Faraday Cages as Protection from Lightning Strike for Electrical Equipment and Facilities

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Abstract – **This paper reveals about Faraday Cage and lightning strike. The Faraday Cage will be tested by applied a high voltage injection from high voltage source that act as lightning phenomena. In this project, the Faraday Cage will be tested in two ways to ensure that Faraday Cage has been design can achieve the objective for this study. The main objective for this study is to make sure faraday cage can protect electrical equipment and facilities safety from lightning strike.**

Keywords - *Faraday Cage, lightning, time rise, time fall, electromagnetic, striking angle*

I. INTRODUCTION

Between earth ground and cloud, there is one of beautiful display of flash phenomena happened. It is happened not depending on time or season. Behind this beautiful phenomena its carries a million of charge that can cause death for living things. Lots of researcher has been study about this phenomena that called lightning phenomena. There are few types of lightning such as cloud to ground, inter cloud and cloud to cloud lightning. These natural phenomena also bring along a dangerous characteristic and will affect to living things and nonliving things because one lightning strike carries a million of voltage and charge.

The objectives of this project are ash shown below:

- To study about electromagnetic field inside the Faraday Cage.
- To observe the lightning strike characteristic.
- To analyze whether Faraday Cage can protect electrical equipment from the lightning strike or not.

A. Faraday Cage

Faraday Cage is enclosure conductors that can block electricity enter inside it. Characteristic of faraday cage is a conductive wall that has been made from conductor material will be surrounded by with positive and negative charge. Within the conductive walls, the force are produce based on the charge and electron will be forced and rearrange when external electric fields are applied. So, the charge can't enter inside the cage because of that arrangement of charge. The distribution of charge that produced inside the cage will be neutralizing the external field. That's make faraday cage is hollow insulation. [1] This elimination of electrostatic charge in electronic industry that produces semiconductor devices disk drive and LCD is the most important part. This is because an unneeded charge will disturb the operation of the devices [5]. Other than that, the easiest thing to understand about ideal hollow conductor is a Faraday Cages. When the external electric supply applied, it is also carrying an electrical field that produces force of charge. The conductors from faraday cages will generating current that rearrange the charge. When the charge has been rearranged its will cancel the field inside the faraday cages and make current from outside cannot enter inside the cage [6].

B. Lightning phenomena

Lightning is typically an atmospheric phenomenon and is a threat to human life, houses, historical monument and electrical systems. Intra cloud discharge is the most common type of lighting which is within the cloud, the flash occurs entirely. In lightning study filed, the cloud to ground discharge is the most popular has been studied by the researcher. This is because cloud to ground discharge is the most

related with people, living things, equipment and facilities on earth because its effects are the most damaging [3]. In electrical power system, the major cause of disruption in overhead distribution system is lightning and it's the main source if consumer complaints because of the interruption of the power supply [4]. Other than that, there are several type of classified of lightning incoming routes into residence such as antenna to antenna, ground potential rise and direct striking at disturbance line [2].

C. Electromagnetic wave

A faraday cage also can avoid electromagnetic wave from entering inside it. Electromagnetic ca be occur from a lot of source such as an electric source, electronic device and radio frequency. There are lot of effect that electromagnetic to human and living things. For example, When electromagnetic occur from radio frequency, our body will be absorbed that radio frequency which carries an electromagnetic wave and it can be a radiation. This radiation will be interaction with water. This Radiation also will increase the temperature and it is depend on the exposed area of our body, efficiency of heat elimination of our body, the strength of the field, duration exposed and thickness of human skin [7]. Electromagnetic wave can cause health problem such as headaches and it also can cause brain cancer if human are exposed to that electromagnetic wave for a certain period. The easiest example is mobile phone. When mobile phone produce the electromagnetic when it is operate, that radiation will effect to the human body and effect the human anti body. [8]

D. Electric field

In electrical engineering field, high voltage electricity is the most common thing. This is because to supply long distance electricity, it needs very high voltage electricity. So, when high voltage flow through the power system and that power system equipment is inside the human community, its will be produces an bad effect to human because a high voltage electricity produce a huge electric field and human will surrounded by electric field. This will make a large biological effect to humans. When human body exposed to an electric fields, the electric fields and current are included in their body. [9] in electrical power system, high voltage are the major elements. Peoples working that deals with high voltage will be more exposed to the current and electric fields, so the risk for them will be higher. The concept of Faraday Cages can be applied to their suit or custom [10].

II. METHODOLOGY

For the Faraday Cage experiment, the testing will be divided to two which is electromagnetic wave test and lightning impulse test. For the first test which is electromagnetic wave test is to ensure an faraday cage that has been design is confirm follow the theoretical. Based on theoretical a faraday cage will be act as hollow shield conductor and its characteristic is it will cancel up waveform from entering inside the cage by rearrange the outside charge and charge from conductive material from faraday cage. This testing is the most important test before lightning impulse testing will be conduct. For the electromagnetic wave testing for mesh steel and aluminum cage is shown such as figure 1. The first step is check whether radio is functioning well. The used of radio for testing object in this testing is because radio used the radio frequency signal which is also carry and electromagnetic wave. The testing is turn on the radio and put it inside the cage. If the radio inside that cage can't receive signal, that's mean an electromagnetic cannot entering inside the cage and this showed that faraday cage is follow the Faraday Cage characteristics.

Figure 1: Electromagnetic testing

Second test is about lightning impulse testing. This testing is a very dangerous testing because it deals with high voltage injection. The minimum of lightning characteristics normally is around 20kA but in high voltage laboratory in UiTM Shah Alam has limitation and its only can achieve 4.3A maximum. A real lightning carries a million volt of voltage but for this testing 70kV injection will be applied because of limitation of laboratory to make sure that equipment is in laboratory not damage for others student to use it. By applying 70kV, the characteristic of lightning can be assumed similar due to graph and shape of arc that occur from the injection.

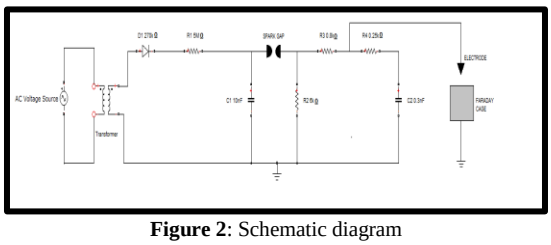


Figure 2: Schematic diagram

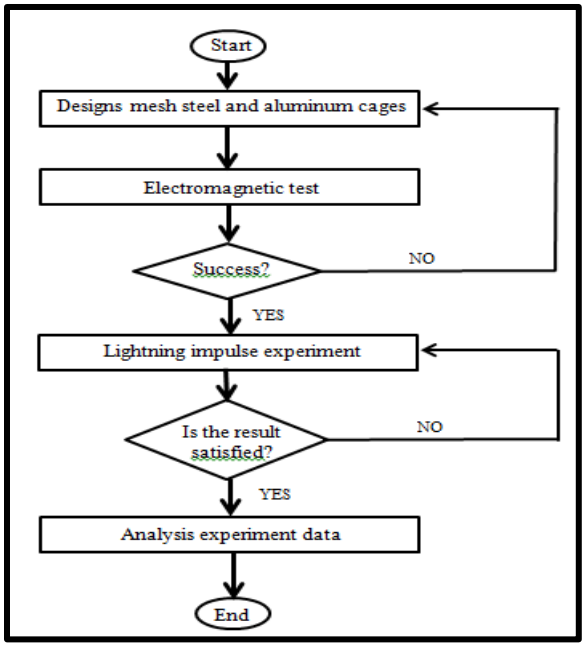
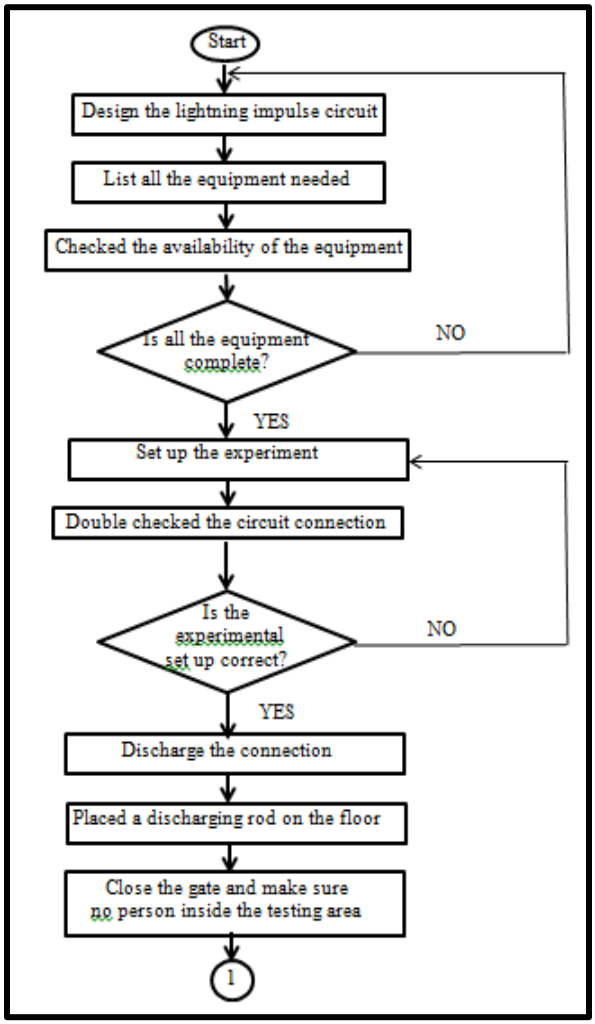


Figure 3: Flow chart of the project



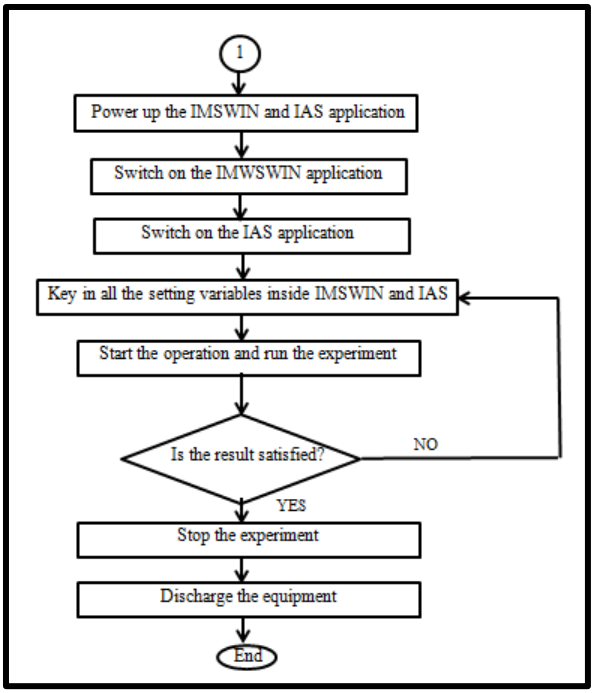


Figure 4: Flow chart of lightning impulse experiment

The project process is shown in the flow chart in the figure 3. Firstly design a lightning impulse circuit. The lightning impulse schematic diagram circuit has been shown in the figure 2 and the flow chart procedure shown in figure 4. Based on the theoretical of lightning strike, the equation 1 to present the impulse waves for the lightning phenomena.

$$V = V_0\left(e^{-\alpha t} - e^{-\beta t}\right) \quad (1)$$

In that equation 1, V_0 is presented to the factor depended due to the peak value. For the lightning phenomena, the value of the equation impulse wave is taken value of 1.2/50μs, α = -0.0146 β = -2.467 and V_0= 1.04V. The front time of impulse wave is controlled by the value of β and α respectively. In this experiment, the manipulation variable is the angle of lightning source. There are five of angle lightning source which are 0º, 30º, 45º, 60º, and 90º from the Faraday Cage. This is to study the effect between the angles and will Faraday Cage protect that radio that inside that cage. The radio will used into this testing. This is because inside radio there are lots of electronic component. In electrical engineering, the most sensitive component is electronic. It is easily to damage when over current or over voltage such as resistor, capacitor and inductor. The antenna and body of radio will touch the faraday cage to see whether Faraday Cage can protect it or not.

III. RESULT AND DISCUSSION

In this experiment, two types of Faraday Cages have been designs which are mesh steel faraday cage and aluminum fully closed Faraday Cage. The size of both faraday cages is same. The different is just the design and material used. The size is of both Faraday Cages is same. It is square shape because to follow in IEC62305 standard is same of height, length and wide. In this result and discussion part will be discuss about the result of lightning impulse injection.

A. Lightning characteristic

Before testing the faraday cage, the characteristic of lightning must be created to ensure there are no problems when testing the lightning impulse injection at faraday cages. The lightning strike phenomena have been shown in figure 5. In this impulse the value of peak is 78kV when the actual setting voltage is 78kV. When the lightning impulse has been inject, the time rise can be measure by look at T_r result means that time rise is time to voltage increase from to reach 90% value of peak. The value from the graph is 1.1189µs. In the figure 5 T_f is the fall time. Fall time is time taken of voltage from 90% decrease to 50%. This is standard character researcher took when studying about lightning graph which is time rise, highest peak value and fall time. The radio will be turn on in this experiment and the antenna will be out little bit to make sure radio is on and to see the effect when high voltage applied to the cage.

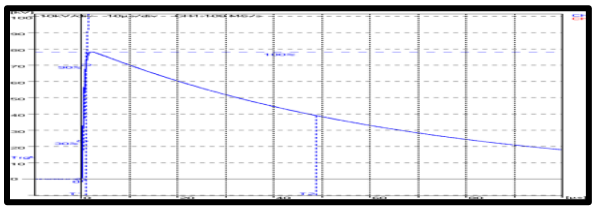


Figure 5: Lightning impulse waveform

B. Effects of angle lightning source

(i) Mesh conductor steel cage

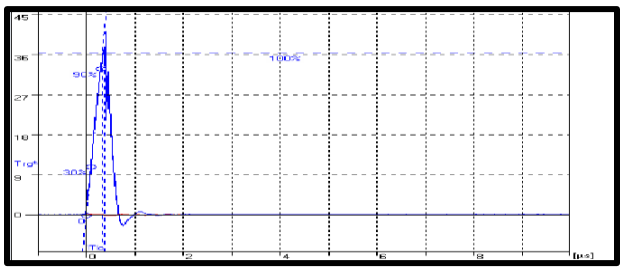


Figure 6: Graph of breakdown voltage against time at 0º angle of lightning source

Based on graph of breakdown voltage at Faraday Cage shown in figure 6 at 0º angle of lightning source, the time rise is 0.335µs and fall time is 0.382µs. During this injection the Up is 36.87kV and the actual injection from the source is 65.27kV. This show a great result because the time fall is very extreme fast means the time taken that faraday cage to discharge the voltage applied during the strike applied is extremely fast.

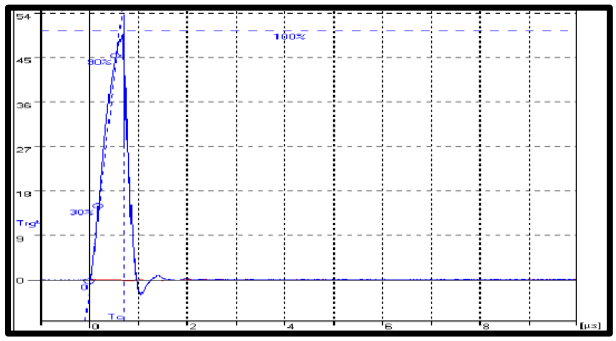


Figure 7: Graph of breakdown voltage against time at 30º angle of lightning source

Figure 7 showed the graph about the breakdown voltage for Faraday Cage mesh steel against time at 30º angle of lightning source. The time rise recorded is 0.523µs and time fall is 0.591µs when 64.18kV actual voltages applied to the cage. The maximum voltage at faraday cage is 47.18kV. This might be high voltage and dangerous but the faraday cage has been blocking the electricity to entering inside the cage.

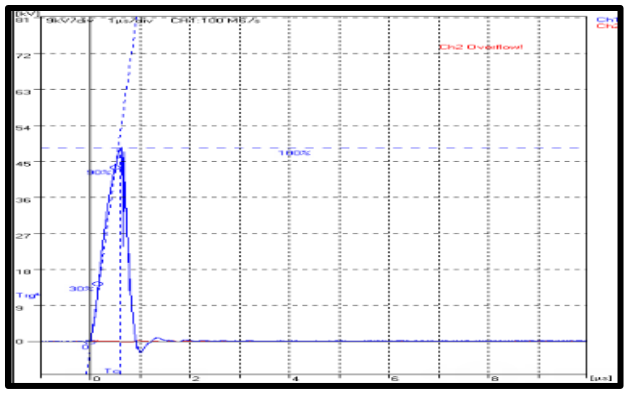


Figure 8: Graph of breakdown voltage against time at 45º angle of lightning source

The maximum voltage at this Faraday Cage is 48.49kV when the actual value of impulse injection is 64.95kV applied to it. The time to reach the 90% of the maximum voltage at that voltage is 0.551µs and the time to the voltage fall to 50% is 0.621µs as shown in the graph of breakdown voltage for 45º angle of lightning source in figure 8.

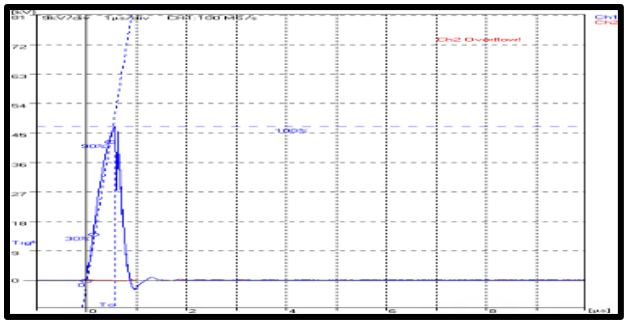


Figure 9: Graph of breakdown voltage against time of 60º angle of lightning source

The figure 9 shown the graph of breakdown voltage against time for 60º angle of lightning source when 64.72kV actual voltage from high voltage source applied to this Faraday Cage, the time rise of voltage at the faraday cage is 0.536µs and the time fall is 0.590µs. The voltage at this Faraday Cage is 47.23kV.

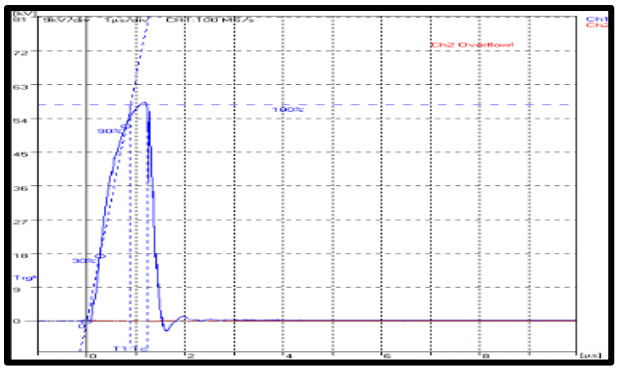


Figure 10: Graph breakdown voltage against time for 90º angle of lightning source

The time rise for 90º angle of lightning source injection is 0.893µs and the time fall is 1.238µs when the maximum voltage at the Faraday Cage is 57.78kV. The all this are recorded when 65.04kV actual voltage was applied as shown in the graph of breakdown voltage against time for 90º angle of lightning source in figure 10.

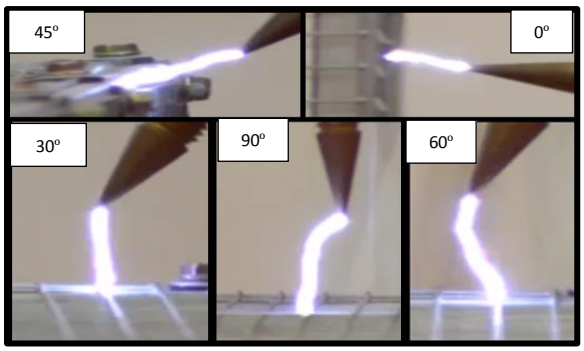


Figure 11: Lightning ladder captured at 0º, 30º, 45º, 60º and 90º angle of lightning source for mesh steel cage

For overall of mesh steel cage testing by refer of all graphs and captured lightning strike in figure 11 analyses, the lowest differences of time fall and time rise is when at angle of lightning source injection at 30º. Time differences time is 0.038µs. This is the extremely fast. This is because based on the theory the rearrange of charge to block the electric field. By the addition with helping of the grounding because of the cage are connect to ground too. The cage was connected to ground because to make sure there is no return current goes back to transformer in the laboratory. Based observation of the testing for the mesh steel cage, the mesh steel cage is achieve the objective to be a Faraday Cage because the radio as the testing object that put inside the cage is during the testing is still functioning well and there are no damage. The radio has been check after each of testing angle. The arc of lightning in this experiment is not follow the angle of lightning source such as shown in figure 11. This is because the mesh steel has lots of hole. It will find the conductor to strike it which is the high potential to discharge. The shape of arc also not straight at 0º, 90º and 60º angle because the movement of electricity will follow the places that have high potential charge for arc to flow.

(ii) Fully closed aluminum cage

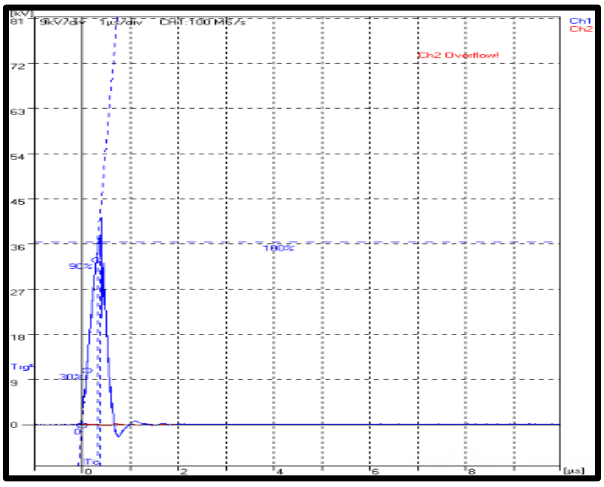


Figure 12: Graph breakdown voltage against time for 0º angle of lightning source

Graph of breakdown voltage against time for 0º angle of lightning source at mesh aluminum Faraday Cage was shown in figure 12. Based on this graph the time rise is 0.372µs showed the time from zero volt raise up to 90%. This is quiet fast and the fall time also fast its time is 0.372µs when 65.84kV voltage was applied. The maximum voltage at faraday cage is 36.58kV

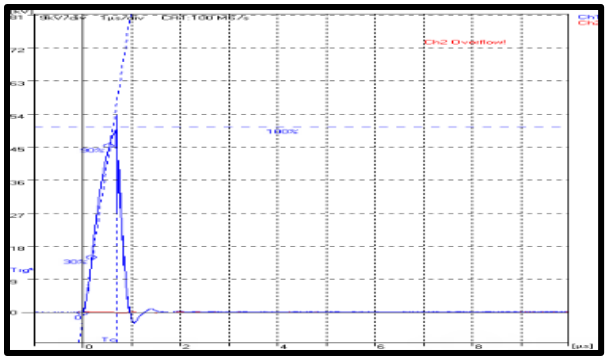


Figure 13: Graph breakdown voltage against time for 30º angle of lightning source

The 64.80kV actual voltage applied make the maximum voltage at faraday cage is 50.68kV. The time rise is 0.606µs and time fall is 0.709µs as show from graph of breakdown voltage against time for 30º angle of lightning source as show in figure 13.

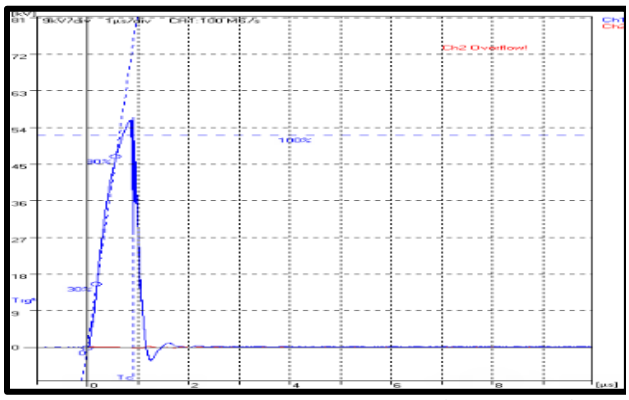


Figure 14: Graph breakdown voltage against time for 45º angle of lightning source

Based on the graph of the breakdown voltage against time for 45º angle of lightning source in figure 14, the time rise when 65.53kV actual voltage applied is 0.634µs and the fall time is 0.912µs. this make voltage at faraday cage is 52.28kV.

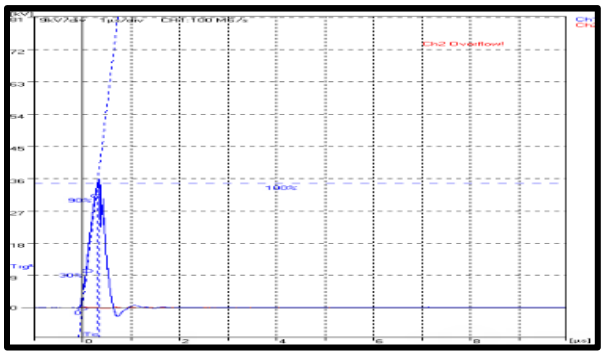


Figure 15: graph breakdown voltage against time for 60º angle of lightning source

The figure 15 showed the graph of breakdown voltage against time for 60º angle of lightning source, when 65.39kV was applied, voltage at this Faraday Cage is 34.86kV. The time rise is 0.311µs and the fall time is 0.356µs.

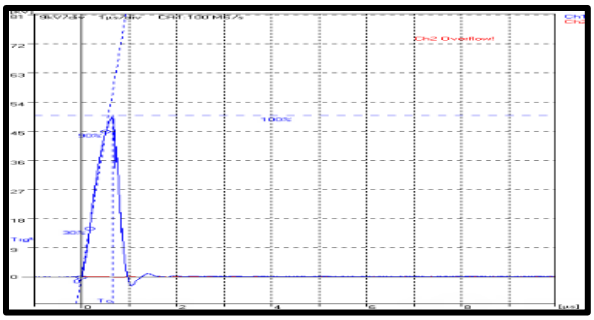


Figure 16: Graph breakdown voltage against time for 90º angle of lightning source

Figure 16 shown the breakdown voltage for the faraday cage aluminum against time at 90º angle of lightning source was applied at actual voltage value 65.32kV. The time rise for this experiment is 0.575µs and the time fall is 0.665µs.

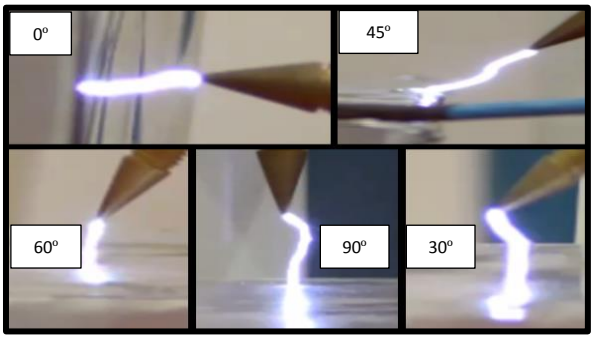


Figure 17: Lightning ladder captured at 0º, 30º, 45º, 60º and 90º angle of lightning source for fully closed aluminum cage

Based on all the result of graph breakdown voltage against time with different angle of lightning source for fully closed aluminum cage, the fastest time to voltage can be assume by see the differences between time fall and time rise is when 0º and 45º angle of lightning source has been injected. The differences of time rise and time fall for both angles is same which 0.045µs is. This is fastest time taken by aluminum faraday cage took to discharge. During this discharge there are no spark occur inside the cage. Along this testing, the radio is still functioning as well. The radio always been check after each of the angle of testing has been done. This showed the faraday cage has been design is has the characteristic of shield conductor and the testing is success. Based on figure 17, the lightning strike from the different angle can be compared. These prove that the lightning arc shape is not move straight. Sometimes,

it will bend such as at 45º, 90º and 30º angle. This is because the lightning will find the higher potential to strike and the lightning arc will not follow the angle of lightning source.

For the whole of this experiment, both of the Faraday Cage which is mesh steel cage and fully closed aluminum cage is success because it protect the radio inside it. The radio is still functioning well. But during the test there are some disturbances of frequency. That phenomenon happened because the magnetic wav from the high voltage injection will disturb the radio frequency. Based on all result by observe from the actual testing and the analysis from graph and data, the best faraday cage is mesh steel cage. This is because mesh steel cage result for the time fall, time rise and the differences of both of it is the lower than fully closed aluminum cage.

TABLE 1: Average of time for the fall time for mesh steel and aluminum

Angle of lightning source(º)	T_f, mesh steel (µs)	T_f, aluminum (µs)
0	**0.4388**	**0.4456**
30	**0.6196**	**0.6442**
45	**0.5526**	**0.7816**
60	**0.5758**	**0.3426**
90	**1.0828**	**0.7096**

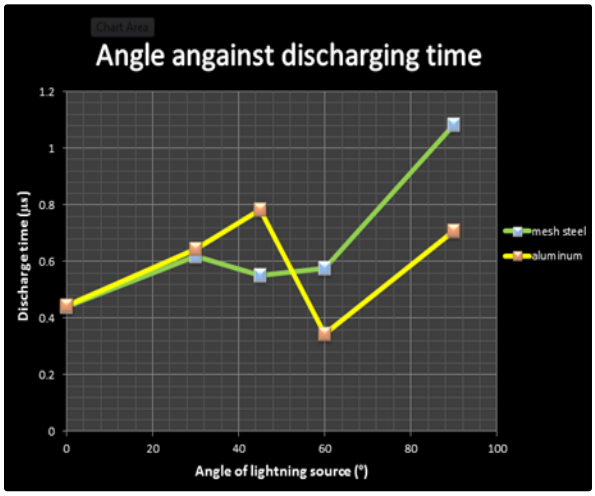


Figure 18: Graph of angle against discharging time.

Table 1 is the average data of time fall or discharge time taken of both cages. Based on all this value, the graph of angle against discharge time has been shown on the figure 18. Based on this graph, discharge time for 0º, 30º and 45º of the mesh steel cage is lower that aluminum cage and for 60º and 90º angle the aluminum cage is lower than mesh steel cage of discharging time.

IV. CONCLUSION

In the nut shell, this project have achieves its objectives. Firstly, the objective is to studying about magnetic field inside the Faraday Cage. Magnetic wave inside the faraday cage is truly hollow base o the two experiment has been done. This is proven when the radio signal cannot enter inside the cage and when high voltage injection to the Faraday Cage, there are no leaking spark inside it.

Secondly is about lightning characteristic. There are lots of lightning characteristic. Based on the experiment the lightning is not follow the angle from lightning source and lightning is not move on straight. It's always find the place have lots of charge and highly potential to strike. This is proven base on capturing high voltage injection arc. Some arc is bending, treeing and straight. It is unpredictable phenomena.

Lastly for overall of this project, the result has been proven by overall experiment in this project that the faraday cage can protect the electrical equipment and facilities including living things and nonliving this from lightning strike.

V. RECOMMENDATION

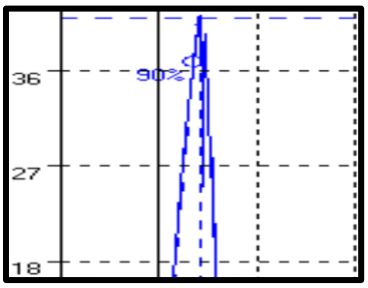


Figure 19: Unexpected graph

After the testing of Faraday Cage has been done, the analysis has been made base on graph picture in figure 19 and data. There few unpredictable things happens base on analysis. On the graph analysis, referring the breakdown voltage of Faraday Cages, when the voltage achieve the maximum at the graph and its start disagreeing but during discharging, there are few voltage start increasing back and start discharging back. Normally it's happened below in 0.010µs. This is unnatural phenomena. When referring the extremely slow motion video, the injection saw a few times after maximum injection. This is maybe because of the environment factor and equipment of laboratory.

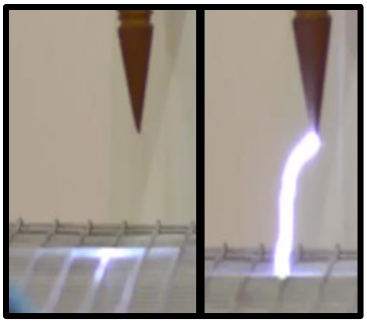


Figure 20: Mysterious phenomena captured at the 30º angle injection for mesh steel cage.

Secondly is based on picture in figure 20, it is happened when 90º angle injection at mesh steel cage only at once. The arc capture start from the cage surface and goes to electrode. All of these phenomena can be further more study by doing research for next project.

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