Modeling of transient caused by lightning strike at Nias high voltage substation using ATP-EMTP case study

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Abstract. Lightning has always been a dangerous threat to power system equipment consisting of: power plants, substations, transmission lines and distribution lines. Commonly, the overhead high voltage transmission line is subjected to lightning strikes. Therefore the protection level against lightning is determined based on the level of insulation of equipment. To prevent damage due to the equipment due to a lightning strike, an arrester is used. In this study, three models of arrester are used as comparison viz. IEEE arrester model, Micaela arrester model and Karbalaye arrester model. The system were simulated by using the Alternative Transients Program (ATP) software. The results show that the lightning arrester is declared successful in protecting the transmission system, where the three lightning arresters have Margin Protection (MP) arrester which reaches 28%. In the simulation, it is known that the IEEE and Karbalaye arrester successfully breakdown the lightning current in transmission system so that the transient overvoltage recorded on the transformer does not exceed the Basic Insulation Level (BIL) value of the transformer. While the Pincenti arrester has also succeeded in reducing the voltage on the system but its value is greater than the transformer BIL of the substation, Teluk Dalam, Nias.

1. Introduction

Lightning has always been a dangerous threat to power system equipment consisting of: power plant, substation, transmission lines and distribution channels. Lightning strikes are very possible to cause damage to insulation, therefore the level of isolation of channels and equipment is determined based on lightning protection. Most air transmission lines can be protected from direct lightning strikes by one or several protective wires which are located above the phase conductor. This protective wire is also called a ground wire, which is connected to the ground through a transmission tower that supports the channel [1]. To prevent damage to equipment due to lightning strikes, arresters are used. Arrester is a protector against overvoltages, both caused by lightning surges and connecting surges. In normal circumstances the arrester acts as an insulator, but if struck by lightning it will act as a conductor with relatively low resistance so that it can conduct an electric current to the ground. After the lightning surge the end, the arrester must immediately to being insulator, so that power breaker does not have time to open. One type of arrester is MOV (metal oxide varistor), which is an arrester without interrupted series. Because this arrester is very dependent on the resistors in the arrester itself [1] [2].

The complexity of direct trials on electrical components to analyze transient overvoltages in high voltage substations has led researchers to create simulators in the form of software to facilitate transient voltage analysis. The ATP-EMTP (Alternative Transient Program of the Electro-Magnetic...
Transient Program) program is very appropriate if used to analyze transients in switching surges or lightning surges because light ATP-EMTP software is also an integrated computer software that is integrated specifically designed to solve transient problems in electric power systems, for concentrated circuits, distributed circuits or a combination of these two circuits because this program specifically provides modeling for generators, circuit breakers, transformers, lightning surge sources and modeling various types of transmission lines [3]. EMTP software is also an integrated computer software that is integrated specifically designed to solve transient problems in electric power systems, for concentrated circuits, distributed circuits or a combination of these two circuits because this program specifically provides modeling for generators, circuit breakers, transformers, lightning surge sources and modeling various types of transmission lines [4].

Related with this project, found that Nias Islands has geographical features such as the sea and mountains which affect sudden extreme weather changes which cause many lightning disturbances. This research simulates transient overvoltages caused by direct and indirect lightning strikes at high voltage substations to protect transformers simulated using ATP / EMTP software with a case study on Gunung Sitoli High Voltage Air Line 70 kV PLN Gunung Sitoli – Teluk Dalam.

2. Method
Modeling of transmission lines using the EMTP was investigated by J. A Martinez [5] [6]. The use of ATP-EMTP software is to simulate an MOV (Metal Oxide Varistor) arrester type with Pinceti Mode and Fernandes Mode on a 900m single line diagram with 132 kV on three towers to evaluate the performance of the arrester modes in protecting the tower and transmission network from direct and indirect lightning strikes [7]. The other research about lightning arrester modeling using ATP-EMPT, which use metal oxide surge arrester IEEE model for counting the value of until 20 kA lightning strike [8]. Then, analyze the effect of lightning on 400 kV AIS (Air Insulated Station) or substations using air insulation which is also simulated with the ATP-EMTP software [9].

2.1 Data Description
To develop the simulation of direct and undirect lightning strikes at High Voltage Air Line 70 kV Gunung Sitoli-Teluk Dalam, we must get data from PLN Wilayah Sumatera Utara. Some data needed for this research are:
1. Tower Data
2. Phase Wire Specification
3. Arrester Data
4. Arrester Characteristic
5. Transformer Data

To support the simulation, first we must design the tower design as shown in Figure below:

![Figure 1. 70 kV High Voltage Air Line Tower Design and Data](image-url)
Transmission Tower Calculation: [10]

1. Calculation of tower surge impedance for phase wire:

\[ Z = 30 \ln \left( \frac{2(h^2 + r^2)}{r^2} \right) \]  \hspace{1cm} (1)

\( Z = \) air impedance (Ω)
\( r = \) tower radius (m)

2. Calculation of tower arm impedance:

\[ Z = 60 \ln \frac{2h}{r} \]  \hspace{1cm} (2)

3. Calculation of tower arm phase wire:

\[ Z = 60 \ln \frac{2h}{4r} \]  \hspace{1cm} (3)

The followings are phase wire, arrester and transformer specification and values:

**Table 1. Phase wire specification**

| Conductor | Sectional Area (mm²) | Diameter (cm) | Resistant (Ω/km) | Reactance (Ω/km) |
|-----------|----------------------|---------------|-----------------|-----------------|
| Phase Wire | 42                   | 2.19          | 0.1218          | 0.2971          |

**Table 2. Arrester specification**

| Type       | Maximum Voltage (kV) | Short Circuit Current (kA) | Uc (kV) | Ur (kV) | Operating Voltage (kV) |
|------------|----------------------|-----------------------------|---------|---------|------------------------|
| PE XLIM 0Q72-YV072 | 77                   | 65                          | 72      | 58      | 61.6                   |

**Table 3. IEEE arrester characteristic**

| I (A) | \( A_0 \) V (Volt) | \( A_1 \) V (Volt) |
|-------|---------------------|---------------------|
| 10    | 148750              | 0                   |
| 100   | 163710              | 130730              |
| 1000  | 178500              | 144500              |
| 2000  | 184960              | 151980              |
| 4000  | 191250              | 157250              |
| 6000  | 193460              | 159460              |
| 8000  | 198730              | 162520              |
| 10000 | 201960              | 164730              |
| 12000 | 205020              | 165750              |
| 14000 | 209270              | 167960              |
| 16000 | 212500              | 168980              |
| 18000 | 217777              | 170000              |
| 20000 | 223210              | 171020              |
### Table 4. Transformer characteristic

| Type       | Rated Power (MVA) | Freq (Hz) | Group Vector | Primary Voltage (kV) | Secondary Voltage (kV) | BIL (kV) |
|------------|-------------------|-----------|--------------|----------------------|------------------------|----------|
| PEXLIM 0Q72-YV072 | 30 MVA             | 50 Hz     | Ynyn0        | 66                   | 20                     | 140      |

3. ATP-EMTP

After getting the data and equipment specifications from PT. PLN Medan, the data will be processed and then modeling will be done using ATP software where the results of the modeling will then be analyzed with lightning current value that can be changes. The modeling made is the AC source, transmission tower, isolator, transformer and IEEE, Karbalaye and also Micaela Model Arrester. The following figure is a series of simulation with lightning conditions striking phase R before arrester modeling is installed.

![Simulation with Lightning Strikes at Phase R without Arrester](image)

**Figure 2.** Simulation with Lightning Strikes at Phase R without Arrester

When lightning is simulated striking one of the phases, there will be transient overvoltage in that phase and the transformer terminal. Figure 3 shows the 10 kA lightning transient voltage waveform with the IEC and CIGRE Standards in the R phase.

![Lightning wave with IEC Standards of 10 kV in phase](image)

**Figure 3.** Lightning wave with IEC Standards of 10 kV in phase
Figure 4. Lightning wave with CIGRE Standards of 10 kV in phase R

Table 5. Simulation with IEC Standards in R phase and transformer without arrester

| Lightning Current (kA) | Lightning Wave t_f/t_tail (µs) | Phase | Voltage on Phase (kV) | Voltage on Transformer without Arrester (kV) |
|------------------------|--------------------------------|-------|-----------------------|---------------------------------------------|
| 10                     |                                | R     | 1.519,8               | 1.275,8                                     |
| 20                     | 1.2/50 (IEC)                  | S     | 454,7                 | 456,2                                       |
|                        |                                | T     | 321,9                 | 457,1                                       |
|                        |                                | R     | 2992,7                | 2.534,6                                     |
|                        |                                | S     | 922,3                 | 913,8                                       |
|                        |                                | T     | 654,2                 | 944,1                                       |
|                        |                                | R     | 4.479                 | 3.822                                       |
| 30                     |                                | S     | 1393,5                | 1.414,7                                     |
|                        |                                | T     | 988,4                 | 1.467                                       |
|                        |                                | R     | 5.958,7               | 5.090,4                                     |
|                        |                                | S     | 1.865,4               | 1.886,7                                     |
|                        |                                | T     | 1.323,9               | 1.958,3                                     |
|                        |                                | R     | 7.438,3               | 6.352                                       |
| 40                     |                                | S     | 2.333,6               | 2.348,6                                     |
|                        |                                | T     | 1.657,9               | 2.428,2                                     |
| 50                     |                                | S     | 2.333,6               | 2.348,6                                     |

According to Table 4, the transformer BIL is 140kV. Figure 4 shows the comparison of the phase voltage at the transformer terminal and the transformer BIL without arrester on the system using CIGRE standard on 10 kA-50 kA lightning.

Table 6. Simulation with CIGRE standards in R phase and transformer without arrester

| Lightning Current (kA) | Lightning Wave t_f/t_tail (µs) | Phase | Voltage on Phase (kV) | Voltage on Transformer without Arrester (kV) |
|------------------------|--------------------------------|-------|-----------------------|---------------------------------------------|
| 10                     | 3.3/77.5 (CIGRE)              | R     | 2.997,1               | 2.534,6                                     |
| 20                     |                                | S     | 924,1                 | 913,8                                       |
|                        |                                | T     | 655,3                 | 944,1                                       |
| 30                     |                                | R     | 4.476,4               | 3.822                                       |
|                        |                                | S     | 1,392,9               | 1,414,7                                     |
The values in the table above can be converted into graphs to make it easier for researchers to see the values in detail as shown in the figures below:

**Figure 5.** Comparison of phase voltage at transformer terminal and transformer BIL with surge current of 10 kA - 50 kA with IEC standard

**Figure 6.** Comparison of phase voltage at transformer terminal and transformer BIL with a surge current of 10 kA - 50 kA using IEC standard

After injecting 10 kA - 50 kA current with 10 kA intervals in ATP Draw simulations, it shows how far the lightning effect to the transformer - as an important equipment in the transmission system - which results if the lightning value more than BIL, it will damage insulation and the equipment due to insulation break down and also reduced transformer’s lifetime. The following is a simulation image after the installation of arresters by the IEEE, Pincenti and Karbalaye methods with arrester and transformer distances according to field conditions (12-15)
Figure 7. Simulation after arrester installation by the (a) IEEE, (b) Micaela and (c) Karbalaye method

4. Result And Discussion

After the simulation is finished, the following result will be seen, such as:
Table 7. Comparison of transformer BIL and terminal transformer before and after using IEEE arrester in IEC and CIGRE mode

| Lightning Injection (kA) | Phase R in Terminal Transformer Before Using Arrester (kV) | Phase R in Terminal Transformer After Using IEEE Arrester (kV) | BIL (kV) |
|-------------------------|----------------------------------------------------------|-------------------------------------------------------------|----------|
|                         | IEC            | CIGRE          | IEC            | CIGRE          |        |
| 10 kA                   | 439            | 636            | 59.21          | 60.29          | 140     |
| 20 kA                   | 822            | 1,238          | 64.61          | 62.67          | 140     |
| 30 kA                   | 1,204          | 1,839          | 71.57          | 64.69          | 140     |
| 40 kA                   | 1,588          | 2,441          | 72.69          | 67.42          | 140     |
| 50 kA                   | 1,970          | 3,046          | 90.81          | 69.79          | 140     |

Due to the transformer terminal voltage value without using arrester is too high, the chart below shows the comparison of the terminal phase R after using arresters with transformer BIL to show the effectiveness of the arrester.

Figure 8. Comparison between phase R using IEEE arrester in IEC and CIGRE mode and transformer BIL.

Table 8. Comparison of Transformer BIL and Terminal Transformer Before and After Using Karbalaye Arrester in IEC and CIGRE Standards

| Lightning Injection (kA) | Phase R in Terminal Transformer Before Using Arrester (kV) | Phase R in Terminal Transformer After Using Karbalaye Arrester (kV) | BIL (kV) |
|-------------------------|----------------------------------------------------------|-------------------------------------------------------------|----------|
|                         | IEC            | CIGRE          | IEC            | CIGRE          |        |
| 10 kA                   | 439            | 636            | 66.96          | 57.70          | 140     |
| 20 kA                   | 822            | 1,238          | 57.77          | 57.75          | 140     |
| 30 kA                   | 1,204          | 1,839          | 58.06          | 57.78          | 140     |
| 40 kA                   | 1,588          | 2,441          | 58.46          | 58.36          | 140     |
| 50 kA                   | 1,970          | 3,046          | 58.82          | 58.70          | 140     |

The chart below shows the comparison of the terminal phase R after using arresters with transformer BIL to show the effectiveness of using the arrester.
Figure 9. Comparison between phase R using karbalaye arrester in IEC and CIGRE mode and transformer BIL

Table 9. Comparison of transformer BIL and terminal before and after using Karbalaye arrester in IEC and CIGRE mode

| Lightning Injection (kA) | Phase R in Terminal Transformer Before Using Arrester (kV) | Phase R in Terminal Transformer After Using Arrester (kV) | BIL (kV) |
|------------------------|--------------------------------------------------------|----------------------------------------------------------|---------|
|                        | IEC          | CIGRE        | IEC          | CIGRE        |                 |
| 10 kA                  | 439          | 636          | 237.16       | 227.19       | 140             |
| 20 kA                  | 822          | 1,238        | 293.37       | 232.28       | 140             |
| 30 kA                  | 1,204        | 1,839        | 340.46       | 300.38       | 140             |
| 40 kA                  | 1,588        | 2,441        | 359.53       | 316.45       | 140             |
| 50 kA                  | 1,970        | 3,046        | 395.51       | 344.99       | 140             |

Comparison of phase R values at the time of lightning current injection with IEC and CIGRE Standards 10 kA - 50 kA compared to the transformer BIL value with focus whether the Micaela arrester is able to work well when overvoltage occurs.

Figure 10. Comparison between phase R using micaela arrester in IEC and CIGRE mode and transformer BIL
5 Conclusion

The conclusions obtained after conducting research are as follows:
1. The connection to the phase wire causes a greater voltage increase than the strikes to the ground wire arising at the transformer terminal.
2. Without using an arrester, the voltage values at the phase are 1,519 kV and 1,275 kV at the transformer terminal after being given a lightning current of 10 kA with the IEC Standard and the CIGRE Standard. This value very far above the BIL transformer of Teluk Dalam, Nias substation.
3. Lightning arrester was declared successful in protecting the transmission system. The IEEE and Karbalaye arresters managed to breakdown approximately so that the transient current did not exceed the transformer BIL value used while the Pincenti or Micaela arrester also succeeded in reducing voltage on the system, but the value was greater than BIL value of the Teluk Dalam, Nias substation transformer because the Micaela arrester functioned better in high voltage or extra high voltage line [14] [15]

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