Design and Implementation of 200 kV Van de Graff Generator with Improved Insulation Characteristics

Submitted by:

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2016-MS-EE-020

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This thesis is submitted in partial fulfillment for the degree of Master of Science in Electrical Engineering

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Declaration

I, Muhammad Bilal Anwar, certify that this work is my own and has not been, in whole or in part, presented for assessment elsewhere. Where material has been used from other sources it has been acknowledged and referenced properly.

Signed: ____________________

Date: ____________________

Acknowledgments

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Dedications

I would love to Dedicate this to my mother, who always believed in me and supported me every time I lack in academic arena. She was a constant wellspring of motivation to my life. Despite the fact that She isn't here to give me strength and support but I always feel her presence that used to encourage me and to endeavor to accomplish my goals throughout my life. Mom, You are not there but your belief in me has made this journey possible.
I also dedicate this degree to my Father who's utmost wish to see me as an Electrical Engineer...

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Abbreviations

VDG	**V**an **d**e **G**raaff
SCR	**S**ilicon **C**ontrolled **R**ectifier
AC	**A**lternating **C**urrent
STP	**S**tandard **T**emperature **P**ressure
ESD	**E**lectro **S**tatic **D**ischarge
RPM	**R**evolution **P**er **M**inute

Abstract

The Vann De Graff is very famous in the electrical industry, high-voltage X-rays, nuclear physics, and dielectric testing. It has gained its importance because of its unconventional design and high voltage capacity with an extremely low current. However, the sensitivity to the environment and over insulation requirements restrict its use immensely and thus it becomes a major reason of ignorance for quite sometimes. Also, the unavailability of an empirical model lacks its proper designing which ultimately fails to deliver efficient performance. This problem has been analyzed sensitively and its solution has been implemented in this research.

The designing in this research is critically analyzed and especially the problem in some critical parts like Designing of Dome is solved by selecting the aluminum material dome with perfect sizing by using the sphere vs charge calculation to get desired voltages. The Teflon Belt material is selected instead of rubber belt for the better performance because Teflon material is more close to "capture" electrons. The Belt is also stretched for more charges to liberate out. But it may cause the breakage of belt, to avoid this we use soft starting of motors using SCR Controlled voltage regulator.

While designing the generator we cannot ignore the insulation of this generator because it possesses very high voltage with a small current that's why the insulation of internal and external part of the generator focused on this research, some parts of the generator must be highly insulated otherwise the charge failed to establish. The functionality of this generator is mainly dependent on weather conditions. The electrostatic charges leak very rapidly in moisture. The insulation is the prime factor for improvement in every Van de Graff generator. The irregularities at the dome surface cause a leakage of charges. So to remove this issue we polished a dome with zinc material. Further we introduce silica gel at the outer side to remove moisture of inner region and for inside part the generator is insulated through a vacuum pump and a bulb which generates the heat to avoid humidity effect.

The rate of discharge is a superior parameter of the execution of the machine than the ideal voltage. Thus we perform two different tests to verify the performance of generator one of the test is conventional voltage test using electrostatic generator and other is gap spark tests. The results with proper testing provide a 200 kV generator with better efficiency than the one commercially available.

Chapter 1

Introduction

For quite a long time, electrostatics was just viewed as a characteristic interest. Extremely high voltages can be produced by the contact of different substances. This reality is the essential rule of VDG generators. This generator was produced to make extensive voltages with low current. More powerful "classroom" sized Van de Graaff generators commonly deliver 500,000 V to 600,000 V [1]. It holds gigantic significance to progressively exhibit a few physical ideas like electrostatics, protection of charge, conduction, and ionization. It is an amazing electrostatic generator which stores a lot of electrical charge on the metal arch (globe) and it is fit for creating colossally extensive static electric possibilities. Friction based (static) electricity is a commonplace idea that we experience regularly [2].

1.1 History of VDG Generator

Electrostatics was first seen by the Greek scientist Thales, who found that amber pulled in light protests when rubbed. For a considerable length of time, this wonder was just viewed as a characteristic interest. Extremely high voltages can be produced by the contact of opposite nature substances. This reality is the essential standard of VDG generators. The VDG generator is named after Dr. Robert J. Van de Graaff who licensed his electrostatic generator in 1935. He built up this generator which makes substantial voltages with the extremely low current. It can be utilized to powerfully show a few physical ideas, including electrostatics, preservation of charge, conduction, and ionization. The Van de Graaff generator is a great electrostatic generator which stores a lot of electrical charge on the metal arch (globe) and it is fit for delivering tremendously extensive static electric possibilities. Static electricity is a familiar concept we encounter on a daily basis [3].

The initial machine design utilized a normal tin can, a very small motor, and a silk strip purchased at a five-and-dime store. Where upon he went to the leader of the material science division asking for a hundred dollars to make an enhanced adaptation. He got the cash, with some trouble. By 1931 he could report accomplishing 1.5 million volts, saying. "The machine is basic, modest, and compact. A customary light attachment outfits the main power required. As per a patent application, it had two 60-cm-measurement charge-amassing circles mounted on borosilicate glass sections 180 cm high the device cost just 90 dollar in 1931. On the off chance that the charged conductor is acquired to interior contact with an empty conductor, the greater part of its charge exchanges to the surface of the empty conductor regardless of how high the capability of the last might be [4].

1.1.1 Basic Working

The rubber belt inside the VDG generator keeps running between two rollers made of opposite materials, making electrons exchange from one roller to the rubber, and from the rubber onto the other roller, Charges are also transferred between the top roller and brush due to the triboelectric effect. Whether the roller gains a positive or negative charge depends on the material properties of the top roller. The free electrons in the ionized air are attracted to the positive charges on the belt and, depending on whether the roller has a positive or negative net charge, this effect can be enhanced. As the belt returns to the bottom it carries either no charge or a net negative charge, depending on the material properties of the roller [5].

This carried charge might want to disseminate itself over as huge a volume as could be expected under the circumstances, in the long run, the charge on the dome achieves a balanced state where the emphatically charged dome starts to pull electrons from the air. That is the reason you hear a snapping sound noticeable all around your generator as it works likewise the charges spread out crosswise over anything you interface with the metal dome, including any human. The reason it's critical to stand them on something electrically insulating is that the charge might want much more to spread out, and try to diminish the impact, and furthermore cause an electric shock as the present streams from the VDG to earth through its terrible human middle person.

1.2 Concept of Charge, Current and Voltages

Electrical current streams when oppositely charged objects are associated together with a decent conductor like a copper wire iron wire or any other conducting material. Electrons spill out of the negatively charged object to the positively charged object. Electrical current can likewise spill out of an object with a high negative charge to a second object that is less contrarily charged. On the off chance that the distinction in electric charge is sufficiently incredible, the current can even move through a poor conductor like air. This is the state where the positively charged dome starts to pull electrons from the air. That is the reason you hear a sharp sound noticeable all around your generator as it works.

1.3 Interactions between Positive and Negative Charges

Charge is an intrinsic (natural) property of particles. Charges can be positive, negative, or neutral. When two charges have opposite signs (positive and negative), they are attracted to one another. When two charges have the same sign (both negative or both positive), they are repelled. Within any material there are both positive and negative charges, and how the material behaves depends on whether there are more positive charges, more negative charges, or an equal number of both (neutral object). The total charge in the universe is always conserved we cannot create new charges or destroy existing ones. Charge can, however, be transferred between objects. Conduction is one process by which a charged object transfers charge to another object through contact.

1.4 Triboelectric Series

The total charge in the universe is always conserved we cannot create new charges or destroy existing ones. Charge can, however, be transferred between objects. Conduction is one process by which a charged object transfers charge to another object through contact as shown in Figure 1.1. Notice that charge is merely exchanged between the

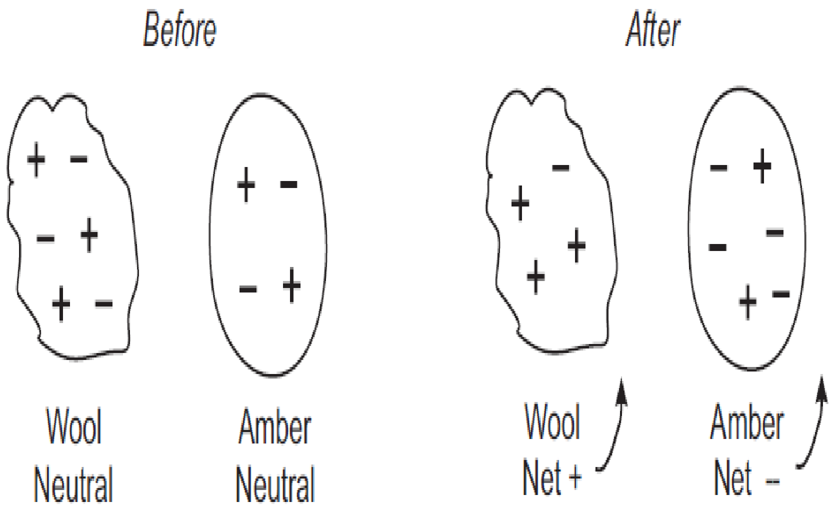

Figure 1.1 Rubbing of opposite charges.

amber and wool and that the total charge stays the same. When objects acquire charge in this way, they can then cling to other objects (attracting them with their charge), or discharge onto another object (like after you acquire a net charge from the carpet and discharge it on a nearby doorknob or an unsuspecting friend) [6].

As one can become acquainted with from, the triboelectric impact is a sort of contact jolt in which certain materials turn out to be electrically charged after they come into frictive contact with an alternate material. Rubbing glass with hide, or a go over the hair can develop tribo power [7]. Most regular friction based electricity is triboelectric. The extremity and quality of the charges delivered vary as indicated by the materials, surface harshness, temperature, strain, and different properties. The triboelectric impact isn't exceptionally unsurprising, and just expansive generalizations can be made according to Figure 1.2[8].

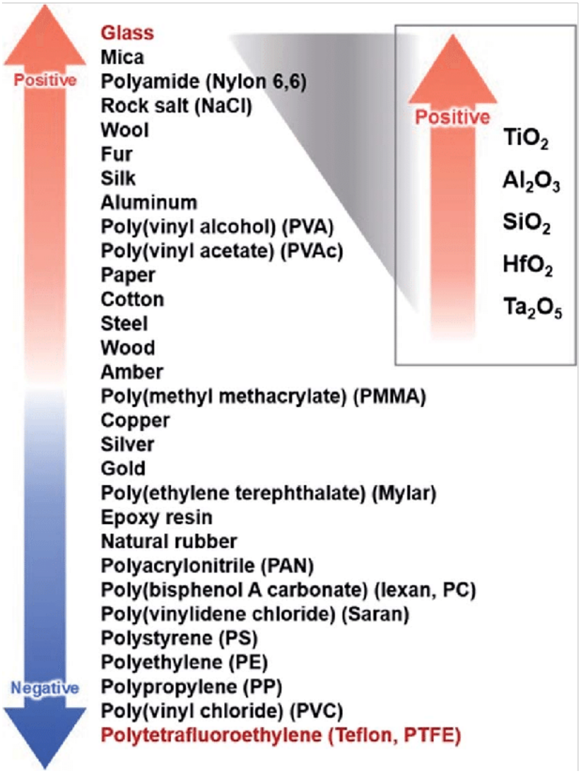

Figure 1.2 Triboelectric series.

1.4.1 Concept of Ionization

The VDG generator also demonstrates the idea of how the surrounding insulation air ionized and allows to conduct the current. Ionization usually occurs at very high potential normally when the electric field intensity becomes very strong, so that it may liberate out the electrons from the surrounding air atoms. When there is a deficiency of charges occurs in air molecule the electrons recombine with the positive ion and this combination can be visualized using released light. This phenomena repeated again and again until the proper discharge from source to earth happens as shown in the Figure 1.3 [9].

1.5 Nature of Electric Field

Some of the objects have an equivalent positive (+) and negative (-) electrical charge, which helps them to make electrically unbiased. Articles obtain an electrical charge by gathering or surrendering electrons. Electrons are subatomic particles with a negative charge that are a typical piece of all issue. A protest that gathers electrons builds up a negative charge while a question that surrenders electrons builds up a positive charge.

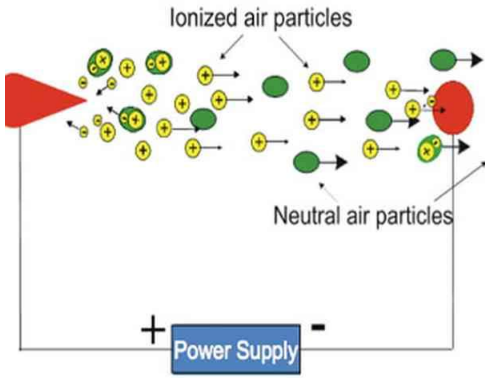

Figure 1.3 Air ionization phenomena.

Any electrically charged particles deliver an electric field which draws in oppositely charged items like a positively charged particle pulls in negatively charged particle and repulses correspondingly charged particle as positively charged particle repulses other positively charged particles.

You can exhibit this with a little balloon on a dry day. Rub the balloon on the hair of your lower arm. As you do, the balloon gathers electrons from your arm and turns out to be negatively charged. In the meantime, the hair on your arm surrenders electrons and turns out to be positively charged. Presently bring the balloon to inside 1-2 inch of your arm. You will observe that the hair stands straight up toward the balloon. The electric field of the negatively charged balloon pulls in the positively charged hair on your arm.

Electrical current started to flow when oppositely charged items are associated together with a decent conductive channel like a copper wire. Electrons spill out of the negatively charged objects. Electrical current can likewise spill out of object with a high negative charge to a second particle that is less negatively charged. In the process that the distinction in electric charge is sufficiently incredible, the current can even course through a poor conductor like air. This is the thing that happens when lightning strikes the earth. Clouds with an extremely solid negative charge are protected from the earth via air. As the negative charge on the cloud manufactures it at long last defeats the protecting hindrance of the air, and current streams through lightning from the cloud to the earth. Similarly the charge is established at the dome of the generator as shown in the Figure 1.4 [9].

1.6 Models of VDG Generator

1.6.1 Simple Motor based VDG Generator

The model of VDG generator as appeared in Figure 1.5 [10] utilized two pulleys of various material to drive the rubber belt. The pulley obtained a positive charge and inside of belt is negativly charge. The brush is available at very close to move negative charges to the dome. The lower brush depletes the positive charges. The motor is

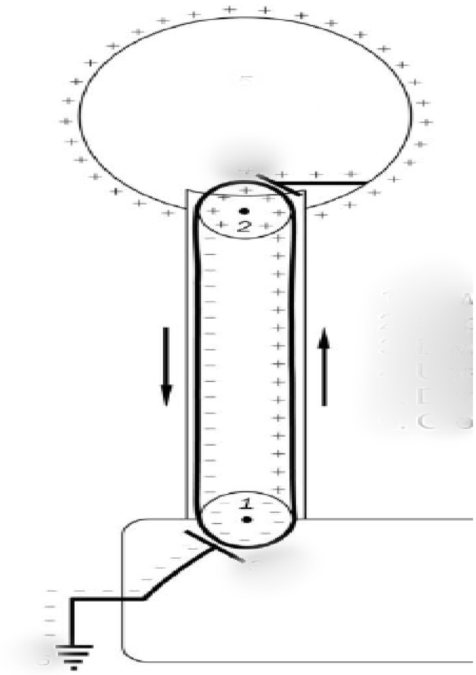

Figure 1.4 Nature of Electric Field developed.

additionally associated with the base pulley of the generator to pivot the belt speedier because of this charges set up and the required electrostatic voltages are produced at the metal dome [11]. The significant issues happen in this model is humidity in the

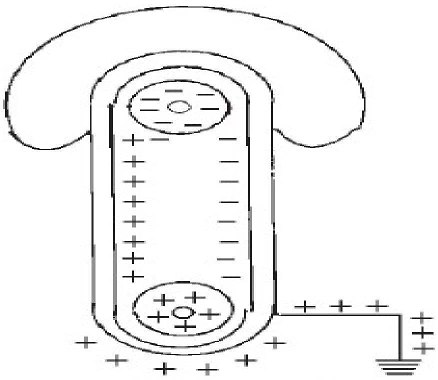

Figure 1.5 Van de Graff generator design.

surrounding air and within the generator which makes the generator tumbles down in charges and consequently neglects to keep up the generated voltage additionally the belt of the generator has an ozone covered layer which may irritate with the humidity and subsequently the life of belt decrease. The creator additionally featured that the change of protection is required in this generator, weaker current accomplished because the belt isn't appropriately producing the electrons as required. The dome of the generator indicates little noticeable flashes show up in dim because of the poor protection at the dome of the generator which drives the generator to drop in the electrostatic yield of voltage [12]. The issues talked about in the generator are significant.

1.6.2 200 kV VDG Model

This VDG generator as shown in Figure 1.6 which uses two pulley and belt structure but with different rollers material as compare to above it uses Teflon pulley as a lower roller which is attached directly to the motor shaft the belt material is of rubber for this generator which passes through the lower roller and at the top, the roller material is aluminum which conducts the positive ions after being in contact with rubber belt and transfer them to the dome. An electrode at the lower and upper side are connected is of the type of wire screen. The issue possesses in the generator is not a proper selection of roller material and due to this it will fail to liberate more charges [13].

Figure 1.6 Van de Graff generator design.

1.6.3 Hand-driven Generator

The belt assumes a critical part in transporting negative charges from the upper brush to the lower brush and positive charges from the lower brush to the upper brush. There is no exchange of charge from the electrical lines. This gadget would work precisely the same on the off chance that it was controlled by an engine. On the metallic dome, the positive charges spread out because of electrostatic repugnance and turn out to be consistently disseminated because of the dome's round shape as shown in Figure 1.7. The development of positive charges on the arch proceeds until the point when ionization force is come to. The potential between the dome of the generator and ground is about one and half million volts. The air between the generator encounters dielectric breakdown and the generator releases the aggregated static charge as a start. This procedure proceeds as long as the generator is moving physically but the major issue in this generator is random motion of the generator due to hand motion which resist its use [14].

1.7 Issues in existing VDG Generators

There are many models of VDG generator with different approaches and various techniques are available some of the generators already mentioned above. These VDG generator are very helpful for the generation of electrostatic charges. These generators are responsible for generating very high electrostatic voltages with a very small current this can be further utilized for many applications but there is a designing flaw present in

Figure 1.7 Hand driven Van de Graff generator design.

most of the models which cannot resist the basic humidity problem and in the humid conditions some models fail to establish the charges the humidity inside of the generator is also the bigger issue for the charges to develop.

The selection of dome material in some generators are very poor they selected rough steal instead of polished steel or aluminum. The rubber is a good material for VDG generator's belt but there is a room for improvement available according to the tribo-electric series. Driving mechanism for some generators are with motors but the variable speed option and the smooth starting of the generator, in order to ease the belt is not available. There are some of the generators in which insulation failure is very prominent and the improvement of insulation required in those cases to remove the weaker current due to this the belt fails to attain the charges.

In further chapters the better design is proposed along with the proper testing of prototype. Chapter 2 shows the improvement in design and insulation of VDG generator in order to resolve the existing issues because there is no empirical and comprehensive design available. Chapter 3 shows the proper testing of the generator with results. This research is carried out with the focus on the critical aspects of designing and improvement in insulation for enhancing the performance. Chapter 4 explains the application of generator in different fields. Chapter 5 shows the maintenance and troubleshooting techniques for this generator. In chapter 6 we conclude our work along with some recommendation.

Chapter 2

Design and Insulation

2.1 Introduction

The insulation is very much needed for designing any type of VDG generator of any size. This insulation improvement is not possible without proper design methodology available. VDG generators proposed in literature were not design using some empirical method and for this reason they fail to provide insulation and thus can not establish the desired amount of charge.
This chapter mainly focuses on:

- *Design of VDG generator*
- *Improved insulation of VDG Generator*

2.2 Design of Generator Parameters

Differnt models of VDG generator are available in markets. All of these generators use different techniques for the development of electrostatic charges. The VDG generator produces high electrostatic voltage with a weak currents. These generators are suitable for some applications but some design flaws have been observed in majority of these models. These VDG generators can't withstand even a slightest humid condition and few models fail to set up the charges at all [13]. The implemented design of our proposed VDG generator is shown in the Figure 2.1.
The design of VDG generator proposed in this research involves following steps:

1. *Design of Dome*
2. *Belt Design and Choice of Material*
3. *Starting Mechanism of Generator*
4. *Selection of Rollers*
5. *Design of combs*

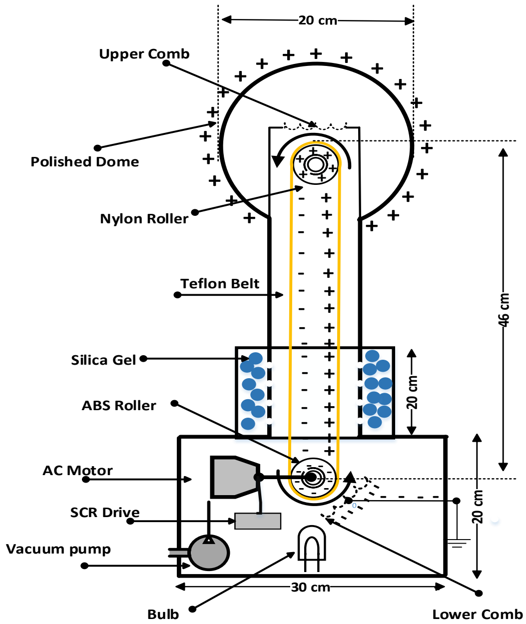

Figure 2.1 Implemented Design of VDG generator.

2.3 Design of Dome

The dome is the very sensitive and vital part for the generation of the charges but even the slight irregularity on the surface of dome causes the failure of whole generator thus the selection of material is very important design parameter of VDG generator.

2.3.1 Selection of Dome Material

The selection of the material for the dome is important for generation of more charges. The literature review indicates that aluminum material is chosen for design of dome due to its low cost and good conductivity compared to cooper. The surface of dome is evened out with zinc coated material which is helpful for limiting the inconsistencies in the arch breakdown. Smooth surface enables the charges to build up on the dome with consistency and furthermore eliminate the effect of corona as shown in Figure 2.2.

2.3.2 Calculation of Dome Size

Domes are available in different sizes and size can cause the deviation in output voltages. The charge estimation equations for sphere are used to explore effect of size. The size of the dome is chosen so that the desired voltage can be generated using VDG generator. For small sized dome the electric field can be calculated using equation 2.1.

$$E = \frac{Q}{4\pi\epsilon r^2} \tag{2.1}$$

Figure 2.2 Implemented Polished Dome

The capacitance needs to be calculated at the dome having radius "r" by using the equation 2.2.

$$C = 4\pi\epsilon r \tag{2.2}$$

The charge makes its way to the dome area and can be calculated by using equation 2.3

$$Q = CV_{\max} \tag{2.3}$$

By substituting the results of equation 2.3 in 2.1

$$E = \frac{CV_{\max}}{4\pi\epsilon r^2} \tag{2.4}$$

By calculating the value of C from equation 2.2 and putting in 2.4

$$R = \frac{V_{\max}}{E} \tag{2.5}$$

Where E is an Electric Field of dome, V_{max} is the maximum voltage capacity of VDG generator and R is the radius of Dome in meter.

The air is normally an insulator and does not allow the current to pass through it but at very high voltages the air becomes conductor. The breakdown of air for 200 kV VDG generator occurs under standard temperature pressure (STP) conditions at 3 MV/m.

$$R = \frac{200kV}{3MV/m} = 7cm \tag{2.6}$$

The proposed VDG generator has diameter of 14 cm. It works as an electrode and gives maximum voltage of 200 kV. Its difficult to get the maximum voltage all the time because of the variance in environmental conditions. To cater this issue correction factor is implemented by taking the diameter of 20 cm which help us to provide the voltage level around 200 kV all the times.

2.4 Belt Design

After selection of material for dome, the next major parameter for the generator design is selection of belt. The size as well as the material of the belt is very important for the generation of charges.

2.4.1 Belt Material

Teflon belt is placed in this model of VDG generator as shown in Figure2.3 rather than the elastic rubber belt for the better performance. Teflon atoms have strong grip on its electrons as compared to other materials. So this material is capable of holding its electrons firmly when it comes in contact with another material making this material more negative. Teflon is more negative thus for better performance Teflon material is used [6].

Figure 2.3 Belt used in VDG Generator

2.4.2 Length of Belt

The length of belt is also critical to choose. The length is a primary factor to control the working of generator. According to literature survey if the belt is more extended and associated more with the rollers then more charges will be liberated out according to the fact that more surface come in contact more electrostatic charges will be generated. The extended length must not exceed 1.25 times un-extended length of the belt otherwise it will break.

2.5 Starting Mechanism of Generator

The rotation of the belt causes the charges to establish at the dome but the smooth rotation is also very necessary. The existing VDG generators have used two methods for rotating the belt.

2.5.1 Manual Starting

The existing VDG generators used the hand driven method for the rotation of belt as shown in the Figure 2.4. This method is easy to drive the generator and generates the voltages but the major issue is inconsistent rotating speed. The motor driven generators have more Revolutions Per minute(RPM) than the hand driven generators [14].

Figure 2.4 Hand driven VDG generator

2.5.2 Motor Based Starting

The AC motor used in the generator has an RPM of about 3000 as shown in the Figure 2.5 which allows the belt to move faster and uniformly. This method of rotation produces the charges that are well settled at the dome. The motor based starting causes one major issue which is the danger of breaking the belt which can be avoided by using methods explained in subsequent sections.

2.5.2.1 Fast starting

If the motor is turned on at its max speed of 3000 RPM the belt is likely to break because the belt is tightly attached with the rollers. Loosen the belt can avoid its breaking but the performance of generator gets affected big time because of lesser interaction of belt with the rollers. To overcome this issue smooth starting mechanism is implemented.

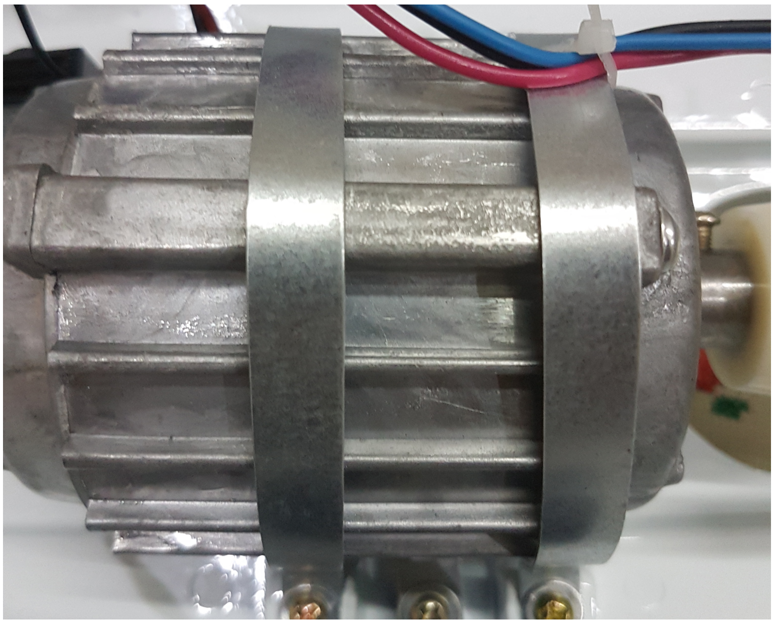

Figure 2.5 AC motor used in VDG Generator

2.5.2.2 Soft starting

The method incorporated in this research is to run the motor slowly at the start which provides more torque and after that gradually increase the motor speed to attain the maximum voltages. For this an SCR based voltage regulator as shown in Figure 2.6 is implemented which controls the motor speed by varying the firing angle. Due to the variable speed parameters the variable voltages can be generated.

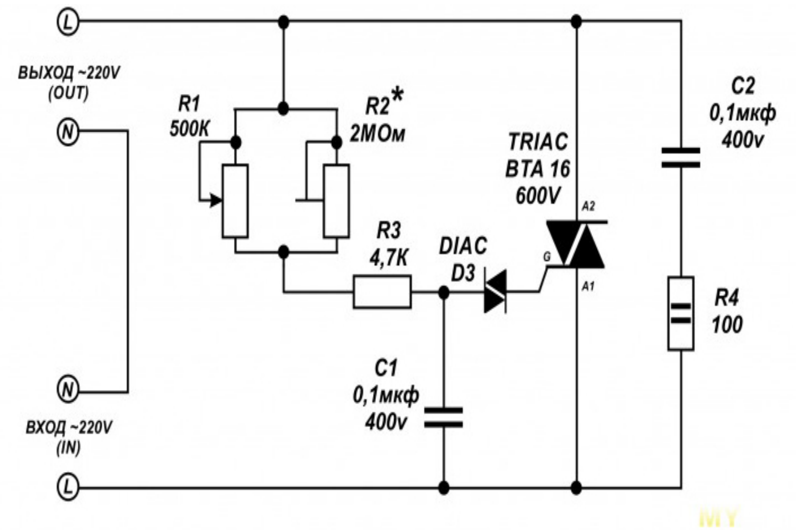

Figure 2.6 Circuit Diagram of SCR Controlled Voltage Regulator

2.5.3 Motor RPM to Belt Velocity

The revolution per minute(RPM) of AC motor is very important in the charge distribution.Variable speed of motor can change the amount of charges and current of the generator is also proportional to speed of motor. The motor is not directly connected to the belt but it is connected through the rollers having radius "a" which can affect the velocity of the generator [15].

$$v = a \times \omega \tag{2.7}$$

Where v is the belt velocity, a is roller's radius and ω is angular velocity.

To convert the angular velocity to the corresponding linear velocity to get the linear relation between them.

$$v = a \times RPM \times 0.10472 \tag{2.8}$$

The AC motor can run at its maximum speed of 3000 RPM. The lower roller's radius is about 22.85 mmwhich is required to achieve desired velocity.

$$v = 22.85 \times 10^{-3} \times 3000 \times 0.10472 = 7.1\ m/s \tag{2.9}$$

2.6 Selection of Rollers

In the primary phase of generator starting, the roller's surface turns out to be firmly electrified. This occurs as it comes in contact with the belt surface and it happens similarly that a balloon is electrified when rubbed with hair. The belt and the rollers are made of two unique materials. When the elastic belt comes in contact with the plastic rollers chemical bonds break and the charges in the surface molecules of the two materials are shared unequally.

2.6.1 Belt and Roller Phenomena

The belt and roller surfaces get oppositely charged and by rubbing them with each other the charges are liberated out. This procedure is called "frictional charging", yet since no rubbing is really required, it's more precise to call it "electrification by contact". In our design the roller gets a positive surface charge, however, this isn't generally valid. The roller's charge depends upon the material used for the belt.

2.6.2 Upper Roller

The upper roller is made of Nylon as shown in Figure 2.7 and it has a width of around 3.8 cm. When the oppositely charged belt moves over the upper roller due to the triboelectric contrast a positive charge is built up on the upper roller and a negative charge is delivered to the belt moving down.

2.6.3 Lower Roller

The lower roller is chosen of ABS material with same width as of upper roller. The ABS roller is shown in Figure 2.8 since it has negative charge creating capacity and at the time

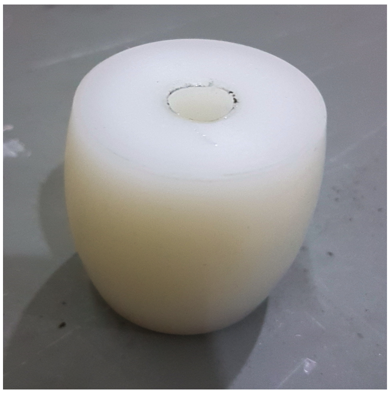

Figure 2.7 Upper Nylon Roller

it gets rubbed with belt positive charge is delivered to the internal part of the belt while moving upward. The distinction of charges is according to triboelectric arrangement [7].

Figure 2.8 Lower Roller of ABS material

2.7 Design of Combs

Charges are pulled from belt by using the attached "combs" placed near the rollers. Genuine contact between the combs and the belt isn't compulsory due to high potential contrasts. Combs can be an extended wire or a sharp edge surface which attracts the high potential. The lower comb is kept at or near earth potential and is used to drain negative charges and leaving the belt with positive charges that are delivered to the upper comb which is connected to the dome.

2.7.1 Material for Combs

The upper and lower brushes are of same material in our generator. The steel combs are used as shown in Figure 2.9, the lower brush is connected to the ground so all negative charges are dumped. The upper roller is positively charged at the arch surface. The gap between the combs and belt is kept up to 2 mm [16].

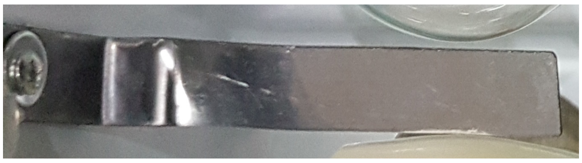

Figure 2.9 Aluminum comb.

2.7.2 Placement of Combs

There might be excessively distance among the belt and wire combs. Positions of combs are changed by bowing until the point that they come quite close usually 3 mm to the belt yet don't come in contact with the belt as shown in Figure 2.10.

Figure 2.10 Gap between roller and comb

2.7.3 Charge Calculation

By using equation 2.2 the value of capacitance developed by the generator's dome to the ground. The dome's radius is 10 cm and standard value of ϵ.

$$C = 4\pi \times (8.85 \times 10^{-12}) \times 0.1 \tag{2.10}$$

$$C = 1.13 \times 10^{-11} F \tag{2.11}$$

By putting the value of capacitance into equation 2.3 to get the charge Q

$$Q = 3.3 \times 10^{-6} C \tag{2.12}$$

2.8 Energy Stored in a VDG Generator

The very low current in VDG generator makes it secure for the surrounding but at the same time the impulse current can be unsafe if the charge stored in the generator is more then 10 Joule.

$$E = \frac{1}{2} C {V_{\text{max}}}^2 \tag{2.13}$$

By inserting the value of capacitance and maximum voltage of the generator in equation 2.13.

$$E = \frac{1}{2} \times 1.13 \times 10^{-11} \times 300000^2 = 0.5085J \tag{2.14}$$

The value of equation 2.14 gives the clear indication that this generator is very safe to use.

2.9 Current of Generator

The measure of current generated by VDG generator is dependent on many variables among which most important factors are RPM of the motor and belt velocity according to the equation 2.8 and 2.15.

$$I = \sigma b v \tag{2.15}$$

Where σ is Gauss's law charge density, b is the width and v is the velocity of belt. The value of σ using equation 2.16

$$\sigma = \epsilon_{\text{o}} \epsilon_{\text{r}} E \tag{2.16}$$

For air ϵ_{r}=1 and standard value of ϵ_{o} and the electric field from equation 2.6.

$$\sigma = (8.85 \times 10^{-12}) \times (3 \times 10^6) = 26\ \frac{\mu C}{m^2} \tag{2.17}$$

By using the values from equation 2.17 and 2.9 for σ and v respectively the equation 2.15 as the belt width is about 50 mm.

$$I = (26 \times 10^{-6}) \times (50 \times 10^{-3}) \times 7.18 = 9.334\ \mu A \tag{2.18}$$

There is a variable speed option in this generator i.e. if the motor is running at the speed of 2000 RPM the velocity of the belt is reduced to 4.7 m/s due to which the current will not be same and can be find the new value of current using the equation 2.15 again.

$$I = (26 \times 10^{-6}) \times (50 \times 10^{-3}) \times 4.7 = 6.2\ \mu A \tag{2.19}$$

The soft starting of generator is required due to which the generator has a velocity of 2.39 m/s at the start and the current at that time is changed and can be calculated as

$$I = (26 \times 10^{-6}) \times (50 \times 10^{-3}) \times 2.3 = 3.1\ \mu A \tag{2.20}$$

The current of the generator is small at the beginning and increments at greatest speed and it can be additionally expanded by enhancing the estimation of σ and by using the better dielectric for protection.

2.10 Insulation of Generator

The usefulness of this generator is primarily dependent on climate conditions. The electrostatic charges release quickly if the dampness in air or water atoms exist and furthermore the residue particles noticeable all around cause an issue. The rate of discharge is a predominant parameter in the working of the machine and the desired voltage is affected phenomenally by the atmos[heric and insulation conditions [17]. For these reasons the insulation is the prime factor for development in each VDG generator and slight spillage may not enable the charges to develop according to the equation 2.21.

$$V = IR \tag{2.21}$$

The current of the VDG generator is 9 micro amperes and better insulation level is required for VDG generator because the voltage level is extremely high which causes this generator to work under extreme care as mentioned in equation 2.22.

$$R = \frac{V}{I} = \frac{200 \times 10^3}{9 \times 10^{-6}} = 2.2\ \text{G}\Omega \tag{2.22}$$

The required insulation of 200 GΩ have to be used and need a special care to be taken while designing these two factors.

1. Insulation of Dome
2. Internal issues

2.10.1 Insulation of Dome

Even a small irregularity on the surface of dome may cause a spillage of charges and consequently the generator is unable to generate desired voltage due to the corona discharge. So a dome is coated with zinc material as shown in Figure 2.11 which will smooth out the irregularities at the surface of dome.

Figure 2.11 Polished Dome surface.

2.11 Internal Issues

The VDG generator behaves abnormal under the humid conditions and moisture in the earth causes the lesser amount of charges to be established and thus needed to take special care inside the generator to do this following method is incorporated.

2.11.1 Vacuum Pump

Humidity in the internal parts of generator is removed by placing a vacuum pump at the base of the generator. The vacuum pump is helpful for removing the dampness inside the generator and furthermore it is the least expensive solution for that specified issue as utilization of any gaseous material inside generator as protector for dampness will require tight packing of the VDG generator as shown in Figure 2.12.

Figure 2.12 Vacuum pump for insulation

2.11.2 Moisture Removal Bulb

A moisture removal filament bulb of 25W is also placed inside the generator so that warmth caused by the bulb will dry out moisture inside the generator which is very handy and cheap solution for removal of moisture as shown in Figure 2.13.

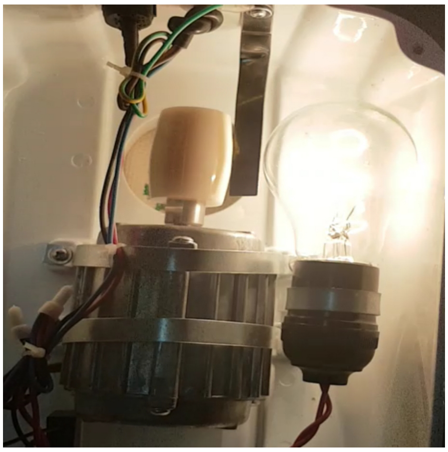

Figure 2.13 Resistive bulb for moisture removal

It isn't difficult to perform electrostatic exhibits in a high dampness condition. One mystery is to fabricate a "hotbox" storage gadget for the device. A tight-fitting cover can be warmed with a little light inside. Anything put inside this container will be dry and its conductive surface dampness will be removed by the warmth.

2.11.3 Silica Gel

The silica is very effective for the moisture removal in industries and also works as drying agent, Silica gel is often used as a preservative for the control of humid environment. The blue colored silica gel is introduced in this project as it is used in drying tower shown in Figure 2.14. The generator is working all the time and if it is not tightly packed the

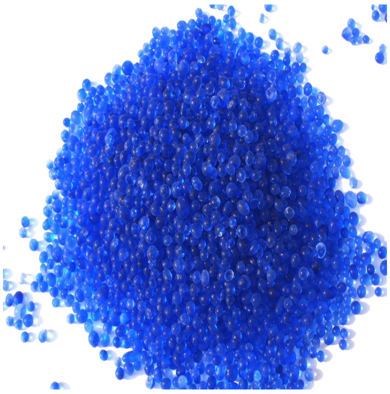

Figure 2.14 Blue colored Silica gel.

moisture may get absorb in the generator. When the generator starts after sometime the moisture effects the working and normally it takes hours to normalize itself. To cater this issue acrylic pipe outer layer is drilled at 45 degree so that silica balls does not have a leverage to get inside the generator. A rubber pipe of 1 inch greater diameter than the inner pipe are used and the introduction of silica balls between these tow pipes are placed to remove the inner moisture. This technique helps to remove the moisture all the times even at the rest condition of generator as shown below in Figure 2.15.

Figure 2.15 Silica gel filled in casing.

2.12 Implemented Hardware of VDG Generator

The hardware is assembled by connecting all the components together as shown in the Figure 2.16. The Figure shows the running of the generator and it is ready for the testing purpose which will be explained in detail in the next chapters.

Figure 2.16 Implemented hardware of VDG generator

Chapter 3

Experimentation and Results

3.1 Introduction

The experimentation part holds different approaches for the testing of the VDG generator. The testing is very essential for describing the existence of the electrostatic charges. Some tests directly indicate the presence of charges and some of methods indirectly indicate the proper working of the generator. The following methods are used for the testing of VDG generator.

- *Electrostatic Voltmeter*
- *Gap Test*
- *Hair Rising Phenomena*
- *Floating Objects*
- *Paperclip Ray or St.Elmo's Fire*
- *Deflecting Flame*
- *Neon Indicator*

3.2 Electrostatic Voltmeter

An existing voltmeter isn't appropriate to measure the voltages produced by the charge on a segregated conductor because it disturbs the charges while taking measurements. An electrostatic voltmeter takes non-reaching estimation without adjusting or disturbing the charge.

The electrostatic voltmeter works by performing a field detection test near the surface to measure charges without reaching the surface. The electrostatic voltmeter drives the conductive lodging of the field detection test to a voltage which nullifies electric field between test device and the surface of interest. This field-nulling condition is accomplished when the voltage on the test matches the unknown voltage on the surface of interest [18].

The charge is frequently illogical to quantify requiring that the charged object should be moved into a Faraday fenced area and afterward estimated using a coulomb meter. In cases where this exchange strategy can't be utilized the charge is regularly assessed by measuring the electrostatic field produced by the charge by using an electrostatic field meter or an electrostatic voltmeter [19].

3.2.1 Electrostatic Voltmeter Working

The working of the electrostatic voltmeter is very effective because the electrostatic voltage is produced by the electric field. If the electric field is measured indirectly the electrostatic voltages are measured. The electric field is established between the plates when the voltage is applied to them and it is possible to have a uniform electric field for easily measuring the voltages [20]. The energy density in equation 3.1 provides the desired electric field at the two plates.

$$W_{\mathrm{d}} = \frac{1}{2}\epsilon E^2 \tag{3.1}$$

Where; ϵ is the permittivity between the two plates and E is the electric field established between the dome and ground.
If the thickness of the plates is dx and the area of the plate is A and the differential volume dw in equation 3.2

$$dw = W_{\mathrm{d}} A dx = \frac{1}{2}\epsilon E^2 A dx \tag{3.2}$$

To find the force F by sorting the equation 3.1 and 3.2 are given in equation 3.3

$$F = \frac{dw}{dx} = \frac{1}{2}\epsilon E^2 A \tag{3.3}$$

Now putting E=V/d in equation 3.3 where d is separation between the plates and V is the voltage to be measured

$$F = \frac{1}{2}\epsilon\frac{V^2 A}{d^2} \tag{3.4}$$

As the plates are oppositely charged so the force of attraction between the plates are present. The meter is used to measure AC or DC values because the force is proportional to the square of the rms value of voltages.

$$F = \frac{1}{2}\epsilon A\frac{{V_{\mathrm{rms}}}^2}{d^2} \tag{3.5}$$

3.2.2 Existing Voltmeter

The schematic diagram of electrostatic voltmeter is as shown in Figure 3.1 this meter is being used to test the electrostatic voltages. It has an ability to measure the voltages upto 30 kV [21].

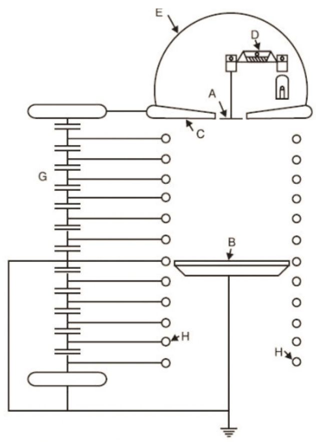

Figure 3.1 Schematic diagram of Electrostatic Voltmeter

The implemented VDG genrator established 200 kV at its dome. For testing of this high volatges one of the strategy is Electrostatic Voltmeter test with some gap distance. Due to some constraints available in electrostatic voltmeter it can measure a voltage up to 30 KV. To solve this issue the British standard of spark gap with respect to the voltages standard number of "BS EN 60052" as shown in the graph Figure 3.2 [22]. The required

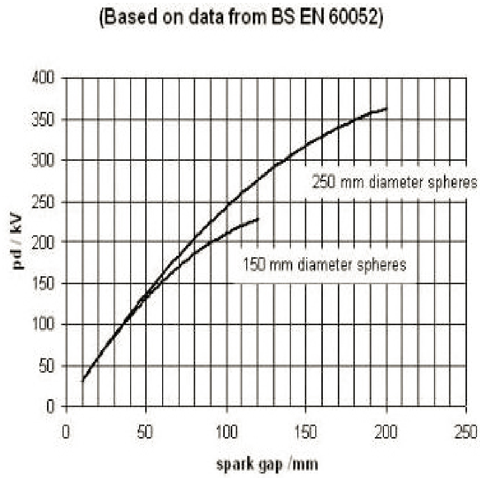

Figure 3.2 Spark gap and Potential difference between air

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gap distance for 200 kV VDG generator is 6 inches but we have introduced 6.5 inches between the testing wire and the charged dome. The dome gives an estimation of 200 kV as shown in Figure 3.3.

3.2.3 Experimental Setup

The implemented VDG generator is setup as shown in the Figure 3.4. This working VDG generator is tested and the results are saved by making video of electrostatic voltmeter for one minute. For proper results the camera frame speed is reduced 4 times which gives 240 values of voltages over one minute interval of time. A similar procedure is repeated for commercially available generator and the results of both are plotted in graph between

Figure 3.3 Reading of Electrostatic Voltmeter

Figure 3.4 Experimental setup for VDG generator

the existing and the implemented generator is shown in Figure 3.5. The graph clearly shows the working of implemented VDG generator is better as compared to commercially available VDG generators in terms of voltage levels produced and positive charge spread at the dome. The implemented VDG generator shows a very smooth response after being fully charged but the conventional generator shows some glitches even after being completely charged. One of the major reason is that the dome is not polished and irregular surface causes break down of charges and corona effect.

3.2.4 Performance Comparison

The table 3.1 shows the performance comparison of both VDG generators in terms of generated electrostatic voltages. The voltage readings are obtained after every 10 seconds and the efficiency is calculated by using equation 3.6. The efficiency of implemented VDG generator is improved by 15% calculated from 240 samples collected in 1 minute by designing an algorithm to evaluate the efficiency.

$$ImprovedEfficiency = \frac{V_{\text{Conv. VDG}} - V_{\text{Impl. VDG}}}{V_{\text{Conv. VDG}}} \times 100\% \tag{3.6}$$

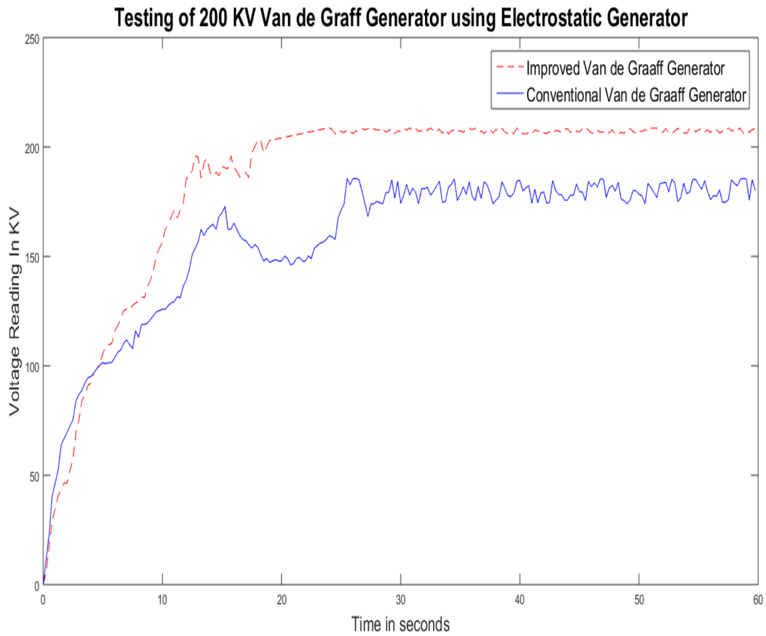

Figure 3.5 Conventional vs Improved VDG generator Graph

Table 3.1 Performance Comparison of both Generators

Time	Conventional VDG	Implemented VDG	Improved Efficiency
10s	125 kV	145 kV	14%
20s	150 kV	200 kV	25%
30s	175 kV	205 kV	15%
40s	180 kV	205 kV	12%
50s	180 kV	205 kV	12%
60s	170 kV	205 kV	17%

3.3 Gap Testing Scheme

Dielectric breakdown occurs when charge developed at the dielectric surface reaches its maximum value or quality of dielectric material used is not good. In the breakdown of air the negative charged electrons are pulled in one direction and the positive charged particles in the other. At the point when air molecules are ionized in a high electric field at that point air changes from an insulator to a conductor. The VDG generator's dome is positively charged and it produces a spark if the ionized air comes close to the dome the imbalance situation occurs and charges try to reach to the equilibrium state as early as possible.

3.3.1 Gap Test with 2 Inch Distance

If the VDG generator is operating at STP and have minimum humidity condition along with low moisture in the environment then it is able to produce a fair level of 1-2" spark after every second as shown in Figure 3.6. The sparking is a proper indicator for charge establishment as compared to the electrostatic voltage test.

Figure 3.6 Gap Test distance of 2", at implemented VDG generator

3.3.2 Gap Test with 5 Inch Distance

With the increase in the distance the discharge time also increases because the air requires more time to breakdown. By introducing an air gap of 5-6" the spark time increases to 3-5 seconds as shown in Figure 3.7.

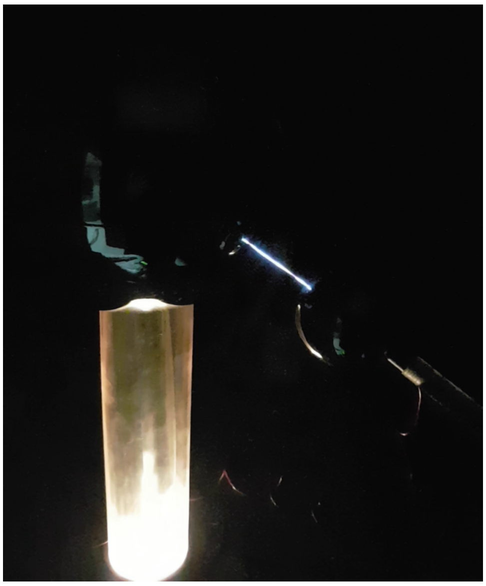

Figure 3.7 Gap Test distance of 5", at implemented VDG generator

3.3.3 Gap Test with 6.5 Inch Distance

The VDG generator can produce a maximum Spark of 6-11" if ideal condition is provided to the generator [10]. For better results in Gap test start the generator for a couple of minutes without releasing the arch and after that greater breakdown voltages can be observed with larger arch. The implemented VDG generator is extremely efficient to deliver a spark within 3 seconds if the separation between the discharge vault and the charging dome is kept up to 6.5 inches. The round discharged dome is more powerful to create bigger and more visible discharges as shown in Figure 3.8. The gap test is the better indicator of VDG generator's performance. The commercially available VDG generator produces a spark after every 4 seconds so the implemented VDG generator is better in this aspect.

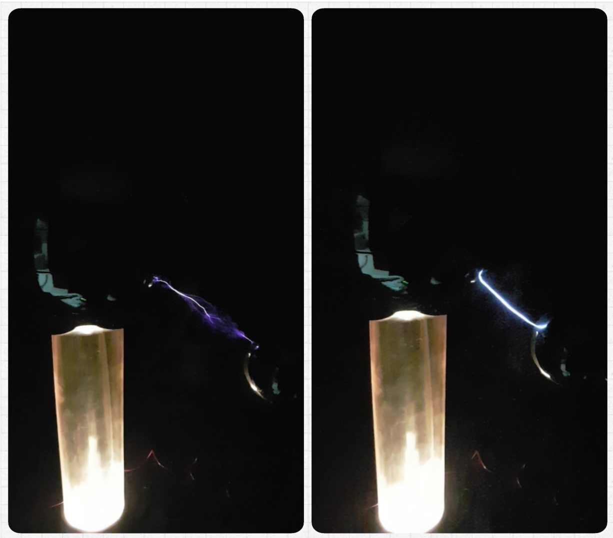

Figure 3.8 Gap Test distance of 6.5", at implemented VDG generator

3.4 Hair Rising Phenomena

There are many experiments of VDG generator but one of the most eye catching test is "hair raising" phenomena. Moving arm toward a running VDG generator can show a hair raising phenomena. It is very necessary for the test person to be insulated properly from ground otherwise the charge cannot transfer to the person completely. By touching the dome of the VDG generator a person observes the hair of the body standing up. Since each of the hair follicles are getting charged to a similar potential they tends to repulse each other. This is the reason the hair really holds up. It would not have any kind of effect if the polarity of the VDG generator were turned around. For whatever length of time that the person is insulated the charge will build up constantly.

Electrostatic charges repulsion between parallel charges each hair of your body attempts to stay separated from each other in light of the current situation. This "raises" hair experience can be felt on head, arms and any where on the body. The testing of the outlined generator has been performed on the hairs of body and it is observed that the electrostatic charges move to the body immediately even if our hand is at some distance from the charged dome as depicted in Figure 3.9.

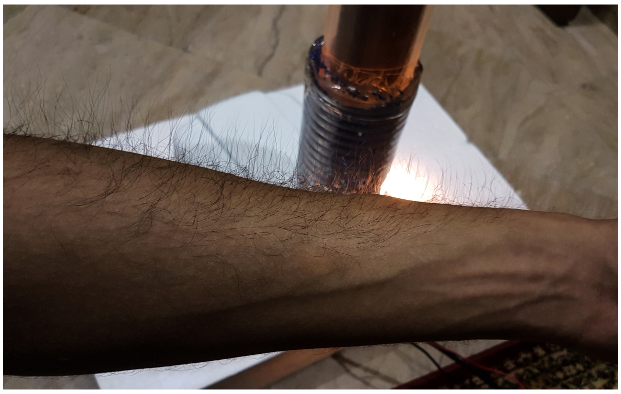

Figure 3.9 Hair Rising Test of Implemented VDG generator

3.5 Floating Objects

There are some objects which when brought close to the VDG generator get charged with same potential as the dome ajd after transferring the charge to those objects they tried to repel itself from the dome.

3.5.1 Aluminum Plates

While measuring the positive charge that gathers on the outer surface of the dome a few questions in this test might appear about the dome. When a portion of its positive charge is exchanged to the objects they are then forced far from the dome in light of the fact that the two surfaces have a similar charge which makes them to repel each other. A little aluminum pie or tart pan over the storage dome before connecting to the generator. Turn the generator on after connecting it to dome the aluminum pan is positively charged and the heap of two or more pie pans lift off each one in turn as shown in Figure 3.10 [23].

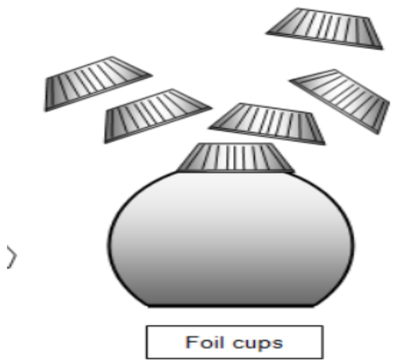

Figure 3.10 Floating Aluminum plates test

3.5.2 Soap Bubbles

To check the electrostatics of the generator send bubbles towards our generator when it is properly charged and is running for a while. When these scattered bubbles come close to the charged globe the positive charge begin to transfer to the bubbles and they get charged positively after that they are repelled from the dome quickly as shown in the Figure 3.11 [23].

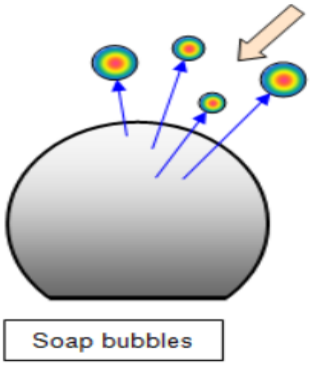

Figure 3.11 Soap bubbles repelling test

3.5.3 Piece of Paper

The piece of papers is charged quickly and when some of the papers at the top of the generator get charged positively they tend to repel each other as well as the dome of the generator to depict the phenomena of oppositely charges particles as shown in Figure 3.12 [23].

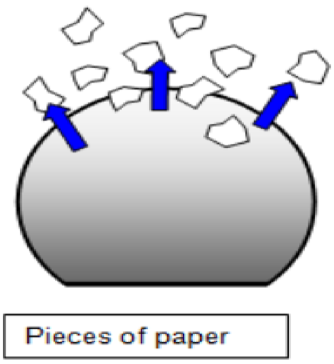

Figure 3.12 Paper Piece repelling test

3.5.4 Plastic Bowl filled with Grains

Another floating object examination is possible with a small plastic bowl. Stick the bowl to the surface of the dome and put some amount of puffed wheat into the bowl. Turn the generator on and let it keep running for some time. Once a positive charge expands on the kernels of cereal they will fly out of the bowl and far from the dome. The kernels may fly out each one in turn or numerous at the same time. In case if the kernels don't start flying out of the bowl in a couple of minutes we should decrease the charge on the dome by bringing the release wand close and after that holding it there for a couple of more minutes. Once more this shows that like charges repel and electric fields create powers that can follow up on objects with mass.

3.6 Paperclip Ray or St.Elmo's Fire

Push a straight stick, needle, or opened up paperclip through a plastic drinking straw so that the metal needle is at a 90° angle to the straw and use this gadget as a pointed conductor. Now start the generator, turn the lights off, hold the tip of the straw and gradually move one pointed end of the needle towards the surface of the arch while the opposite end of the needle is pointed away frame the vault at a 90° angle.

As the metal gets close to the vault (more often than not 1-3"), a black out enduring sparkle might appear at the tip of the needle and a more it is grounded the bigger sparkle will show up between the opposite ends of the needle and the arch. This electrical spark is called St. Elmo's fire and shows how a pointed object creates a crown release in a solid electric field.

Any sharp point on the surface of the dome will deliver a corona effect or point release that discharge the generator's electric field into the air. This spillage is most common where the two parts of the arch join and it keeps the generator from achieving its full voltage potential. Try different things like fixing the two arch parts with electrical tape to diminish this spillage and improve the starting capability of the generator [4].

3.7 Deflecting Flame

The VDG generator can make an electrical breeze that is sufficiently intense to avoid the fire of a light and turn a toy windmill or propeller. To produce a breeze connect a long, thin metal pole or needle to the side of the generator's dome ensuring that the metal touches the arch. Run the generator, lit a flame and hold it before the point. The fire should lean far from the generator. To perceive how far the impact of the breeze is observed gradually move the light far from the generator until the point when the fire is not deflected [24].

3.8 Neon Indicator

The VDG generator can light up, fluorescent tubes and even small neon tubes. For best outcomes perform these analyses in a dark room. Bring the knob towards the dome when the generator is working. A non-leading holder for the light to abstain from accepting a shock as we approach the dome. The outside glass surface which is closest to the dome obtains positive charge. The charge releases on the glass surface to release power. As discharge occurs, positive charges race through the whole bulb lighting it up as shown in Figure 3.13. Explore different avenues regarding separations among bulb and dome [10]. The bulb will stop glowing if the distance between the dome and bulb tip is more than 12 inches. At far distance the glow is more prominent but delayed. The light will likewise sparkle more brilliantly. Bring the bulb closer the light gets dimmer. If the knob touches the arch, the light might be nonstop or glinting however the power is low.

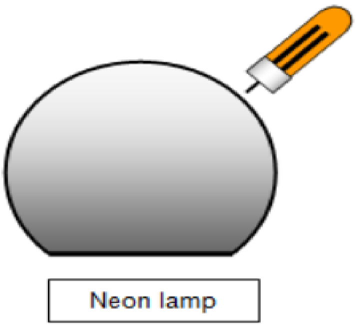

Figure 3.13 Neon test experiment

3.8.1 Experimental Circuit

Associate a little capacitor (.01uF, 250V) in parallel with a little neon pilot light (NE-2 or NE-2H). Hold one wire among fingers and bring the other wire towards the charged dome of a working VDG. The bulb will start blazing. Do not touch the two leads otherwise a bigger shock from the capacitor. For better performance 1-Mega resistors leads introduced as shown in the Figure **??**. The nearer we bring the wand to the VDG the speedier the neon bulb will streak. Utilize a bigger capacitor for slower, brighter glimmering, or a littler one for a quick, diminish light [25].

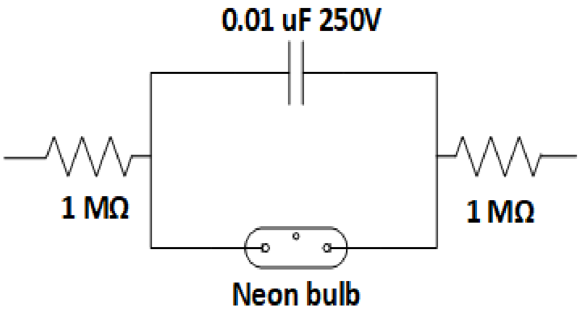

Figure 3.14 Circuit Diagrm of neon wand

Chapter 4

Applications of VDG generator

4.1 Introduction

The designed VDG generator generates high voltages and low currents which is required in numerous application like Atomic Physics, Nuclear Physics, Materials Science, and Medicine.VDG can also be used for accelerating electrons to process materials, in proton accelerator to perform atomic physical science tests, for delivering fiery X-beam bars in atomic pharmaceutical,in physical science instruction, and in entertainment industries. Applications like Faraday's chamber can also use it to demonstrate the electric charges that exist on outer surface of a charged empty conduit. This exploration will likewise help different specialists by giving a base to the planning and working improvement of this generator according to their necessity. Other use and applications of VDG generator are:

- *Nuclear Physics*
- *Semiconductor industries*
- *Electrostatic X-Ray Generator*
- *Medical Field*
- *Equipment Testing*
- *Faraday's cylinder*

4.2 Nuclear Physics

It utilizes VDG generator for one of the principal procedures to consider the nuclear material in atomic science before the landing of palatable systems to check particles [26]. In nuclear physics VDG generator has following applications.

4.2.1 Fasten the Proton

One of the major application describes VDG generator with the accompanying parameters having proton vitality in a range of 0.3 to 2.0 MeV with monochromaticity of 1 mil and beam current of 50 nA - 10 µA. A VDG generator gives high monochromatic 1 mil light emissions particles with streams of roughly 1mA and energies that are constantly flexible in a range of 0.1 to 10.0 MeV. These qualities of the generators and in addition small size make them attractive for atomic material science estimations.

An essential data about thickness capacity of neutron spectra nuclear levels and about a nature of one-molecule energized conditions of cores and their quantum qualities were acquired when responses of (p,n), (d,p) and (t,α)types were estimated. Estimations of (α,p) = (p, α) type immediate and previous responses were utilized to contemplate nuclear frameworks symmetry including their opportunity reversal. Fission abilities of a few short-half-life cores were analyzed by estimating (p,p'f), (d,pf), (t,pf), (α, α'f), (^{3}He,df) and (t, αf) responses. ^{3}He(p,n), ^{7}Li(p,n) , ^{2}H(d,n) , ^{3}H (α ,n) responses are utilized to be wellsprings of moderately low foundation, monoenergetic ceaselessly movable neurons inside a scope of 0 to 20 MeV neutron pillars that are essential for delicate 'restricted white range' neutron estimations.

The VDG generators are extremely helpful for application ponders. (p, α), (α,2n), (t,n) and (d,2n) responses enactment techniques are used to identify H, , ^{2}H, Li, Be, B, C, N, O admixtures, in molecule initiated gamma ray discharge strategy, in molecule instigated X-ray emanation (PIXE), and in addition Rutherford backscattering. These strategies all together give recognition to the majority of the substance components down to a centralization of n1n g/g and profundity and surface dissemination of parts with a precision of 0.1 µm. Quickened particles directing technique is created for recognizing precious stone blemishes and for finding doped cores in the gem structures. Particle light emissions VDG generators have a wide use for microelectronic materials adjustments. Since ninetieth century the generators have been improved for embedding particles of a wide range that gives them to contend particle mass-spectrometers successfully[27].

4.2.2 He Ions Production

The VDG generator can be modified to generate Helium ions. A particle hotspot for collimated light emissions doubling the charged helium particles has been developed and tested. It contains an einzel focal point to keep up a very much engaged pillar and a crossed field analyzer that grants just a single part of the shaft to leave the source gathering. Pillar streams of 1 to 2 microamperes investigated $(He4)^{++}$ or $(He3)^{++}$ions are realistic from the source to get together for quickening in a VDG generator. Up to 0.25 µA of $(He4)^{++}$ shaft has been acquired at the passageway to the bar tubes after quickening in a VDG generator. The source can likewise be utilized with H^+, D^+, and He^+ particles. By applying an RF voltage to the re director plates, it has been discovered conceivable to beat the independently ionized shafts. A beat light emission/2 µA of $(He3)^{+}$ions with a heartbeat width of 7 ns has been obtained [28].

4.2.3 Ion Smasher

It is named ion smasher since it produces a high vitality radiations which are the basis of atomic physics. The configuration drew on the involvement with pressurized machines by Barton, Mueller, and Van Atta at Princeton, and Herb, Parkinson, and Kerst at the University of Wisconsin. The weight tank is 30-ft wide and 47-ft high and the highest point of the machine is 65-ft above the ground level. Since the voltage was conveyed along the segment lesser standoff separations were required on lower parts which represents the pear shaped structure of the tank. The 30 ft-long high speed vacuum tube comprised of a heap of porcelain rings with 12-in breadth interleaved with metal spacers formed the quickening terminals.

At the highest point of the quickening tube we have four sections of porcelain protectors around shell containing the particle source, a belt-driven generator for power, and sets of needles to charge the two principle belts that go along the gathering. Tube was empty. At its lower end we have attractive analyzers to isolate the quickened particles having the best possible charge and mass. The assault of targets took place on the ground floor and under ground if additional protection was required [29].

4.2.4 Rare Isotopic Extraction

This generator is exceptionally useful to speed up extremely rare isotopic and radioactive atoms which is very essential in nuclear physics. Sometimes we put a VDG generator into a huge vessel with legitimate insulation and compactness and the beams then created are used for the restorative applications [30].

4.2.5 Initiator and Accelerator for Reactions

This generator is very helpful for starting many reactions as some of the nuclear reaction required and provide initial push to complete the reaction as high voltage pulse generated by generator is sufficient for the atoms. It can be utilized to observe the resonance response of fluorine under proton assault at two distinct energies of 0.334 and 0.927 Mev. This generator is additionally used as an initiator in numerous responses and quickening agent for particles and electrons [31].

4.3 Semiconductor Industries

The damage of electrostatic discharge (ESD) is a well-known problem in the semiconductor industry [32]. When human body (operator) comes in contact with electrostatic sensitive semiconductor device during manufacturing process, damage to the oxide and other active parts of the device is caused by transfer of charge between device and human body. The VDG generator can be used as a mobile dissipater with a slight modification which is very helpful in semiconductor industry the main use of this generator is to neutralize static charges generated by the human body [33].

4.3.1 Working Principle

Semiconductor industry adopts preventive and protective approaches like grounding the human body with a wrist strap when it is being properly worn and connected to ground via a 1.0 Mega Ohm resistor. The charge on the operator is neutralized with the electrons from Earth ground keeping the voltage potential of the operator close to zero volt and at the same time controls the discharge time such that the operator would not feel the electrical shock while connecting to utility ground as shown in Figure 4.1 to neutralize the charge and setting up ESD preventive and protective workstation. Wearing a wrist strap is impractical for the operator and it causes psychological effects as the operator would not like to be strapped. A literature survey and review of many large semiconductor manufacturing industries have revealed that there is no alternative method used to neutralize charge from human body besides wearing a wrist strap.

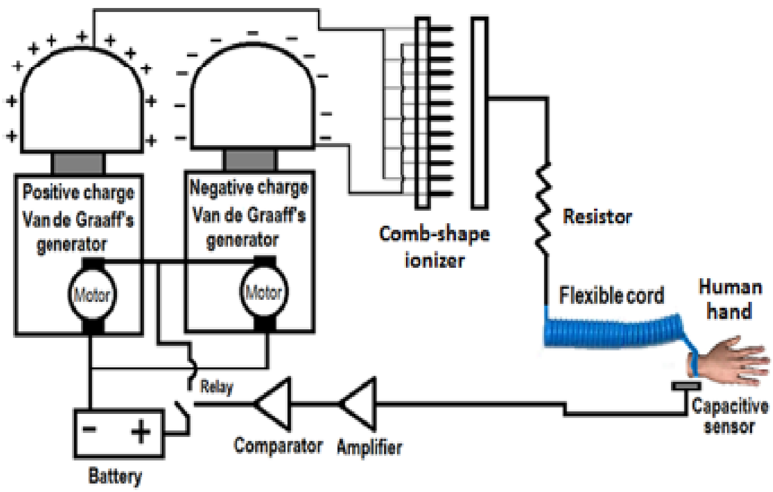

Figure 4.1 Design concept of a mobile static dissipater

The charge generator can be designed using the design concept of a VDG generator as explained in this thesis VDG generator to generate equal amount of positive and negative charge cloud to neutralize the charge of the operator. It is a design that will revolutionize the technique of electrostatic discharge for human body in the semiconductor industry. This is very effective and safe technique [34].

4.4 Electrostatic X-Ray Generator

It can be designed just like VDG generator. This can be equally useful in the areas of science and medical by making some alterations. If the generator is placed in a major vessel filled with the Freon gas the X-beams can be generated as our VDG generator produces variable voltages thus it is very helpful for the generation of X-rays [35].

The X-rays have high frequency and these must be pinpointed in order to be high-precision X beams. So the source must produce very sharp beam. X-beam tubes must possess very high running voltages which must be at least 200 kV in normal conditions and to get higher vitality tubes was unrealistic in past but with proper insulation we can use even greater voltages. After developments in the VDG machine providing 200000 volts or more X beams turned out to be exceptionally penetrative capable of entering steel plate few inches thick and that's how the generation of Xrays became possible [36].

4.5 Medical Field

In therapeutics VDG generator can be utilized for detection of silicon in the human lungs by the shrewd technique for determining the age of neutrons by using a 2MV VDG generator. This has been extremely effective to create a beam of light emitting many neutrons which is very useful in inelastic scrambling and provides a quantitative noninvasive strategy for the investigation of silica troubles in uncovered laborers. Silicon is estimated utilizing the quick neutron inelastic disseminating response ^{28}Si(n,n'γ)^{28}Si which emanates 1779 keV γ-beams introduction to silicon is unsafe for lung tissues making fibrosis and driving silicosis [37].

4.6 Food Preservation

Accelerated electrons can be used to clean substances and process food. Only few radiation sources can be used for producing nourishment light. Energies produced by these radiation sources are too low to actuate radioactivity in any material. X-beam machines having the greatest vitality produced from the VDG generator broadens the timeframe of realistic usability of a few organic products including bananas, mangoes, and other fruit.

Medium measurements can be utilized to control shape development on strawberries, raspberries and blueberries increasing their time span of usability. Top opening of mushrooms can likewise be postponed by moderately low dosage light and cool stockpiling. Illumination can create alluring physical changes in a few sustenances. Bread produced using illuminated wheat has more prominent portion volume when certain batter details are observed. When organic products like grapes are illuminated they yield more juice when squeezed than non-lighted ones [38].

4.7 Educational and Demo Purpose

The VDG generator is essential for the demonstration purpose in universities and colleges it is very helpful to understand the concept of static electricity. Lightning effect can also be understood using VDG generator if the discharge wound come close to the charged dome the illustration of lightning and corona effect is depicted. Hair rising phenomena is very popular in entertainment industry it is actually the base of static electricity as the charges flow into the body and if the demonstrator is properly insulated thus these charges try to discharge through the hairs of body.

4.8 Equipment Testing

Some of the electrical equipments require some testing of very high pulse and as this generator is very helpful for the generation of very high potential and thus can be useful for testing of equipment.

Chapter 5

Maintenance and safety of VDF Generator

5.1 Introduction

The VDG generator requires intermittent maintenance to keep working smoothly for a long time take precautionary measures against electrical shock potential.

- *We have to make sure that belt and rollers don't have dust, girt or lubricant after every few hours of function. We have followed the belt exclusion method and the rollers and belt's clean-up practice any time we have observed a buildup or in case our generator is not working appropriately. Sometimes we had to polish the rollers to remove lubricants.*
- *The exterior parts of the generator need to be cleaned with soft wet cloth.*
- *Occasionally it is necessary to clean the plastic section with a delicate fabric hosed with foamy water. Sometimes this needs to be done with the belt and rollers evacuated. We should try not to utilize liquor or solvents that could cause any harm to the plastic.*
- *Belt must be removed before putting away the generator for broadened time frames (i.e. a while). This will shield the belt from losing its flexibility.*
- *Belt must be monitored continuously in order to avoid any damage. Worn or harmed belt must be immediately replaced.*
- *We need to store the generator in a spotless dry place to forestall tidy collection or dampness retention.*

5.2 Belt Replacement

This system needs to evacuate or supplant the belt. The belt must be replaced by unplugging the generator. The upper part of the dome is removed and base cover plate is removed by evacuating the four screws and washers. The belt slides off the open end of the lower roller. The finish roller is lifted off the brass brackets and the belt slides off the best roller gathering.

5.3 Belt and Rollers Cleaning

Filth, muck, and lubricant will gather upon the belt and rollers after certain time.Our machine is charged electrically and is prone to filth and lubricant in the air. Filth or lubricant stuck between the rollers and belt will get in the way of moving charges from the arena to ground and disturbs a charge set up on the arena. Cleaning up some parts of generator makes our generator to provide maximum performance.

The apex of the dome is removed. The belt is dragged in reverse direction from the higher roller and dirt is checked on the roller. In case if we see filth upon the roller then it is time to clear it out. The belt is removed by using above mentioned method and top and bottom rollers are washed by using a soft cloth soaked into alcohol. We should not use the detergents or other solvents to clean the rollers as it may harm or hinder with the electrical process of these parts. Both inner and outer parts as well as belt is cleaned with free cloth soaked into foamy water.

This is done effectively by laying an area of the belt on a spotless surface and rubbing the belt in strokes. We may need to rub toward the edges to evacuate any minor particles on the belt that meddle with electron exchange. The belt is washed well with water and after that completely dried out with a delicate fabric. Any remaining water on the surface of the belt can be dried out with a hair dryer. Any extra oil is wiped off the upper roller shaft and spacers. Any oil on the belt or surface of the rollers will disturb generator's working. Brushes are also replaced if important.

5.4 Belt and Rollers Calibration

There are chances that the belt doesn't fit the base of the section then move the lower roller on the motor shaft without being concerned whether the belt is fixated on the lower roller. The generator must be unplugged and the set screw is relaxed that holds the lower roller on the engine shaft. Lower roller is re positioned and set screw is fixed again. Generator is turned on to verify whether the belt is focused in the segment now. Now generator is ready to use. The base cover plate is put again at the highest point of the dome.

5.5 Belt Tension Adjustment

The tension of the belt needs to be adjusted whenever needed to change the belt or if the belt starts to slip on the rollers. It is important to adjust tension of belt to extend its life. Our VDG generator has belt pressure screws to remove slack while extending which will expand the life of the belt while working at high voltages.

5.5.1 Safety

Avoid excessive stress on the belt or it will not handle the weight on the motor bearing and life of belt will be reduced. The belt pressure is adjusted using screws until the belt never slips again on the roller.

5.6 Adjustment of Combs

The two combs are situated near belt and base rollers and these may influence the charge development at the dome surface. These two combs must be changed in accordance with inside 1/8" to 1/4" as compared to the belt to create ideal charge development. The lower brush particularly may cause modification as it is connected to the charge establishing terminal. Highest point of the dome is removed along with the base cover plate by opening the four screws and washers. The upper brush is examined and positioned so that the hole between the belt and brush is between 1/8" and 1/4". The hole ought to be genuinely uniform.

Slacken the brush alteration screws to do this. The lower brush is observed and it can be turned toward or far from the belt and roller by first releasing the metal establishing nut. Position must be so that the hole between the belt and lower brush is between 1/8" and 1/4". To control the lower brush somewhat with a couple of pincers if important to adjust the brush parallel to the lower roller.The belt must be pivoted by hand to ensure that no piece of the belt contacts the combs. There is fluctuation in the thickness of the belt and some wobble of the rollers as they pivot. To ensure that the pivot the belt are not fully upset.

5.7 Cleaning of the Column and Dome

At whatever point the cleaning of the belt and the roller is required it is likewise a smart approach to remove dust from the plastic segment or any metal part. Even very tiny particles that will gather in the segment after some time during its working can missalign the belt and it can get rubbed within the section and create plastic tidy. The small dirt elements can stick to the belt and effect the working of generator.

The cleaning of entire section is required by rubbing a delicate fabric. Hair dryer is sometimes needed for drying after this operation. The oil development at the dome surface can cause discharge that leaks voltage into the encompassing air. Due to this leakage of voltages this the generator is unable to achieve its full potential.

5.8 High Air Humidity Issues

As the moisture increases the plastic parts of the Van de Graaff generator rollers and section, which are intended to work as insulators, allows the little flow of current. Since a VDG generator creates high voltage and low amperage and this conductivity disturbs functioning of generator.Dampness noticeable all around additionally scatters the electric charge before it can be developed on the arch. The execution of our generator may start to tumble off as humidity in air exceeds over 60% and maybe not work at all over 80-90% relative humidity.

The humidity is too high by rubbing a balloon on the hair of our arm. Balloon is moved away and back again toward the hair on our arm. If the hairs stands up the air is sufficiently dry for the generator to work. If the hair does not stand up at that point the dampness is too high for the generator to work properly.

Another option to dry the air if it is humid is by utilizing the 25-watt drying light placed in the base of the unit while the unit is running.Light is turned on for 10-15 minutes and checked whether the warmth from the knob is enough to lessen the humidity inside the generator. Turn the light on for longer intervals in higher humidity conditions. This drying light isn't intended to stay on continuously. It is turned on just when required.

5.9 Lubrication of Generator

By applying a drop of oil to some of the parts of generator helps the generator to work properly specially the motor shaft and the upper roller require an attention due to its excessive rotations. But during the lubrication be very careful about the oil droplet that they do not drop on the belt because greasy condition on belt causes some issues and same is true for the roller surfaces. These oily surfaces may essentially reduce the efficiency of your generator if not handled well.

5.10 Safety

As indicated by the equation 2.14 this generator is absolutely safe to use yet at the same time the general population with cardiovascular pacemakers or other such electronic therapeutic inserts might never be able to use this generator. Release of electricity produced via friction could make the electronic gadget harmful or to produce a glitch.

5.11 Troubleshooting of VDG Generator

There might be a possibility that our VDG generator isn't working appropriately and as a result the starting of generator is delayed and the charge establishment is disturbed. The possible issues are addressed in the table 5.1.

5.11.1 Power Cord Failure

The possibility is the power isn't given to the generator effectively and to remove this issue power wires and incorrectly assembled parts must be checked.

5.11.2 Humidity Issue

The generator doesn't work effectively under the humid conditions. Check whether you can dry out internal parts of your generator with a hairdryer or need to turn the vacuum

Table 5.1 Troubleshooting

Problem	Reasons
Belt is not moving properly	Generator is not on Belt tension is high
Generator does not shows the Gap test spark	Environment is humid Dirty belt or rollers Dirty dome or column or Incorrect comb adjustment
Generator produces abnormal sounds	Belt Position is disturbed and rollers interfering with body or Upper roller has some issue in bearing or motor shaft is noisy

pump on to remove the dampness.

5.11.3 Loosen the Belt

Take the belt out and extend it twice to about two fold its length without overstretching. Belts might be fragile and break if these are overstretched. Their is a chance that the belt is in exposed to cool climate and can defrost it out in boiling water and after that dry it out.

5.11.4 Remove the Dirt from Belt, Body and Dome

The belt is cleaned with water and dried out. For globe and body utilize a dishwasher.

5.11.5 Clean Nylon Pulley with Alcohol

Remove higher pulley and wash completely with alcohol. Lower pulley is ABS and isn't influenced with alcohol so use simple cloth for dust removal.

5.11.6 Adjustment of Brushes

There might be excessive freedom of movement among belt and wire combs. Combs are changed by twisting until the point when they come in close vicinity of 1/8" (3 mm) of the belt however don't come in contact with the belt.

5.11.7 Allow Warm-up Period

Run the generator for a couple of minutes before performing analysis. This regularly balances high humidity. Dry out any moisture within the segment with a hair dryer before testing.

5.11.8 Regular Maintenance

Belt must be washed after every 50 hours of running with liquor, flushing altogether. To clean upper pulleys utilize harsh fabric, sand paper, scotch brite and steel fleece to wipe off any stored water. Lower pulley must be cleaned with a spotless material.

Chapter 6

Conclusion and Future work

6.1 Conclusion

This research will provide a basic method for designing VDG generator of any size and producing any amount of voltage. There will be no need to design VDG generator using hit and trial method rather this model can be used for design purposes and the parameters can be changed accordingly. The leakage insulation and other types of insulation affect the performance of this type of generator and this is the major reason for performance degradation of generator. This issue has been critically addressed in the research and this will remove the common deficiency associated with humid conditions.

We have utilized silica gel to remove the dampness and moisture from the generator. A vacuum pump is also placed to evacuate dampness other than silica gel. Issues caused by uneven surface of dome are resolved by coating aluminum arch with zinc. Since the motor speed is controlled electrically, the variable voltages can be achieved. The 200 kV generator is designed and implemented in this paper. Our proposed generator is providing better performance than industrially available VDG generators. This generator can be utilized in atomic material science, semiconductor enterprises, X-beams ages, skipping ball impact, hair rising wonder and neon indicators

6.2 Future Work

To improve the performance of this generator further improved by improving some parts of the generator like replacement of the well polished aluminum material dome with fine polished copper dome. The copper has better conductivity and good capability of handling charges that allows the generator to run smoothly.

The insulation of inner parts of generator is improved but for further improvement we need to improve the packaging of the generator by adding SF6 gas inside tower which will act as a perfect insulator for internal parts if the generator is tightly packed.

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