Determination of Appropriate Overhead Line Insulator in Sumatra due to Contamination Severity

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***Abstract* — Insulator is one of the important equipment to support electrical power delivery which flow through the transmission line. Considering its very important role, the selection of insulators must be certainly based on deep analysis so that the insulator we choose works properly. There are several standards that can be used in selecting isolators, but in this paper the standards that will be used for case study analysis are IEC and IEEE standards. Case studies that will be used for the selection of insulators are for Sumatra that located in Indonesia which is a tropical country and certainly has special environmental characteristics that can influence the selection parameters of an insulator. There are several parameters that are commonly used in selecting overhead isolators those are power frequency voltage, environmental condition (contamination), switching over voltage, and lightning over voltage. Using environmental condition, it is found that the pollution category of Sumatra area is heavy, which influence the selection of insulation material.**

Keywords: insulator, IEC, IEEE, Sumatra, Indonesia, environmental condition

I. INTRODUCTION

Electrical distribution system is generally divided into 2 types of system, those are high voltage systems and high current systems. The effectiveness of both systems can be compared based on the ratio between the magnitude of the high system and the value of the amount used by consumers. For example the ratio between the current used by consumer is 15 A and the current of transmission line is 1500 A so that the ratio is 1 : 100 while the voltage ratio used by consumers is 115 V with high voltage value is 115 kV so that the ratio is 1 : 1000. Systems with high current require the addition of a conductor cross section while a high voltage system requires high reliable insulation. With this comparison it can be said that systems that use high voltage are more effective and efficiently applied than the systems with high currents. Electrical distribution systems in Indonesia and in the world generally use high voltage systems so that the selection of reliable insulators and equipment insulation systems is very important.

Based on the insulation material used, the insulator is divided into 3 types, those are ceramics, glass and polymer. Each of these materials has advantages and disadvantages. The selection of insulator material must be based on electrical, mechanical, and environmental conditions where the insulator will be installed. Based on the application, the insulator is divided into 2 types, those are station insulator and line insulator. Stations insulator are used to support the performance of buses near electrical equipment such as switchgear, transformers, hollow bushings that transfer high voltage to the inside of power equipment, etc. while the insulator (line insulator) is used as a separator between the tower and conductor and support conductors from towers (withstand mechanical loads of conductors). We can determine the material, design, or configuration of an insulator based on a comprehensive study of the parameters of conditions that affect its performance, especially for the line insulator because this insulator line faces a much wider environmental condition.

This paper discusses the recommendation of material selection, structure and configuration of insulators for high voltage systems in the tropics, especially Indonesia. The discussion begins with the theory and standards obtained based on the study of literature and then compares the real conditions in the field.

II. BASIC THEORY

A. Insulation System

Insulation system is a system on high voltage equipment that serves to prevent the flow of electric current both between 2 voltage equipment or between equipment which have voltage with other equipment that have no voltage in an electrical system. In overhead line transmission, each conductor are isolated using surrounding air while conductors with towers or supporting poles are separated by solid insulating material which is generally called an insulator. Beside on the transmission lines, insulators are also found in electrical distribution line, substations and power dividing panels. The following images in Figure 1 are examples of insulators application in high voltage equipment.

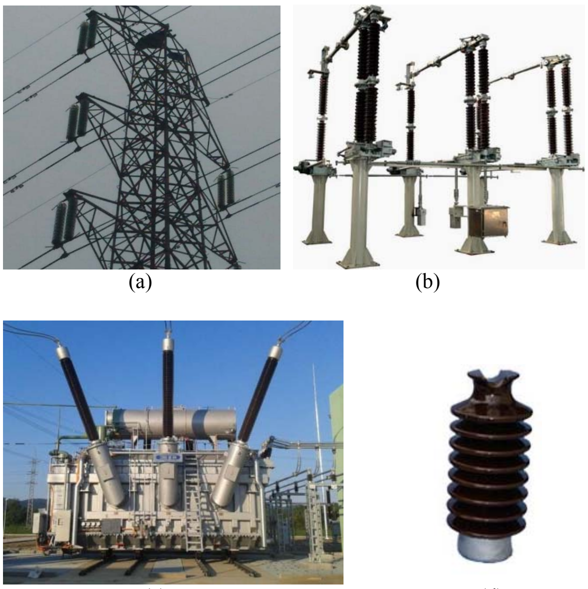

Figure 1. (a) Insulator on the transmission pole; (b) Insulator on the separation switch; (c) Transformer bushings; (d) Distribution network isolators

Compared to the other high voltage equipment such as generators, transformers, GIS and switchgear, or cables, insulator damage has a portion of 35% as a factor causing high voltage system failure where 90% of damage is caused by insulation problems [1-3]. The failure of this insulator can be derived from thermal stress due to leakage currents that continue to increase due to aging factors, ultraviolet radiation and environmental effects or can also come from mechanical stresses from conductors. If the stresses are not well calculated / predicted, the insulator can run in to a breakdown, either in the form of flashover or in the form of a mechanical breakdown.

B. Parameter of Insulator

Based on IEEE 1243-1997 standard "IEEE Guide for Improving the Lightning Performance of Transmission Lines", the design of external insulation on high voltage transmission line is determined by four parameters those are power frequency voltages, contamination, switching overvoltage, and lightning overvoltage. Lightning and pollution contamination must be monitored for all voltage levels while for switching voltages must be monitored more for voltage levels above 345 kV [4].

1. Power Frequency Voltage

Continuous voltage (power frequency voltage) is a power frequency voltage which is considered to have a constant and continuous rms value applied to each terminal of the isolation configuration [5]. From this explanation we can know that insulators must be able to hold the voltage of the system continuously or must be able to perform its function as a separator between the phase wire and the tower or ground properly.

2. Environmental Condition / Contamination

Transmission insulator is an insulator that must be ready to face various environmental conditions compared to other insulators because the transmission insulator is installed along the electric power distribution line so that the environmental conditions that are passed are different. The main contamination of insulators is industrial pollution and sea salt.

The electrical conductivity of insulator surface caused by contaminations is usually expressed as Equivalent Salt Deposit Density (ESDD). The electrical conductivity of the moistened layer of pollution can be expressed as a layer conductivity. This value is obtained by dividing the form factor of an insulator by measured resistance. There is a nonlinear relationship between layer conductivity and ESDD.

3. Switching Overvoltage

Switching overvoltage has a peak time of 20 - 5000 μs and a time up to half is less than 20,000 μs. In general, this wave front value is important because it has a significant effect on the value of Critical Flash Over (CFO) voltage. The minimum CFO occurs at the critical wave front (CWF), which is equal to about 50 times the strike distance in meters (m). For wave front smaller or larger than CWF, the CFO value increases. CFO increases by around 10% when the wave front is between 1000 μs to 2000 μs which usually occurs when we use low-side transformer switching. More switching voltage is generally caused by:

- Line energization and reclosing overvoltage
- Typical phase-ground switching overvoltage
- Typical switching phases overvoltage
- Longitudinal switching overvoltage
- Fault overvoltage
- Load rejection overvoltage
- Inductive and capacitive current switching overvoltage

The waveform of this switching overvoltage can be seen in the following Figure 2. (IEEE 1313.1-1993)

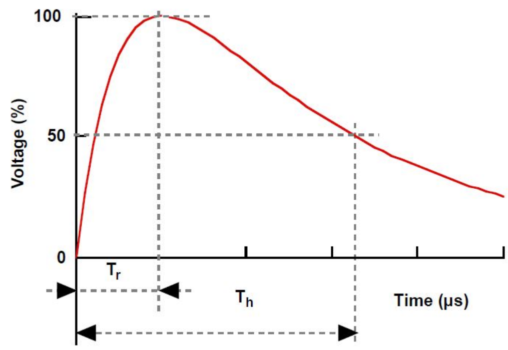

Figure 2. Waveform of switching overvoltage 250/2500

4. Lightning Overvoltage

Lightning voltage is a faster-front voltage with a peak time of 0.1 - 20 μs. lightning overvoltage is caused by the following:

- Direct strike with the phase line (shielding failure)
- A flash on the ground wire but there is a flashover to the conductor wire (back flashover)
- A strike with the ground which is relatively close to the conductive wire which induces more voltage to the conductive wire (induce voltage)

The waveform of this lightning overvoltage can be seen in the following Figure 3. (IEEE 1313.1-1993)

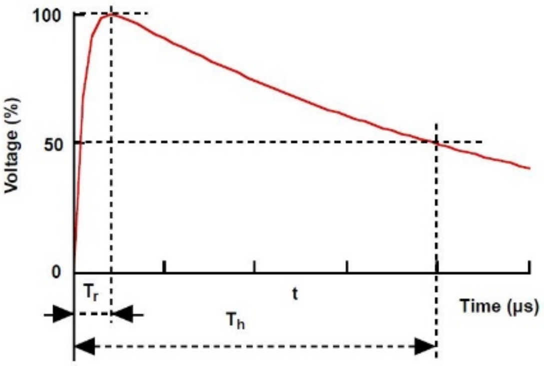

Figure 3. Waveform of lightning overvoltage 1.2/50

IEC 60815-1 mention that the selection and dimensioning of outdoor insulators is an involved process. A large number of parameters have to be considered for a successful result to be obtained. For a given site or project, the required inputs are considered under three categories: system requirements, environmental conditions of the site and insulator parameters from manufacturer's catalogues [6]. Each of these three categories contains a number of parameters as indicated in Table 1 below.

Table 1. Input parameters for insulator selection and dimensioning

System Requirements	Environmental Conditions	Insulator Parameters
Type of system :	Pollution types and levels :	Overall Length :
Maximum operating voltage across the insulation	Rain, fog, dew, snow and ice	Type
Insulation coordination parameters	Wind, storms	Material
	Temperature, humidity	Profile
Imposed performance requirements	Altitude	Creepage distance
Clearance, Imposed geometry, dimensions	Lightning, earthquakes	Diameters
	Vandalism, Animals	Arcing distance
Live line working and maintenance practice	Biological Growth	Mechanical and electrical design

III. DATA & ANALYSIS

As a tropical country, Indonesia has a fairly high intensity of UV radiation with temperatures reaching 39.5°, humidity rate of 87%, and has a relatively high annual rainfall of 3,548 mm [7-9]. Besides that, Indonesia is the country with the second longest coastline in the world with a length of more than 81000 km which makes the use of insulators especially in coastal areas is very crucial thing as result of high levels of sea salt pollution [10]. This paper will analyze the selection of insulators in the Sumatran region assuming that in there will be built high voltage transmission line of 500 kV. Environmental data and natural conditions are obtained from real conditions in the field sourced from authorized institutions in Indonesia.

Sumatra as one of the big islands in Indonesia has almost the same natural conditions as other islands in Indonesia, so the challenges of the electric power system faced in Sumatera are similar to the challenges of the electrical power system on the other islands.

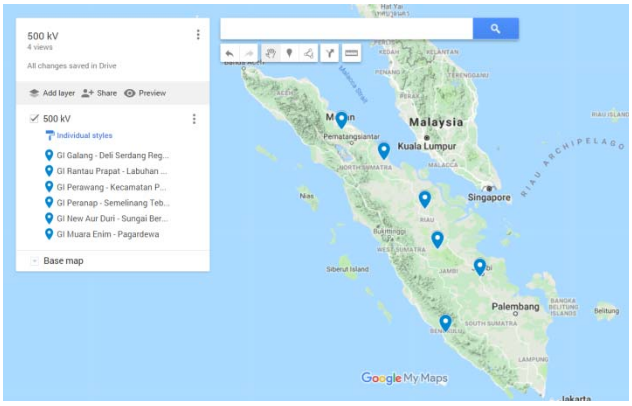

Figure 4. location of existing substations in Sumatra

Figure 4 above is a map of the location of the existing substation (GI) transmission line in Sumatra. The following Table 2 is a calculation about the closest distance from the coast to the substation that was built :

Table 2. Distance of the substation from the coast

Substation	Distance from sea (km)
Muara Enim	9,7
Aur Duri	83
Peranap	154
Perawang	80,5
Rantau Prapat	22
Galang	34

The next thing that needs to be considered is the environmental conditions that are passed by the transmission line. The following Table 3 show the environmental condition between above substation.

Table 3. environmental condition between substation

Substation – Substation	Environmental Condition
Muara Enim – Aur Duri	Oil palm plantation
Aur Duri – Peranap	Oil palm plantations, rubber plantations, shrubs, weeds, rice fields and acacia gardens
Peranap – Perawang	Oil palm, scrub, rubber, rice fields, swamps and forests
Perawang – Rantau Prapat	Palm plantation, Rubber and beside Jalinsum road
Rantau Prapat - Galang	Palm plantation, rubber plantation, rice field

If we build the transmission line between substation above we know that the transmission line will passed through generally palm oil plantation, rubber plantation, rice field area, acacia garden, beside the road, shrubs, and forest.

After the condition of the real environment is known, then we compare these conditions with the standard. One standard that explains the effect of environmental conditions on insulators, especially the value of the creepage distance is the IEC 60815 standard. The following Table 4 describe the recommended creepage distance of insulator from IEC 60815-1.

Table 4. Recommended Creepage Distance

Typical Environments	creepage distance mm/kV
I. Very Light ▪ > 50 km from any sea, desert, or open dry land ▪ > 10 km from man-made pollution sources Within a shorter distance than mentioned above of pollution sources, but ▪ prevailing wind not directly from these pollution sources ▪ and/or with regular monthly rain washing	12,7
II. Light ▪ Areas without industries and with low density of houses equipped with heating plants ▪ Areas with low density of industries or houses but subjected to frequent winds and/or rainfall ▪ Agriculture &Mountainous areas ▪ All these areas shall be situated at least 10 km to 20 km from the sea and shall not be exposed to winds directly from the sea	16,0
III. Medium ▪ Areas with industries not producing particularly polluting smoke and/or with average density of houses equipped with heating plants ▪ Areas with high density of houses and/or industries but subjected to frequent winds and/or rainfall ▪ Areas exposed to wind from the sea but not too close to coasts (at least several kilo metres distant)	20,0
IV. Heavy ▪ Areas with high density of industries and suburbs of large cities with high density of heating plants producing pollution ▪ Areas close to the sea or in any case exposed to relatively strong winds from the sea	25
V. Very Heavy ▪ Areas generally of moderate extent, subjected to conductive dusts and to industrial smoke producing particularly thick conductive deposits ▪ Areas generally of moderate extent, very close to the coast and exposed to sea-spray or to very strong and polluting winds from the sea ▪ Desert areas, characterized by no rain for long periods, exposed to strong winds carrying sand and salt, and subjected to regular condensation	31

If we compare the real environmental conditions with the IEC 60815 standard, the pollution category for the 500 kV Sumatra system is categorized as Light. However, some conditions in the field such as humidity and the number of small insects that have the potential to become pollutants for insulators, the pollution condition is recommended for categorized as Heavy category.

There are several creepage distance values for each insulator disk based on IEC 60305. One of the commonly used is an standard profile insulator with a 295 mm creepage distance while the fog type isolator has a creepage distance of 525 mm. Then we use the value of the creepage distance to calculate the number of insulator disk that is needed based on the pollution category. Table 5 shows the result of calculation example to calculate the number of insulator that is needed for 500 kV system. To get the number of insulator we use the formula :

$$n = \frac{V_{LN} \times L_C}{Creepage\ distance} \qquad (1)$$

With equation (1), we can get the result as in Table 5.

Table 5. Calculation Example

Creepage distance	Pollution category	Number of insulator
295 mm	Light	16
	Heavy	25
525 mm	Light	9
	Heavy	14

Based on the table above we can find out that greater creepage distance value for each disk insulator make the number of insulators needed will be less. Determination of the number of insulators is very important because it relates to other equipment, especially tower design which requires calculation of the clearance parameters which are influenced by the total length of the insulator. Actually, there are other factors that need to be considered in the selection of these insulators, especially switching over voltage,

IV. CONCLUSION

Determination of the number of insulators based on IEC & IEEE must remark several parameters there is power frequency voltage, lightning overvoltage, contamination, and switching overvoltage. for insulators at voltage levels above 345 kV the main parameters to consider are pollution contamination and overvoltage switching. Pollution category that is right for the Indonesian region, especially the Sumatran region which is dominated by agricultural areas based on the IEC standard is light pollution. But because there are special factors in the area, the pollution category is made into heavy pollution which affects to the number of creepage distances and has an effect on the difference in the number of insulator pieces that is needed.

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