

Analysis of Arcing Horn on Disk Insulator Configuration in 150 kV SUTT at PT PLN (Persero) Unit Induk Pembangunan Sumatera Bagian Tengah

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ABSTRACT

The reliability of the electric power transmission system on 150 kV High Voltage Overhead Transmission Lines (SUTT) is strongly influenced by insulation coordination, particularly in the disk insulator string and arcing horn assembly, which functions to divert electrical flashover caused by overvoltage so that the insulator is not damaged. Under the existing condition, it was found that the installed arcing horn was designed for a 12-disk insulator configuration, while the actual string used only 10 disk insulators, thereby changing the distance between the arcing horns and affecting its breakdown voltage. This study aims to analyze the effect of changes in disk insulator configuration on the arcing horn breakdown voltage and to evaluate the potential risk of insulation unreliability resulting from this mismatch. The research method involves technical data collection of the insulator string and arcing horn configuration, calculation of Critical Flashover Voltage (CFO) using the rod-plane gap method based on CIGRE recommendations, visualized through COMSOL Multiphysics 5.5 simulation. The results show that the 12-disk insulator configuration has an arcing horn distance of 1.352 m with a breakdown voltage of 709.8 kV (positive) and 1209.219 kV (negative), while the 10-disk insulator configuration has a distance of 1.060 m with a breakdown voltage of 556.5 kV (positive) and 995.333 kV (negative). Nevertheless, both configurations still satisfy the insulation coordination principle because the arcing horn breakdown voltage remains lower than the insulator breakdown voltage, with an insulation margin to BIL of 108% (12 disks) and 73.3% (10 disks). The smaller the gap distance, the higher the potential for flashover and the risk of system unreliability, so adjustment of the arcing horn distance is still recommended.

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1. INTRODUCTION

On a 150 kV overhead transmission line (Saluran Udara Tegangan Tinggi, SUTT), the disk insulator string and the pair of arcing horns fitted to its two ends work as a single insulation-coordination assembly: the air gap between the horns is meant to flash over first whenever the line experiences a lightning or switching overvoltage, so that the discharge bypasses the insulator surface. Insulation coordination of this kind is evaluated by comparing the strength of each insulating path against the overvoltage stresses expected on the system [8]. Because that gap is set by hardware manufactured for a specific number of insulator disks, any mismatch between the disk count assumed in the horn design and the disk count actually installed changes the horn-to-horn distance and, with it, the voltage at which the horn is expected to flash over. This relationship between disk count, horn geometry, and flashover voltage is the central concern of the present study; the criteria used to select the insulator material or disk count for a given pollution level are not re-

examined here, since they are already governed by established national and international standards such as SPLN and IEC.

The strength of an air gap to withstand voltage before breaking down is governed largely by the length of the gap itself: a longer arcing-horn gap withstands a higher voltage, while a shorter gap lowers the flashover voltage and raises the likelihood of a disturbance. Field studies on 150 kV lines in West Sumatra report that a shorter arcing-horn gap is associated with a lower flashover voltage and a higher frequency of line disturbances [1], and that lightning accounts for roughly two-thirds of the disturbances recorded on these lines, with the trip-out rate depending on tower-footing resistance and horn-gap length [2], [3]. Related work on the same network shows that adjusting the horn gap to an appropriate length can more than halve the trip-out rate [1], [4], and that tower-footing resistance interacts with span length and horn-gap length to determine the overall trip-out ratio [5].

A flashover on the insulator does not only damage that local component; it can also trip the transmission line, interrupt power delivery, reduce system reliability, and trigger further disturbances through load redistribution on the network. In the line examined in this study, the installed arcing horn was found to be a design intended for a 12-disk insulator string, while the string actually in service uses only 10 disks. Because the horn brackets in this suspension-set hardware are fixed to the top and bottom end-fittings of the string rather than to individual disks, removing two disks shortens the string - and, geometrically, the horn-to-horn gap - by the combined length of those two disks. The resulting gap is therefore shorter than the value the horn was originally designed for, which in principle lowers the air-gap flashover voltage and raises the likelihood of a flashover event.

Based on this problem, the objectives of this study are: (1) to analyze how the change from a 12-disk to a 10-disk insulator configuration affects the arcing-horn flashover voltage on a 150 kV SUTT system; and (2) to identify and evaluate the potential insulation-coordination risk that this mismatch between the arcing-horn design and the as-installed disk count may introduce.

The novelty of this study lies in applying this evaluation directly to an as-built field condition rather than a hypothetical design case, combining an analytical CFO calculation based on the CIGRE-recommended rod-plane gap correlation with a finite-element potential and field simulation used only to corroborate the calculated values, so as to provide a technical recommendation that transmission asset managers can act on directly.

2. METHOD

This study uses a technical analysis approach with a descriptive-quantitative method: the condition and configuration of the insulation system are described from available technical data, after which calculations are carried out to assess the suitability of the arcing horn design. The research location is the 150 kV SUTT KID - Pakning Lot 2 project, Bukit Batu Subdistrict, Bengkalis Regency, under PT PLN (Persero) Unit Induk Pembangunan Sumatera Bagian Tengah.

The data collected fall into three groups: (1) disk insulator configuration data, covering the number of disks, installation arrangement, and total string length; (2) specification data for the U120BP-type disk insulator, covering operating voltage, creepage distance, dimensions, and puncture withstand voltage; and (3) arcing horn design and dimension data, covering shape, gap distance, and installation position relative to the insulator, all sourced from approval drawings and manufacturer datasheets (Sediver and PPC Insulators).

The number of disk insulators required is obtained by dividing the required minimum creepage distance by the creepage distance per insulator unit, following SPLN 10-3B:1993:

$$n = L / l \quad (1)$$

where n is the number of disk insulators (units), L is the minimum insulator creepage distance (mm), and l is the creepage distance per insulator unit (mm). The required minimum creepage distance is itself obtained from the maximum system voltage multiplied by the specific creepage distance factor for the applicable pollution level (SPLN 10-3B:1993):

$$L = V \times k \quad (2)$$

where V is the maximum system voltage (kV) and k is the specific creepage distance factor (mm/kV). Next, the flashover strength of the arcing-horn air gap is characterized by its Critical Flashover Voltage (CFO) - the crest value of a standard lightning impulse at which the gap has a 50% probability of flashing over - rather than by a single deterministic breakdown voltage. For a rod-plane gap under standard atmospheric conditions, the CFO for positive and negative lightning-impulse polarity is estimated from the empirical correlation originally reported by Hileman [6] and reproduced in the EPRI Insulator Reference Book [7]:

$$\text{CFO}_{\text{r-p}(+)} = 525 \times d \quad (3)$$

$$\text{CFO}_{\text{r-p}(-)} = 950 \times d^{0.8} \quad (4)$$

where $CFO_{r-p(+)}$ and $CFO_{r-p(-)}$ are the 50%-probability flashover voltages for positive and negative polarity (kV), respectively, and d is the arcing-horn gap length (m), valid for $1\text{ m} \leq d \leq 8\text{ m}$. The disk insulator string itself is characterized in this study by its series puncture withstand voltage - the sum of the per-unit puncture withstand ratings given in the manufacturer's datasheet - which serves as the reference value against which the horn-gap CFO is compared, rather than treating the two quantities as the same physical mechanism. As a further check on the insulation coordination, the protective ratio (PR) and protective margin (PM) of the disk insulator string relative to the system's Basic Insulation Level (BIL) are evaluated following IEEE Std 1313.1 [8]:

$$PR = V_{\text{withstand}} / V_{\text{reference}} \quad (5)$$

$$PM = (PR - 1) \times 100\% \quad (6)$$

To corroborate the calculated CFO, a finite-element potential and electric-field simulation of the horn-and-insulator geometry was built in COMSOL Multiphysics 5.5, following the modeling approach used for insulator strings elsewhere [9]. The simulation solves for the electric potential and field-magnitude distribution around the arcing-horn gap under an applied impulse voltage equal to the calculated CFO; it is used only to visualize where the field concentrates along the gap, not to derive an independent flashover value, since flashover is a discharge phenomenon rather than a field quantity with its own spatial distribution. Figure 1 shows the single suspension-set construction that is the object of this analysis, consisting of a disk insulator string fitted with double arcing horns at its top and bottom.

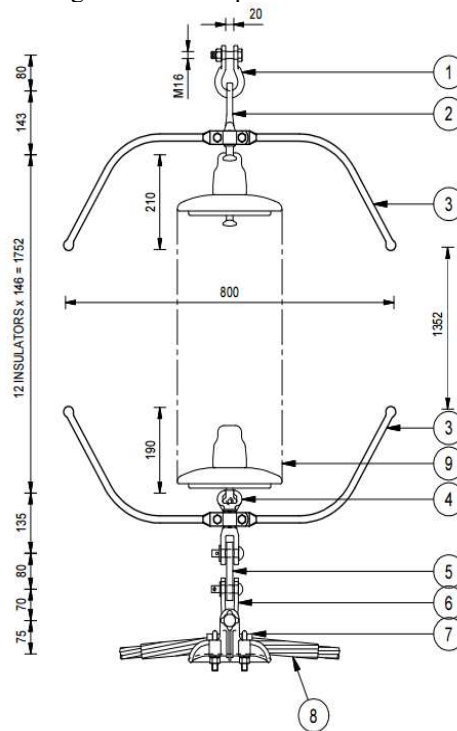


Figure 1. Construction of a single suspension set with double arcing horns on a 150 kV SUTT disk insulator string

The analysis proceeds from the literature review and the collection of U120BP insulator and arcing-horn specification data to the calculation of the horn-gap CFO and the insulator string's series puncture withstand voltage. These two results are then compared: if the horn-gap CFO is lower than the insulator's withstand voltage, in accordance with SPLN T3.008-1:2021, the arcing horn is taken to function as the intended controlled discharge point and the insulator is considered protected; the analysis then proceeds to the results and discussion, and to the conclusions and recommendations.

3. RESULTS AND DISCUSSION

3.1. Disk Insulator Configuration

The 150 kV line at the research location runs through an area with a heavy pollution level, so following SPLN 10-3B:1993 a specific creepage distance factor of 25 mm/kV applies. With a maximum system voltage of 170 kV (SPLN T6.001:2013), equation (2) gives a required minimum creepage distance of $L = 170 \times 25 = 4250\text{ mm}$. The U120BP insulator has a creepage distance per unit of 445 mm (glass) and 440 mm (ceramic), so equation (1) gives a required disk count of 9.55 units (glass) and 9.66 units (ceramic).

Rounding up to a whole number of disks, both materials are installed with 10 disk units. This calculation is what shows the as-installed 10-disk string to satisfy the minimum creepage distance required for a heavy pollution level, rather than that compliance being assumed in advance.

3.2. Arcing Horn Flashover Voltage

Based on the manufacturer's approval drawing, the horn-to-horn distance in the design for a 12-disk insulator string is 1352 mm (1.352 m), and each disk insulator is 146 mm long. Because the horn brackets in this hardware are fixed to the string's end-fittings rather than to individual disks, removing two disks from the string shortens the horn gap by exactly the combined length of those two disks ($2 \times 146 \text{ mm} = 292 \text{ mm}$); the gap for the 10-disk string is therefore $1352 \text{ mm} - 292 \text{ mm} = 1060 \text{ mm}$ (1.060 m). This proportional relationship holds specifically for this suspension-set hardware, where the end-fitting position is fixed relative to the string length; it should not be assumed to hold for every arcing-horn design. Figure 2 shows the resulting change in horn geometry, with the horn dimensions (length $P = 400 \text{ mm}$, height $T = 250 \text{ mm}$) kept unchanged between the two configurations.

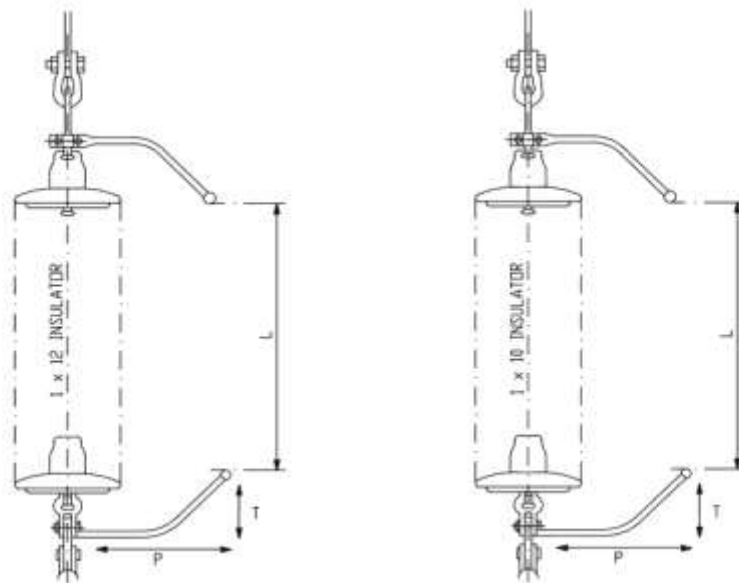


Figure 2. Change in the arcing-horn gap resulting from the reduction of the disk insulator count from 12 to 10 units

Applying equations (3) and (4) gives a CFO of 709.8 kV (positive polarity) and 1209.219 kV (negative polarity) for the 12-disk string, against 556.5 kV and 995.333 kV for the 10-disk string, a reduction of 153.3 kV and 213.886 kV, respectively. Table 1 summarizes these results.

Table 1. Arcing-horn flashover voltage (CFO) for each disk insulator configuration

Configuration	Horn Gap (m)	CFO Positive (kV)	CFO Negative (kV)
12-disk string	1.352	709.8	1209.219
10-disk string	1.060	556.5	995.333

The potential and field-magnitude distribution obtained from the COMSOL simulation, showing the field concentrated at the tip of the horn electrode in both configurations, which is where a discharge is expected to initiate. Comparing these CFO values against the series puncture withstand voltage of the disk insulator string - 1560 kV for 12 disks and 1300 kV for 10 disks, based on a 130 kV per-unit rating - shows that the horn-gap CFO remains below the string's withstand voltage in both configurations and at both polarities (709.8 kV and 1209.219 kV against 1560 kV; 556.5 kV and 995.333 kV against 1300 kV). This indicates that a lightning-induced discharge would still be expected to flash over at the arcing-horn gap before reaching the insulator surface in either configuration, so both configurations satisfy the insulation-coordination principle of SPLN T3.008-1:2021, even though the 10-disk gap sits slightly below the 1.095-1.241 m range recommended by SPLN 121:1996 (75%-85% of the string's total length).

3.3. Insulation Margin to BIL

The protective ratio and protective margin of each configuration relative to the 150 kV system's 750 kV BIL were evaluated using equations (5) and (6); Table 2 lists the results.

Table 2. Results of the insulation margin analysis relative to BIL

Configuration	Disk String Withstand Voltage (kV)	BIL (kV)	Insulation Margin (%)
10-disk	1300	750	73.3
12-disk	1560	750	108

A protective ratio above one in both configurations shows that the disk insulator string's withstand voltage exceeds the BIL requirement. Because the BIL is fixed while the string's withstand voltage scales with the number of disks, the 12-disk configuration reaches a substantially larger margin (108%) than the 10-disk configuration (73.3%). This margin over the BIL, however, describes the insulator string in isolation; it does not by itself determine whether the arcing horn will actually intercept a discharge before the insulator does, since that determination depends on the horn-gap CFO evaluated in Section 3.2, not on the insulator's margin to BIL.

3.4. Relationship between Arcing Horn Gap and Flashover Voltage

Figure 3 plots the CFO against disk count for both insulator materials. The plotted values confirm a proportional relationship between the horn-gap distance and the CFO: a longer gap requires a higher voltage to flash over. The negative-polarity CFO is consistently higher than the positive-polarity CFO at both disk counts, consistent with the higher field generally required to initiate a negative streamer discharge. The CFO values coincide exactly between glass and ceramic material at a given disk count, because equations (3) and (4) depend only on the gap length d , not on the insulator's dielectric material; any performance difference between the two materials would have to come from a different parameter, such as creepage distance under pollution, rather than from the horn-gap CFO calculated here.

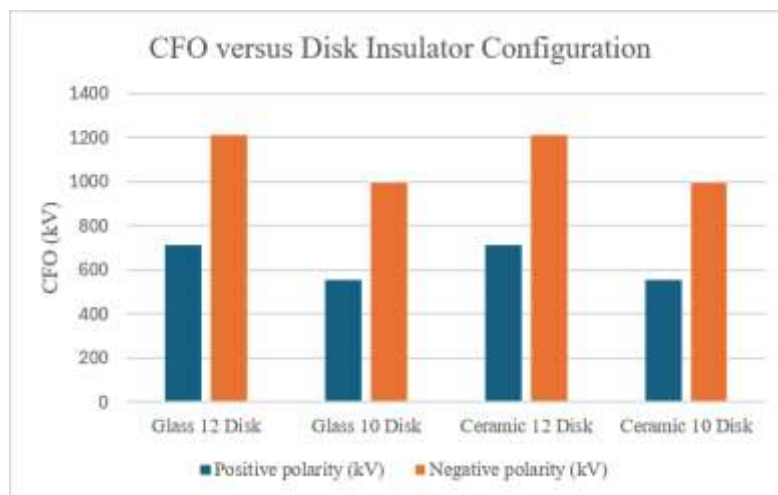


Figure 3. CFO plotted against disk insulator configuration

Taken together, these results show that shortening the arcing-horn gap from 1.352 m to 1.060 m, as happens when the disk count is reduced from 12 to 10 without resizing the horn, lowers the gap's flashover voltage by 153.3 kV at positive polarity and 213.886 kV at negative polarity. Although both configurations still satisfy the insulation-coordination principle discussed in Section 3.2, a narrower gap is expected to flash over at a lower transient overvoltage, which over repeated events could accelerate electrode erosion at the horn tips and contribute to more frequent transient disturbances on the line, broadly consistent with the gap-length dependence reported for this network's overall trip-out performance [10], [11]. Quantifying the resulting change in outage rate, failure rate, or lightning flash density, however, would require field or statistical operating data that fall outside the scope of the present analytical and simulation-based study.

3.5. Comparison of Glass and Ceramic Disk Insulators

Table 3 compares the datasheet parameters of the two disk insulator materials available for this line - the Sediver U120BP toughened-glass unit and the PPC Insulators U120BP porcelain unit - both of which were used as the basis for the series puncture withstand voltage applied in Sections 3.2 and 3.3.

Table 3. Comparison of glass and ceramic U120BP disk insulator datasheets

Parameter	Glass (Sediver)	Ceramic (PPC)
Dielectric material	Toughened glass	Porcelain
Disk diameter / spacing	280 mm / 146 mm	280 mm / 146 mm
Creepage distance	445 mm	440 mm
Mechanical failing load	120 kN	120 kN
Dry / wet power-frequency withstand	85 kV / 50 kV	85 kV / 50 kV
Lightning impulse withstand	125 kV	125 kV
Puncture withstand voltage	130 kV	130 kV
Approximate weight	5.5 kg	8.0 kg

Because the two materials share the same mechanical rating, power-frequency and impulse withstand voltage, and unit spacing, the CFO and series puncture withstand voltage calculated in Sections 3.2 and 3.3 apply equally to either material; the only functional difference between them is the 5 mm shorter creepage distance of the porcelain unit and its roughly 45% higher weight, which affect pollution performance and mechanical loading on the tower rather than the lightning-impulse flashover behavior analyzed in this study. In practice, the lighter glass unit is also easier to inspect visually, since a cracked or punctured glass shell tends to shatter and expose the fault, while an equivalent defect in a porcelain shell is often concealed inside the cement cap; this inspection advantage does not change the CFO result but is a relevant operational consideration when selecting a replacement unit for the disk-count correction recommended in Section 4.

3.6. Implications of the Gap Mismatch for Insulation Coordination and Maintenance

The gap reduction from 1.352 m to 1.060 m analyzed in Section 3.2 does not, by itself, place either configuration outside the insulation-coordination principle in SPLN T3.008-1:2021; both gaps still flash over below the withstand voltage of their disk insulator string. It does, however, move the 10-disk configuration's protective margin closer to the geometric recommendation in SPLN 121:1996 than intended, and general practice for arcing-horn maintenance points to two related concerns that follow from any unplanned gap-shortening. First, a narrower gap flashes over at a lower transient overvoltage, so it can be expected to discharge somewhat more often than a gap sized for the correct disk count, and repeated arcing at the same fixed electrode tips gradually erodes the rounded profile discussed in Section 2, which over time changes the effective gap length and the CFO computed from equations (3)-(4). Second, because the arcing horn is only a passive, uncontrolled spark gap and cannot itself interrupt the follow current from the network [14], any additional discharge event it takes on is still cleared through the network's own protection and, if frequent enough, is reflected in higher line maintenance activity. Confirming whether either effect is significant on this specific line would require monitoring data - discharge counts, electrode wear measurements, or protective-relay trip records - that were not part of the technical datasheets and approval drawings used in this study, so the present analysis supports the geometric and dielectric recommendation in Section 4 without extending it into a quantified reliability or maintenance-cost projection.

4. CONCLUSION

This study shows that installing an arcing horn sized for a 12-disk insulator string onto the as-built 10-disk string shortens the horn-to-horn gap and lowers its calculated flashover voltage, while the CFO of each configuration remains below the series puncture withstand voltage of its own disk insulator string. This is a necessary, but not sufficient, condition for the horn to protect the string, and it should not be read as a demonstration of complete insulation coordination, which would require a statistical treatment of overvoltage stresses and margins beyond the scope of this study. Because the 10-disk gap also falls slightly short of the range recommended by SPLN 121:1996, the arcing horn should be resized or repositioned to match the as-installed disk count, and any future change in disk configuration on this line should be followed by a re-evaluation of the horn gap; the effect of the mismatch on outage rate, failure rate, or lightning flash density can only be established with field or statistical data.

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