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Analysis of Arresters in the 20 KV Distribution Network at PT.PLN (Persero) ULP Bukittinggi

Eathia Sehra Imelda[a*], Zas Ressy Aidha[a], Akbar Abadi[a]

[a] *Electrical Engineering Department, Politeknik Negeri Padang, Limau Manis, Padang, 25176, Indonesia*
Corresponding author: eathiasehraimelda0@gmail.com

***Abstract*— On medium voltage overhead lines (SUTM), short circuit faults often occur due to lightning strikes and overload faults.A safety or protective device is a device that functions to protect or secure an electric power distribution system by limiting the overvoltage or overcurrent flowing in the system, and channeling it to the ground. There are 2 methods of placing Lightning Arrester (LA) and Fuse Cut Out (FCO) as protection in distribution substations, namely placing Lightning Arrester (LA) before Fuse Cut Out (FCO) and placing Lightning Arrester after Fuse Cut Out (FCO).Knowing the differences in the construction of installing Lightning Arrester and Fuse Cut Out, and making a comparison with the application of ETAP simulation to get a conclusion about which construction is suitable for use. For distribution substation Portal Lightning Arrester After Fuse Cut Outfor the PLN voltage value will continue to flow, the output will be clean up to the last bus even if there is a disturbance in the increase in voltage such as a lightning strike, then the lightning strike will go directly to the ground or groaning so the disturbance will be directly held by the Grounding. For One Line Diagram of Lightning Arrester Portal Distribution Substation After Fuse Cut Outfor the PLN voltage value will continue to flow, the output will be clean up to the last bus even if there is a disturbance in the increase in voltage such as a lightning strike, then the lightning strike will go directly to the ground or groaning so the disturbance will be directly held by the Grounding.Characteristics of Lightning Arrester rated voltage 24 kV, discharge current, 87 kV, the protective factor contained in the distribution channel is 20% greater than the TID, so this LA has provided a good protective factor.**

***Keywords*— Arrester, Distribution Network, ETAP Simulation, Fuse Cut Out, PLN.**

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I. INTRODUCTION

On medium-voltage overhead lines (SUTM), short circuits caused by lightning strikes and overloads frequently occur. These disturbances can damage high-voltage equipment, control equipment, telecommunications, and other equipment (Arismunandar, 2004). A safety substation is a device that functions to protect or secure the electric power distribution system by limiting the overvoltage or overcurrent flowing through the system and channeling it to the ground. Therefore, a safety substation must be able to withstand the system voltage to ensure continuous service to the load center is not disrupted indefinitely. Furthermore, the safety substation must also be able to conduct or channel the overcurrent without damaging other network equipment (Tobing, 2003).

There are two methods for installing Lightning Arresters (LA) and Fuse Cut-Outs (FCO) as protection at distribution substations: installing a Lightning Arrester (LA) before the Fuse Cut-Out (FCO) and installing a Lightning Arrester after the FCO. Each method has a different impact on mitigating incoming lightning impulse voltage disturbances (Maskun, 2023).

To make it easier to determine the reliability of the Lightning Arrester and Fuse Cut Out installation conditions, ETAP software is used. ETAP can be used to create electric power system projects in the form of single line diagrams and grounding system paths for various forms of analysis (Hayusman et al, 2017).

This study discusses the advantages and disadvantages of installing arresters before and after FCO, rated voltage, discharge current, protective factors found in the 20 Kv ULP Bukittinggi distribution channel, and obtains differences in conditions when disturbances or obstacles occur using the E-TAP 19.0.1 application

II. MATERIAL AND METHOD

A. Fuse Cut Out

In distribution systems, the FCO used works by melting when it passes a current exceeding its rated current limit. Typically, an FCO is installed after the PTS or LBS to protect the feeder from short circuits and is installed in series with the network it protects. FCOs are also often found in transformers.

This is weak in distribution networks. Because an FCO is simply a piece of wire with a cross-section adjusted to the maximum current allowed to flow through the wire, the wire used in this fuse breaker is selected based on its low melting factor and high conductivity. This melting factor is determined by the material's temperature. Common materials used for this fuse breaker are silver wire, copper wire, zinc wire, tin wire, or wire alloys of these materials. Silver wire is the most commonly used of these wires, as it has the lowest Specific Resistance (μΩ/cm) and a low Melting Point

B. Lightning Arrester

A lightning arrester is a protective device for electrical equipment against overvoltages caused by lightning or power surges. This device acts as a bypass around the insulation, creating a path for the lightning current to flow easily to the grounding system, preventing excessive voltages from damaging the insulation of electrical equipment. This bypass must be designed to prevent interruption of the 50 Hz power system. Under normal conditions, the arrester acts as an insulator. When a surge occurs, the device acts as a conductor with relatively low resistance, allowing it to conduct high currents to the ground. After the surge dissipates, the arrester must be able to quickly return to its insulating state. Its function is to protect electrical equipment in the network system from overvoltages. In large substations, arresters are installed on transformers to ensure protection of the transformer and other equipment from overvoltages.

C. ETAP

ETAP (Electric Transient and Analysis Program) is a software program that supports electric power systems. It can operate offline for electric power simulation, online for real-time data management, or for real-time system control. ETAP includes a variety of features, including those used to analyze electric power generation, transmission systems, and distribution systems. ETAP can perform the following electric power analyses:

1. Power flow analysis
2. Short circuit analysis
3. Arc flash analysis
4. Transient stability analysis

In electrical power analysis, a single-line diagram is a simplified notation for a three-phase power system. Instead of representing separate three-phase lines, the diagram uses a single conductor. This simplifies diagram reading and circuit analysis. Electrical elements such as circuit breakers, transformers, capacitors, busbars, and other conductors can be represented using standard symbols for single-line diagrams. The elements on the diagram do not represent the physical size or location of electrical equipment, but it is a common convention to arrange the diagram in a left-to-right, top-to-bottom order, similar to switches or other equipment.

In the study “Arrester Analysis on the 20 Kv Distribution Network at PT. PLN (Persero) ULP Bukittinggi” the author used quantitative and qualitative research methods. Quantitative research involves data collection based on measurements, the results of which are presented mathematically. Qualitative research involves data analysis based on quantitative measurements.Data Collection

a. Data collection is carried out by requesting existing data. Data is obtained by following the procedures established by PT PLN (Persero) ULP Bukittinggi.
b. Data Processing
   Data processing begins with data input. The processing of installation data for the old and new constructions is then compared. The installation data is then calculated. The transformer TID, arrester discharge voltage, and arrester protection factor are then calculated.

III. RESULTS AND DISCUSSION

Each Distribution Substation in its construction is equipped with a lightning surge protection device that uses an Arrester. Arrester/LA (Lightning Arrester). Lightning Arrester is positioned in such a way and if possible its position is as close as possible to the equipment to be protected. The installation can be placed before or after the Fuse Cut Off. Both methods have advantages and disadvantages but both remain a reference in the installation in the field. For very long overhead lines, the installation of LA after FCO can be considered by using an H type fuse link. Meanwhile, for short overhead lines, the installation of LA before FCO is a better choice.

In the review and field study that has been conducted to the West Sumatra PLN Regional Unit, the tendency of installing Lightning Arrester is done after the Fuse. So in its application in the field, construction with this model has been applied in almost all PLN Portal Substations and gradually and continuously in the future all will be changed to this construction model. The main consideration in the field that is the reason for this construction change refers to the PLN Director's Decree in 2010 which states that the construction of Portal Substations with the placement of Lightning Arrester after FCO is a priority in every Portal Substation, but the opposite construction is still permitted.

The installation of a Lightning Arrester before or after the FCO in a portal substation construction depends on the desired protection objectives and operational considerations. Installing a Lightning Arrester before the FCO will provide comprehensive protection to all equipment where the Lightning Arrester will protect before the FCO works. Meanwhile, installing a Lightning Arrester after the FCO will better protect the transformer after the FCO trips and can ensure that the Lightning Arrester continues to function even if the FCO trips. In its application, the choice of this configuration is usually adjusted to the substation protection design, the type of disturbance that often occurs, and the required priority level (Hajar, 2017).

1. *ULP Bukittinggi (GD 026/Bukittinggi/160kVA)*

This substation is located on Jalan Jendral Sudirman, precisely in front of the Bukittinggi City Post Office. At the Portal 026 substation, the FCO is placed above the Arrester. The replacement was carried out in 2023, with the reason for this construction change being for ease of maintenance and system reliability. Prior to the change, there had been one recorded FCO outage since 2020. This substation is located in the city center, acrucial position considering the large number of customers it serves. To mitigate the possibility of an Arrester failure, the substation's construction was changed from placing the FCO after the Arrester to placing the FCO before the Arrester.

There is no effect of reducing disturbances from this construction change because the consideration of replacing the construction was made for reasons of risk mitigation of damage to the Arrester and ease of maintenance if a disturbance occurs at some point, repairs do not require turning off the feeder.

FIGURE 1. Portal Substation Construction Before Construction Changes Source: Personal Field Documentation

In the above construction, the Arrester does not work optimally. If a traveling wave occurs due to lightning on the SUTM conductor, it will cause a reflection between the conductor entering the power transformer and the LA, the FCO is used to inhibit or dissolve the incoming overcurrent, while the arrester is used to inhibit overvoltage. Therefore, the FCO and arrester are installed in such a way as to protect the transformer properly. Overvoltage on the transformer causes the transformer to be damaged and can cause impulse voltage on the transformer that can exceed the BIL limit and have a bad impact on the transformer so that it can be damaged due to being struck by lightning. The distance between the transformer and the arrester is made not far apart, the Arrester is made as close as possible to the transformer. because according to the current SPLN regulations, the transformer and arrester are made without distance.

The construction of the protection system installation on this distribution pole is considered not to have run effectively, because if a lightning strike occurs, the surge wave directly strikes towards the LA, resulting in reflection between the conductor and the transformer, and can also cause damage to the transformer which causes impulse voltage on the transformer, the transformer experiences overvoltage due to the lightning surge, and sudden power outages. The working principle of the construction of the arrester installation before the FCO, If an overvoltage occurs, the voltage will propagate directly to the LA, thus securing the transformer. If damage occurs to the LA cable, damage to the transformer occurs because coordination with the FCO is ineffective because the arrester is installed before the FCO. Therefore, the process of voltage propagation to ground is ineffective because the circuit in the image above only has one path to ground.

For simulation using ETAP application can be seen below. For One Line Chart of Distribution Substation Portal Lightning Arrester Before Fuse Cut Out, in the condition of a voltage problem due to lightning or network disturbance, the voltage value from PLN will be disturbed after the transformer, the value that should be clean output causes disturbance automatically. Then the electricity produced will be a change in the gi and if it is automatically connected to the electricity it will cause a fire because the incoming value is unstable. So if lightning occurs on the portal installed with the Arrester position before the FCO, it will immediately error because the Grounding or grounding of this portal cannot withstand it so this portal is given a switch as anticipation of disturbances.

In this diagram, the initial image of the Arrester portal before the FCO has no voltage and current values, this portal is in a position not yet Run. The portal has not been given any disturbance or voltage, this portal is still in the Off state as in figure 4.5. The switch is in the Off position, the switch is in the locked position (A). There is no disturbance as in figure 2.a and what if the switch is in position (B) as in figure 2.b means the switch is releasing or there is a disturbance in figure 2

a b

FIGURE 2. Symbols and Descriptions of Switches in Locked Position (A) and Released Position (B)

The portal image when it has been RUN can be seen in Figure 4. Here the portal already has voltage and current values starting from the values of PLN, this PLN value means the voltage value, distribution current and BUS is the medium voltage air duct (SUTM) and TG transformer.

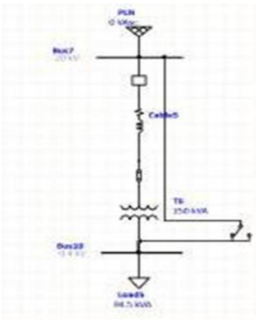

FIGURE 3. One-Line Diagram of Lightning Arrester Portal Distribution Substation Before Fuse Cut Out (Position A Not Yet RUN)

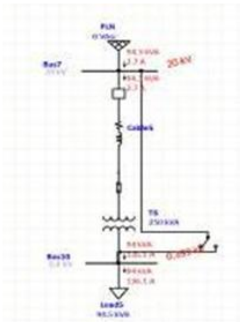

FIGURE 4. One-Line Diagram of Lightning Arrester Portal Distribution Substation Before Fuse Cut Out (Position A is Already RUN)

To see the table of voltage and current values in each component in the One Line Diagram of the Lightning Arrester Portal Distribution Substation Before Fuse Cut Out as in Figure 4., see Table 1.

TABLE I
Voltage and Current Values of a Single-Line Diagramof a Lightning Arrester Portal Distribution Substation Before Fuse Cut Out

NO	PLN	BUS 7	TG	BUS 10
1.	0	0	0	0
2.	94,3 kVA 2,7 A	94,3 kVA 2,7 A	250 kVA	94 kVA 136,1 A

The advantages and disadvantages of installing an Arrester before FCO are :

a. The advantage is that lightning surge protection is not affected by the possibility of an FCO rupture. If the FCO is located below the arrester, if the arrester is damaged and the FCO breaks, repair and replacement of the arrester can only be carried out after the feeder/network has been turned off.
b. The disadvantage is that LA fails to match the feeder system, the retaining conductor is longer.

FIGURE 5. Portal Substation Construction After Changes to Arrester Installation Analysis After Fuse Cut Out (FCO) ULP Bukittinggi (GD 541/PLNUP3PYK/160KVA)

This construction ensures that if there is a disruption to the protection system on the distribution line, the FCO will disconnect first, minimizing overvoltage on the LA. Therefore, this construction can reduce damage to the transformer installed in the distribution substation. It is more effective to install the FCO first, followed by the LA. If a lightning surge occurs, the FCO will be the first to be touched. If a disruption still occurs, the LA can intercept the lightning and directly transmit the current to the ground at the distribution substation.

For the Single Line Diagram of the Lightning Arrester Portal Distribution Substation After the Fuse Cut Out for the PLN voltage value will continue to flow, the output will be clean up to the last bus even if there is a disturbance in the increase in voltage such as a lightning strike, then the lightning strike will go directly to the ground or groaning so the disturbance will be directly held by the Grounding.

In this diagram, the initial image of the Arrester portal after the FCO has no voltage and current values, this portal is in a position not yet Run. The portal has not been given any disturbance or voltage, this portal is still in the Off state as in figure 4.13. At this Off condition, the switch is made to disconnect or is not connected to the disturbance. The switch is in the Off position, the switch is in the locked position (A) there is no disturbance as in figure a and what if the switch is in position (B) as in figure b means the switch is releasing or there is a disturbance in figure 6.

a b

FIGURE 6. Symbols and Descriptions of Switches in Locking Position (A) and Release Position (B)

The portal image after it has been RUN can be seen in Figure 7. Here the portal already has voltage and current values starting from the values available from PLN, this PLN value means the voltage value, distribution current and BUS is the medium voltage overhead line (SUTM) and TG transformer.

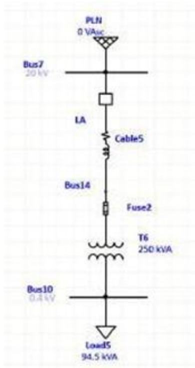

FIGURE 7. One-Line Diagram of the Lightning Arrester Portal Distribution Substation After Fuse Cut Out (Not Yet RUN)

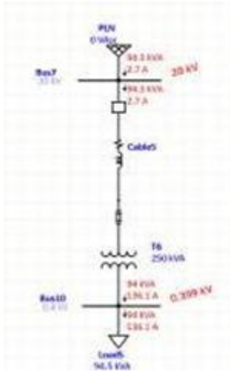

FIGURE 8. One-Line Diagram of the Lightning Arrester Portal Distribution Substation Before Fuse Cut Out (Already RUN)

To see the table of voltage and current values in each component in the one-line diagram of the Lightning Arrester portal distribution substation before the Fuse Cut Out as in Figure 8, see Table 2.

TABLE 2.
Voltage and Current Values of a Single-Line Diagram of a Lightning Arrester Portal Distribution Substation After Fuse Cut Out

NO	PLN	BUS 7	TG	BUS 10
1.	0	0	0	0
2.	94,3 kVA	94,3 kVA	250 kVA	94 kVA
	2,7 A	2,7 A		136,1 A

The advantages and disadvantages of installing an arrester after the FCO are:

a. The advantage is that if the LA is damaged it does not shut down the SUTM system.
b. The disadvantage is that the Fuse Link is vulnerable to lightning surges. The FCO is placed first, followed by the arrester. If the arrester is damaged, the FCO will certainly break, making it easier to find the fault because the FCO is already disconnected from the feeder network.

2. Lightning Arrester Rated Voltage

If a fault occurs at the protection system rating limit that exceeds the TID, the LA wire breaks, causing damage to the transformer. When planning a distribution transformer protection system, the first step in determining the location of protective equipment against potential lightning surge hazards is determining the basic impulse insulation strength.

The transformer to be protected is located on a medium-voltage overhead line (UMV) with the following data:

Installed capacity	: 160 kVA
Primari voltage	: 20 kV
Secondary voltage	: 220 / 380 V

This type of transformer is a type of substation that is installed on a pole with a primary system voltage of 20 kV, so equation 2 can be used to find the highest voltage or maximum voltage.

Vmaxx = Vnominal x 1.1
Vmax = 20 x1.1
Vmax = 22 Kv

The 20 Kv distribution system of PT.PLN (Persero) UP3 ULP Bukittinggi is grounded with a low resistance grounding coefficient of 100% (Grounding is not always effective), the system voltage is 20 Kv, so to determine the Rated Voltage on the LA, equation 1 is used for the maximum voltage and equation 2 for the rated voltage.

a. Maximum voltage capacity
Vnominal + 10% (factor toleransi)
Vmaxx = Vnominal x 1.1
Vmax = 20 x1.1 Vmax
= 22 Kv
b. Arraster voltage rated
Vp = Vnominal x 1.1 Vp = 20 x1.1
Vp = 22 Kv
According to Table 1 in the standard attachment, the rated voltage is greater than 24 kV, so the rated voltage taken for a 20 kV system is 24 kV.

c. Channel characteristics
   1. Cross-sectional area: 6mm
   2. Wire height above ground level: 9m
   3. Neutral point is grounded with a resistance of 40 ohms
d. Lightning Arrester Characteristics
   1. Rated voltage 24 kV
   2. Nominal discharge current 5 kA
   3. Wavefront spark voltage 100 kV
   4. Standard spark voltage 87 kV
   5. Maximum residual voltage at nominal current 87 kV

3. Arus Pelepasan Impuls Lightning Arrester

Having 3 conductor insulators. The traveling wave obtained is 355Kv. The cross-sectional area or radius of the overhead conductor wire is 6mm. The height of the wire above the ground is 9 meters. Therefore, to determine the arrester impulse discharge current, equation 4 can be used

$$I_{a=}\frac{2Ud-Ua}{Zs}$$

$$Z = 60\ I_n \frac{2h}{r}$$

$$Z = 60\ I_n \frac{2 \times 9m}{6}$$

$$Z = 480{,}3 \text{ ohm}$$

So the impedance value is taken as 500 ohms, so the arrester impulse discharge current is 1,246 kV.

4. Protective Factor

The protection factor is the ratio between the TID voltage difference of the protected equipment and the arrester's operating voltage. The arrester's operating voltage for a 20 kV system is set at 87 kV, with an additional 10% of the arrester's protection level, taking into account the factory tolerance of the connecting cable. Equation 3 can be used to find the protection factor.

$$F = \frac{TID-TP}{TP} \times 100$$

Tp (Protective Level)

$$Tp = Va \times 1.1$$
$$= 87 \times 1.1$$
$$= 95{,}7 \text{ kV}$$

Therefore, the lightning protection level can be taken as 97.5 kV with the transformer TID set at 125kV. The protection factor is:

$$F = \frac{TID-TP}{TP} \times 100$$

$$Fp = \frac{125-97{,}5}{97{,}5} \times 100$$

$$Fp = 23.44\ \%$$

The protection factor is 20% greater than the equipment TID, so this lightning arrester provides a good protection factor.

IV. CONCLUSION

Based on the analysis, we can conclude:

1. Installing a lightning arrester before the FCO will provide comprehensive protection to all equipment, as the lightning arrester protects it before the FCO operates. Installing a lightning arrester after the FCO will further protect the transformer after the FCO trips and ensure the lightning arrester remains functional even if the FCO trips.
2. For distribution substations, the portal lightning arrester will continue to flow after the fuse cutout, ensuring the PLN voltage continues to flow, ensuring a clean output all the way to the final bus. Even if a voltage surge occurs, such as a lightning strike, the lightning strike will go directly to the ground, or "gronding," so the disturbance is immediately intercepted by the grounding. For the Single Line Diagram of the Portal Lightning Arrester Distribution Substation, after the fuse cutout, the PLN voltage will continue to flow, and the output will be clean all the way to the last bus. Even if a voltage increase occurs, such as a lightning strike, the lightning strike will go directly to the ground, or groaning, so the disturbance will be immediately intercepted by the grounding.
3. The characteristics of the PT. PLN (Persero) UP3 ULP Bukittinggi Arrester have a rated voltage of 24 kV, a discharge voltage of 87 kV, and a discharge current of 5 kA.

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