Investigating, Analyzing and Improving of Electric Field and Voltage Distributions along 230 kV High Voltage Insulators

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Abstract – **High voltage insulators play an important role in electrical power systems in terms of energy transmission systems. It is use to separate or support the electrical conductor on high voltage electricity supply network. However, due to the coupling capacitance between the disc insulator and conductors, the voltage and electric field of the insulator will be uneven greatly; hence it may easily lead to corona, insulators' surface deterioration and even flashover. In this paper, several 230 kV insulator strings with different types of materials which are porcelain, glass and silicon rubber were simulated using SOLIDWORKS and EMS software and their electric fields and voltage distributions were calculated and compared together. Tower and conductor were included in all simulations and also the effect of number of discs along the insulator string on voltage distributions over insulator strings was investigated. All the methodology, simulation result and discussion will be discussed more in this paper.**

Keywords – Finite Element Method (FEM), Porcelain Insulator, Glass Insulator, Silicon Rubber Insulator, Electric Field and Voltage Distribution, Transmission Tower and Conductor

I. INTRODUCTION

Insulators are widely used in electrical power systems to provide electrical insulation property and mechanical support for overhead transmission lines and insulator strings are also very common due to their high mechanical strength, easy installation and operation, and low cost. Normally, transmission insulators are made of different materials such as polymers, glass, porcelain and etc. Different materials of high voltage insulator have different densities, tensile strengths and performing properties on the high voltage insulators.

Due to the coupling capacitance between the disc insulator and conductors, the voltage of the insulator will be uneven greatly. Furthermore, outdoor insulator with electric stress condition and weather conditions such as heat, fog, rain and etc also will affect the voltage distribution of the insulator. Therefore, it will cause the voltage disribution on the insulators is 3 to 5 times greater than others where this problem may cause insulator failure [1].

The main objective in this project is to investigate, analyze and improve the electric field and voltage distribution performance along the high voltage insulators. The objectives that need to be achieved for this research are:

- Design and modeling of high voltage insulator by using SOLIDWORKS 2017 in 2Dimensions and 3-Dimensions respectively.
- Design, investigate and analyze the electric field and voltage distributions along the high voltage insulators with and without the transmission tower and conductors respectively.
- Design, investigate and analyze the electric field and voltage distributions of three different types of materials which are porcelain insulators, glass insulators and silicon rubber insulators along the high voltage insulators respectively.
- Optimize a design to improve the performance of voltage distributions along the high voltage insulator.

Many studies and experiments have been investigated and carried out in terms of electric field and voltage distribution, effect of contamination level on flashover voltage (FOV), contamination level monitoring and etc. are documented under HVAC. As the development of power electronics devices and the load penetration has increased rapidly, nowadays, the HVDC technology is being considered for some long distance transmission lines. The advantages of HVDC are there are no (capacitive) charging currents, no stability problems (frequency), higher power transfer and high flexibility and controllability [2]. The main contributions and significances for this research project are identified as follows:

- To reduce the possibility of insulator failure by propose a optimize design of the high voltage insulator.

- To help the high voltage engineers to take care of the regions where the condition of the insulators (dry or wet condition) will affect the voltage distribution of insulators in terms of designing of high voltage insulators.
- n terms of electrical utilities, designers and engineers can choose the suitable devices dimensions and suitable materials that be used for insulators.

II. CONCEPT AND THEORIES

In electric power transmission system, insulators are among the important devices. This means that insulator can call as a very poor conductor. A material that ignore the formation of electric field and the electric charge is completely restricted just can call as a true insulator. From electrical and electronic point of view, the function of the insulators can be clearly seen. Also, supporting or separating electrical conductors without letting the current pass through themselves is their functions too.

1. Electric Field Distributions

The life and performance along the high voltage insulators will be affected by electric field distributions. The behaviour of electric field should be given the main consideration in the design process in order to improve the performance of electric field distributions along the insulators [4]. There are several methods to calculate electrical field distributions. However, it has been known that electric field calculation has been a complex issue. There are several reasons, such as lack of analytical methods due to complex geometry of the physical system, boundary conditions and intricate mathematical calculations. There are several ways which electric field calculation can be categorized are analytical, experimental, analogue methods and numerical methods.

A simple way for calculation of electric field distribution is calculating of electric potential distribution. After that, electric field distribution is calculated by minus the gradient of electric potential distribution. Due to electrostatic field distribution, the equation can be written as follows [5, 6]:

$$E = -\nabla V \qquad (1)$$

From Maxwell's equation:

$$\nabla E = \frac{\rho}{\varepsilon} \qquad (2)$$

where ρ is the resistivity Ω/m and ε is dielectric constant of dielectric material ($\varepsilon = \varepsilon_0\varepsilon_r$). ε_0 is air or space dielectric constant (8.854×10−12 F/m), ε_r is relative dielectric constant of dielectric material. Placing (1) in (2) would give Poisson's equation as shown as below:

$$\nabla\varepsilon\,\nabla V = -\rho \qquad (3)$$

Without space charge (ρ = 0), Poisson's equation becomes Laplace's equation as shown as below:

$$\nabla\varepsilon\,\nabla V = 0 \qquad (4)$$

And finally expansion of (4) for homogenous media in Cartesian coordinates is:

$$\frac{\partial^2 V}{\partial x^2} + \frac{\partial^2 V}{\partial y^2} + \frac{\partial^2 V}{\partial z^2} = 0 \qquad (5)$$

Besides that, calculation of the electric field distribution along insulators usually carried out on several numerical analysis methods which are Charge Simulation Method (CSM), Boundary Element Method (BEM), Finite Element Method (FEM) and Finite Difference Method (FDM). By comparing this 4 methods, FEM will be chosen in this paper.

FEM is calculated by using Maxwell's equations in the differential form, it is a solution of numerical method of FEM [7]. Dividing the entire problem space including the surrounding region into a number of non-separated called finite elements are the basic features of FEM. This process is called meshing. These finite elements can take a number of shapes. But generally for triangles are used for 2D analysis and tetrahedron for 3D analysis. The advantage of FEM is it is well suited to problems with complicated geometry. Furthermore, FEM can be simulating if the problem is with irregular geometric matching. However, the disadvantage of FEM is mass conversion of this method. Furthermore, the complex code structure of the FEM was more than FDM [8, 9].

2. Voltage Distributions

As mentioned before voltage and electric field distribution of insulator string is uneven because of the effects of stray capacitive currents. This phenomenon can lead to corona discharge on insulator surface and therefore should be considered before insulator usage. The uniformity degree of voltage distribution depends on insulator unit capacitance, the number of units, cross-arm length and corona ring parameters.

String efficiency (η) is used to determine the level of uniformity of voltage distribution of insulator string. The formula is:

$$\eta = \frac{V}{n \times V_{max}} \times 100\% \qquad (6)$$

where V is the line voltage that across over the insulator strings; Vmax is the maximum voltage that drops on single discs that across the insulator strings; n is the number of discs used along the insulator string; ηis the percentage of string efficiency that across the insulator strings [10].

However, when there are many units in the string of the insulator, the calculation will become very complicated and tedious. Hence, following equation as shown as below can be used.

$$V_x = \frac{2\sinh\left(\frac{\sqrt{k}}{2}\right)\cosh\left[\sqrt{k}\left(n - x + \frac{1}{2}\right)\right]}{\sinh\left(n\sqrt{k}\right)} \times V \qquad (7)$$

where Vx = Voltage across the xth unit; V = Voltage across the string; K = Ratio of shunt to mutual capacitance; N = number of units in the string [11].

For better studying of voltage distributions along the high voltage insulator, all the values of the voltages along the high voltage insulator can be normalized as shown as equation below:

$$\%V_n = \frac{V_n}{(V/\sqrt{3})} \times 100\% \qquad (8)$$

where Vn is the voltage of n-th unit of the insulator; V is the line voltage that across over the insulator strings (230 kV) %Vn is the normalized voltage of the same unit in % [12].

III. SYSTEM DESIGNS AND CONFIGURATIONS

1. Systems Designs (SOLIDWORKS Software)

As this project is mainly focused on the high voltage insulator, hence the model of the insulator has to be developed. The designs of high voltage insulator in 2-Dimensions and 3-Dimensions are shown as figure below respectively:

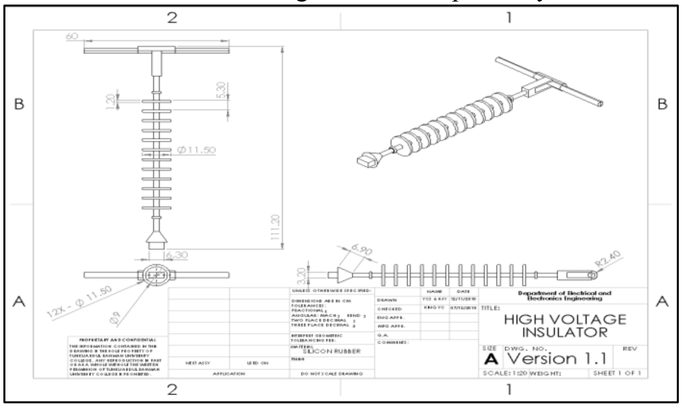

Figure 1: High Voltage Insulator (2D Drawing)

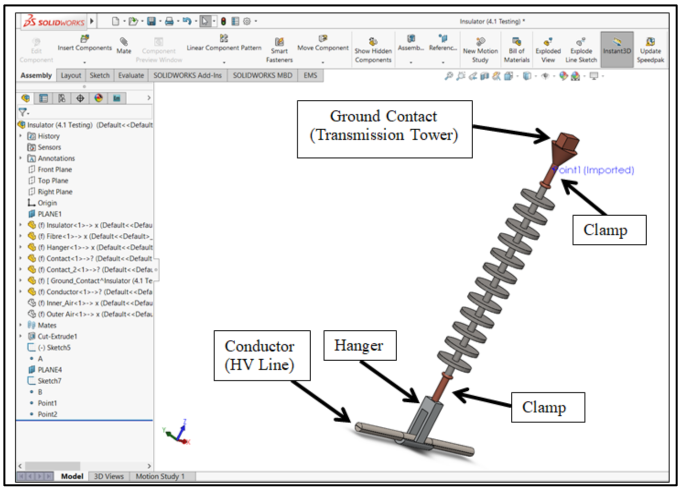

Figure 2: High Voltage Insulator (3D Drawing)

2. System Configurations (EMS Software)

After the high voltage insulator has been designed, some configurations that need to make for the insulator in order to perform the simulation and analysis in more authentic and more accurate. The configurations of the insulator can be done by using EMS (Electromagnetic and Electromechanical Simulations) software. This software is fully integrated in SOLIDWORKS 2017.

Since this project was mainly focused on voltage distributions analysis, hence electrostatic problem is chosen from the EMS Manager Tab. The solution parameter will be taken as default and recommended type which is Multi-Core Iterative Solver Type with normal accuracy. Next, the insulator has to be assigned some of the materials based on the parameters below:
Note: R.P stands for Relative Permittivity and its Permittivity Type is Isotropic

Material	R.P	Conductivity (S/m)	Thermal Conductivity (W/m.K)	Dielectric Strength (V/mm)
Copper	1	5.70×10^7	3.85×10^2	0
Fiberglass	5.5	0	0	2.50×10^8
Aluminum	1	3.82×10^7	2.50×10^2	0
Air	1	0	2.40×10^2	3.00×10^6

Table 1: Parameters of materials for the components

After that, applying fixed voltage which is 230 kV for the highvoltage insulator and the last step is the most important steps which is mesh control and mesh create. Meshing on high voltage insulator is a very important and crucial method in designing procedure. EMS will generate a mesh on the insulator based on its global element size, tolerance and local mesh control specifications. Furthermore, user can specify different sizes of elements for components. The element size can be specified very large to obtain a faster solution. However, it will not very accurate. To obtain an accurate solution, the element size has to be smaller and thus the time for the software to solve the solution is very slow and it is often suggested. After creating the mesh, the insulator can be simulated and analyzed.

IV. EFFECTS OF TRANSMISSION TOWER AND CONDUCTOR

This section will be mainly focused to investigate the effects of transmission tower and conductors for the high voltage insulator in terms of electric field and voltage distributions. The insulator will be designed in two cases. One is the high voltage insulator with the presence of transmission tower and conductors and another case is the high voltage insulator without the presence of transmission tower and conductors. The electric field and voltage distributions along the high voltage insulators in these two cases will be observed and analyzed.

1. Insulator Designs

The designs of the high voltage insulator with the transmission tower and conductor and the high voltage insulator without the transmission tower and conductor are shown as figure below respectively. Assume the high voltage insulator used is silicon rubber insulator.

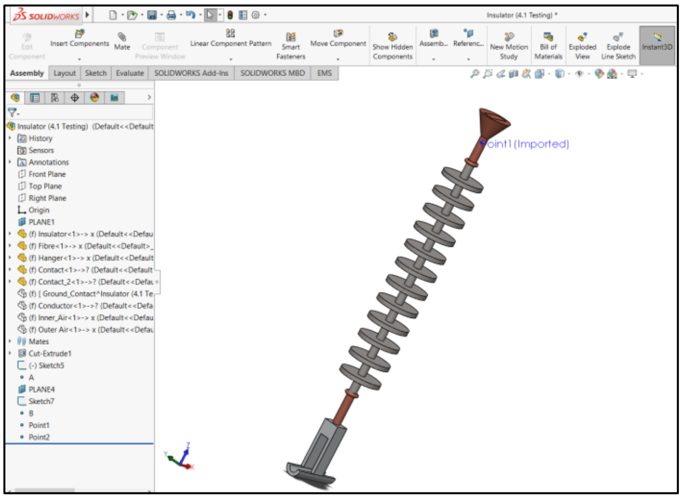

Figure 3: High Voltage Insulator without Transmission Tower and Conductor

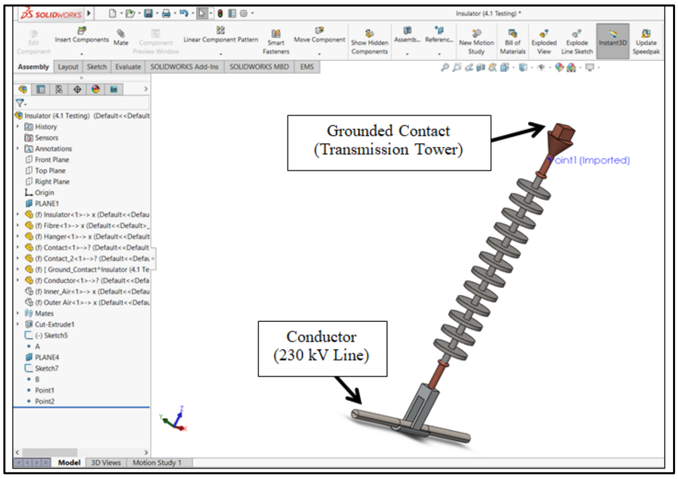

Figure 4: High Voltage Insulator with Transmission Tower and Conductor

2. Electric Field Distributions (Results & Analysis)

2.1 Without Transmission Tower and Conductor

The results of the insulator that without transmission tower and conductor in terms of electric field distributions are shown as figure below respectively.

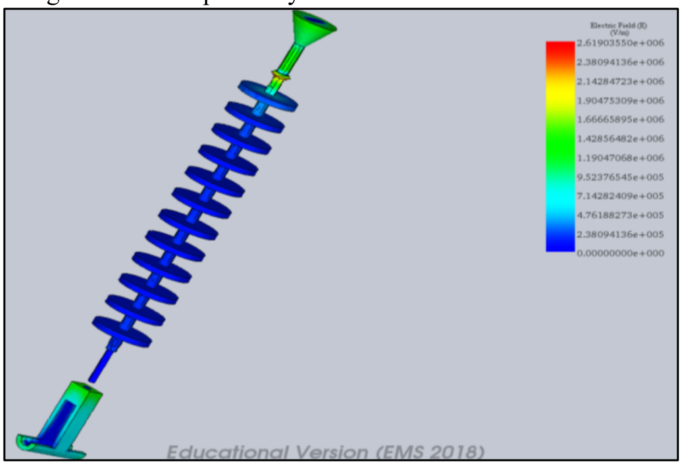

Figure 5: 3-D Fringe Plot (without transmission tower and conductor)

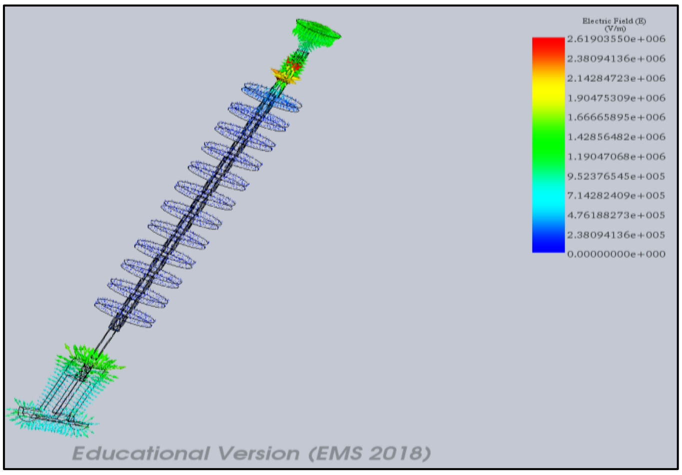

Figure 6: 3-D Vector Plot (without transmission tower and conductor)

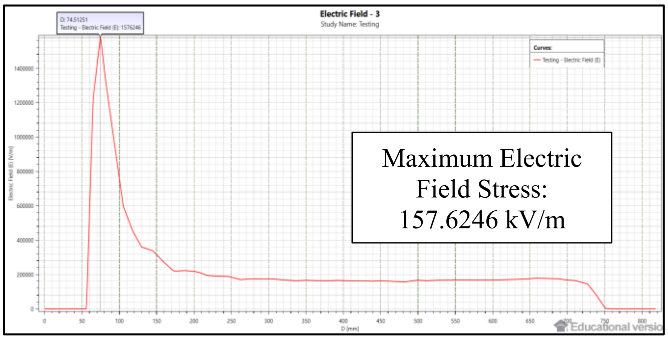

Figure 7: 2-D Graph Plot (without transmission tower and conductor)

The graph above shows that the electric field increases until the peak value and then drop again to its initial value. This is because the insulator is not connected to the transmission line and conductor. This can be seen from the model of three dimensional line plot. At that figure, there is a gap between the insulator with the transmission line, so there is no connection of electric field between them.

2.2 With Transmission Tower and Conductor

The results of the insulator that with the transmission tower and conductor in terms of electric field distributions are shown as figure below respectively.

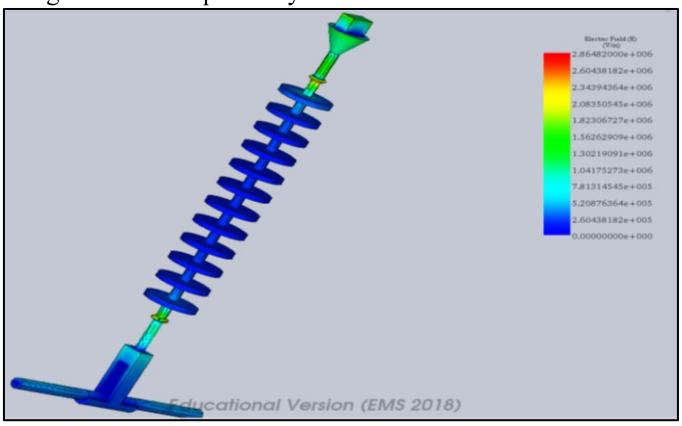

Figure 8: 3-D Fringe Plot (with transmission tower and conductor)

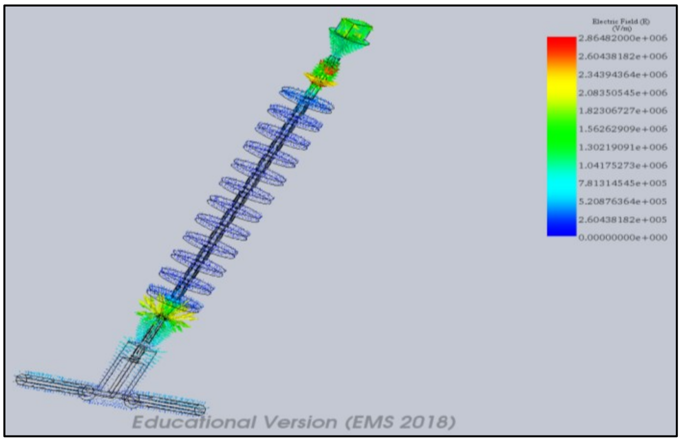

Figure 9: 3-D Fringe Plot (with transmission tower and conductor)

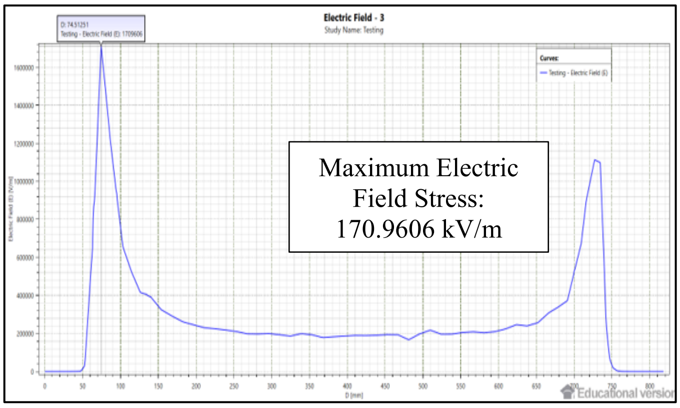

Figure 10: 2-D Graph Plot (with transmission tower and conductor)

The graph above shows that the electric field increases until the peak value and constant for a while. After that, the electric field increases to the peak value again and then drop to its initial value. This is because the insulator is fully connected to the transmission line and conductor. This can be seen from the model of three dimensional line plot. At that figure, there is a fully connection between the insulator with the transmission line, so the electric field will flow from the transmission line and conductor to the insulator.

2.3 Depth of analysis (Justifications)

From the graph above, the electrical field stress will be very high and then reduces to a constant value when the insulator is start operates. This is the insulator itself have mutual capacitance and shunt capacitance. The capacitor will store the current and startly current will be very high then only it will reduces rapidly. However, as the starting electric field is very high, it will have a chance to break the insulator. Hence, improvement need to be made in order to solve this problem. From this experiment, insulator with transmission line and conductor is the best choice. In another words, insulator with transmission line and conductor which means in three dimensional form while insulator without transmission line and conductor is two dimensional form. Two dimensional form is not suitable for simulation as the anlayzing result of electric field will less accurate.

3. Voltage Distributions (Results & Analysis)

3.1 Without Transmission Tower and Conductor

The results of the insulator that without transmission tower and conductor in terms of voltage distributions are shown as figure below respectively.

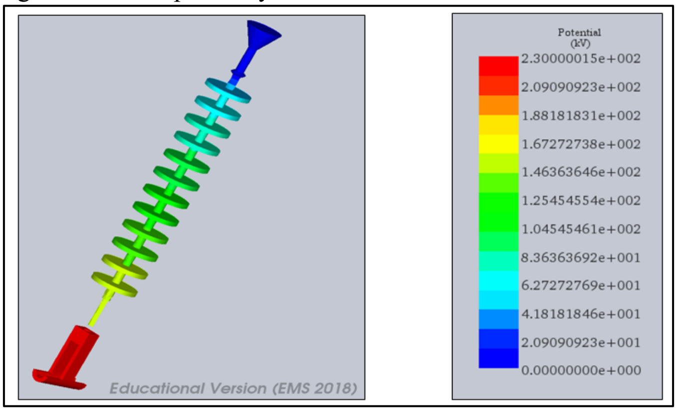

Figure 11: 3-D Fringe Plot (without transmmission tower and conductor)

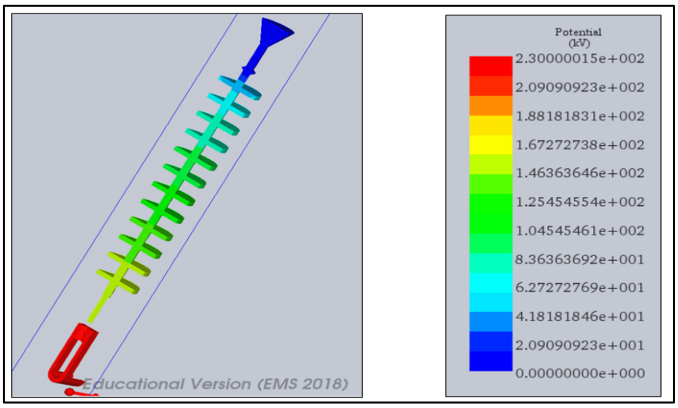

Figure 12: 3-D Section Clipping Fringe Plot (without transmission tower and conductor)

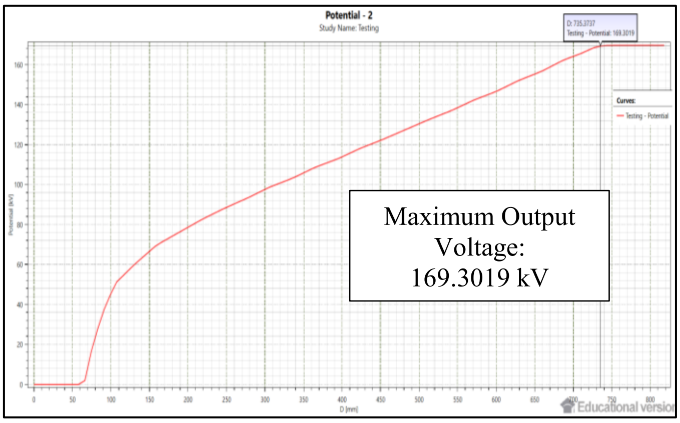

Figure 13: 2-D Graph Plot (witout transmission tower and conductor)

For the insulator that without the conductor and transmission tower, even though that the input voltage is 230 kV, however, the maximum output voltage is only 169.3019 V. This is because without the conductor and transmission tower, there will be some voltage and current loss towards the air and this also will cause some disturbance of electric field and it might lead to insulator failure.

In terms of string efficiency, the voltage that drops on single discs that across the insulator strings have to determined. All the readings for each voltage of the insulator discs without the transmission tower and conductors are recorded as shown as table below:

Location of discs (n)	Voltage Distributions (kV)
1^{st}	67.85
2^{nd}	9.20
3^{rd}	9.20
4^{th}	9.20
5^{th}	8.05
6^{th}	8.05
7^{th}	9.20
8^{th}	9.20
9^{th}	9.20
10^{th}	9.20
11^{th}	12.65
12^{th}	19.55

Table 2: Voltage distributions drops across the insulator strings (without transmission tower and conductor)

From the above readings, the string efficiency of the insulator string is determined by using Equation (6) as shown as below:

$$\eta = \frac{230k}{12 \times 67.85k} \times 100\%$$

$$\eta = 28.25\%$$

It can be shown that the insulator that without the transmission tower and conductor has the ability that can withstand from being breakdown is 28.25%.

3.2 With Transmission Tower and Conductor

The results of the insulator that with the transmission tower and conductor in terms of voltage distributions are shown as figure below respectively.

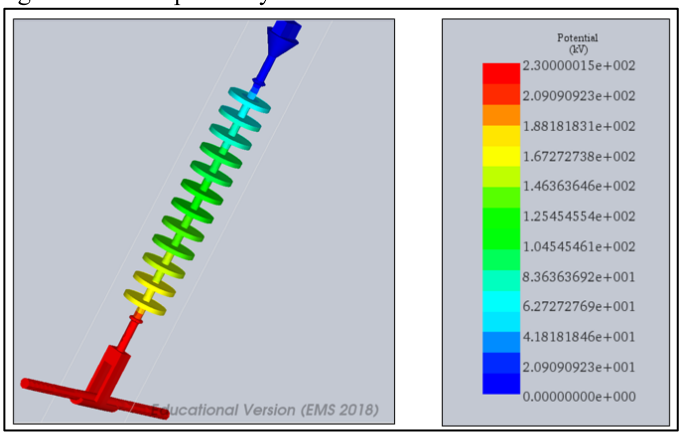

Figure 14: 3-D Fringe Plot (with transmmission tower and conductor)

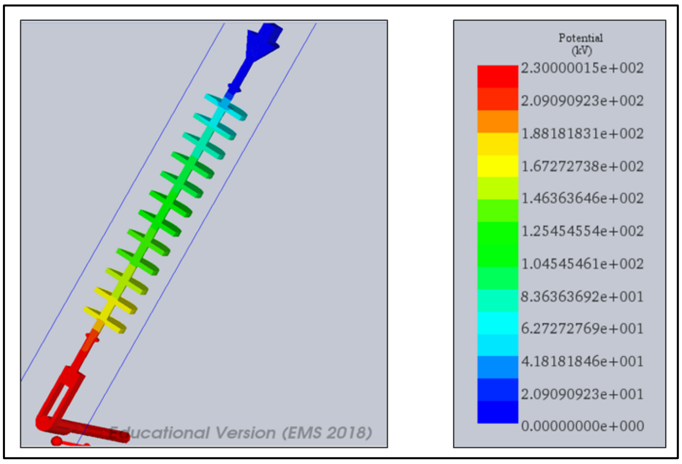

Figure 15: 3-D Section Clippig Fringe Plot (with transmmission tower and conductor)

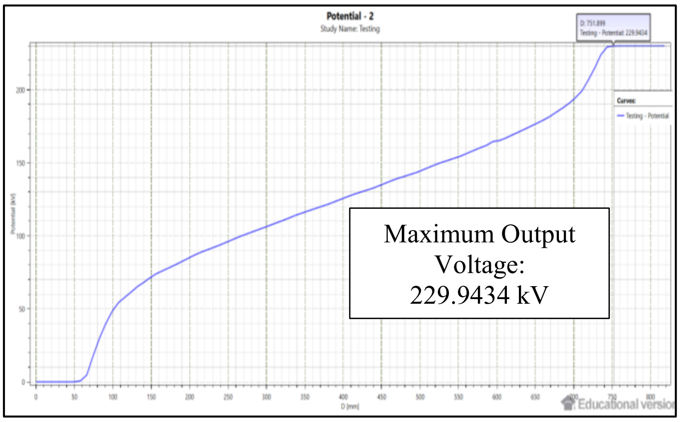

Figure 16: 2-D Graph Plot (with tranmission tower and conductor)

The maximum output voltage, Vmax for the insulator that connected with the conductor and transmission tower is 229.9434 V. Hence, the operating voltage is working normally on the insulator with the transmission tower and conductor.

In terms of string efficiency, the voltage that drops on single discs that across the insulator strings have to determined same with the previous method. All the readings for each voltage of the insulator discs that with the transmission tower and conductors are recorded as shown as table below:

Location of discs (n)	Voltage Distributions (kV)
1^{st}	43.70
2^{nd}	14.95
3^{rd}	11.50
4^{th}	10.35
5^{th}	10.35
6^{th}	10.35
7^{th}	10.35
8^{th}	10.35
9^{th}	10.35
10^{th}	10.35
11^{th}	12.65
12^{th}	13.90

Table 3: Voltage distributions drops across the insulator strings (with transmission tower and conductor)

From the above readings, the string efficiency of the insulator string is determined by using Equation (6) as shown as below:

$$\eta = \frac{230k}{12 \times 42.55k} \times 100\%$$

$$\eta = 45.05\%$$

It can be shown that the insulator that with the transmission tower and conductor has the ability that can withstand from being breakdown is 45.05%.

3.3 Depth of Analysis (Justifications)

Comparing the two cases efficiency of insulator strings above, it can be seen that the efficiency of insulator string with the conductor and transmission tower (η = 45.05%) is higher than the insulator string without the conductor and transmission tower (η = 28.25%).

The voltage distributions along the high voltage insulator can be normalized in order to better studying by using Equation (8). All the data had been recorded as shown as table below:

Location of discs (n)	Voltage Distributions (kV)	Normalized Voltage Distributions (%)
1st	42.55	32.91
2nd	14.95	11.26
3rd	11.50	8.66
4th	10.35	7.79
5th	10.35	7.79
6th	10.35	7.79
7th	10.35	7.79
8th	10.35	7.79
9th	10.35	7.79
10th	10.35	7.79
11th	12.65	9.53
12th	13.90	10.47

Table 4: Normalized Voltage Distributions and Voltage Distributions across the high voltage insulators with conductor and transmission Tower

Location of discs (n)	Voltage Distributions (kV)	Normalized Voltage Distributions (%)
1st	67.85	51.10
2nd	9.20	6.90
3rd	9.20	6.90
4th	9.20	6.90
5th	8.05	6.10
6th	8.05	6.10
7th	9.20	6.90
8th	9.20	6.90
9th	9.20	6.90
10th	9.20	6.90
11th	12.65	9.53
12th	19.55	14.72

Table 5: Normalized Voltage Distributions and Voltage Distributions across the high voltage insulators without conductor and transmission Tower

All the data recorded was plotted in a graph as shown as figure below:

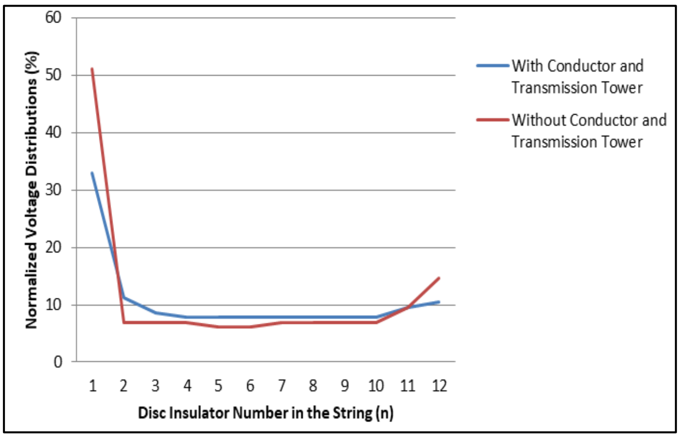

Figure 17: Graph of Normalized Voltage Distributions against Disc Insulator Number in the String

From the plotted graph above, it can be seen that the 1st disc insulator in the string with the conductor and transmission tower is only sustained 32.91% of the applied voltage. However, for the insulator that without the conductor and transmission tower, the 1st disc insulator in the string has to sustain about 51.10% of the applied voltage. As a summary, the different between the two scenarios was too high and hence it is to conclude that the insulator that without the conductor and the transmission tower was not suitable to use for simulations [13]. Therefore, an insulator model of conductor and transmission tower with the dimensions that stated at the previous chapter will be included in the next simulations.

V. EFFECTS OF TYPES OF INSULATOR UNITS

This section will be mainly focused to investigate the effects of voltage distributions for different types of high voltage insulators. There are 3 types of high voltage insulators that will be performed the simulation in this project which are porcelain insulators, glass insulators and silicon rubber insulators. All the voltage distributions along these 3 different types of high voltage insulators will be observed and analyzed.

1. Parameters of Insulators and Designs

All the parameters of the material and the design of insulator model in terms of porcelain insulators, glass insulators and silicon rubber insulators are shown as table and figure below respectively.

Note: R.P stands for Relative Permittivity and its Permittivity Type is Isotropic

Material	R.P	Conductivity (S/m)	Thermal Conductivity (W/m.K)	Dielectric Strength (V/mm)
Porcelain	3.78	0	0	8.00×10^6
Glass	7.50	0	0	3.00×10^7
Silicon Rubber	4	0	0	2.50×10^7

Table 6: Parameters of materials

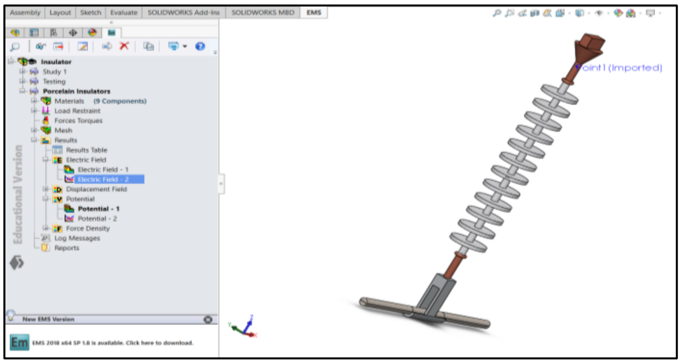

Figure 18: Insulator Design (Porcelain Insulator)

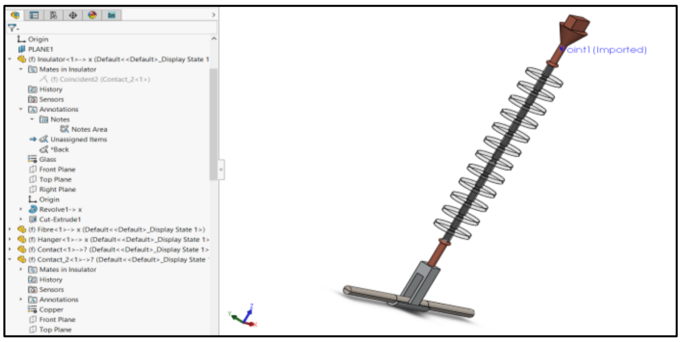

Figure 19: Insulator Design (Glass Insulator)

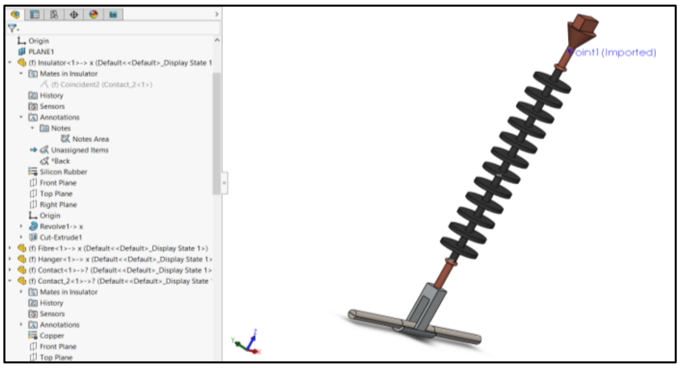

Figure 20: Insulator Design (Silicon Rubber Insulator)

2. Electric Field Distributions (Results & Analysis)

2.1 Porcelain Insulators

The results of the porcelain insulators in terms of electric field distributions are shown as figure below respectively.

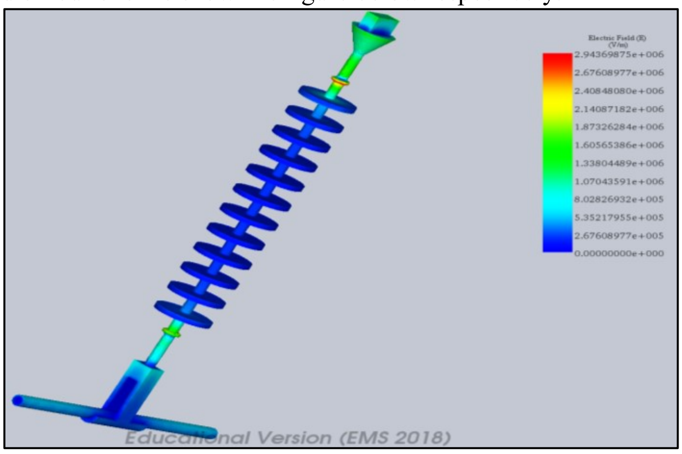

Figure 21: 3-D Fringe Plot (Porcelain Insulator)

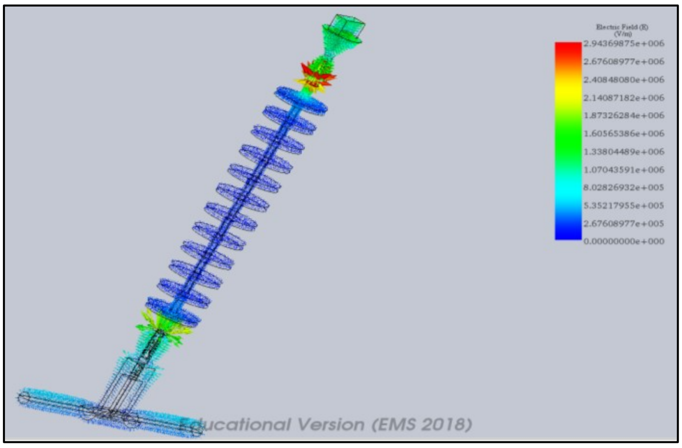

Figure 22: 3-D Vector Plot (Porcelain Insulator)

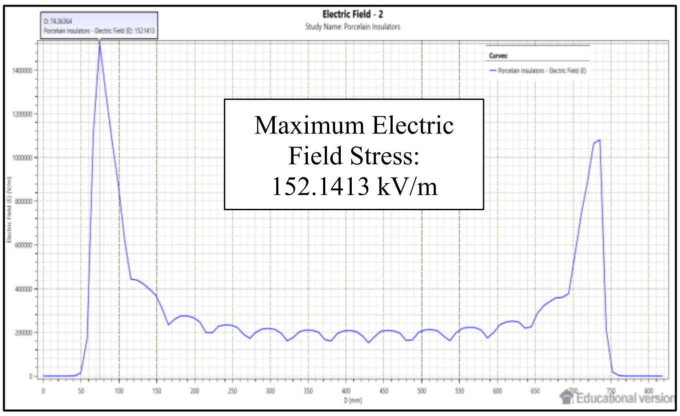

Figure 23: 2-D Graph Plot (Porcelain Insulator)

2.2 Glass Insulators

The results of the glass insulators in terms of electric field distributions are shown as figure below respectively.

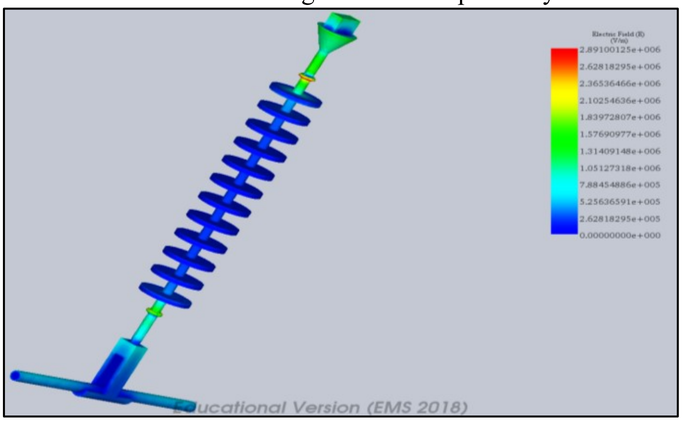

Figure 24: 3-D Fringe Plot (Glass Insulator)

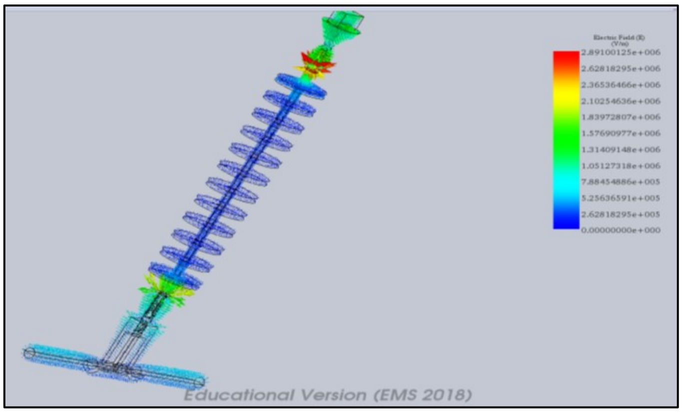

Figure 25: 3-D Vector Plot (Glass Insulator)

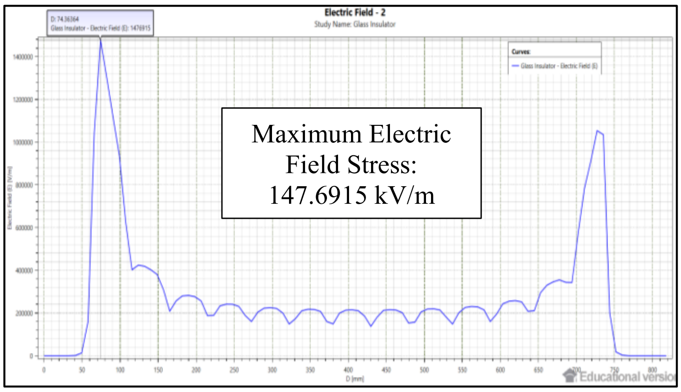

Figure 26: 2-D Graph Plot (Glass Insulator)

2.3 Silicon Rubber Insulators

The results of the porcelain insulators in terms of electric field distributions are shown as figure below respectively.

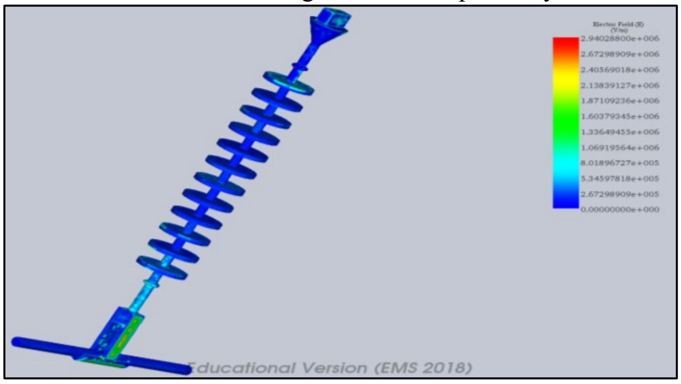

Figure 27: 3-D Fringe Plot (Silicon Rubber Insulator)

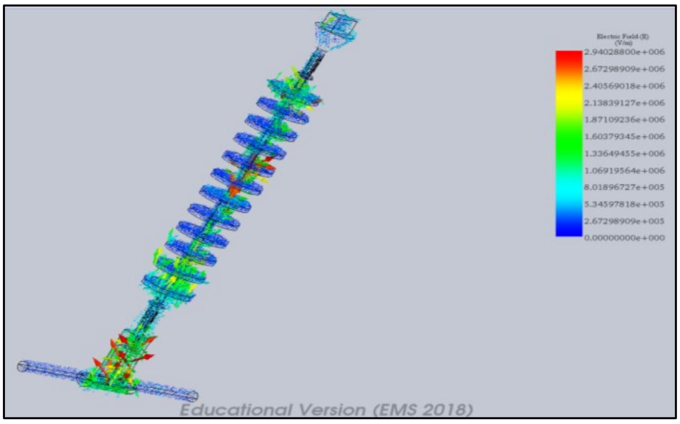

Figure 28: 3-D Vector Plot (Silicon Rubber Insulator)

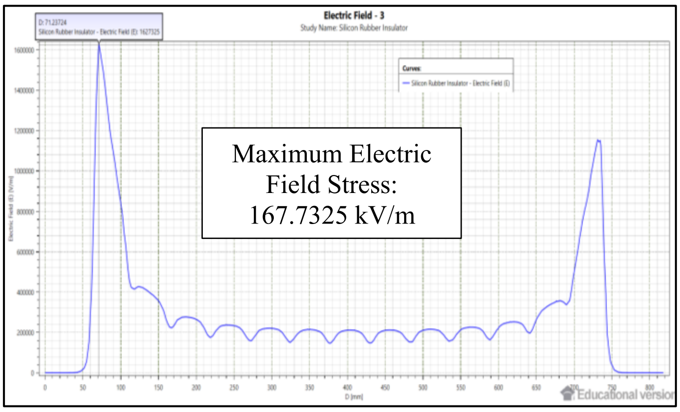

Figure 29: 2-D Graph Plot (Silicon Rubber Insulator)

2.4 Analysis & Discussions

From the above results, it can be seen that the maximum electric field stress for the glass insulator is the most lowest one (147.6915 kV/m) compared to porcelain insulator (152.1413 kV/m) and silicon rubber insulator (167.7325 kV/m). It is to deduced that the silicon rubber insulator is not suitable for use as the electric field stress is too high. It will have a chance to cause insulator failure.

As a conclusion, the lower the maximum electrical field stress, the lower the probability the breakdown to happen. In this case, the glass insulator having the lowest maximum electrical stress. However, nowadays porcelain insulators are more preferable than the glass insulator. This is because glass insulators cannot be cast in irregular shapes when operated in high voltage due to irregular cooling internal strains are caused and it is fragile [14]. Due to this disadvantages, glass insulator are less frequently used compared to porcelain insulators. By this, it is more preferable to choose as this insulator as it can be vulnerable for damage and subsequent breakdown. Consequently, it can be long-lasting.

3. Voltage Distributions (Results & Analysis)

3.1 Porcelain Insulators

The results of the porcelain insulators in terms of voltage distributions are shown as figure below respectively.

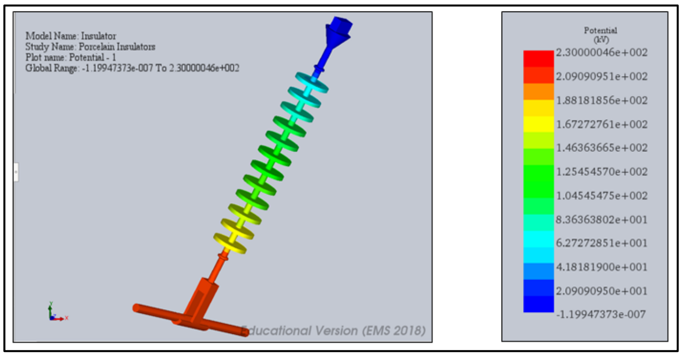

Figure 30: 3-D Fringe Plot (Porcelain Insulator)

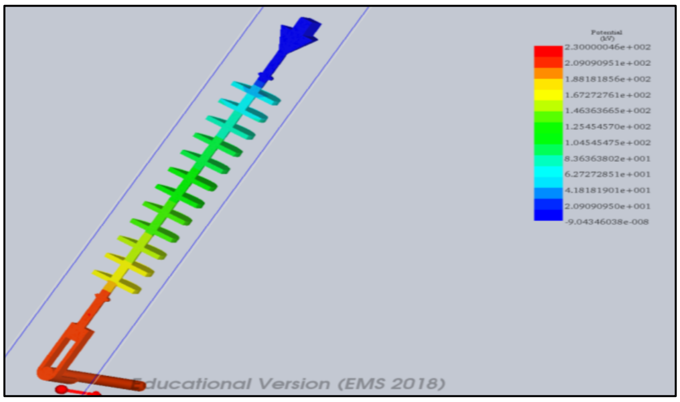

Figure 31: 3-D Section Clipping Fringe Plot (Porcelain Insulator)

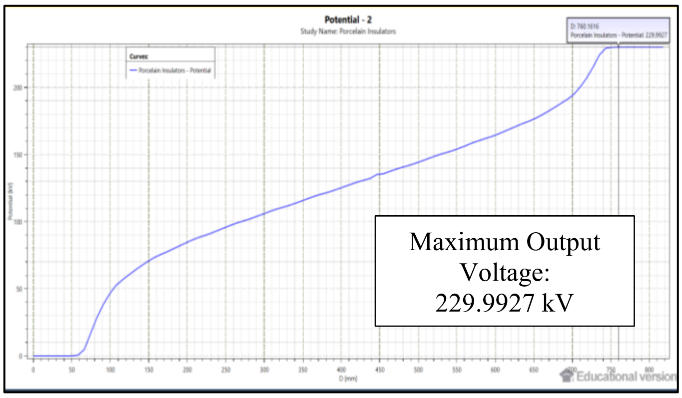

Figure 32: 2-D Graph Plot (Porcelain Insulator)

3.2 Glass Insulator

The results of the glass insulators in terms of voltage distributions are shown as figure below respectively.

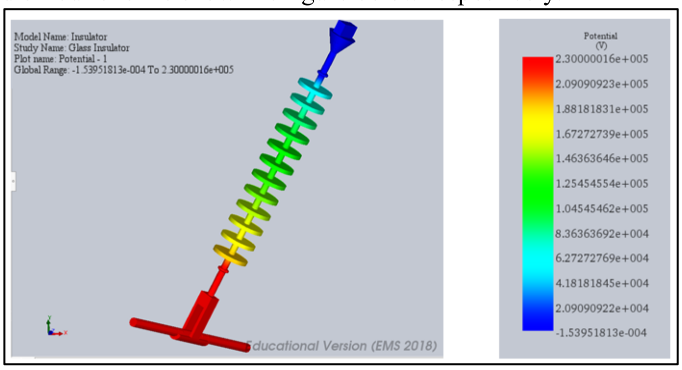

Figure 33: 3-D Fringe Plot (Glass Insulator)

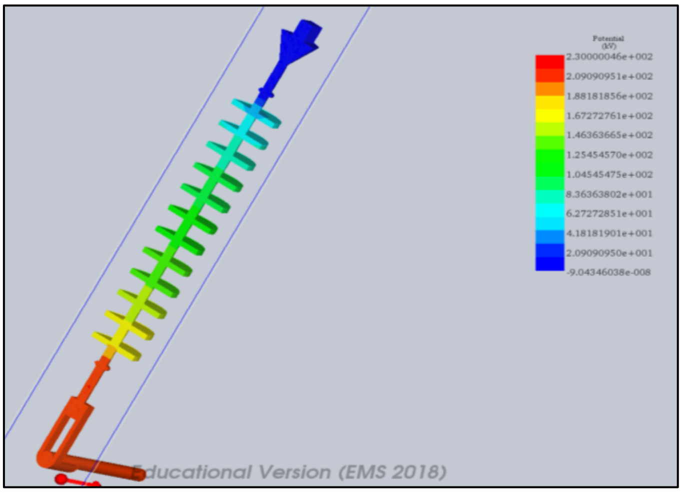

Figure 34: 3-D Section Clipping Fringe Plot (Glass Insulator)

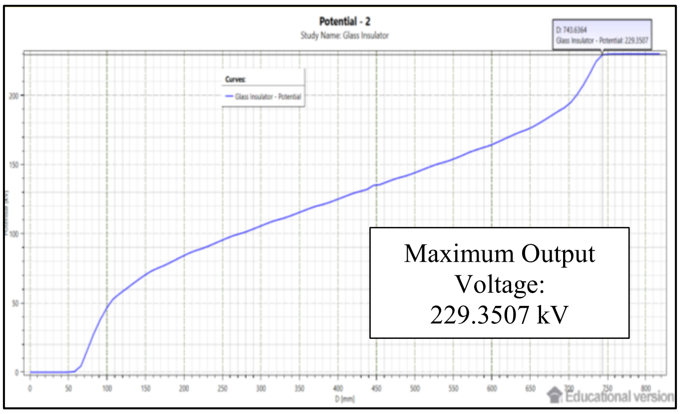

Figure 35: 2-D Graph Plot (Glass Insulator)

3.3 Silicon Rubber Insulator

The results of the silicon rubber insulators in terms of voltage distributions are shown as figure below respectively.

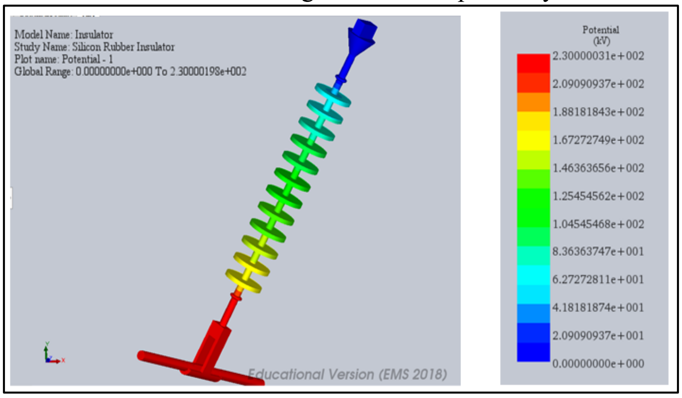

Figure 36: 3-D Fringe Plot (Silicon Rubber Insulator)

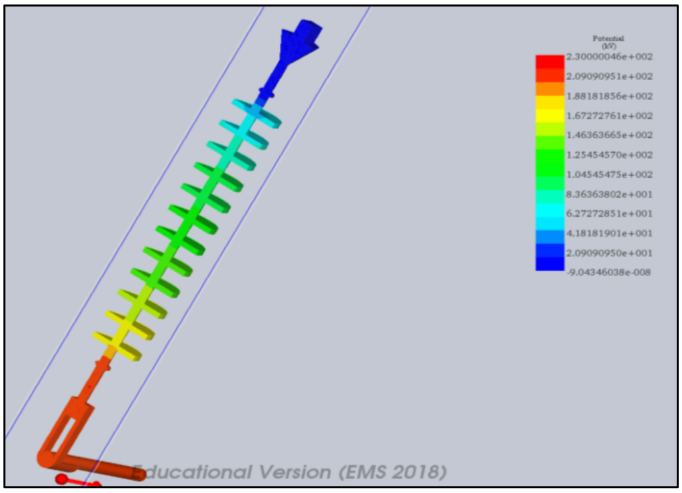

Figure 37: 3-D Section Clipping Fringe Plot (Silicon Rubber Insulator)

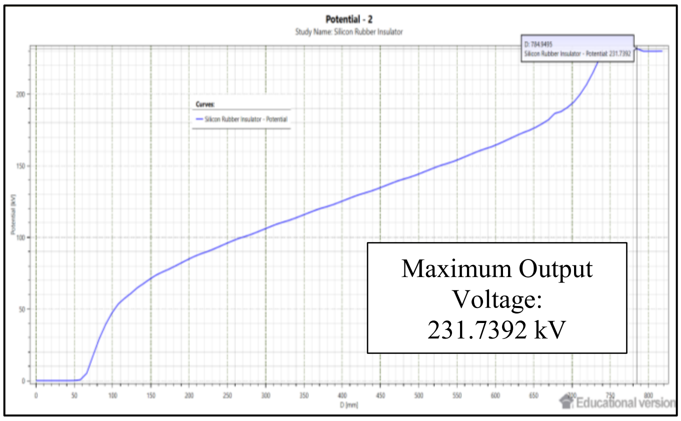

Figure 38: 2-D Graph Plot (Silicon Rubber Insulator)

3.4 Analysis & Discussions

From all the results that obtained above, it can be seen that the maximum output voltage for all 3 different types of high voltage insulator is almost the same. The only difference is that the maximum output voltage occurs along the 3 different types of insulator is the length of the insulator. For porcelain insulator, the maximum output voltage occurs at the length of 760.1616 mm with a voltage of 229.9297 V. For glass insulator, the maximum output voltage occurs at the length of 743.6364 mm with a voltage of 229.3507 V. Lastly, for silicon rubber insulator, the maximum output voltage occurs at the length of 784.9495 mm.

In terms of string efficiency, all the voltage distributions across the 3 different types of insulator strings are almost same with each other. Hence, all 3 different types of high voltage insulator (porcelain insulator, glass insulator & silicon rubber insulator) have the same value of efficiency as stated as previous section (η = 45.05%).

As a conclusion, the voltage distributions along 3 different types of high voltage insulators (porcelain insulators, glass insulators & silicon rubber insulators) are almost the same with each other. Hence, it can be deduced that different types of high voltage insulator will not affect the voltage distributions along the high voltage insulator [15]. Although there is no effect of voltage distributions, however, there will be effect on electric field distributions along the high voltage insulators. This is because different types of materials have different parameters in terms of relative permittivity, conductivity, dielectric strength and etc.

VI. EFFECTS OF NUMBER OF DISC UNITS IN THE INSULATOR STRING

For this section, it will be mainly focused on the voltage distributions along the high voltage insulator with different number of disc units in the insulator string. From the previous chapter, the number of disc units in the insulator string is 12, however, in this chapter, the number of disc units in the insulator string will be modified as 10, 8 and 6. The voltage distributions that across the high voltage insulator with 12, 10, 8 and 6 disc units (n) in the insulator string will be observed and analyzed. The material for the high voltage insulator that will be used is silicon rubber insulator.

1. Insulator Design

The model design of the insulator with 12, 10, 8 and 6 discs units (n) in the insulator string are shown as figure below respectively.

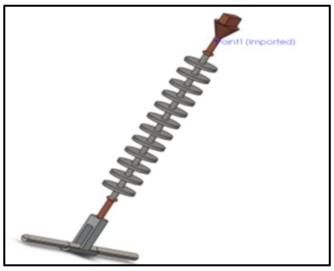

Figure 39: Insulator with 12 discs

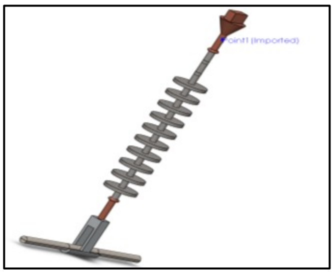

Figure 40: Insulator with 10 discs

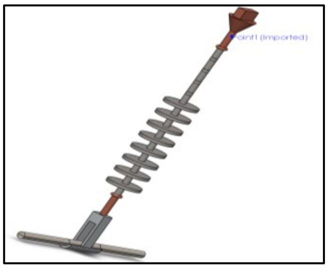

Figure 41: Insulator with 8 discs

Figure 42: Insulator with 6 discs

2. Voltage Distributions (Results & Analysis)

2.1 Insulator Discs Units = 12

The simulation testing and results of voltage distribution along the high voltage insulator with 12 discs units are shown as figure below respectively.

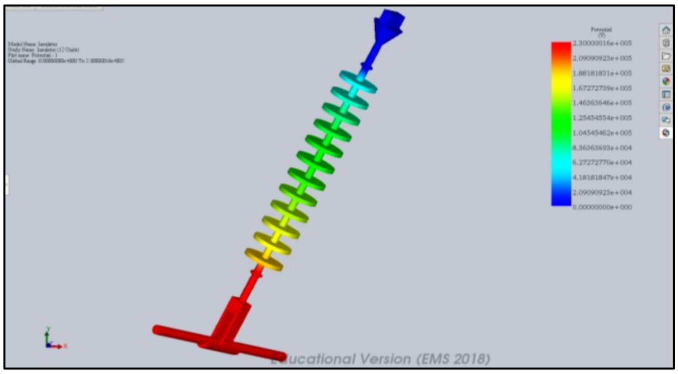

Figure 43: 3-D Fringe Plot (n = 12)

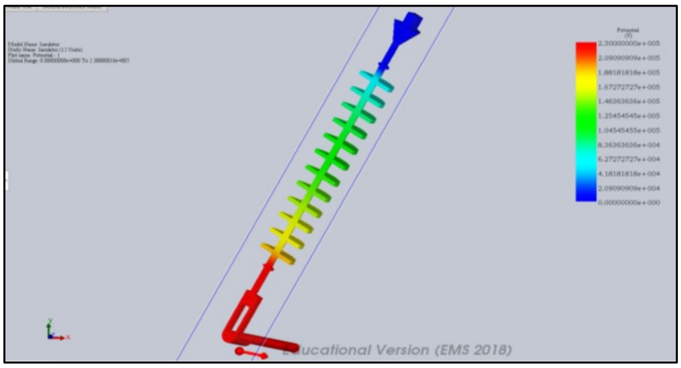

Figure 44: 3-D Section Clipping Fringe Plot (n = 12)

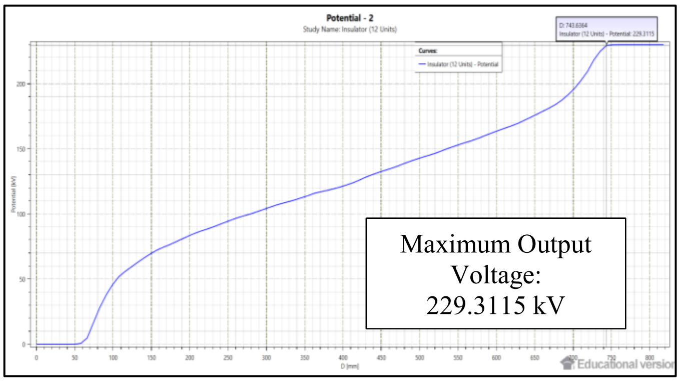

Figure 45: 2-D Graph Plot (n = 12)

2.2 Insulator Discs Units = 10

The simulation testing and results of voltage distribution along the high voltage insulator with 10 discs units are shown as figure below respectively.

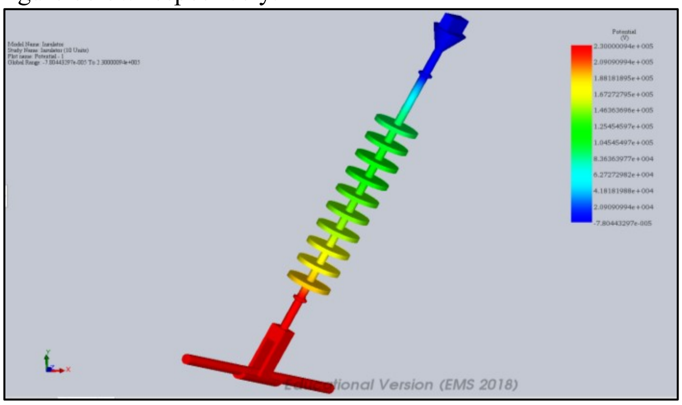

Figure 46: 3-D Fringe Plot (n = 12)

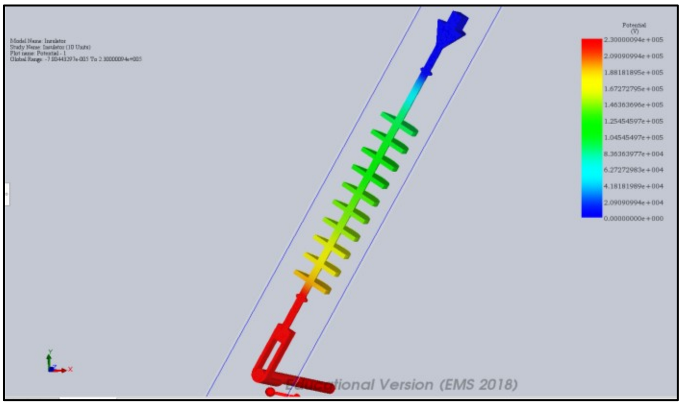

Figure 47: 3-D Section Clipping Fringe Plot (n = 10)

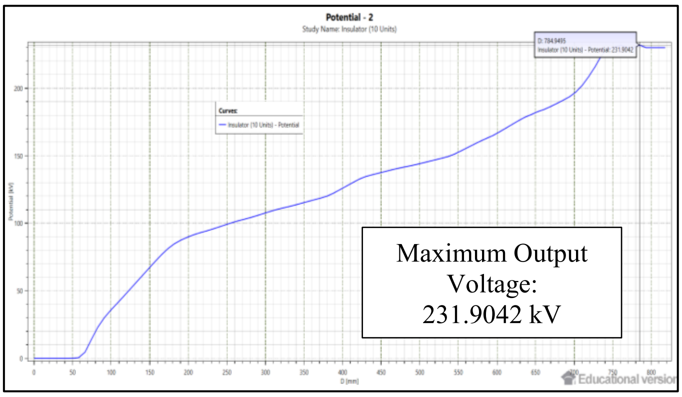

Figure 48: 2-D Graph Plot (n = 10)

2.3 Insulator Discs Units = 8

The simulation testing and results of voltage distribution along the high voltage insulator with 8 discs units are shown as figure below respectively.

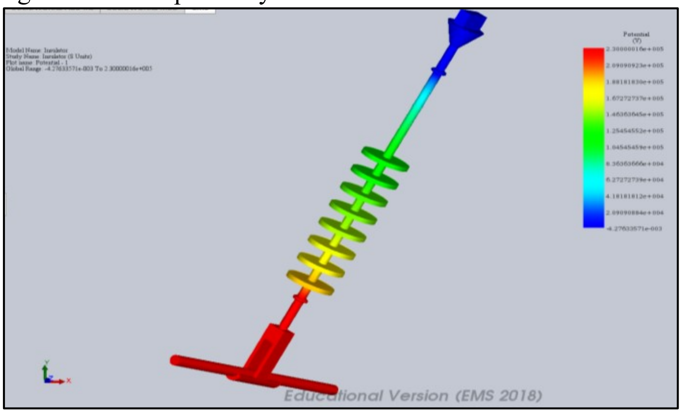

Figure 49: 3-D Fringe Plot (n = 8)

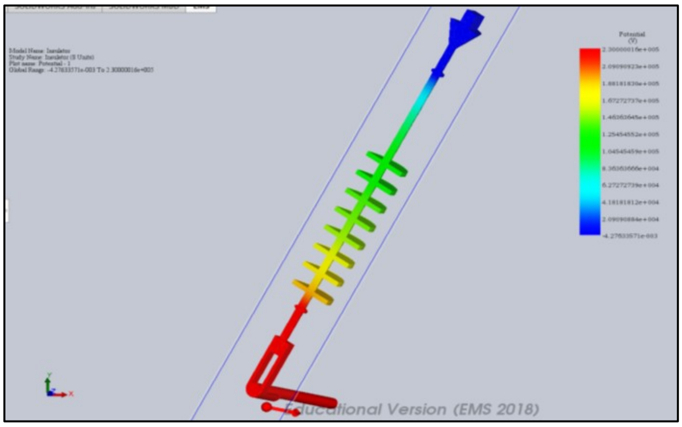

Figure 50: 3-D Section Clipping Fringe Plot (n = 8)

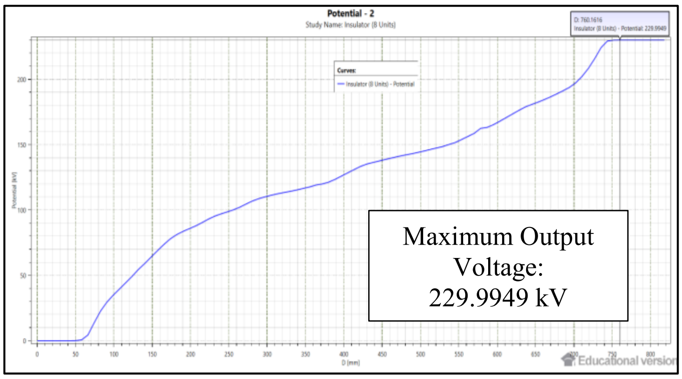

Figure 51: 2-D Graph Plot (n = 8)

2.4 *Insulator Discs Units = 6*

The simulation testing and results of voltage distribution along the high voltage insulator with 6 discs units are shown as figure below respectively.

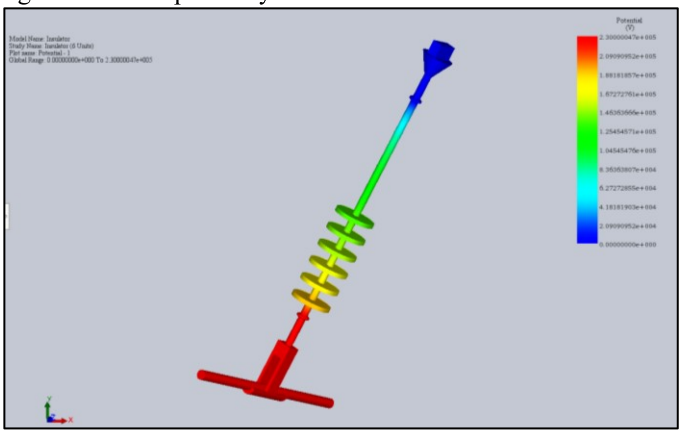

Figure 52: 3-D Fringe Plot (n = 6)

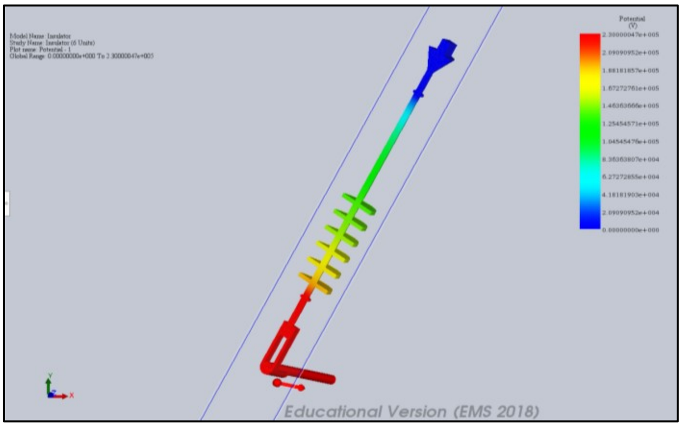

Figure 53: 3-D Section Clipping Fringe Plot (n = 6)

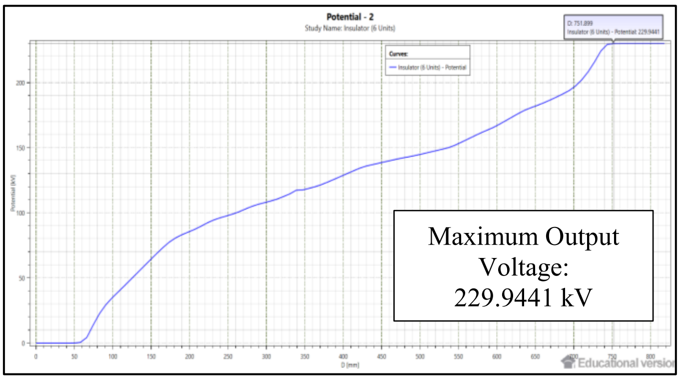

Figure 54: 2-D Graph Plot (n = 6)

2.5 *Analysis & Discussions*

This section will discuss on the voltage distributions along the high voltage insulator with different number of discs units in terms of the string efficiency. As this simulation was carried out in multiple times, hence the data obtained will not be shown at here. The string efficiency were calculated by using Equation (6) as shown as table below.

<u>For n = 12</u> $\eta = \frac{230k}{12 \times 42.55k} \times 100\%$ $\eta = 45.05\%$	<u>For n = 10</u> $\eta = \frac{230k}{10 \times 43.85k} \times 100\%$ $\eta = 52.45\%$
<u>For n = 8</u> $\eta = \frac{230k}{8 \times 44.35k} \times 100\%$ $\eta = 64.83\%$	<u>For n = 6</u> $\eta = \frac{230k}{6 \times 45.10k} \times 100\%$ $\eta = 85.00\%$

Table 7: Calculation of string efficiency

From all the string efficiency calculation above, it can be deduced that the string efficiency will be increase as the number of disc units across the high voltage insulator is decrease. However, as the number of disc units across the high voltage insulator is increase, the maximum voltage drop in a single disc insulator will be slightly increased. This maximum voltage drop may cause flash over on the high voltage insulator and results insulator failure.

Thus, suitable design for the high voltage insulator must follow the rated input voltage and the rated of high voltage insulator by taking the efficiency of the insulator string and maximum voltage drop on single discs units of the high voltage insulator into consideration. In order to design a suitable high voltage insulator, a standard which is IEEE C62.82.1-2010 – IEEE Standard for Insulation Coordination must be referred.

VII. CONCLUSIONS AND FUTURE RECOMMENDATIONS

1. Conclusions

The electric field and voltage distributions along the high voltage insulators has been studied in terms of the effect of transmission tower and conductor on the insulator string, effect of types of high voltage insulator and the effect of number of discs units in the insulator strings. From the results obtained, a few contribustions and conclusions had been made concerning the purpose of this investigations.

- A full insulator model has been designed by using the SOLIDWORKS 2017 and simulated by Electric and Magnetic Simulation (EMS) software. The methodology for designing the high voltage insulator has also been discussed.
- From the experiment on effect of insulator with transmission line and conductor, the insulator with transmission line and conductor is more suitable for designing and analyzing as it is in three dimensional form. From this, it can be deduced that two dimensional form is not that suitable as it will affect the accuracy of analyzing.
- From the experiment on effect of different types of insulators which are glass insulator, porcelain insulator and silicon rubber insulator, glass insulator shows the least maximum electrical stress, so it is more preferable for the insulator in transmission tower. By this, the breakdown will less happen and the maintenance fees can be reduced. But in nowadyas, porcelain insulator replaces the glass insulator as permittivity of glass and tensile make insulator cannot long-lasting.
- From the experiment on effect of different number of discs units acorss the insulator string, It is to conclude that if the number of disc units along the high voltage insulator is decrease, the efficiency of the insulator string will be increase, however, the maximum voltage drop across the single discs units along the high voltage insulator will be increase. Hence, in order to design a suitable high voltage insulator, IEEE C62.82.1-2010 – IEEE Standard for Insulation Coordination must be referred.

All of insulators simulated in this work are common in power system; hence it is believed that the results can be very useful for the manufacturers and utilities.

2. Future Recommendations

It is very hard to reduce completely on the problems on voltage distributions along high voltage insulator by only relying on limited numbers of case studies and software packages. To further study more about this project on voltage distributions along the high voltage insulator, a list of topics and the future recommendations can be make as shown as below:

- Effects of Corona Ring on Electric Field and Voltage Distributions over 230 kV High Voltage Insulator
  The model insulator for this project can be modified by designing a corona ring with the high voltage insulator in order to improve the electric field and voltage distributions along the high voltage insulator. The corona ring can be designed in different dimensions and the result can be compared in terms of string efficiency and maximum electric field stress.

- Effects of the Electric Field and Voltage Distributions along the High Voltage Insulator in Various Conditions
  In order to investigate more details on electric field and voltage distributions along the high voltage insulator, the high voltage insulator also can be designed in various conditions such as the dry and clean conditions, wet conditions, contaminated conditions and etc. Obviously, differnet conditions of the high voltage insulator will affect the electric field and voltage distributions respectively.

- Investigating and Analyzing on Electric Field and Voltage Distributions along the Broken High Voltage Insulator
  The model insulator can be designed as broken insulator in order to investigate the performance on electric field and voltage distributions along the broken high voltage insulator.

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