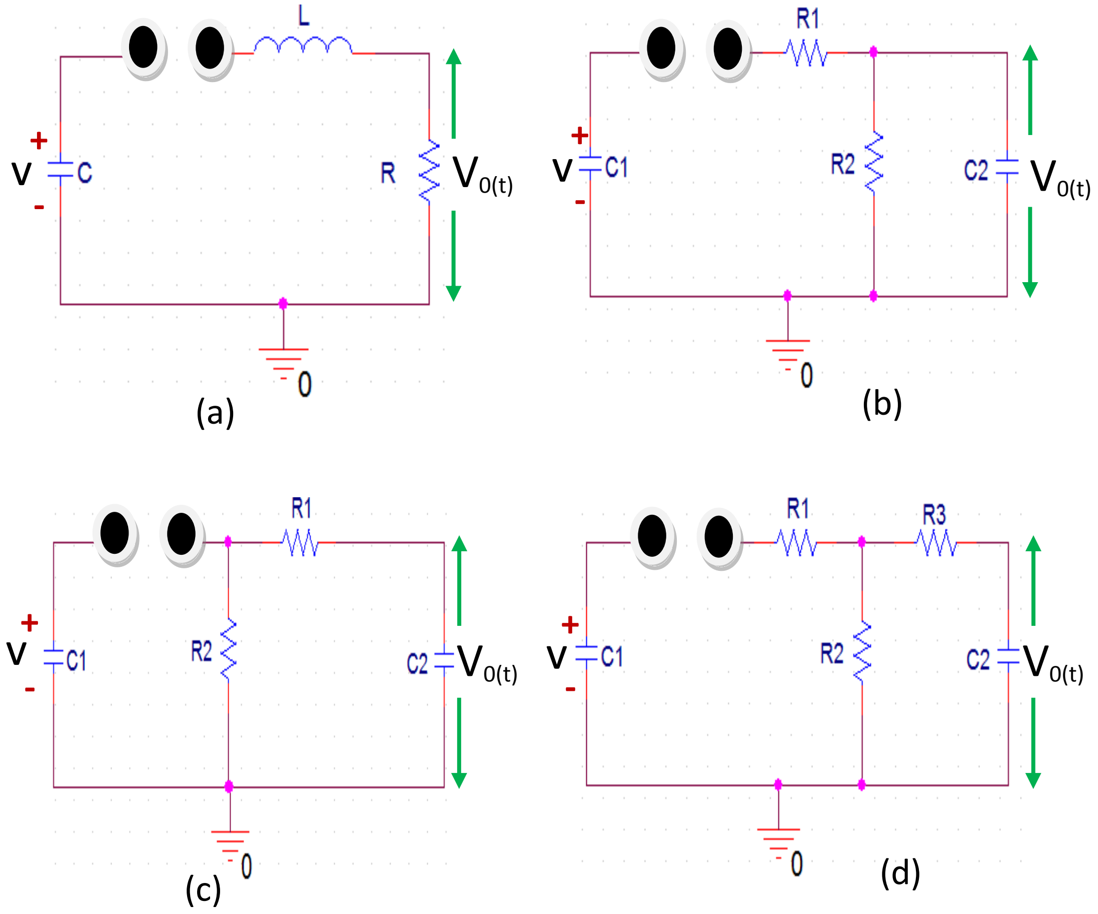


Figure 2.2: Circuits for Producing Impulse Waves [4]

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_1, R_2, C_2 or other combination) by sparking gap G. The output voltage Vo (t) gives rise to the desired double exponential impulse wave shape. The impulse generator is designed based on Marx circuit. Figure 2.2(c) is a basic single stage Marx generator circuit.

2.2.2 Improvement

The Improved Impulse Marx generator works same as the standard Impulse Marx generator i.e. the energy storage capacitor, C_1, is charged from the high voltage direct current (HVDC) power supply. The output waveform is controlled by the interaction of the front resistor R_1 and the tail resistor R_2 with the energy storage capacitor C_1

and the load C_2. The only difference is that the switch here acts as a potential divider that divides the tail resistor. The advantage of this method is that this circuit design helps in proper shaping of the impulse wave as the standard wave i.e. It helps in reducing the errors in rise time and tail time. The rise in peak voltage is not that considerable [6].

2.3 Multi Stage Marx Impulse Circuit

2.3.1 Standard

Due to the difficulties faced in very high voltage switching of the spark gap, increase in circuit element size, requirement of high direct current voltage to charge capacitor and difficulties in corona discharge suppression from the structures during charging period the extension of the single stage to multistage impulse generator is made[5-7].

A multistage generator is developed by cascading smaller single stage generator to generate high magnitude of output voltage. The primary requirement is to charge capacitors through the rectifier circuit and when all the capacitor reaches to the fully charged state then spark gaps are allowed to break down causing the capacitors to add in series. As a result the nominal output voltage is equal to the input voltage multiplied by the number of stages in the impulse generator circuit. At first, n capacitors are charged in parallel to a voltage (V) by a high voltage DC power supply through the resistors. The spark gaps used as switches have the voltage V across them, but the gaps have a breakdown voltage greater than V, so they all behave as open circuits while the capacitors charge. The last gap isolates the output of the generator from the load; without that gap, the load would prevent the capacitors from charging [1-3]. To create the output pulse, the first spark gap is caused to break down (triggered); the breakdown effectively shorts the gap, placing the first two capacitors in series, applying a voltage of about 2V across the second spark gap. Consequently, the second gap breaks down to add the third capacitor to the stack, and the process continues to sequentially break down all of the gaps. The last gap connects the output of the series stack of capacitors to the load. Ideally, the output voltage will be nV, the number of capacitors times the charging voltage, but in practice the value is less.

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The Improved Impulse Marx generator works same as the standard Impulse Marx generator i.e. the energy storage capacitor, C_1, is charged from the high voltage direct current (HVDC) power supply. The output waveform is controlled by the interaction of the front resistor R_1 and the tail resistor R_2 with the energy storage capacitor C_1 and the load C_2. The only difference is that the switch here acts as a potential divider that divides the tail resistor. The advantage of this method is that this circuit design helps in proper shaping of the impulse wave as the standard wave i.e. it helps in reducing the errors in rise time and tail time. The rise in peak voltage is not that considerable [6].

In multistage Marx generator circuit resistive voltage divider are used in order to minimize the level of voltage to a measureable value across each capacitor [5],[6]. It consists of two impedances which are connected in series and a tapping is introduced in between these resistors in order to connect the sphere gap. Usually charging resistance is chosen to limit the charging current to about 50 to 100mA, while the generator capacitance is chosen such that the product of charging resistance and generator capacitance is about to 10s to 1 minute [4]. The discharge time constant will be too small (microseconds), compared to the charging time constant which will be few seconds. For designing the circuit of Marx Impulse Generator various equations were used. The standard impulse wave was calculated using:

$$v = v_0 * \left[e^{-\alpha t} - e^{-\beta t}\right] \tag{2.1}$$

Where, α and β are constants of microsecond values. V0 is the applied DC voltage. The efficiency of each stage was given by

$$\text{Efficiency} = \frac{V}{V_0} \tag{2.2}$$

Where, V is the peak output voltage; V_0 is the applied DC voltage. It can also be given by

$$\text{Efficiency} = \left(\frac{1}{1+(C2*n)C1}\right) + \left(\frac{1}{1+\left(\frac{R1}{R2}\right)}\right) \tag{2.3}$$

Where, C_1,C_2 are charging and discharging capacitors, R_1, R_2 Are front and tail resistors and n is the number of stage [5,6].

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. Therefore, we can go for an optimum number of stages for the generation of high impulse voltages through impulse generator circuit.

2.4 Standard Impulse Waveform

The induced overvoltage in power system are characterized by their shapes, magnitudes, time periods and frequency of occurrence. Two types of overvoltage normally prevail in power system which takes the system to unstable stage. The unstable condition arises when the peak amplitude of the nominal operating voltage exceeds. The induced Transient over voltages caused by lightning and switching surges causes steep build up voltages on transmission line and other equipment. Experimental records show that these waves have a rising time of 0.5 μsec to 10 μsec and decay 50 % of the peak value of the order of 30μsec to 200 μsec. The wave shapes are arbitrary and unidirectional. The standard wave rise time and fall time for a lightening impulse wave is 1.2 μsec and 50 μsec respectively [5], [6], [13].

The kind of wave shape related with the lightening impulse voltage is given by the equation (1) where α and β are constants in the range of microseconds and V0 is the charging voltage.

$$v = v_0 * \left[e^{-\alpha t} - e^{-\beta t}\right] \qquad (2.4)$$

This equation explains that lightning is a doubly exponential curve which rises quickly to the peak and falls relatively slow to zero values. Impulse voltages are defined in terms of their time periods i.e. rise time, fall time and also the peak voltage.

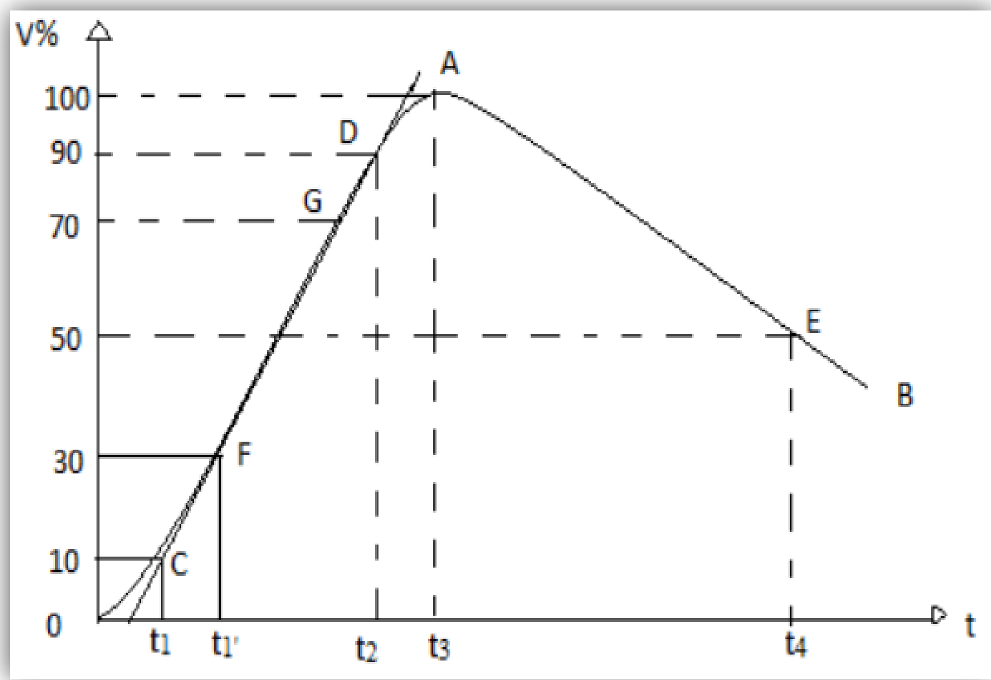

Figure 2.3: Standard Impulse Wave

The rise time is defined as the time taken for the impulse to rise from 10% of peak value to 90% of peak value and the tail time is defined as the time taken for the impulse to drop to 50% of the peak value. Now as shown in Figure 2.3 the rise time is given by t_1 and fall time by t_4.

2.5 Novel Application of LabVIEW in High Voltage Engineering

This project has been done by Deepak Kumar Singh. It was focused on developing a LabVIEW simulation circuit that would generate an impulse voltage wave, and to develop a practical circuit that could produce an impulse voltage by using One stage impulse generator (1.2/50 μsec, 5 V DC input). So generation and simulation of an impulse wave has been carried out by the help of LabVIEW Multisim Software Package.

A practical Marx circuit has been made and its comparison has been drawn with standard impulse voltage. Data acquisition of the practical impulse voltage generation circuit has been performed.

Generally, for a given one stage Marx generator circuit (Figure 2.1) the limiting values of generator capacitance C_1 and load capacitance C_2 varies as depicted in Table 2.1.

TABLE 2.1: LIMITING VALUES OF C1/C2 FOR DIFFERENT STANDARD WAVE

T_1/T_2 (μs)	1.2/5	1.2/50	1.2/200	250/250
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 Figure 2.1 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 [1].

$$T_1 = 3R_1C_e \tag{2.5}$$

Here, Ce is given by the following equation: $C_e = \frac{C_1 C_2}{C_1 + C_2}$, R_1Ce is the charging time constant in micro-second. For discharging or tail time, the time for 50% discharge is approximately given below.

$$T_2 = 0.7(C_1 + C_2)(R_1 + R_2) \tag{2.6}$$

With approximate formulae, the wave front and wave tail can be estimated to within ±20% for the standard impulse waves. Equation (2.5) can be written as:

$$R_1 = \frac{T_2\,(C_1 + C_2)}{3C_1C_2} \tag{2.7}$$

Equation (2.6) can be written as:

$$R_2 = \frac{T_2}{0.7(C_1 + C_2)} - R_1 \tag{2.8}$$

2.5.1 One Stage Marx Generator Circuit

A practical circuit model of one stage Marx Generator circuit is built as shown in Figure 2.4. The circuit consists of transformer, discharging capacitor C_2 is 1 μF, discharging resistor R_2 is 6.3 Ω, charging capacitor C_1 is 10 μF, damping resistor R1is 0.5 Ω and switch. Combinations of four 1 Ω resistors are connected in parallel and three 2.1 Ω resistor connected in series to obtain the resultant 0.5 Ω (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.

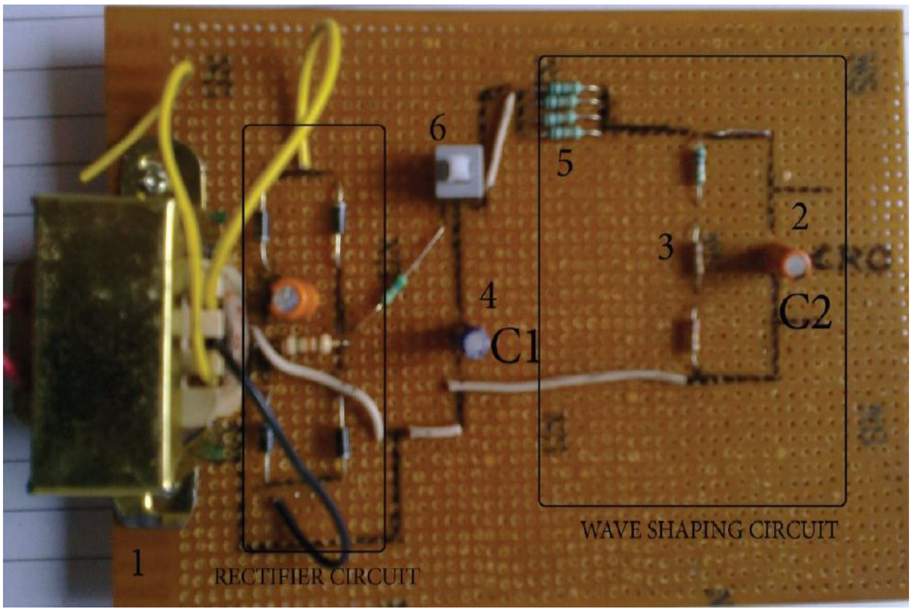

Figure 2.4: Practical One Stage Marx Generator Circuit [21]

In one stage Marx impulse voltage generator circuit, all the components are placed in the Multisim project board as shown in Figure. 4.1. 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) to equation (4). 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 2.1). Assuming the charging capacitor C_1 to be 10 µF and discharging capacitor C_2 as 1 µF, 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 R1 is 0.44Ω ≈ 0.5Ω and R2 is 6.04 Ω ≈ 6.2 Ω By simulating the circuit with these parameters the result obtained is as follows.

Output peak impulse voltage is found to be 3.44V. Efficiency of the circuit is (3.44 / 5)× 100 is equal to 68.8%. Rise time is found to be 1.25 × (40.86 – 40.0944) or 0.957µs. Tail time is found to be (91.2678 - 40.0944) i.e., 51.1734µs. In designing the circuit using LabVIEW Multisim software, the sphere gap for triggering the lightning was replaced by the use of a switch, as shown in Figure 4.1. The circuit was simulated in LabVIEW Multisim using end time value 0.02 second and maximum time step input 2e009 second. Impulse waveform can be seen on oscilloscope output as well as the grapher output. The grapher output waveform can be auto scaled and all the parameters of impulse wave can be calculated from the grapher output tab. Rate of simulation can be changed by changing the value of maximum time step input. The simulated circuit and its waveform are shown in Figure 2.5 and Figure 2.6[21].

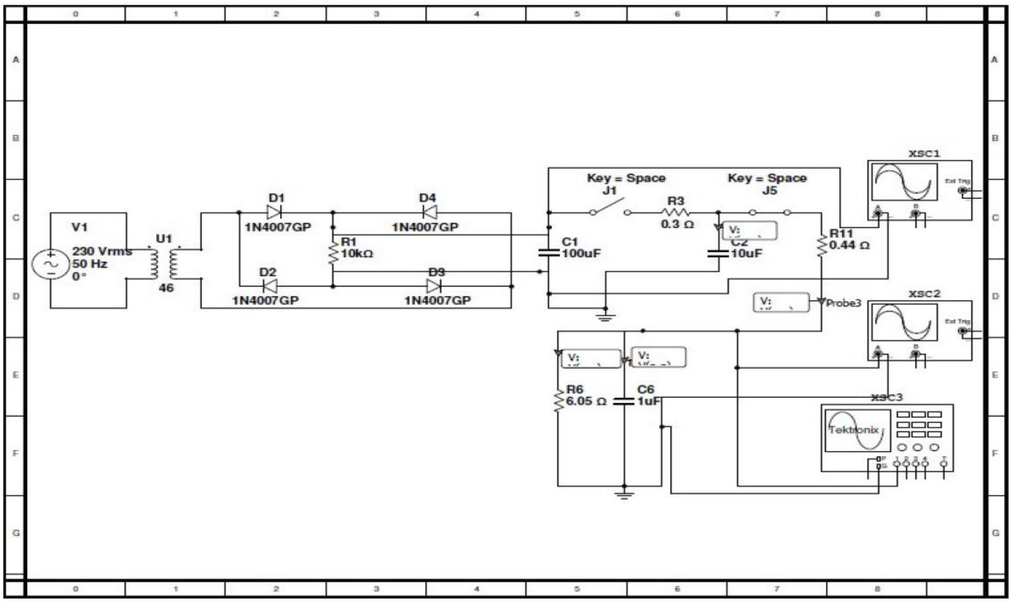

Figure 2.5: Simulation Circuit for One Stage Marx Generator [21]

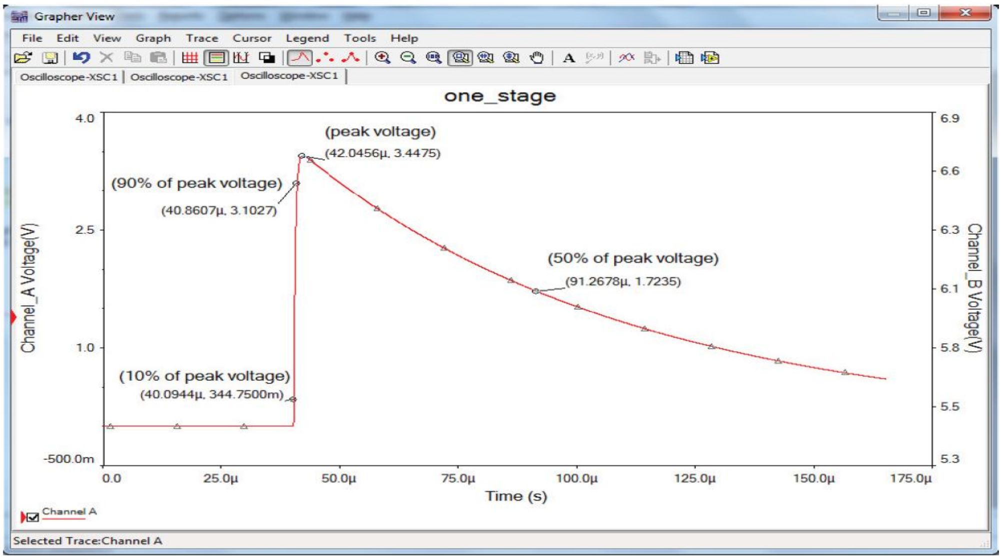

Figure 2.6: Graph Output Showing a One Stage Marx Circuit [21]

So, generation and simulation of one impulse wave has been carried out by the help of LabVIEW Multisim Software Package. A practical Marx circuit has been made and its comparison has been drawn with standard impulse voltage. However, only one stage impulse generator has been used in this project and at the low voltage(5 kV DC). As shown on the graph above, there's a big difference between the peak value of simulation and practical circuit.

2.6 Using PSpice in Teaching Impulse Voltage Testing of Power Transformers to Senior Undergraduate Students.

Behrooz Vahidi and Jamal Beiza is the writer of this research. This paper describes an efficient method of teaching impulse voltage testing of power transformer to undergraduate students of power system groups in electrical engineering departments, as a part of a high-voltage course for senior undergraduate students. The paper shows how to simulate the power transformer and impulse generator to teach students the basis of impulse voltage testing of power transformers and to practice analyzing the test results. In the first part of the paper, the effect of wave shaping of the voltage waveform is simulated to teach the behavior of the impulse generator and in the second part, impulse voltage testing of a transformer is simulated [10].

In this research, the circuit that has been used by the author looks complicated and they used six stage impulse generator. The circuit is more suitable to construct the circuit of impulse generator using hardware. Thus, in this present project the simple circuit is chosen to being simulated using PSpice software simulation.

2.7 Determining Ideal Impulse Generator setting From a Generator Transformer Circuit Model.

This research has been done by Robert M. Del Vecchi, Rajendra Ahuja and Robert Dean Frenette. The researchers were more focused on determining ideal impulse generator using transformer circuit model. In this research, the authors were referred a standard voltage waveform to be applied to the various transformer terminals undergoing an impulse test. Although these waveforms differ in peak value or basic impulse level (BIL), they have similar time characteristics. From the Figure below, the important parameters are the rise time to reach the peak value t_p and the fall time to fall to 50% of the peak value t_f [11].

A common parameterization for this waveform is given by

$$V = A(e^{-\alpha t} - e^{-\beta t}) \tag{2.9}$$

where;

V=output impulse voltage α, β and A = constant (can be determined from t_p, t_f and the 100 BIL level).

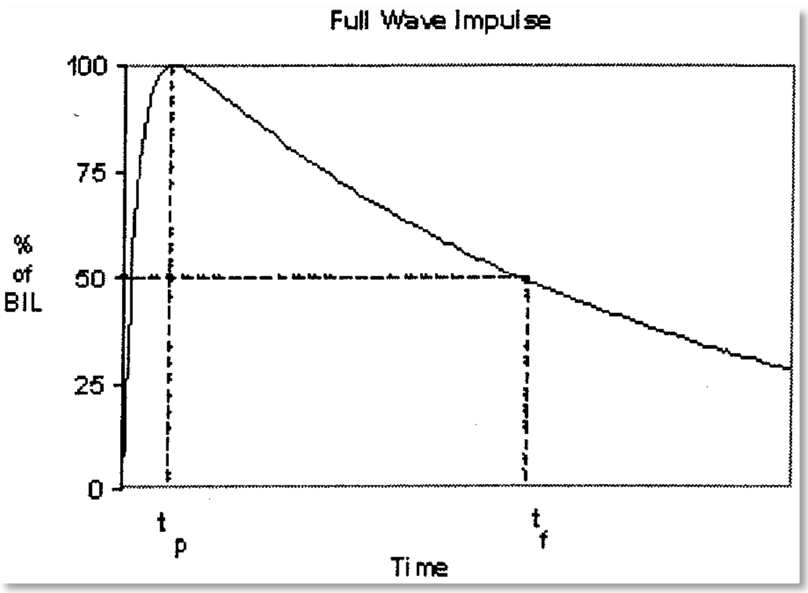

Figure 2.7: Standard full-Wave Impulse Waveform [11].

Transformer has been used in this research to generate the impulse of lightning generator. In this research, the authors more focused on the circuit design. Compare to the present project, the circuit with the specific value is constructed, simulated and analyzed.

2.8 Design Of A Single Phase High Voltage GE DC Power Supply At 15KV Output Using Voltage Doubler Circuit.

This paper describes the design and implementations of a single phase high voltage DC power supply at 15 kV output. This explain the detail description of the simulation, design, development and implementation of the hardware work to build a high voltage DC power supply in the laboratory and its simulation works done by using PSpice software. The designed DC power supply it can be used in industrial applications. Simulation and experimental results are presented in terms of performance and implementation.

2.8.1 Voltage Doubling Principle

In this paper, the main concept of this work is to study the voltage doubler circuit based on simulation and hardware implementation and finally based on Cockcroft-Walton (C-W) voltage multiplier circuits to fabricate a DC power supply in the laboratory at the output range of 15 kV. The conventional technique is used because the designed multiplier circuit is intended to be applied either for impulse generator charging units or for laser excitation[17]. The main components of the DC power supply are rectifier diodes and capacitors. The simplest unregulated power supply consists of three parts namely, the transformer unit, the rectifiers unit and the capacitors unit. The design specifications of the voltage doubler circuit are in Table 2.2.

Table 2.2: Circuit Design Specifications [22]

Input voltage	220 volt
Output voltage	15 kV
Single phase transformer	1:1
DC Capacitor voltage level	850 volt
Capacitance value	1 µf
Rect. Diodes max. voltage level	4000 v
Forward current	0.25 A

Figure 2.8 shows the schematic for a half-wave voltage doubler. In fact, the doubler shown is made up of two half-wave voltage rectifiers. Here C_1 and D_1 make up one half-wave rectifier and C_2 and D_2 make up the other rectifier.

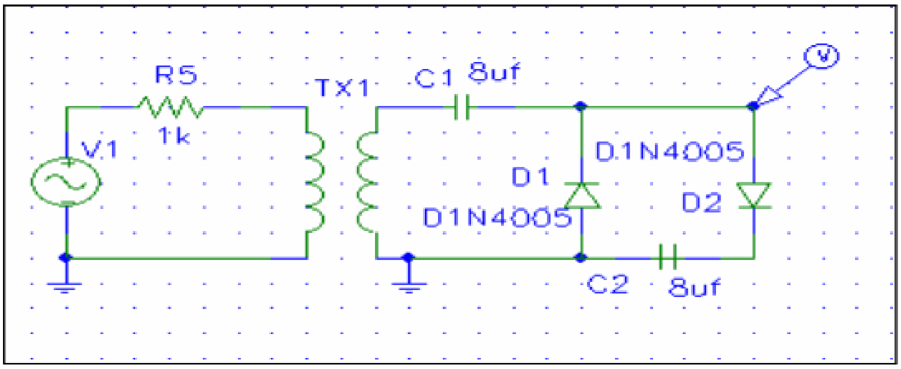

Figure 2.8: Connection Diagram of the Half-wave Voltage Doubler Circuit [22]

The input voltage of the voltage doubler circuit for the simulation has been set to 220 volt and the output obtained is 440 volt. It shows the voltage doubler circuit functioning as expected in Figure 2.9.

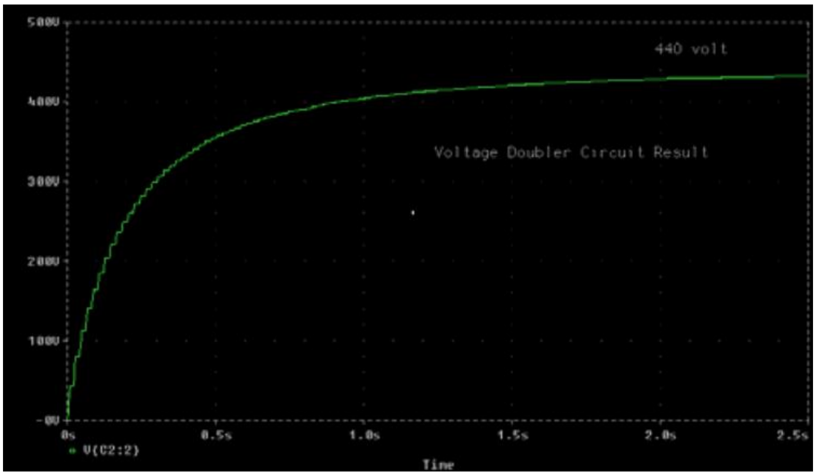

Figure 2.9: Simulation Result Voltage Doubler Circuit [22]

Figure 2.10 shows the simulation output voltage and Figure 2.11 show the output current of the designed high voltage DC power supply for the proposed 15 kV circuit.

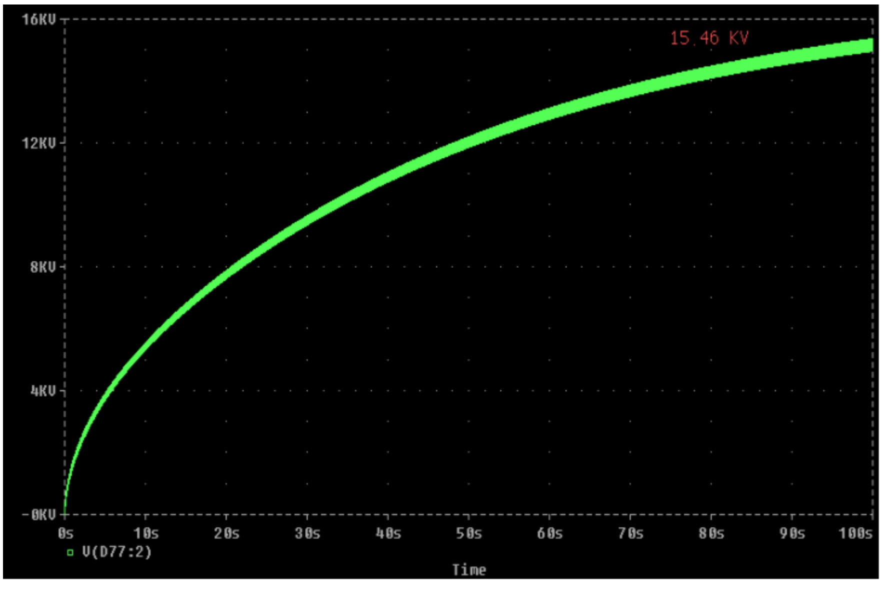

Figure 2.10: Simulation Result 15 kV DC Power Supply [22]

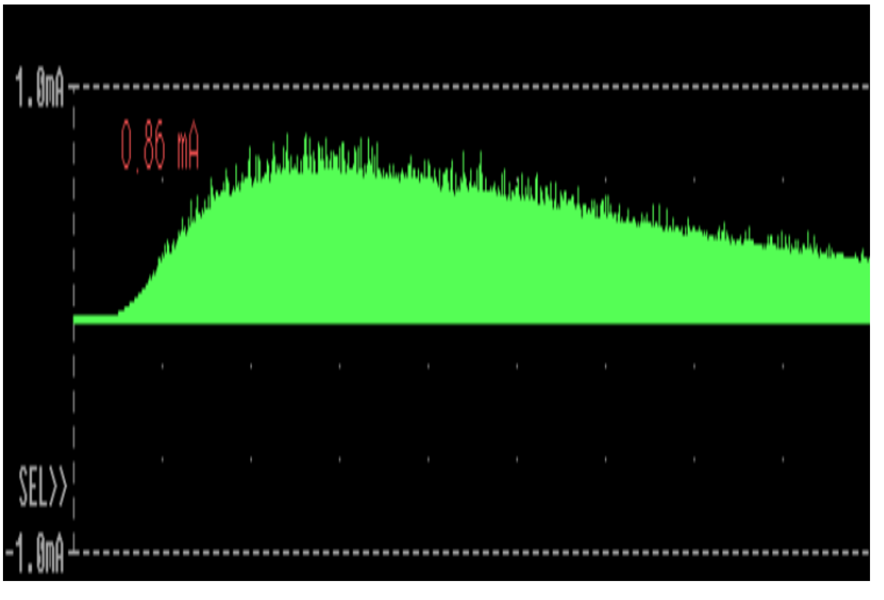

Figure 2.11: Simulation Output Current of DC Power Supply [22]

The simulation results are corroborated by implementing and testing the circuits in the laboratory. The input voltage was set at 220 volt and the output obtained is 471 volt. So according to the simulation circuit, it should be 440 volt but it has given a higher value than its simulation result as shown in Figure 2.12.

Figure 2.12: Experimental Output Voltage of Doubler Circuit [22]

Figure 2.13 shows that the output of the designed DC power supply is 15 kV and it is tested and installed as well as Figure 14 shows the hardware implementation for DC power supply in the laboratory.

Figure 2.13: Output Voltage of the DC Power Supply [22]

Figure 2.14: Constructed DC Power Supply in Lab [22]

A PSpice based design for high voltage DC power supply at 15 kV output has been proposed and developed. The system hardware has been implemented and tested in the laboratory. The simulation and experimental results has been observed to be in agreement. The designed DC power supply can be used for multiple purposes such as impulse generator charging units, laser excitation or test on cables in industrial application [22].

2.9 High Voltage Measurements

High voltages can be measured in a variety of ways. Direct measurement of high voltages is possible up to about 200 kV, and several forms of voltmeters have been devised which can be connected directly across the test circuit. High Voltages are also measured by stepping down the voltage by using transformers and potential dividers. The sparkover of sphere gaps and other gaps are also used, especially in the calibration of meters in high voltage measurements. Transient voltages may be recorded through potential dividers and oscilloscopes. Lightning surges may be recorded using the Klydonograph[16].

2.9.1 Direct Measurement of High Voltages

2.9.1.1 Electrostatic Voltmeters

One of the direct methods of measuring HV is by means of electro-static voltmeters. For voltages above 10 kV, generally the attracted disc type of electrostatic voltmeter is used. When two parallel conducting plates (cross section area A and spacing x)are charged q and have a potential difference V, then the energy stored in the is given by

$$\text{Energy stored } W = \frac{1}{2} C\, V^2 \text{ so that changes } d\,W = \frac{1}{2} V^2\, d\,C = F\, d\,x \qquad (2.10)$$

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