Impact of Arrester Models in Placement Determination at 150 kV Srondol Substation

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***Abstract*— Arrester is one of the most important equipment to protect substation equipment from overvoltage interference caused by lightning stroke. Previous studies had been issued several theoretical models for arrester in analytical purposes. However, no record about the use of models in practical. In substation, placement and amount of arrester are crucial aspects in design to protect the transformer and other vital equipment inside the substation. This work gives the impact analysis of arrester model as part of design in placement and distance inside Srondol 150 kV substation, Central Java Indonesia. An overvoltage interference caused by direct lightning stroke to the phase wire is simulated by using ATPDraw to observe the voltage value after impulse waveform passing through the arrester. There are three tested models i.e. IEEE model, Pinceti Model and Fernandez model to know the arrester effectiveness to reduce overvoltage below basic insulation level (BIL) of equipment. Several obtained results show the suitable modes to reduce the voltage based on provided distance location and number of arrester.**

Keywords—arrester model, substation, lightning protection, ATPDraw

I. INTRODUCTION

Substation is a part of the electric power system components. Substation distributed electrical power from power plant to main load, so it has to be highly reliable. Lightning is one of the natural phenomena which can cause overvoltage interference [1]. Metal oxide arrester is one of the protection tool of overvoltage interference in substation or transmission line [2]. That overvoltage value is expected to not exceed than basic insulation level (BIL) of electrical equipment. Based on IEEE C62.22 standard, arrester can applied in the substation inlet to protect the equipment like power transformer [3]. Srondol 150 kV substation gets power supply through overhead line transmission 150 kV for 8.045 kms 24 towers from Pandean Lamper-1 and 2, to provide electrical power for middle voltage and low voltage consumers through 20 kV feeder and to connect Pandean Lamper substation and Krapyak substation. Therefore, Srondol 150 kV substation is expected for having high reliability. In Srondol 150 kV substation, arrester equipment is applied in the substation inlet and transformer terminal. The gap between arrester and transformer with non-linear resistance characteristic can be analyzed by ATP/EMTP software in the reference [4]. In reference [5], some of arrester models are used to analyze the overvoltage interference caused by lightning stroke to the transmission line. However, the research about determination of arrester distance with different model of arrester using the field parameter has not been doing yet. Hence, in this research, both of the gap placement and amount of arrester analysis in the substation is using 3 kinds of arrester model, which is IEEE Model, Pinceti Model, and Fernandez Model based on Srondol 150 kV substation parameter. These three types of models is dedicated to evaluate suitable the most arrester model during overvoltage interference in the substation and arrester discharge voltage caused by direct lightning stroke to the phase wire.

II. ARRESTER MODEL

A. IEEE Model

Fig. 1 shows IEEE arrester model [6]. There are two non-linear resistance which were separated by resistor and inductor connected parallel. In this model, capacitor represents the height of arrester.

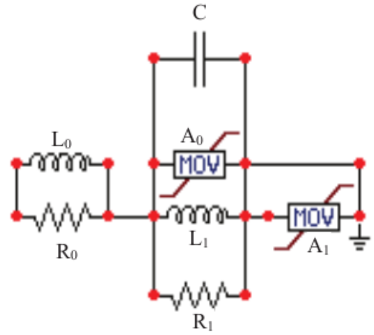

Fig. 1. Model of Arrester IEEE

The IEEE arrester parameter could be calculated by 1 – 5:

$$L_0 = 0.2 \times \frac{d}{n} \quad (1)$$

$$R_0 = 100 \times \frac{d}{n} \quad (2)$$

$$L_1 = 15 \times \frac{d}{n} \quad (3)$$

$$R_1 = 65 \times \frac{d}{n} \quad (4)$$

$$C = 100 \times \frac{n}{d} \quad (5)$$

Where:

d is arrester height in meter, and n is amount of parallel column from metal oxide

B. Pinceti Model

Fig. 2 shows Pinceti arrester model [7]. Those model based on IEEE arrester model. However, there are several modification, in the Pinceti model, the capacitance value is zero or it can be neglected, and resistance at the inlet is set in 1MΩ.

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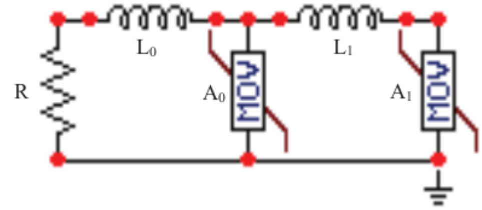

Fig. 2. Model of Arrester Pinceti

The Pinceti arrester parameter could be calculated by 6 and 7:

$$L_0 = \frac{1}{4} \cdot \frac{V_{r1/T2} - V_{r8/20}}{V_{r8/20}} \cdot V_n \qquad (6)$$

$$L_1 = \frac{1}{12} \cdot \frac{V_{r1/T2} - V_{r8/20}}{V_{r8/20}} \cdot V_n \qquad (7)$$

Where:

Vn = Voltage ratings of arrester, kV

Vr1/T2 = Residual voltage for circuit surge current Fast-Front 10 kA (1/T2 µs)

Vr8/20 = Residual voltage for surge current 10 kA (8/20 µs)

C. Fernandez Model

Fig. 3 shows Fernandez arrester model [8]. This model is based on IEEE arrester model too. However, the inductance value in the inlet can be neglected and resistance is set as 1MΩ.

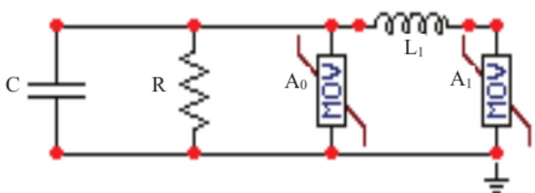

Fig. 3. Model of Arrester Fernandez

The Fernandez arrester parameter could be calculated by 8 and 9:

$$C = \frac{1}{55} \cdot \frac{V_{r8/20} - V_{ss}}{V_{r8/20}} \cdot V_n \qquad (8)$$

$$L_1 = \frac{2}{5} \cdot \frac{V_{r8/20} - V_{ss}}{V_{r8/20}} \cdot V_n \qquad (9)$$

Where:

V_n = Voltage ratings of arrester, kV

V_{SS} = Residual voltage for circuit surge current 500 A

$V_{r8/20}$ = Residual voltage for surge current 10 kA (8/20 µs)

III. ARRESTER PROTECTION SYSTEM MODELLING

To analyse the performance of arrester protection system, we hit the phase wire with lightning stroke in 150 kV substation with an amplitude of 10 kA. However, arresters are expected to be able to prevent the lightning stroke interference, so that voltage surge value does not exceed than basic insulation level in the IEEE C62.22 standard.

A. Data of Srondol 150 kV Substation

Srondol 150 kV substation receives electrical power supply through overhead line transmission 150 kV for 8.045 kms or 24 towers from Pandean Lamper-1 and 2 and those lines are connected to busbar 1 and 2. There are several equipments like Circuit Breaker (CB), Disconnecting Switch (DS) and two step down transformers. There are two arresters protect substation from a high voltage disruption, those arrester are located at an substation entrance channel and transformer terminal as shown in Fig. 4.

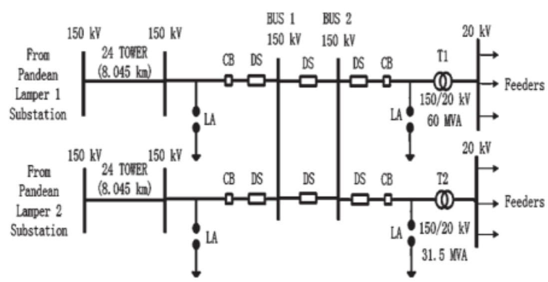

Fig. 4. Scheme of Power Network

Table I shows data contain a list of equipment and grounding values at Srondol 150 kV substation. This data is used for analyse the performance of arrester protection system caused by lightning stroke interference.

TABLE I. DATA OF SRONDOL 150 KV SUBSTATION

Parameter	Values	Unit
Arrester height (d)	1.63	m
Amount of Column Arrester (n)	1	
Voltage system (Vn)	150	kV
Foot tower resistivity	3.35	Ohm
Ground tower resistivity	3.35	Ohm
Tower height	40.55	m
The length of the tower arm	6.6	m
Amount of tower	24	
The length of transmission line	8.045	km
The size of the transmission conductor	282.5	mm
The size of the substation conductor	800	mm
Grounding substation resistivity	0.22	Ohm
Arrester rating	10	kA
Power transformer rating	150/20	kV
Residual arrester voltage 1/2 µS (10 kA) (Vr1/T2)	391	kV
Residual arrester voltage 8/20 µS (10 kA) (Vr8/20)	360	kV
Residual arrester voltage 30/60 µS (1 kA) (V_{SS})	296	kV

B. Modelling of Transmission System and Srondol 150 kV Substation

In this study ATPDraw is used to evaluate arrester protection in Srondol 150 kV substation which is connected to

150 kV transmission line with 8.045 km long and it supported by twenty four towers as shown in Fig. 5.

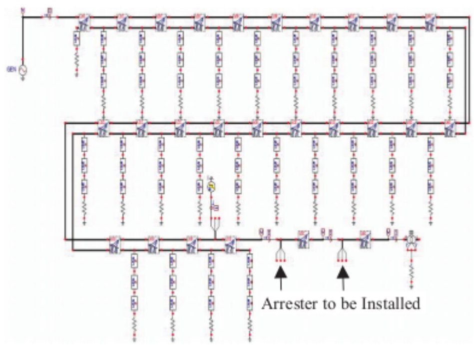

Fig. 5. ATP Scheme of Power Network

C. Direct Lightning Strike to Substation with ATPDraw Simulation

The waveform of lightning surge refers to IEEE C62.11-2005 standard, so the waveform of fast-front lightning surge test is 1.2/50 µs [9] and it is shown In Fig. 6.

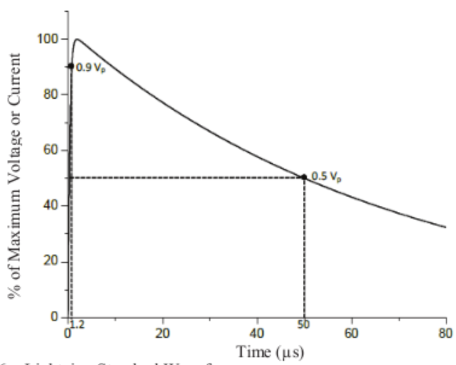

Fig. 6. Lightning Standard Waveform

Fig. 7 Illustrates a simplified model for the transmission line and the placement of arrester at substation using ATPDraw. In this figure, a 60 MVA transformer has a primary rating voltage of 150 kV.

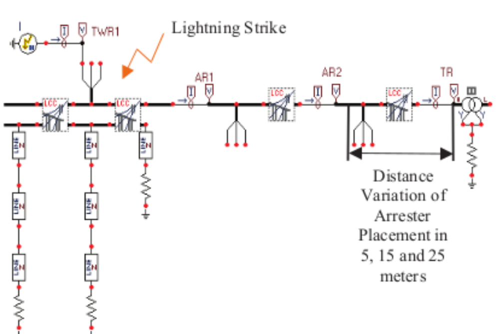

Fig. 7. ATP Scheme for Lightning Strike Simulation

In this study, three different cases is proposed to be investigated and analyzed. The first case is condition without lightning arresters, the second is arrester installed on the terminal of the transformer, and the third is two surge arresters are installed at the entrance of the substation and the terminal of the transformer. During the experiment, lightning hits phase C at the distance between the transmission towers, i.e. 0.33 kilometers far from the Srondol 150 kV substation. The source of lightning on ATPDraw software is represented by a Heidler component for IEEE C62.11-2005 standard waveform 1.2 x 50 µs and amplitude 10 kA.

IV. RESULT AND ANALYSIS

The assessment in this work includes overvoltage and residual voltage of arresters. The arrester separation space from transformer is in the distance range 5, 15 and 25 meters. In each case, the analysis covers the basic insulation level (BIL) of the transformer and error residual voltage of the arrester provided manufacture's datasheet. Moreover, for the same case, the analysis for arrester addition at the entrance substation is also done.

A. Parameters of Arrester Models

Table II shows the initial computed parameters for the above three models are shown.

TABLE II. PARAMETERS OF ARRESTER MODELS

Parameters	Arresters Model		
	IEEE	**Pinceti**	**Fernandez**
R_0/R	163 Ω	1 MΩ	1 MΩ
L_0	3.2E-6 mH	3.22e-3 mH	10.66e-3 mH
R_1	105.95 Ω	-	-
L_1	2.4e-5 mH	1.07e-3 mH	-
C	6.13e-11 pF	-	0.48 pF

For Case-1, the simulated system during the experiment is carried out without a arrester installed at a transformer terminal and entrance substation. The result shown in Fig. 8 provides information voltage at terminal primary voltage of transformer when lightning struck directly to the C phase wire using ATPDraw. Since there is no arrester are installed, the maximum voltage is over 5587 kV which is much higher than the BIL value (≤750 kV) based on IEEE C62.22 standard [3].

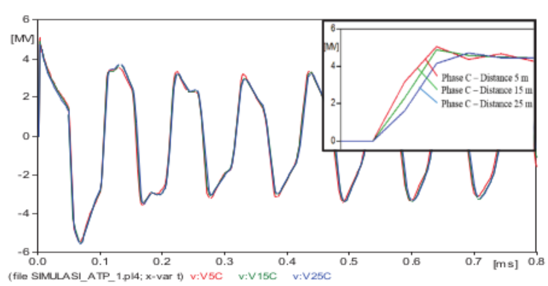

Fig. 8. Case-1, The Voltage at Transformer (Arrester not Installed)

In the first experiment for Case-2, the IEEE arrester model is used in the simulation for overvoltage evaluation in Srondol 150 kV substation caused by lightning struck directly to the C phase wire. This evaluation is using ATPDraw. Fig. 9 show the values of the terminal transformer voltage on the primary side 150 kV when distance arrester is 5 m, 15 m and 25 m, maximum voltage for each distance is 508 kV, 563 kV and 613 kV.

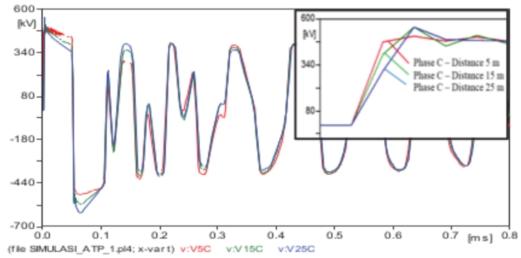

Fig. 9. Case-2, The Voltage at Transformer with One Arrester is Installed Using IEEE Model

In the second experiment for Case-2, arrester model Pinceti is used in the simulation for overvoltage evaluation in Srondol 150 kV substation caused by lightning struck directly to the C phase wire. This evaluation is using ATPDraw. Fig. 10 show the values of the terminal transformer voltage on the primary side 150 kV when distance 5 m, 15 m and 25 m, maximum voltage for each distance is 537 kV, 570 kV and 618 kV.

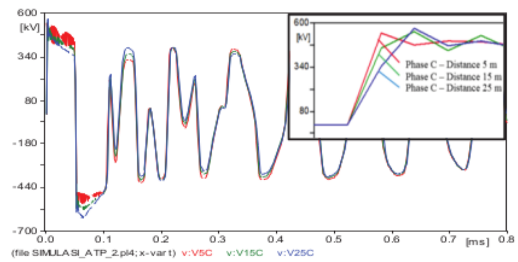

Fig. 10. Case-2, The Voltage at Transformer with One Arrester is Installed Using Pinceti Model

For the last experiment in Case-2, arrester of Fernandez model is used in the simulation for overvoltage evaluation in Srondol 150 kV substation caused by lightning struck directly to the C phase wire. This evaluation is using ATPDraw. Fig. 11 show the values of the terminal transformer voltage on the primary side 150 kV when distance 5 m, 15 m and 25 m, maximum voltage for each distance is 624 kV, 562 kV and 599 kV.

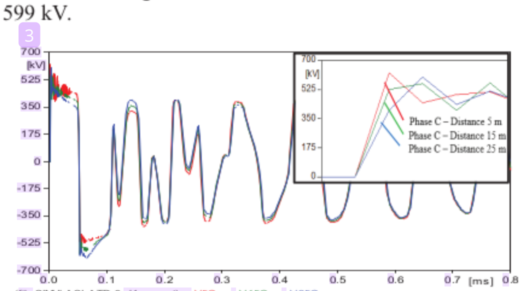

Fig. 11. Case-2, The Voltage at Transformer with One Arrester is Installed Using Fernandez Model

In the first experiment in the Case-3, IEEE arrester model is used in the simulation for overvoltage evaluation in Srondol 150 kV substation caused by lightning struck directly to the C phase wire. This evaluation is using ATPDraw, same as with Case-2, this case added arrester at the entrance of the substation. Fig. 12 show the values of the terminal transformer voltage on the primary side 150 kV when distance 5 m, 15 m and 25 m. The maximum voltage for each distance is 423 kV, 460 kV and 438 kV.

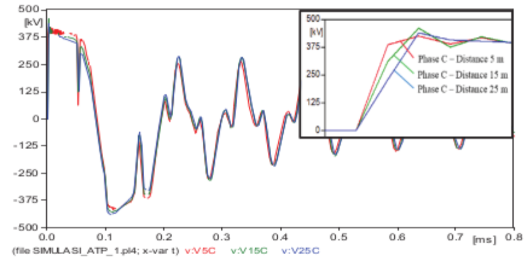

Fig. 12. Case-3, The Voltage at Transformer with Two Arrester is Installed Using IEEE Model

In the second experiment at the Case-3, Pinceti arrester model is used in the simulation for overvoltage evaluation in Srondol 150 kV substation caused by lightning struck directly to the C phase wire. This evaluation is using ATPDraw, same as with Case-2, this case added arrester at the entrance of the substation. Fig. 13 show the values of the terminal transformer voltage on the primary side 150 kV when distance 5 m, 15 m and 25 m. The maximum voltage for each distance is 430 kV, 457 kV and 452 kV.

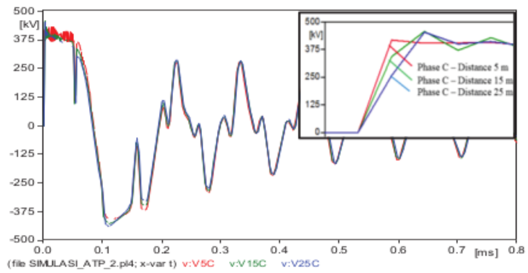

Fig. 13. Case-3, The Voltage at Transformer with Two Arrester is Installed Using Pinceti Model

In the last experiment at the Case-3, arrester model Fernandez is used in the simulation for overvoltage evaluation in Srondol 150 kV substation caused by lightning struck directly to the C phase wire. This evaluation is using ATPDraw, same as with Case-2, this case added arrester at the entrance of the substation. Fig. 14 show the values of the terminal transformer voltage on the primary side 150 kV when distance 5 m, 15 m and 25 m. The maximum voltage for each distance is 453 kV, 450 kV and 459 kV.

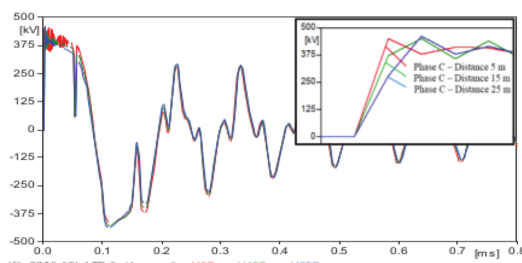

Fig. 14. Case-3, The Voltage at Transformer with Two Arrester is Installed Using Fernandez Model

To become a good protection system, arrester must be able to reduce the overvoltage so that the voltage should not exceed the basic insulation level (BIL) of equipment.. Ratio of basic insulation level does not less than 20% [4]. If this ratio was less than 20% will result in destructive damage for transformer. Calculation result are shown Fig. 15 and Fig. 16.

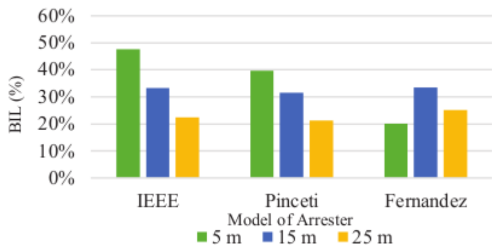

Fig. 15. Percentage of BIL for Each Arrester Models for Case-2

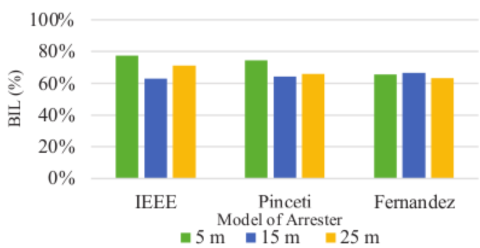

Fig. 16. Percentage of BIL for Each Arrester Models for Case-3

Error calculation results of the expected residual voltage arrester by referring to arrester manufactures datasheet are shown in Fig. 17 and Fig. 18 for each arresters models. Case - 3 gives the smallest results for residual voltage, so two surge arresters installed at the entrance of the substation and the terminal of the transformer becomes the best recommendation in design of placement of arrester in substation.

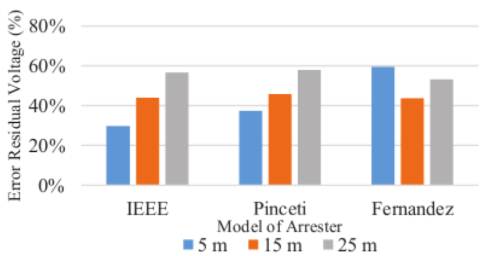

Fig. 17. Error of Residual Voltage for Each Arrester Models for Case-2

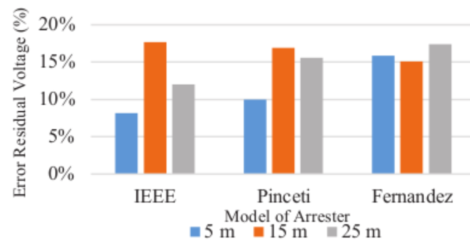

Fig. 18. Error of Residual Voltage for Each Arrester Models for Case-3

TABLE III. COMPARISON RESIDUAL VOLTAGE FOR CASE-3

Model Arresters	Manufacture's Specification (kV)	Simulation Results (kV)	%Error
IEEE	391	440	11.20
Pinceti		446	12.39
Fernandez		454	13.87

Based on calculation of percentage basic insulation level (BIL), the location of arrester mounted at the entrance substation is better than arrester installed only on the terminal of transformer. BIL percentage can reach 77% while before only 48%. The three model of arrester give the same curves as different peak voltage. Based on Table III, the IEEE arrester model has the smallest residual voltage error than the others.

V. CONCLUSION

Installation of arresters on Srondol 150 kV substations accordant to IEEE C62.22 standard, the voltage value does not exceed than basic insulation level (≤750 kV). Adding the arrester in the substation inlet could increase the protection performance as it is recommended in Case-3. Among three models, the IEEE model give us the most accurate representation of arrester because give the lowest error for the values given by manufacture.

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