Risk based approach for surge arrester replacement

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Abstract. Surge arrester is a critical component in tropical countries since the likelihood to have a lightning stroke in the transmission system is higher in comparison to those in sub tropics. Therefore, assuring the reliability of this component is important. However, the surge arresters are sometimes being overlooked during the replacement plan because of its insignificant price in comparison to the protected assets. Transmission utility mostly just install and forget. This paper presents a methodology to replace the High Voltage (HV) and Extra High Voltage (EHV) surge arresters based on the risk of a failure. The condition assessment based on resistive leakage currents and the statistical reliability curve based on lifetime assessment define the likelihood of failure. While the consequences are based on the ENS (Energy Not Served), Customer Satisfaction, Leadership, and Environmental Impact. The risk is then estimated by multiplying the likelihood of failure and consequences. It can be used to prioritise replacement, particularly when resources (budget, spares, workability) are limited.

1. Introduction

Lightning incidence in tropical countries, like in Indonesia, is higher in comparison to those in sub tropics. Therefore, a surge arrester becomes critical in transmission system in order to avoid breakdown of the equipment. The surge arrester cuts the overvoltage by passing the surge current through the ground [1]. However, people mostly just install and forget the equipment, and the time to replace the surge arrester is arguable.

This paper proposes replacement based on risk if an arrester fails. Risk equals to the likelihood of failure times the consequences. The condition assessment based on 4955 resistive leakage currents and the survival probability curve define the likelihood of failure. While the consequences are based on the ENS (Energy Not Served) and type of served customers.

2. Functions and possible failure modes of Surge Arrester (SA)

It is important to understand functions and possible failure modes to estimate a likelihood of failure of a SA. A surge arrester could be divided into subsystems and each subsystem provide a subfunction of an arrester. Table-1 shows sub functions and the related key components of each subsystem of a surge arrester. The key components of a SA are shown in Figure 1.
Table 1. Sub systems and related functions of a surge arrester.

| Sub System       | Sub Function                                                                 | Key Components                  |
|------------------|------------------------------------------------------------------------------|---------------------------------|
| Active part      | Being Capacitive under frequency voltage, and supplies surge current to the   | Metal Oxide Block               |
|                  | earth according to its rating when a surge occurs.                           |                                 |
| Insulation       | To insulate the live part of a surge arrester with the ground.                | Porcelain insulation, sitting-insulation |
| Pressure relief  | Releasing the excess of pressure inside the surge arrester that occurs        | Sudden-pressure relief diaphragm |
|                  | shortly after a surge.                                                       |                                 |
| Connector        | Arrester connection with HV conductor, and arrester connection to ground wire. | Bolt and nuts, Jumper, connectors |
| Grading Ring (if | To distribute the electric field along the surface of SA.                    | Grading Ring                    |
| any)             |                                                                               |                                 |
| Grounding/       | Path to pass the current surge to the earth.                                 | Grounding Wire                  |
| earthing         |                                                                               |                                 |

Figure 1. A schematic diagram of a Surge Arrester [2].

There are two general deteriorations of SA [2]: 1. Protective characteristics deterioration (when the ability to cut the surge drops below its design), and 2. Insulation deterioration. Aging of the metal oxide due to moisture ingress contributes to the protective deterioration. While insulation deterioration mostly took place at the support insulators due to environmental cycle. Table 2 provides a summary of failure modes of a SA and related possible detections [2-6].

Table 2. Failure modes of Surge Arrester.

| Failure Modes                                      | Category of deterioration          | Possible detection               |
|----------------------------------------------------|-----------------------------------|---------------------------------|
| Sealing defects \rightarrow moisture ingress \rightarrow Metal Oxide (MO) Degradation | Protective characteristics deterioration | Leakage Current Monitoring (LCM), Thermal image |
| Contamination due to pollutants \rightarrow surface discharge on insulator surface | Insulation deterioration          | Visual Megger Test (Offline)    |
| Overloading due Temporary Over Voltage (TOV)\rightarrow MO Degradation | Protective characteristics deterioration | LCM, Thermal image              |
| Internal Partial Discharges \rightarrow MO Degradation | Protective characteristics deterioration | LCM, Thermal image              |
3. Estimating the likelihood of failure of SA

Even in normal operation, asset could deteriorate. Humid environment could deteriorate the active part, particularly when leaks occur at the housing of SA. The cycles, i.e. the times the active part passing the surge, also reduce the protective characteristics of SA. It is a challenging task to predict when an arrester should be replaced as shown by a schematic diagram in Figure 2. A Surge Arrester should be replaced somewhere in between point of P (Possible detection of failure) and F (fail occurs) [7]. In this work, the likelihood of fail of an arrester is defined by two parameters: the resistive LCM measurement [3-6] and the reliability curve.

Figure 2. Deterioration curve of a Surge Arrester. The SA performance is reduced with the time/cycle.

3.1. Estimating a likelihood of failure of SA based on the resistive LCM measurement

Resistive leakage current measurement (LCM) is a known method to check the status of active part in SA. The reliability of this method in field experience is arguable, however in this paper, we provide a statistic method to analyse the measurement results. The LCM gives the resistive leakage by compensating the total leakage current with the current induced by the stray capacitive electric field adjacent to the SA [5]. The resistive leakage value usually in the order of micro-Ampere (µA). 4955 measurements have been collected from a case study in Indonesia, which cover surge arresters operate at 500kV, 150kV, and 70kV systems. Figure 3 to 5 sequentially show the maximum resistive current, Ir (max), as a function of operating time, from measurements of surge arresters at voltage levels of 70kV, 150kV, and 500kV.

Figure 3. Ir (max) as a function of operating time (left) & Histogram of Ir (max) (right) of 70 kV SA.
From figures 3 to 5, it can be seen that the resistive leakage current tends to increase as a function of operating time. Maximum limit of Ir could be decided based on histogram by taking, for example, 80% of population. With this approach, the norm for the maximum Ir, are as follows:

For 70 kV SA : 100 µA
For 150 kV SA : 150 µA
For 500 kV SA : 500 µA

The likelihood of failure of SA is high when the Ir (max) is above the limits.

3.2. Estimating a likelihood of failure of SA based on the survival probability curve [8]

Based on failure records, a survival probability curve can be developed. Figure 6 gives the survival probability of SA from a case study with 8 years observation periods.

It depends on the management decision whether at what level the survival probability of a population could be accepted. For example, when 95% of survival probability is selected, then it can be assumed
that the likelihood of failure is high, when the SA has been in operation for: 31 years (for 70kV SA), 27 years (for 150kV SA), and 22 years (for 500kV SA).

4. Defining consequence matrix
A consequence matrix defines the impact of a failure to the business values. In this work, the consequences are classified into five levels, namely, “Low”, “Moderate”, “Serious”, “Severe”, and “Catastrophic.” Meanwhile, the business values include: Safety, Extra Fuel Cost, Energy Not Served (ENS), Customer Satisfaction, Leadership, and Environmental Impact. Table 3 gives the consequence matrix as taken from [9].

| Severity Level | Importance Rank | Business Value |
|----------------|-----------------|----------------|
| Catastrophic   | 1 Safety        | Cause death (Fatality) |
|                | 2 Extra fuel cost | Cause permanent disability |
|                | 3 Energy not served | >75,000 – 750,000 USD |
|                | 4 Equipment cost | >2,000,000 USD |
|                | 5 Customer satisfaction | Very high potential riot |
|                | 6 Leadership | Committed to law/ legal action |
|                | 7 Environment | Catastrophic contamination, national warning |
| Severe         |                | Cause permanent disability |
|                | 2 Extra fuel cost | >75,000 – 750,000 USD |
|                | 3 Energy not served | >4000 MWh |
|                | 4 Equipment cost | >200,000 USD |
|                | 5 Customer satisfaction | Very high potential riot |
|                | 6 Leadership | Committed to law/ legal action |
|                | 7 Environment | Catastrophic contamination, national warning |
| Serious        |                | Cause permanent disability |
|                | 2 Extra fuel cost | >75,000 – 750,000 USD |
|                | 3 Energy not served | >4000 MWh |
|                | 4 Equipment cost | >200,000 USD |
|                | 5 Customer satisfaction | Very high potential riot |
|                | 6 Leadership | Committed to law/ legal action |
|                | 7 Environment | Catastrophic contamination, national warning |
| Moderate       |                | First aid injury, medical aid |
|                | 2 Extra fuel cost | >750 – 7500 USD |
|                | 3 Energy not served | >40 – 400 MWh |
|                | 4 Equipment cost | >2000 – 20,000 USD |
|                | 5 Customer satisfaction | High potential riot |
|                | 6 Leadership | Top management and government officials are involved |
|                | 7 Environment | Catastrophic contamination, national warning |
| Low            |                | Near miss |
|                | 2 Extra fuel cost | ≤750 USD |
|                | 3 Energy not served | ≤750 USD |
|                | 4 Equipment cost | ≤2000 USD |
|                | 5 Customer satisfaction | No potential riot |
|                | 6 Leadership | Handled by local substation supervisor |
|                | 7 Environment | Low contamination |

5. Risk based approach for SA replacement
By following steps 3 and 4, risk of failure of each SA in systems could be estimated by multiplying the likelihood of failure and consequences. The replacement prioritisation can now be based on the risk (see Figure 7). This approach is beneficial when resources (mainly budget) are limited.

![Figure 7. Replacement prioritization based on risk.](image)

6. Conclusion
A risk-based approach for surge arrester replacement has been presented in this paper. The approach combines the likelihood of failure with the consequences if a SA fails. Different approaches are available to estimate a likelihood of failure as in this paper a statistical and condition assessment methods are given. Meanwhile, the consequences should not only focus on the impact of an equipment, but also to the business values.

References
[1] Andrew H 1999 Insulation Coordination (USA: John & WilleyPublisher)
[2] Hinrichsen V 2001 Metal-Oxide Surge Arresters (Siemens AG)
[3] Lundquist J, Stenstrom L, Schei A and Hansen B 1990 New method for measurement of the resistive leakage currents of metal-oxide surge arresters in service IEEE Transactions on Power Delivery 5 4 1811-1822
[4] Tyagi R K, Sodha N S and Jain S M 2001 Condition monitoring of surge arresters through third harmonic resistive leakage current measurement In Doble Client Conference
[5] Schei A S L E 2000 Diagnostics techniques for surge arresters with main reference to on-line measurement of resistive leakage current of metal-oxide arresters International Conference on Large High Voltage Electric Systems (CIGRÉ 2000) 1-10
[6] Purnomoadi A P and Hakim Y 2008 Study on Resistive Leakage Current Monitoring of Metal Oxide Surge Arresters Proceedings of the 14th Asian Conference on Electrical Discharge
[7] Moubray J 1991 Reliability-Centered Maintenance (Industrial Press)
[8] Purnomoadi A, Supriyadi G and Munir B S 2019 An Alternative Method for Accelerated Reliability Testing of Energy Meter in PLN Indonesia Asia Pacific Conference On Research in Industrial and System Engineering (APCORISE)
[9] Purnomoadi A P, Rodrigo Mor A and Smit J J 2019 Health Index and Risk Assessment Models for Gas Insulated Switchgear (GIS) Operating under Tropical Conditions International Journal of Electrical Power and Energy Systems 117