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Potential and Electric Field Characteristics of Broken Porcelain Insulator

H. Rosli, N. A. Othman, N. A. M. Jamail, M. N. Ismail
Department of Electrical Power Engineering, Faculty of Electrical & Electronic Engineering,
Universiti Tun Hussein Onn Malaysia (UTHM), 86400 Batu Pahat, Malaysia

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ABSTRACT

Overhead line insulators can be damaged for various reasons during their service life. Porcelain or glass insulators once damaged can affect the reliability of power system networks. This paper presents the study of voltage and electric characteristics along the surface of a broken porcelain insulator located in a string of 10 unit insulators. Three models of broken porcelain insulators were being proposed and the analysis results on voltage and electric characteristics were individually collected. The broken porcelain insulator with the most significant effect were then being investigated in the strings of 10 unit insulators. The finite element software of Quickfield was used to analyze the voltage and electric characteristics. Form the presented results, it is proven that the single porcelain insulators with broken shed at the nearest to the electrode terminal gave the most significant effect of voltage and electric field distribution pattern along the creepage distance. However, when this type of broken insulator was included in a string of 10 unit insulators, maximum average value of voltage achieved once the broken insulator was located at the HV terminal. Meanwhile, the highest electric field strength was recorded when the broken insulator was located in the middle of the string.

Corresponding Author:

N. A. Othman,
Department of Electrical Power Engineering,
Faculty of Electrical & Electronic Engineering,
Universiti Tun Hussein Onn Malaysia (UTHM),
86400 Batu Pahat, Malaysia.
Email: ndiana@uthm.edu.my

1. INTRODUCTION

Overhead transmission lines can carry alternate current (AC) or direct current (DC) or both in an electric power system. Overhead AC transmission lines carry three phase current and the transmission voltages are between the range of 69kV and 765kV. However, the DC voltage transmission tower lines are revolve in pairs for positive and negative current [1].

High voltage (HV) power lines have been widely used to transmit the electric energy from the power stations to the consumers. Since a large part of power generation takes place at significant distances from consumer, transmission lines must be employed to carry the power generated to its destination. It is well known that overhead transmission generally consists of three primary components which are conductors, insulators and tower structures.

Overhead transmission insulators can be considered cheap when compared with other HV equipment. However, these insulators play an important role in protecting the most expensive equipment which subsists in the power system network. Moreover, a reliable transmission network is partly dependent on overhead transmission insulators [2]. More than a million units of overhead insulators have been providing an excellent service over than 25 years in both transmission and distribution lines. However, these insulators must be designed not only to withstand electrical stress but also to tolerate the mechanical forces applied by the surroundings to successfully fulfil their functions. There are two main types of insulators that is commonly used in power system network which are ceramic and polymeric insulators.

Ceramic insulators which consist of glass and porcelain are the earliest insulators used in the power system transmission lines [3]. The pictorial view of glass and porcelain insulators is depicted in Figure 1. Both insulators have been used for over a century and their application can be considered as a safe choice. The raw materials for glass insulators includes soda ash, feldspar and cullet as well as a few other ingredients that crushed to form powder and melted in a furnace [4]. Toughening significantly increases the mechanical strength, making the glass shell suitable for the use of HV insulator. Meanwhile, high strength electrical grade porcelain for line insulators is usually made by the classical wet process. Raw materials like clay are mixed in water to facilitate blending. Therefore, even a small crack in the porcelain insulator may effect on the puncture strength of the insulator [5].


(a) (b)

Figure 1. Example of (a) glass insulator and (b) porcelain insulator

The common types of insulators like porcelain, glass and polymer have been used according to their respective capabilities. However, there are many factors that can bring to the insulators failure. The examples of intrinsic and external factors of the insulation failures includes radial cracking, pin corrosion, brittle fracture, damage to bulk dielectric and spontaneous shattering [6]. Since the outdoor insulators particularly porcelain are subjects to electric stress and weather conditions, the insulator tends to be broken due to unequal rate of expansion and contraction of porcelain, steel and cement caused by climate conditions. Apart from that, improper glazing on the insulator surface also can cause the moisture to stick on it with the deposited dust; hence a conducting path may be produced and lead to the flashover occurrence. The flashover occurrence may cause overheat on the insulator and may result in cracking and shattering process. Besides, it is accepted that the insulator may break the weak portion when experiencing a mechanical stress [7].

In the presence of higher stress or over-voltage, glass insulators in a string may result in completely broken sheds. However, porcelain insulator only can be broken in chunk and leaves a large remaining pieces of their shed under same conditions. It is worth mentioning that the porcelain insulators still can serve the transmission line even though in broken or partially broken condition. However, how long these insulators can withstand to serve the line is still questioned since the broken insulator may cause other insulator to withstand the remaining voltage allocated for that particular insulator. This situation may results in the voltage and electric field distribution alteration. The alteration of voltage and electric field distribution may affect the insulator in terms of the life span and ultimately lead to the insulation breakdown after a certain period of time. Therefore, this paper presents an analysis of broken porcelain insulator on voltage and electric characteristics.

2. SIMULATION WORKS

In this paper, cap and pin type porcelain insulator of ANSI 52-3 type is used as main subject [8]. The insulator is miniature in free space using QuickField software for the simulation purpose. Technical parameters of the porcelain insulator [9] is tabulated in Table 1 while the cross section area of porcelain insulator is presented in Figure 2 [10]. The simulation was conducted in AC analysis problem type with the voltage of 11kV and 132kV was applied to the insulator pin for single insulator and insulator string, respectively. It is important highlighting that the simulation was conducted in axisymmetric axis which require only a cross section area in the simulation works

In order to analyse the voltage and electric characteristics of broken porcelain insulator subjected dissimilarity of the broken types, three distinct configurations are used namely;

1. Case A1: Broken porcelain insulator with broken shed 1.
2. Case A2: Broken porcelain insulator with broken shed 2.

3. Case A3: Broken porcelain insulator with broken shed 3.

For each case, the number of broken shed is different as indicated in black circles in Figure 3. As clearly seen from the figure, the number of mesh is increased at the broken part approaches the insulator pin.

Table 1. Technical parameters of the simulated porcelain insulator [10]

Material	Relative Electric Permittivity, ε (Ω•m)	Conductivity, σ (S/m)
Cement	2	0
Porcelain	6.0	1.0^{-10}
Air	1	3×10^{-15}

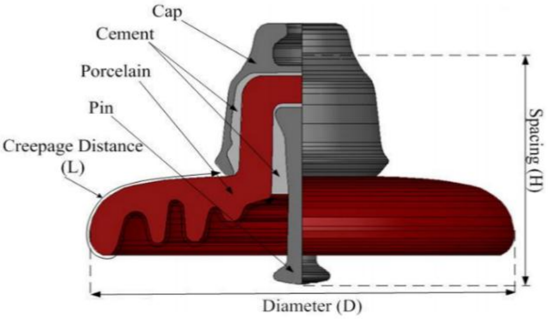
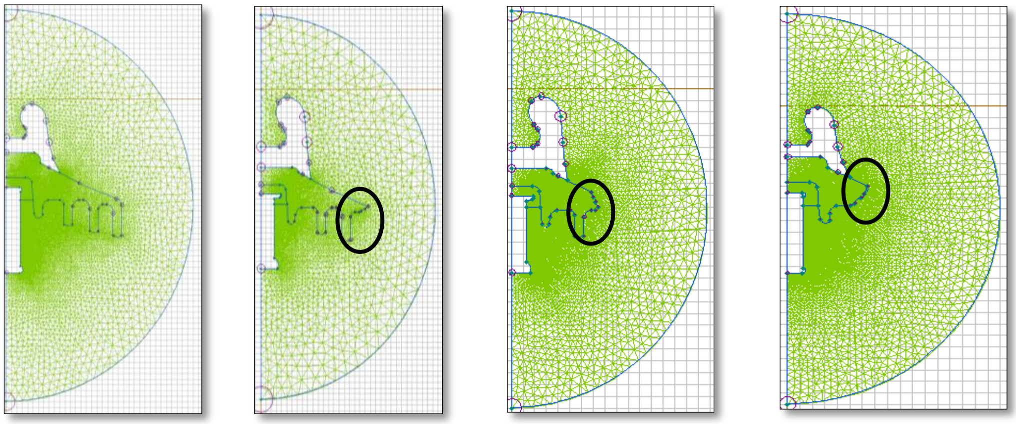


Figure 2. The cross section area of a porcelain insulator [10]



(a) (b) (c) (d)

Figure 3. The configuration of broken insulator for (a) Perfect, (b) Case A1, (c) Case A2, (d) Case A3

3. RESULTS AND ANALYSIS

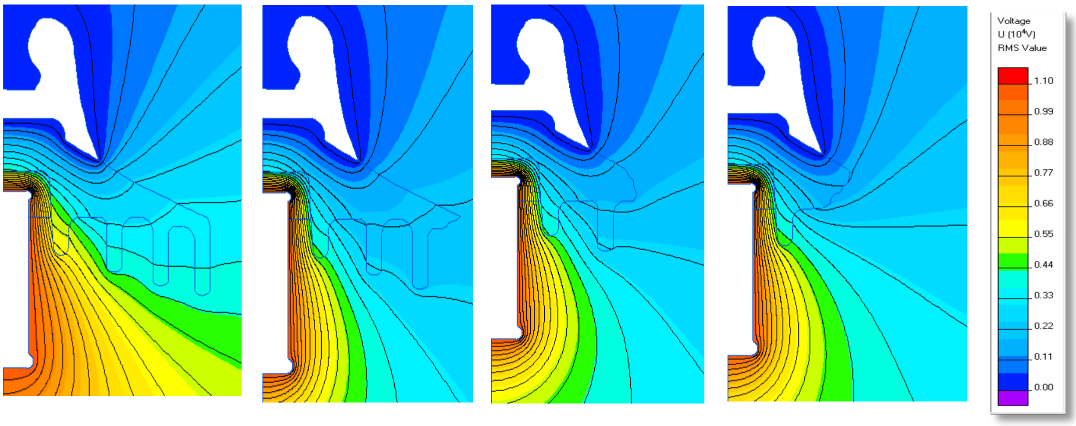
All results presented in this section was obtained based on contour plot that measured along the insulator creepage distance. The discussion is divided into four sections mainly concern on single broken porcelain insulator and its effects on an insulator string.

3.1. Voltage Distribution of Single Porcelain Insulator

All results presented in this section was obtained based on contour plot that measured along the creepage distance. However, it is predicted that the performance of the string will be a little affected by varying the location of broken insulator in string [11]. Figure 4 shows the contour of potential distribution across single porcelain insulator. From the simulation contour in Figure 4(a), it can be seen that the perfect porcelain insulator has the highest potential in the region nearest to steel pin (around shed 4). The potential pattern can be said as uniformly decreased when the measured distance get further from the shed 4. However, when the insulator shed is broken, it is observed in Figure 4(b) to Figure 4(d) that the high potential was distributed more near the steel pin. It is also apparent that the equipotential lines getting narrower when the insulator shed is broken. It is worth stating that the colour pattern of the contour indicates the different potential value across each insulator.

Figure 5 illustrates the potential distribution along creepage distance for all cases of broken porcelain insulators when compared to the perfect insulator. It is apparent that the potential distribution of perfect insulator retain the highest value compared to the broken insulators; this findings affirmed by [12]. Generally, the potential distribution pattern can be said as non-uniform along the creepage distance when measured from HV electrode for all cases. However, the broken shed of case A3 bears the most significant potential value and contribute the highest percentage reduction of potential compared to other cases as the reduction value is the highest when compared to perfect case.

Table 2 shows the maximum and minimum value of voltage for perfect and all cases of broken porcelain insulators. From the tabulated data in Table 2, it can be said that the maximum reduction of potential value occurred in case A3 when almost all shed is broken. Therefore, it can be summarized that the nearer the broken of shed of an insulator to the HV electrode, the more potential value will be fluctuated.



(a) (b) (c) (d)

Figure 4. Contour of potential distribution across single insulator for (a) Perfect; (b) Case A1; (c) Case A2; and (d) Case A3

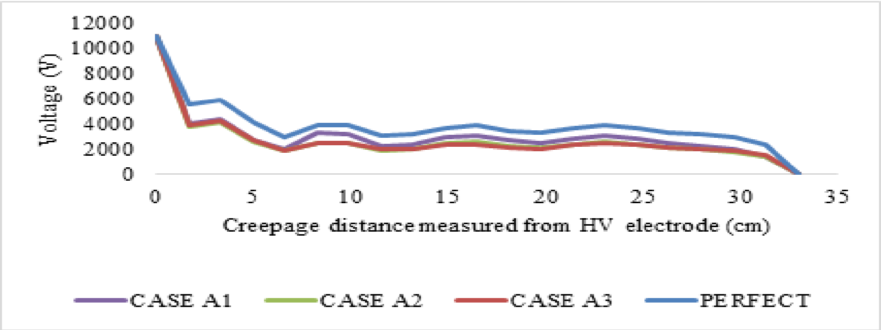


Figure 5. Potential distribution for all cases of broken porcelain insulators when compared to the perfect insulator

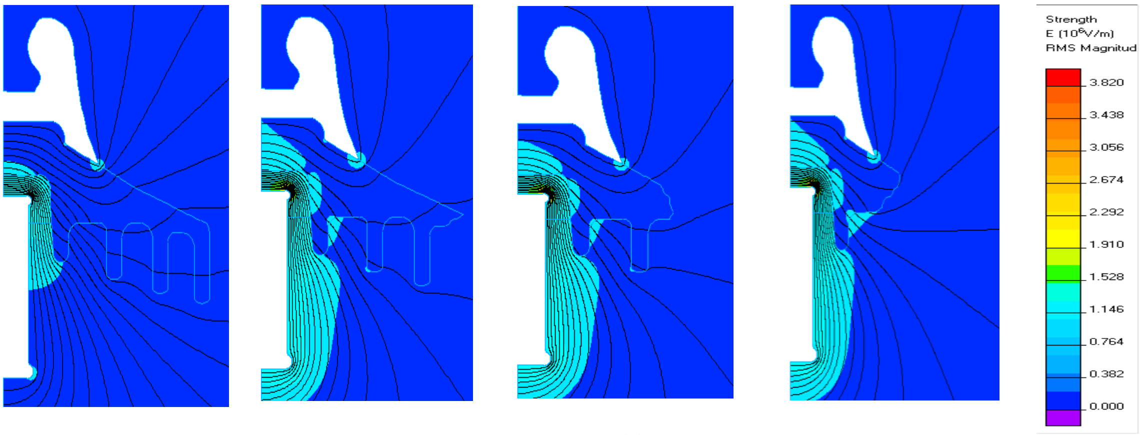
Table 2. The highest and lowest value of voltage

Insulator	Voltage (V)	
	Max	Min
Perfect	5934.69	2366.38
Case A1	4219.12	1576.54
Case A2	4098.83	1466.89
Case A3	4008.28	1041.81

3.2. Electric Field Distribution of Single Porcelain Insulator

Based on R. Krishnan study, it has been proven that the insulators do not conduct any current from the current density profile through insulators [13]. Therefore, in this paper, the maximum electric field across the creepage distance of each insulator is taken by placing the contour line on it. Figure 6 shows the colour pattern of electric field distribution for single perfect porcelain insulator and all cases of broken porcelain insulators. From the simulation contour in Figure 6(a), it can be seen that the perfect insulator has the most narrowed equipotential lines of electric field distribution in the region nearest to steel pin. However, the equipotential lines of electric field distribution is increased when the shed of the insulator is broken as shown in Figure 6(b) to Figure 6(d) which is similar to the findings in [14].

Figure 7 illustrates the graphs of electrical field distribution of single porcelain insulator compared with all cases of broken porcelain insulators. Generally, the distribution of electric field for perfect and all broken cases single porcelain insulator presents the similar pattern along the creepage distance. However, there is a slight decrease in the electric filed strength value at beginning before become almost constant in the middle of the contour across insulators and experienced a fast develop at the end for perfect insulator. Contrarily for all broken case where the electric field strength is much higher at the beginning and lower at the end when compared to perfect insulator.



(a) (b) (c) (d)

Figure 6. Contour of electric field distribution across single insulator for (a) Perfect; (b) Case A1; (c) Case A2; (d) and Case A3

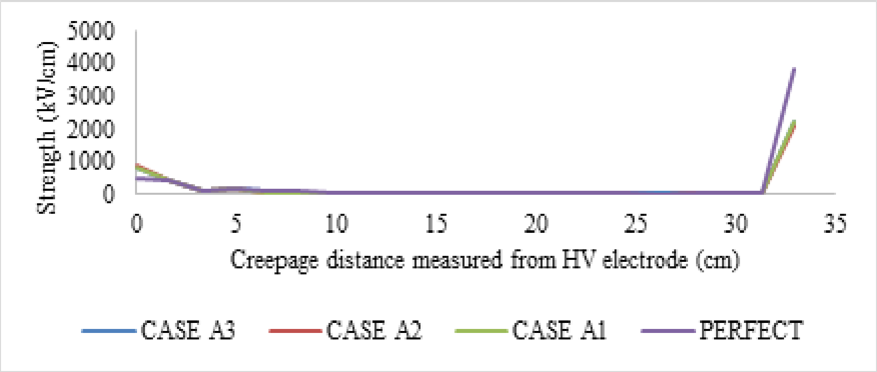


Figure 7. Electrical field distribution of single porcelain insulator compared with all cases of broken porcelain insulators

Table 3 shows the maximum and minimum value of electrical field of the four cases of single porcelain insulator. It is appear to indicate that the broken of insulator in the shed nearest to the electrode bears the most effect of electric field distribution across the insulator.

Table 3. The highest and lowest value of electric field

Insulator	E-Field (kV/cm)	
	Max	Min
Perfect	3821.07	14.25
Case A1	2210.09	17.32
Case A2	2256.44	12.74
Case A3	2099.28	14.56

Different cases of broken porcelain insulators presented has been concluded that the porcelain insulator with broken shed 3 has the most significant effect on potential and electric field distribution. Therefore, further investigation of the most significant effect of broken porcelain insulator on voltage and electric characteristics were tested on 10 units of insulator strings in different location of the broken insulator which are near the electrode, in the middle, near the ground and alternate position.

3.3. Voltage Distribution across a Porcelain Insulator String

Insulator strings with different locations of broken single porcelain insulator were simulated and produced a contour plot of the string with different colour patterns. The colour patterns of the contour indicate the diverse potential value across each insulator in the string [15]. In order to analyse the effect of broken Case A3 on voltage and electric characteristics in a string insulator, four dissimilar configurations are used. Each configuration are assigned as shown in Table 4 for each cases the location of the broken porcelain insulator from Case A3 in the previous section.

Table 4. The designation of string insulator with broken porcelain insulator

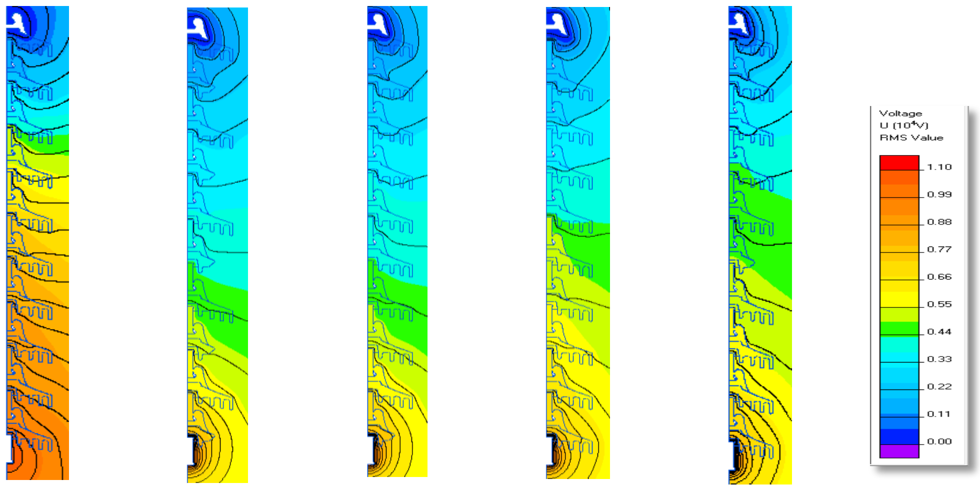
String with 10 units of porcelain insulators	Designation
No broken porcelain insulator present	Perfect
Broken porcelain insulator located alternately with perfect insulator	B1
Broken porcelain insulator located near HV electrode terminal	B2
Broken porcelain insulator located near ground terminal	B3
Broken porcelain insulator located in the middle of the string	B4

From the simulation contour of Figure 8, it can be observed that perfect insulator string the distribution of potential is gradually decreased from the insulator pin to the insulator cap. However, in the presence of broken insulator in the string, the potential pattern increased in variant with different location of the broken insulator approached to transmission line. Based on the graph, the potential is not uniformly distributed across each insulator. The first insulator that is located at the HV electrode (near the transmission line) bears the highest potential value for all cases. The potential is then decreases in the next insulators along to the ground electrode.

Figure 9 shows the potential distribution of 10 units of porcelain insulator in a string. It is obvious from the figure that the voltage distribution is affected when broken insulator exists in the string. This finding is supported by Xiu-chen [16] which concluded that the insulators near the earth are sensitive to the voltage-change of the insulator near the power line, but the latter are not sensitive to that of the frontier. By their analysis, it can be concluded that the sensitivity of string insulator is most affected when broken insulator exist near the ground (earth).

According to Azordegan et al. [17], the electromagnetic radiations are stronger at the end of positive cycle for a cracked insulator while the electromagnetic radiations are stronger at the end of negative cycle for a polluted insulator. This supported the observation from the present findings when the potential distribution decreases along the string due to cracks on the porcelain insulator shed. Besides that, the mechanical strength reduction of insulator also causing undesired partial discharges.

The lowest average potential value of 50kV was recorded at the B1 case string with 35.06% reduction from the perfect string insulator can be calculated from Figure 9. The graph is then dramatically decrease for all the cases. It can be shown that the potential which should bear by the first insulator have been transferred to the second insulator and so on. Table 5 tabulates the average, maximum and minimum value of voltage across string with 10 units of porcelain insulator in all cases. It is noticed that the average value indicate that the presents of broken insulator in a string affects the voltage across the string insulator. But, the result shows that the B4 case bears the most significant effect on the potential distribution of string with 10 units of porcelain insulator due to the highest reduction value of voltage at the end of the string insulator in ground terminal.



(a) (b) (c) (d) (e)

Figure 8. Potential distribution of string porcelain insulator for (a) Perfect string insulator, (b) B1 string insulator, (c) B2 string insulator, (d) B3 string insulator, and (e) B4 string insulator

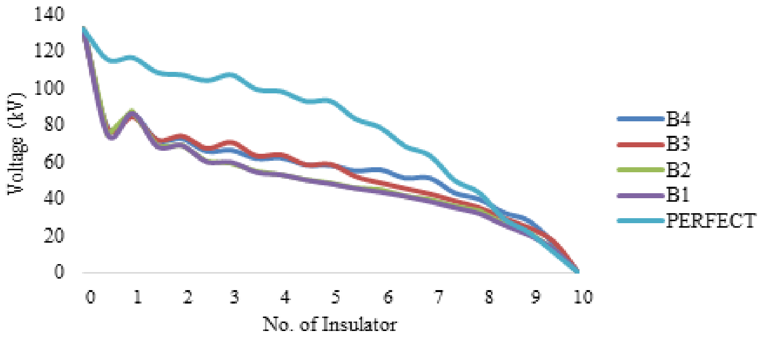


Figure 9. Potential distribution of all cases of string insulators

Table 5. The highest and lowest value of voltage in string insulator

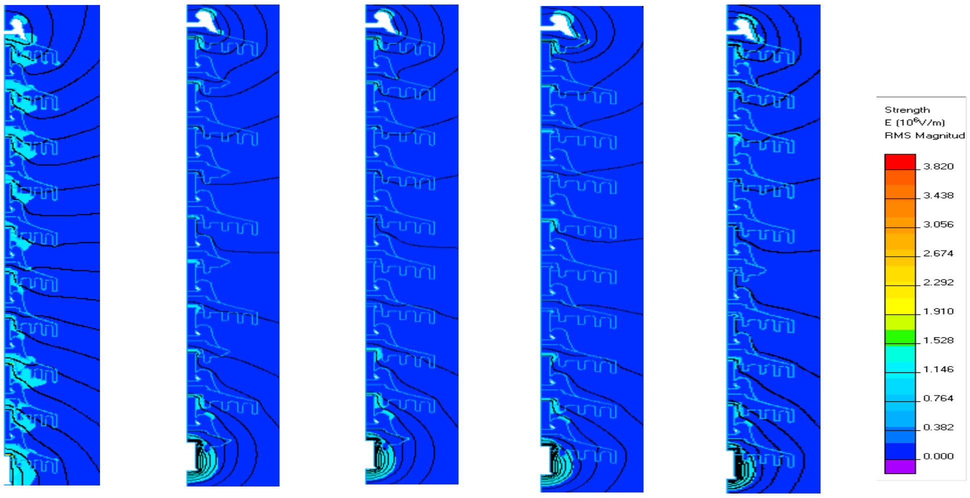
String	Voltage (kV)		Average (kV)
	Max	Min	
Perfect	116	11	77
B1	86	13	50
B2	88	13	51
B3	84	17	55
B4	86	16	56

3.4. Electric Field Distribution across a Porcelain Insulator String

The maximum electric field across the contour distance of each insulator along the string is taken as the strength across each insulator. Figure 10 shows the electric field distribution in string with 10 unit of insulator. It is observed that the present of the broken shed in the insulator has decreased the average electric field distribution in string; this findings is agreed by Shahat [18]. Figure 11 shows the electric field distribution of 10 units of porcelain insulator in a string. From Figure 11, the distribution pattern can be said as similar for all cases of strings. The first insulator that is located nearest to the line for Case B3 has the highest electric field.

According to the research lead by Akbari [10], who studied on finite element analysis of disc insulator type and corona ring effect on electric field distribution over 230kV insulator string. They found that as the distance from insulator string increases, the dependency of electric field to insulator material and profile decreases. Apart from that, Anjum [11] has proved that varying the position of the insulator disc within the string has little or no effect on the level of classification performance. By relating to the conclusion, it has confirmed the similarity patterns in the present findings in Figure 10.

In addition, a study conducted by Palhade [19] found that the high temperature produced in current carrying conductor is not enough to transfer over an insulator assembly component during a short period of time. It could be safe to assume that the temperature is not high enough to significantly affect the performance in terms of mechanical and thermal characteristics of an insulator assembly for short duration in this study. Hence, the data obtained from broken porcelain insulators in all cases of string insulator has not been affected much by the temperature of the current. However, in real operation of overhead HV insulators, electrical and mechanical loading, variable atmospheric condition and environmental pollution may degrade the bonding characteristics of cement, even disc material which is basically brittle in nature leading to failure of insulator assembly.



(a) (b) (c) (d) (e)

Figure 10. Electric field distribution of string porcelain insulator for (a) Perfect string insulator, (b) B1 string insulator, (c) B2 string insulator, (d) B3 string insulator, and (e) B4 string insulator

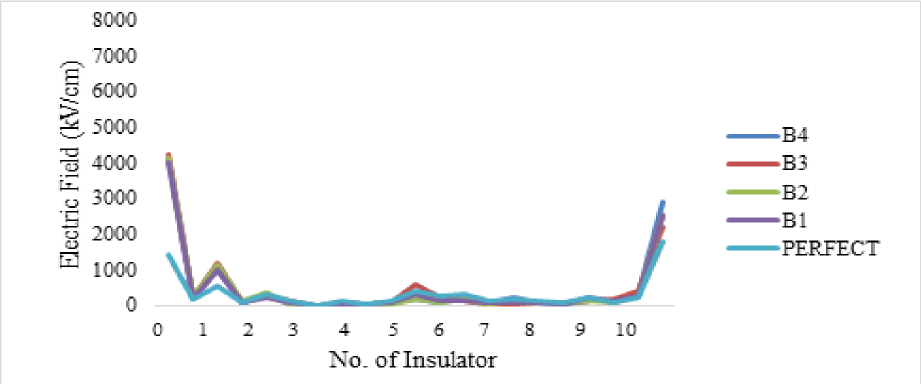


Figure 11. Electric field of broken insulator in string

Table 6. The highest and lowest value of electric field in string insulator

String	Electric Field (kV/cm)		Average (kV/cm)
	Max	Min	
Perfect	1791.2	1.0	313.5
B1	2513.5	1.3	454.4
B2	2510.1	0.8	465.8
B3	2186.3	1.4	488.4
B4	2883.8	1.1	484.2

Table 6 shows the electric field value in all cases of string insulator with and without broken porcelain insulator. The result shows that highest value of electric field distribution is found in the first insulator in Case B3 based on Figure 11. Meanwhile, highest value of electric field was found in case B4 at the tenth insulator as mentioned in Table 6.

4. CONCLUSION

This paper set out to explore the influence of broken shed in porcelain insulator in terms of voltage and electrical characteristics. From the results obtained, a few conclusions had been made concerning the purpose of this investigation.

1. The single porcelain insulator denoted a bulk reduction of voltage and electric field when the broken of the shed in the insulator was near the electrode.
2. In HV string insulator with 10 units of porcelain insulator, the potential distribution experienced the most diminutive value when the broken porcelain insulator were located in the string near the ground. In addition, the potential distribution average were the least when the broken and perfect insulator were arranged alternately in the string.
3. Consequently, the investigation of electric field distribution has shown that a hulking strength of average when the broken insulator was ascertain near the ground when assimilated to the string insulator without any broken insulator.

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BIOGRAPHIES OF AUTHORS

Hanan Rosli was born and raised in Sungai Petani, Kedah, Malaysia on January 24, 1994. After completing high school in MARA Junior Science College (MJSC) Kepala Batas (2011), she went to Kedah Matriculation College for a year and pursue her study in Bachelor of Electrical Engineering (Hons) in UTHM, Johor (2017). Her research interest is more focus in high voltage insulation field.

Nordiana Azlin Othman was born in Johor, Malaysia on January 19, 1986. She received Diploma in Electrical Communication and B.Eng in Electrical Engineering from Universiti Teknologi Malaysia (UTM) respectively in 2007 and 2010. She completed her PhD in Space Charge Distirbution at Institute of High Voltage and High Current (IVAT) in Faculty of Electrical Engineering, UTM. Her research interest includes the detection and diagnostics of partial discharge and space charge in insulation for condition monitoring.

Nor Akmal Mohd Jamail is a lecturer of Universiti Tun Hussein Onn Malaysia since 2008. She received the Bachelor degree in Electrical Engineering from Universiti Teknologi Malaysia in 2005, M.Eng in Power System from Universiti Tun Hussein Onn Malaysia in 2007 and Ph.D. in High Voltage Engineering from Universiti Teknologi Malaysia, in 2015. Her research interests include condition monitoring of polymer nanocomposite insulation for HV purpose, dielectrics and electrical insulation. She is registered with the Board of Engineers Malaysia (BEM).

Muhammad Nafis Ismail was born on 1982 in Johor, Malaysia. He received B.Eng in Electrical Engineering fron Universiti Teknologi Malaysia (UTM) in 2005. He previously worked as an Electrical Engineer at BQE Engineering from 2005 to 2007 and currently work as an Electrical Instructor at University Tun Hussein Onn Malaysia.