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Experimental Investigation on The AC Breakdown Strength of Air Under Various Uniformities

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Abstract: High Voltage AC (HVAC) is widely used in power systems, especially in transmission and distribution systems. Those systems use a very high or extra high voltage to transmit the power from the power generation to the consumer. To ensure that the power delivered to the consumer is efficient, all equipment involved such as the generator and transformer must have good insulation and can withstand high electrical stress and pressure. This insulation is important as protection to the equipment from suffering severe damage due to high voltage and current. Hence an investigation and an experiment were performed by using air as insulation. The experiment was performed based on the TERCO document catalog that provides the procedure and equipment list. In this project, there are five types of electrode pairs that have been used such as sphere-sphere, rod-rod, rod-sphere, sphere-plane and rod-plane with different gap distances from 0.5 cm to 3.0 cm. This experiment was conducted in an HV laboratory to observe the breakdown voltage before using Finite Element Method Magnetics 4.2 (FEMM 4.2) software to obtain the electric field intensity, maximum electric field and field utilization factor for each pair of electrodes. There are some calculations were involved to obtain another parameter. The result such as breakdown voltage of air, distance gap and maximum electric field relationship were discussed in this project as well as the relationship between field utilization factor and gap distance. After all the analysis and discussion, sphere-sphere electrodes were found to be the best electrode pairs compares to others due to their high breakdown voltage which is 88.50 kV, low maximum electric field (E_{max} = 35.12 kV/cm) and has highest field utilization factor, η =0.84 all at gap distance 3.0 cm.

Keywords: AC Breakdown Voltage, Air Gap Distance, Max Electric Field, Field Utilization Factor

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1. Introduction

Generally, in high voltage power system, it consists of a complex configuration starting with a generation system, transmission system and distribution system networks with overhead and underground power lines for supplying the energy to the consumer premises as per the requirement. The recent increase in industrial and economic development nowadays requires increasing use of electrical energy, which must be efficiently transmitted in large quantities over long distances. This is made possible in the power system by introducing the higher-level voltage of transmission.

As the demand for higher voltage consumption in this rapid growth, it has given an opportunity to power engineers to develop quality insulation to sustain the high voltage power system over the long term [1]. Related to this successful operation of a wide range of high-voltage components it depends on the right choice of electrical insulation for certain applications and levels of voltage.

Currently, in the high voltage power system, there are various materials such as solids, liquids and gases are used for insulation purposes to protect the high voltage electrical equipment from incipient failure [2]-[3]. Studies by power engineers have shown that the obvious problem in high-voltage electrical equipment is the degradation of insulation. That equipment is mainly prone to breakdown and partial discharges due to lightning, switching actions and high electric fields. Once the power system is completely designed and operative, it is necessary to protect it from faults. If the power system is not secured and stable, the economic costs for power delivery also increase [4]. Thus, to protect such equipment several types of conductive electrodes with protective gaps are widely used in the world. There are many types of electrode configurations used but commonly, standard sphere electrodes are used for this purpose compared to others.

Even though the electron valence of each insulator is tightly bonded to their atoms, they cannot withstand an indefinite amount of voltage supplied. An insulator is known as a material that does not conduct an electrical current in which there is no current flow through them [5]. When sufficient voltage is applied, any insulators will eventually surrender or succumb to the “pressure” of electrical and there will be the flow of electrons.

Breakdown strength also known as “striking voltage” [6] where the maximum electric potential that a material can withstand before the electrical current passes through the insulator and then the material is no longer acts as an insulator. There are several types of insulating materials such as solid, gases and liquid, but the air is usually used as an insulating medium in different high voltage electrical equipment and overhead line as its breakdown strength is 30kV/cm.

2. Materials and Methods

2.1 Flow of the Project

For the overall flow project, there are two parts that have been carried out to observe the final result, firstly by conducting experiments in high voltage laboratory and the second one by using FEMM software to obtain maximum electric field, E_{max} as shown in Figure 1. In addition, there are also some calculations applied to get the average of electric field, E_{ave} and field utilization factor, η.

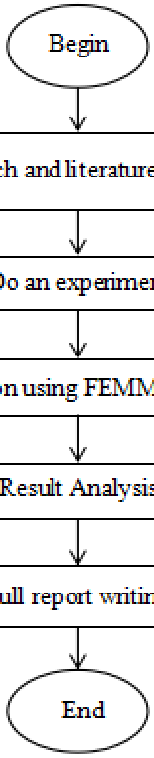


Figure 1: Flowchart of project

The electrode configuration with the different gaps ranging from 0.5 cm to 3.0 cm with increments of 0.5 cm each is shown in Figure 2.

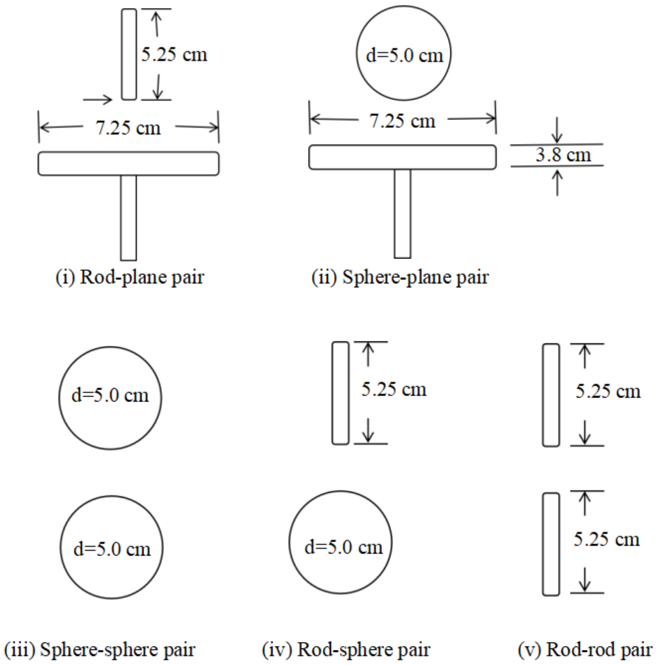
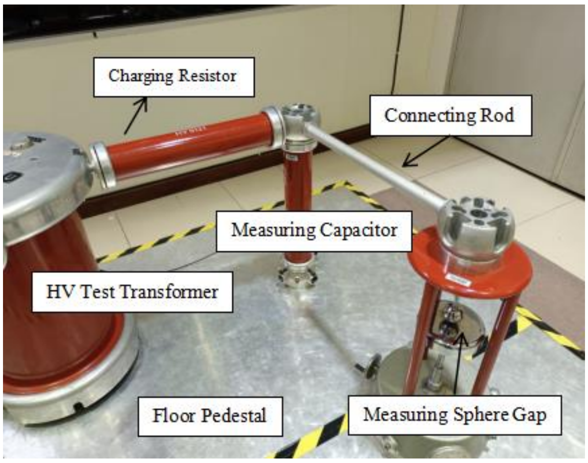


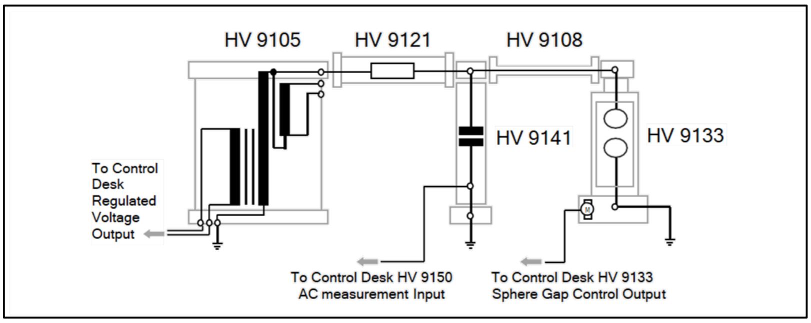
Figure 2: Electrode configuration of air gap distance

2.2 Experimental Setup for Air Breakdown Voltage

The experimental setup consists of a high voltage test transformer, a measuring capacitor, connecting rod, charging resistor, measuring sphere gap and floor pedestal. Figure 3 shows the circuit diagram and circuit configuration of the AC voltage test setup (the experiences have been performed in the high voltage laboratory of UTHM). There are five types of electrode pairs used such as sphere-sphere electrodes, sphere-plane electrodes, rod-rod electrodes, rod-sphere electrodes and rod-plane electrodes.



(a)



(b)

Figure 3: (a) Circuit diagram of AC Voltage Test Setup (b) Circuit configuration of AC Voltage Test Setup

2.3 Simulation using FEMM software

In this study, Finite Element Method Magnetics (FEMM 4.2) software was used to obtain the maximum electric field, E_{max} and the electric field intensity for each type of electrodes paired with various air gap distances. The flow of the simulation is shown in Figure 4.

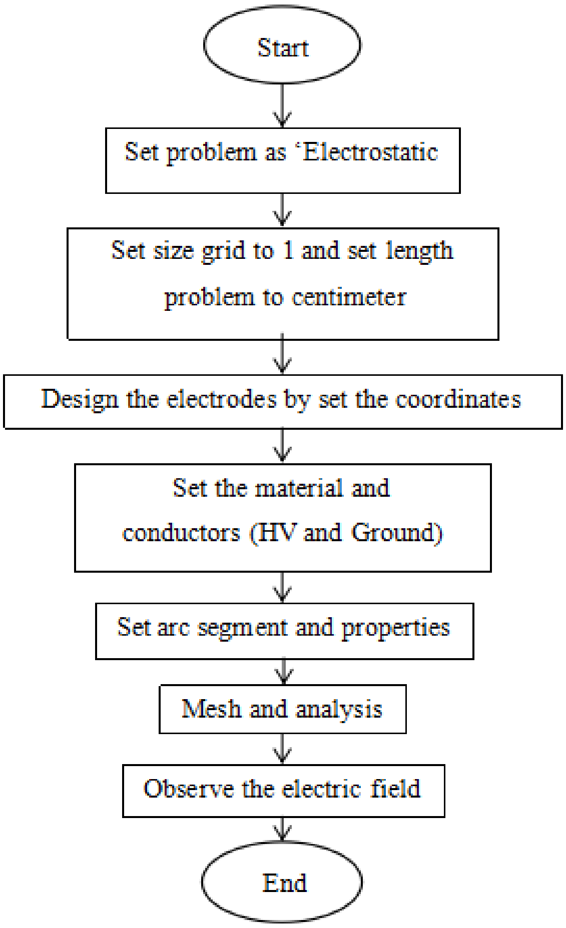


Figure 4: Flowchart of FEMM 4.2 software simulation

The breakdown voltage obtained from performing the experiment was used as a parameter in FEMM software. The electric field intensity or electric field pattern for each electrode pair is observed by referring to the indicator colour provided in FEMM software as shown in Figure 5. Color that is on the top indicates the high electric field while the bottom indicates the low electric field.

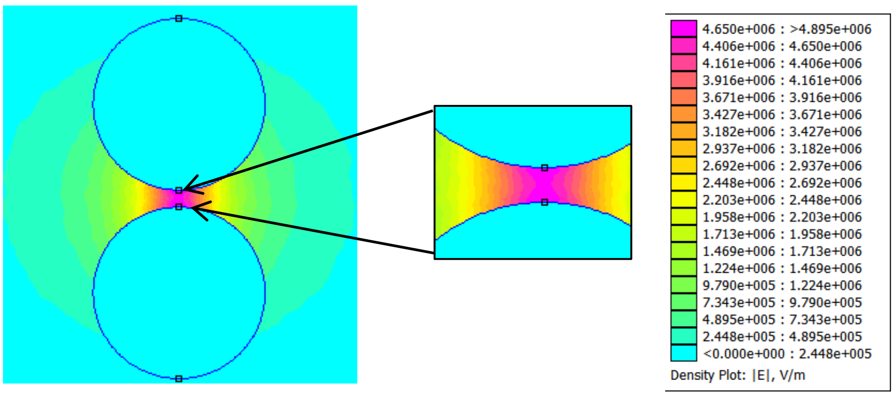


Figure 5: Electric field pattern and its color indicator

3. Results and Discussion

3.1 Results

The result for this project was obtained by performing the experiment and simulation using FEMM 4.2 software. For average electric field and the field utilization factor, it is the result of calculations using Eq (1) and Eq (2). The result of breakdown voltage, average electric field, E*ave* and maximum electric field for each electrode configuration are shown in Table 3.1.

$$\eta = \frac{E_{ave}}{E_{max}} \quad \text{(Eq. 1)}$$

$$E_{ave} = \frac{V}{d} \quad \text{(Eq. 2)}$$

Table 1: Result of breakdown voltage, average electric field and maximum electric field

Electrode Pair	Air Gap, d (cm)	Breakdown Voltage $U_o(kV)$	Average Electric Field, E*ave* (kV/cm)	Maximum Electric Field, E*max* (kV/cm)
Sphere - Sphere	0.5	23.85	47.70	49.03
	1.0	37.24	37.24	39.51
	1.5	51.72	34.48	37.68
	2.0	67.20	33.60	37.83
	2.5	78.89	31.56	36.49
	3.0	88.50	29.50	35.12
Rod - Rod	0.5	21.44	42.88	127.95
	1.0	29.64	29.64	107.90
	1.5	35.13	23.42	81.22
	2.0	40.48	20.24	90.46
	2.5	43.24	17.30	77.01
	3.0	46.46	15.49	68.40
Rod - Sphere	0.5	18.95	37.90	103.87
	1.0	25.19	25.19	91.60
	1.5	31.36	20.91	81.22
	2.0	35.58	17.79	88.07
	2.5	38.83	15.53	76.95
	3.0	43.68	14.56	89.32
Sphere - Plane	0.5	20.05	40.10	42.62
	1.0	36.70	36.70	41.50
	1.5	49.17	32.78	38.93
	2.0	56.02	28.01	34.94
	2.5	67.93	27.17	35.49
	3.0	74.02	24.67	33.56
Rod -Plane	0.5	17.33	34.66	91.04
	1.0	22.72	22.72	80.14
	1.5	26.71	17.81	79.58
	2.0	30.90	15.45	69.54
	2.5	33.71	13.48	73.09
	3.0	38.95	12.98	76.36

3.2 AC Breakdown Voltage

Based on Table 1 and Figure 6, both show the result of AC breakdown voltage that have obtained by performing an experiment in the HV laboratory. By observing the result, the breakdown voltages increased with the increment of air gap distance. It obviously shows the sphere-sphere electrode has the highest breakdown voltage in each of the air gap distances while the rod-plane has the lowest breakdown voltage in each air gap distance. At 3.0 cm, the breakdown voltage for the sphere-sphere electrode is 88.50 kV which is highest than the others at the same gap distance.

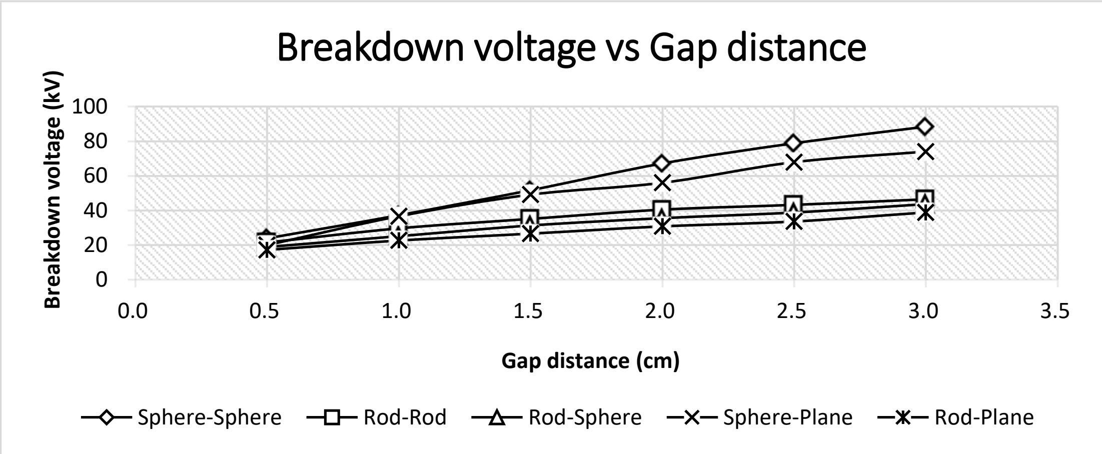


Figure 6: Breakdown voltage against air gap distance for each electrode pair

3.3 Maximum Electric Field, E_{max}

The result of the maximum electric field was obtained from simulation using FEMM software. Based on Table 1 and Figure 7, both show that the maximum electric field gradually decreased with the increment of the air gap distance. Rod-rod electrode has the highest value of E_{max} at 0.5 cm with 127.95 kV/cm and continued decrease until air gap distance is 3.0 cm. Also, it can be observed that the sphere-sphere electrodes and sphere-plane electrodes almost have the same pattern of the graph. This is due to the uniformities of the electric field in both electrodes and also both electrode pairs have a slightly difference in breakdown voltage compared to others. However, the sphere-plane electrodes have the lowest E_{max} at 3.0 cm with 33.56 kV/cm.

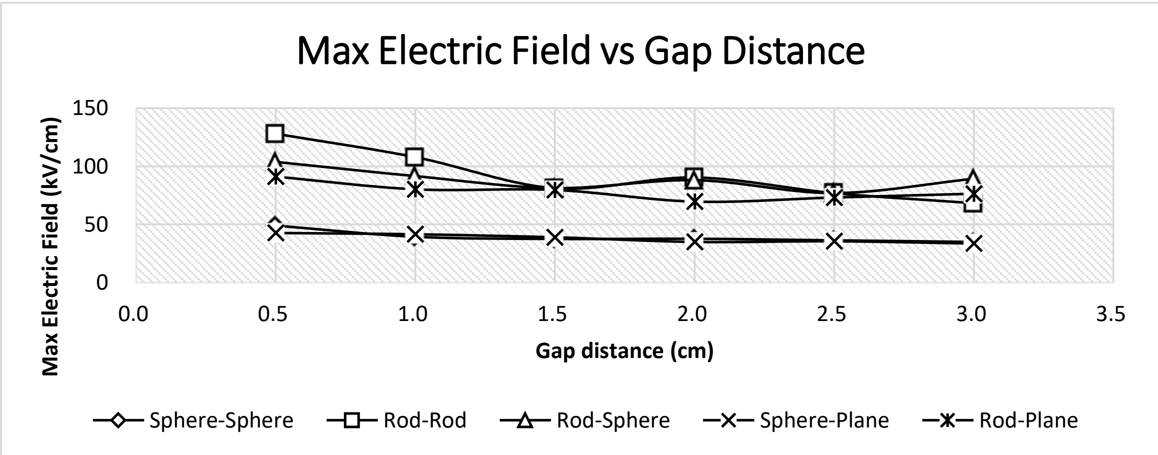


Figure 7: Maximum electric field against air gap distance

3.4 Relationship between maximum electric field and breakdown voltage

Based on Table 1 and Figure 8, the maximum electric field, E_{max} decreased when the air gap distance increased. The result of this relationship is also related to the air gap distance that starts from 0.5cm until 3.0cm. For this section, the sphere-sphere electrode has a breakdown voltage of 23.85 kV at 0.5 cm with 49.05 kV/cm of E_{max}. Then, when the air gap distance increased, the breakdown voltage of this electrode pair increased while the E_{max} decreased. At 3.0 cm, it has 88.50 kV of breakdown voltage and 35.12kV/cm of E_{max}.

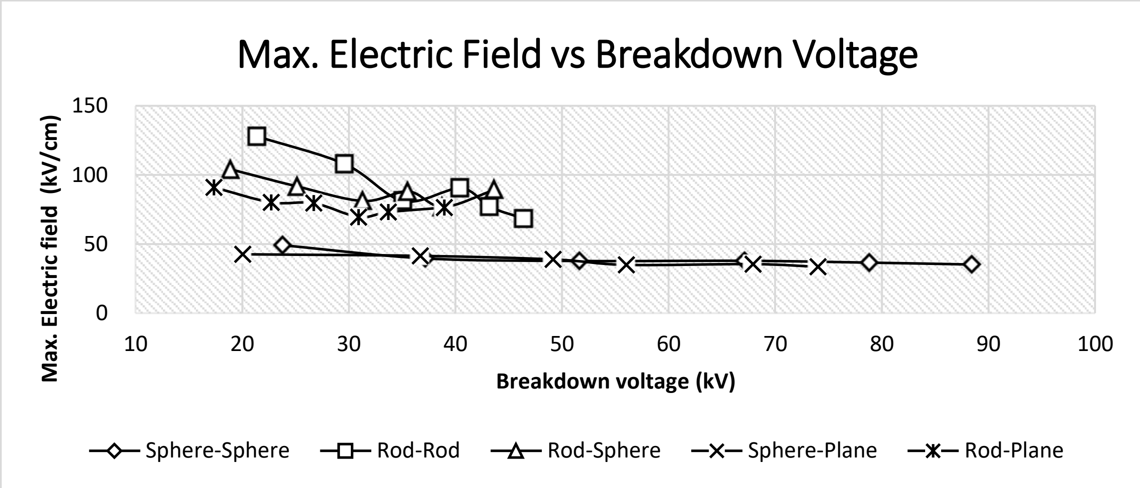


Figure 8: Maximum electric field against breakdown voltage

3.5 Relationship between field utilization factor against air gap distance

Based on Table 2 and Figure 9, the field utilization factor for each different electrode pair decreases with the increase in the gap distance. This field utilization factor is obtained from the calculation by using Eqn. (1). The range of obtained is from 0.17 to 0.97. Among all of the electrode pairs, the sphere-sphere electrode has the highest at each gap distance. The field utilization factor is related to the maximum electric field which is inversely proportional to the E_{max} the greater value of E_{max}, produces a lower field utilization factor. The field utilization factor also depends on the configuration of electrodes.

Table 2: Result of field utilization factor, η

d (cm)	Sphere-sphere	Rod-rod	Rod-sphere	Sphere-plane	Rod-plane
0.5	0.97	0.34	0.36	0.94	0.38
1.0	0.94	0.27	0.28	0.88	0.28
1.5	0.92	0.29	0.26	0.84	0.22
2.0	0.89	0.22	0.20	0.80	0.22
2.5	0.86	0.22	0.20	0.77	0.18
3.0	0.84	0.23	0.16	0.74	0.17

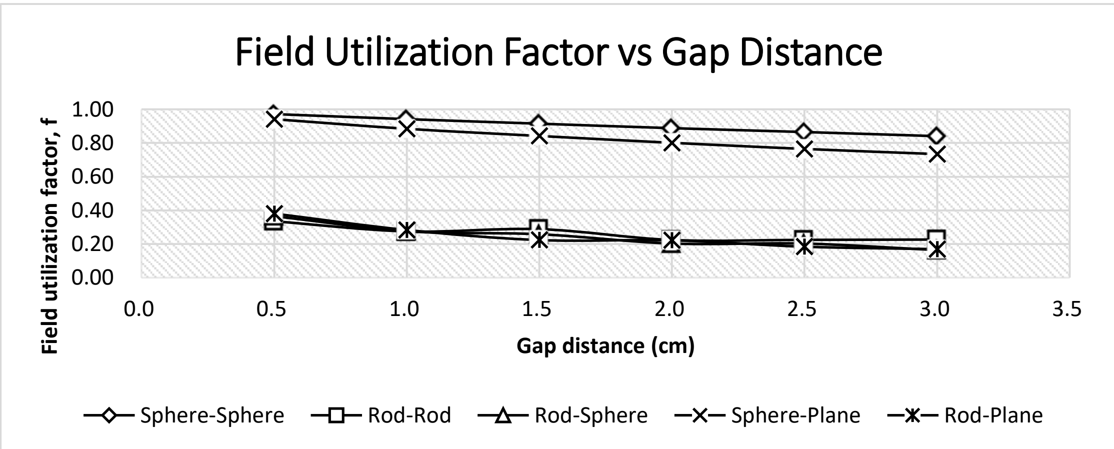


Figure 9: Field utilization factor against air gap distance

4. Conclusion

Based on the results that have been analysed, it is found that the sphere-sphere electrode is the best among the other electrode pairs. At 3.0 cm, the sphere-sphere electrode has 88.50 kV breakdown voltage, with 35.12 kV/cm of $E_{max}$and with the field utilization factor of 0.97. This is further amplified based on the result that it has the highest breakdown voltage for each different gap distance compared to others. The highest breakdown voltage, the lowest maximum electric field which in this case the sphere-sphere electrode does not have the lowest electric field but the rod-plane electrode does. The maximum electric field value influences the value of the field utilization factor for electrode pairs. The lowest maximum electric field will produce a high filed utilization factor based on Eq (1) which states the filed utilization factor is inversely proportional to the maximum electric field, E_{max}.

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References

[1] Subrata Karmakar, “An Experimental study of Air Breakdown Voltage and its Effects on Solid Insulation”, Journal of Electrical System, J.Electrical Systems 8-2(2012): 209-217, 2012.

[2] Asima Sabat, S Karmakar, “Simulation of Partial Discharge in High Voltage Power Equipment”, International Journal on Electrical Engineering and Informatics, Volume 3, Number 2, 2011.

[3] Webster, J.G. and Ahmed, A. (2017). Electric Power Generation and Transmission System. In Wiley Encyclopedia of Electrical and Electronics Engineering, J.G. Webster (Ed.). https://doi.org/10.1002/047134608X.W6134.pub2

[4] Sauoabh, Sexena, Maroof, Ali, Alok, Singh and Kapil Gandhi, “Various Types of Circuit Breakers used in Power System for Smooth Working of the Transmission line” MIT International Journal of Electrical and Instrumentation Engineering, Vol. 2, No.2, pp 106 – 111, 2012.

[5] Ben Finio, “Which Materials Conduct Electricity?”, Scientific American. Retrieved June 16, 2016. [Online] https://www.scientificamerican.com/article/which-materials-conduct-electricity/

[6] C. L. Wadhwa, “High Voltage Engineering”, published by New Age International (P) Limited, 2nd edition 2007.