

Effective Health Monitoring of Metal Oxide Surge Arresters (MOSA) – Case Study

Anil Khopkar¹ Umesh Soni²

Electrical Research and Development Association (ERDA), Vadodara, Gujarat, India.

Email: anil.khopkar@erda.org

Abstract:

Overvoltage in power system is frequent phenomenon system which is not possible to avoid, but, damaged caused by it can be certainly controlled. Lightning Arresters are installed in the system for the overvoltage protection of transmission and distribution system. During normal operating condition Arrester acts as an insulator whereas, it offers conductive path during overvoltage. Hence, it is a core protective device for transmission & distribution system against lightning over voltages. It consists of zinc oxide (ZnO) elements so called as metal oxide surge arrest (MOSA). Due to ageing effect MOSA degrades under influence of continuous operating voltage, pollutants and surge voltages. Degradation of MOSA increases the leakage current flowing through it which results increased in temperature of surge arrester. The resistance of zinc oxide elements decreases as temperature increases. As a results leakage current increases, which again increase the temperature of a MOSA. This results in to thermal runaway conditions for MOSA. After thermal runaway condition it does not return to normal condition. This condition is basic reason for failure of MOSA. So, condition monitoring of surge arresters should be done at periodic intervals. Various Offline and online condition monitoring techniques are available for health assessment of MOSA. Offline condition monitoring techniques has main drawback that we need to remove surge arrester from the system, so system shutdown is required. As no need to take system shutdown online condition monitoring techniques preferred. ERDA has expertise of various condition monitoring techniques of MOSA and conducted online health monitoring of various ratings of MOSA up to 400 kV. The amplitude of total leakage current (I_T) and amplitude of resistive leakage current (I_R) have been considered as indicators for surge arrester condition monitoring. This paper presents ERDA's experience of the condition monitoring of MOSAs with case studies.

Keywords:

Surge Arrester, leakage current, Resistive leakage current,

1. Introduction :

In transmission and distribution networks, overvoltage can arise due to natural phenomena such as lightning or from switching operations involving large electrical loads. To safeguard the power system against these surges, Metal Oxide Surge Arresters (MOSA) are employed. Under normal operating conditions, an ideal MOSA exhibits very high impedance, but during an overvoltage event, it provides a low-impedance path to ground. The precise nonlinear voltage-current (V-I) characteristics of Zinc Oxide (ZnO) have led to the widespread adoption of MOSA, effectively replacing other types of surge arresters [1]. However, MOSA performance can deteriorate over time due to various operating conditions, voltage stresses, temperature variations and humidity. This degradation compromises the arrester's ability to protect against surge voltages, thereby affecting the overall protection reliability of the system. A failed MOSA can result in system failure, damage to nearby substation equipment and also pose safety risks to personnel working in the vicinity. Therefore, maintaining the health of MOSA is as critical as monitoring other substation equipment. Condition monitoring plays a vital role in ensuring the safe and reliable operation of the electrical power system. Electrical Research and Development Association (ERDA) offers facilities for online condition monitoring of MOSA. This system evaluates parameters such as I_T , I_R , and third harmonic component of the resistive leakage current (I_{R3rd}) [2].

For over two decades, ERDA has been actively engaged in developing and implementing online condition monitoring techniques for MOSA. This paper presents various monitoring methodologies and shares ERDA's practical insights through case studies.

2. MOSA Equivalent Circuit:

The equivalent circuit of a Metal Oxide Surge Arrester (MOSA) is modeled as a resistive branch connected in parallel with a capacitive branch as shown in figure 1. In this representation, C denotes the equivalent capacitance, while R represents the nonlinear resistor. When a voltage V is applied across the surge arrester, a total leakage current (I_T) flows through it. This total current comprises two components: the resistive current (I_R) and the capacitive current (I_C).

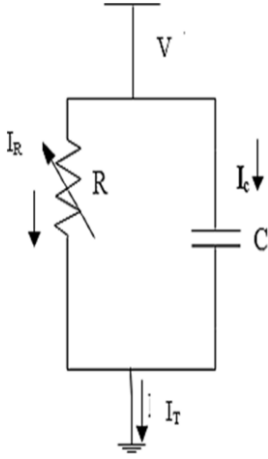


Figure 1: Equivalent Circuit of MOSA

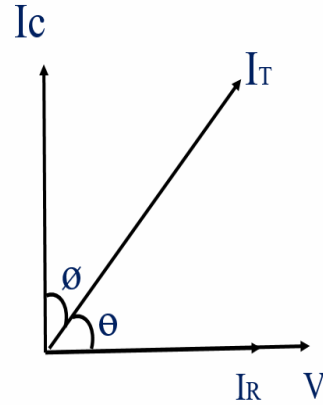


Figure 2: Phasor diagram of leakage current

The total current (I_T) flowing through a MOSA is the vector sum of its I_C and I_R components. While the I_C remains largely unaffected by the degradation of the arrester, the resistive current varies significantly with MOSA deterioration [3]. Figure 2 illustrates the phasor diagram showing the applied voltage (V), total leakage current (I_T), resistive leakage current (I_R), and capacitive leakage current (I_C). When applied voltage increases, the resistive component of the leakage current tends to surpass the capacitive component [4]. Typically, the capacitance of a ZnO element varies from 60 pF·kV/cm² to 150 pF·kV/cm², with this values of capacitance, magnitude of I_C ranging from 0.2 mA to 3 mA. Studies have shown that capacitive current remains relatively stable and does not exhibit significant variation due to the ageing or degradation of metal oxide resistors [5]. Hence, it is not considered a reliable indicator of arrester health. In contrast, the resistive leakage current is highly sensitive to changes in the voltage-current characteristics of the ZnO elements, making it a valuable diagnostic parameter. Therefore, monitoring the resistive component is an effective method for assessing the condition of metal oxide surge arresters. [6-7].

3. Failure modes of MOSA:

MOSA energized at its Maximum Continuous Operating Voltage (MCOV) under normal operating condition. This generates temperature of the ZnO blocks within the arrester to rise slightly higher than ambient temperature. Eventually, a thermal equilibrium is established where the heat generated by the ZnO blocks is balanced by the heat dissipated into the surrounding air. However, if the power frequency voltage across the arrester increases—due to events such as system disturbances, faults, or switching operations—a significant current begins to flow through the MOSA, leading to a further rise in temperature. When the overvoltage is sufficiently high, the heat produced by the ZnO blocks can exceed the arrester's dissipation capacity, creating a risk of thermal runaway. This condition can ultimately result in the failure of the surge arrester. The failure mechanism of MOSA under such conditions is illustrated in the accompanying figure 3.

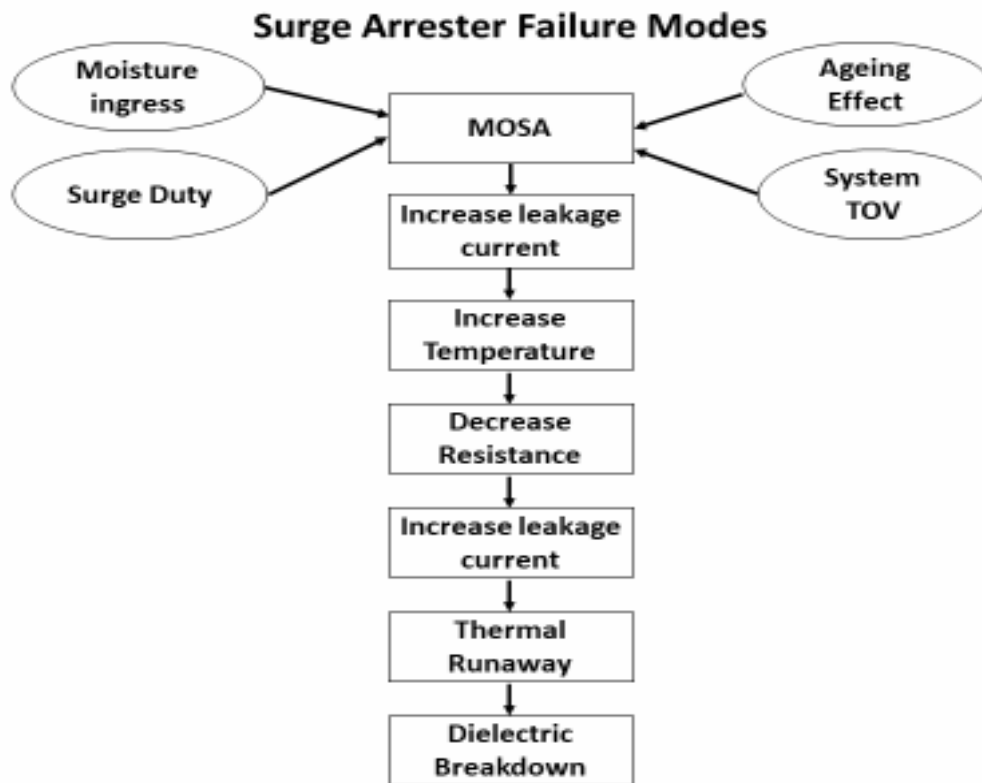


Figure: 3 Process of MOSA failure

4. Techniques to check healthiness of MOSA:

Methods to check healthiness of MOSA are thermal imaging, surge counter performance, measurement of total leakage current, power loss measurement, measurement of resistive current, measurement of insulation resistance [3]. Thermal imaging of MOSA is easy and reliable but less sensitive. From condition surge counter connected at the bottom of MOSA, its condition can be detected, but this method is not reliable and having very less sensitivity. Measurement of insulation resistance (IR), having low sensitivity as carried out at maximum up to 5 kV dc. Also not possible IR measurement online condition. Measurement of total leakage current is also having low reliability as surface leakage current is also part of total leakage current. Measurement of power loss is reliable and higher sensitivity but it requires to measure resistive current flowing through MOSA. Hence, measurement of resistive leakage current flowing through MOSA extracted from total leakage current is reliable technique to check its healthiness. There are various techniques has been suggested to determine resistive component of leakage current.

4.1 Techniques for Determining Resistive Element from Total Leakage Current:

The resistive portion of total leakage current can be assessed using various techniques, which are categorized into the following groups [4].

Technique A: Direct Measurement Techniques

A1: Utilize the applied voltage signal as a reference to directly measure the peak resistive current or to distinguish it from the total current.

A2: Compensate for the I_C of leakage current using a voltage signal.

A3: Compensate for the I_C without relying on a voltage signal.

A4: Achieve compensation by combining the leakage currents from all three phases.

Technique B: Indirect Measurement via Harmonic Analysis

This approach involves analyzing the harmonic content of the leakage current and includes three sub-methods:

B₁: 3rd harmonic analysis of the leakage current.

B₂: 3rd harmonic analysis with additional compensation for harmonics present in the system voltage.

B₃: 1st harmonic analysis of the leakage current.

Technique C:

Direct Measurement of watt loss, this method involves calculating the resistive component by directly measuring the power losses associated with the leakage current.

Among these, B₂ technique is considered most suitable for evaluating leakage current under actual service conditions of surge arresters. The measurement set-up has been shown in figure 4.

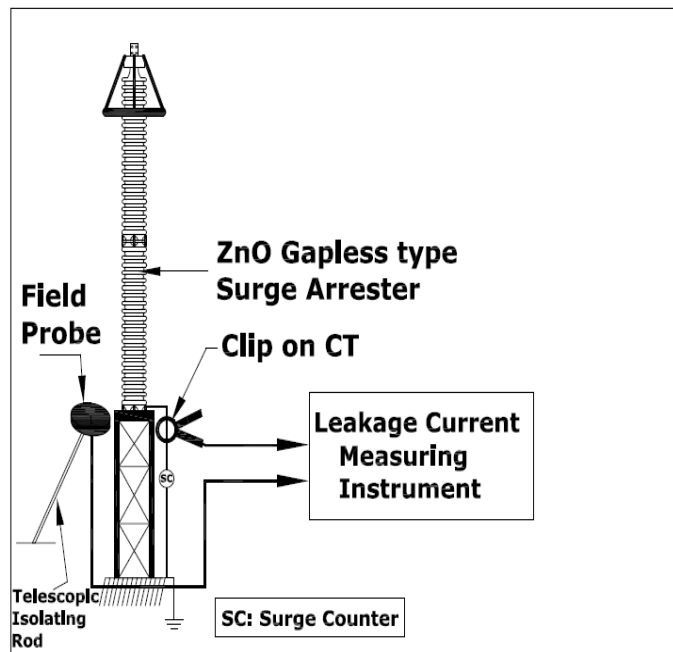


Figure 4: Measurement schematic of Leakage current in MOSA

5. Case study on 220 kV and 132 kV MOSA:

For condition assessment of MOSA, measurement of total leakage current and resistive leakage current has been carried out using Leakage Current Monitor (LCM) kit. The measurement of all the MOSAs were carried out online mode. The measurement of I_R has been done with compensation of supply harmonics. The measurement circuit has been shown in figure 3.

5.1 Analysis of obtained results of 220 kV MOSA:

The measured leakage currents of MOSA installed in 220 kV system has been investigated for consecutive three years. Magnitude of measured total leakage has been given in table 1. Magnitude of resistive leakage current component has been given in table 2.

Table 1: Total leakage current of 220 kV MOSA

	220 kV MOSA Total leakage current		
	2023	2024	2025
MOSA-1	545.6	568.4	654.5
MOSA-2	644.5	678.5	684.8
MOSA-3	689.7	723.5	756.4
MOSA-4	608.5	834.2	1059.4
MOSA-5	698.8	724.5	743.2
MOSA-6	878.5	905.2	969.4

Table 2: Resistive current of 220 kV MOSA

	220 kV MOSA Resistive leakage current		
	2023	2024	2025
MOSA-1	38.6	41.5	45.3
MOSA-2	40.1	43.2	46.5
MOSA-3	30.5	34.2	35.3
MOSA-4	69.6	72.4	135.8
MOSA-5	55.6	60.2	68.1
MOSA-6	63.3	88.5	168.1

There is no variation found in amplitude of measured total leakage current for MOSA-1, MOSA-2, MOSA-3 and MOSA -5. There is no variation found in amplitude of measured resistive current for MOSA-1, MOSA-2, MOSA-3 and MOSA -5. So all these MOSAs were found healthy. Yearly trend of total leakage current and resistive leakage current has been shown in figure 5 and figure 6 respectively.

For MOSA -4, amplitude of measured total leakage current increased from 608.5 μAp to 834.2 μAp after one year. However, amplitude of the resistive leakage current is almost same. Hence, MOSA-4 declared as healthy. But after one year measured amplitude of total leakage current increased from 834.2 μAp to 1059.4 μAp . Also, amplitude of measured resistive leakage current increased from 72.4 μAp to 135.8 μAp . Since, there is large increment observed in resistive leakage current observed, it was suggested to repeat the measurement after three months. There was no increased trend observed after three month measurement hence, it was advised to clean the MOSA and keep the MOSA in service and observed resistive current trend after one year.

For MOSA -6, amplitude of measured total leakage current increased from 878.5 μAp to 905.2 μAp and amplitude of the resistive leakage current increased from 63.3 μAp to 88.5 μAp . Hence, MOSA-6 is healthy but advise to repeat measurement after one year and observed the trend of resistive leakage current. After one year measured amplitude of measured total leakage current increased from 905.2 μAp to 969.4 μAp . Also, amplitude of measured resistive leakage current increased from 88.5 μAp to 168.1 μAp . Since, there is continuous increased trend observed in restive leakage current, it was advice to replace the MOSA-6. Yearly trend of measured total leakage current and resistive leakage current has been in shown in figure 7 and figure 8 respectively.

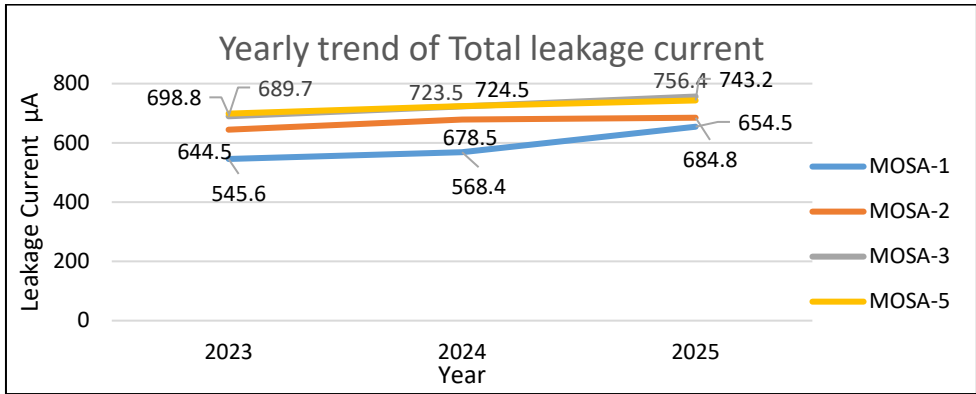


Figure 5: Yearly trend of measured total leakage current for 220 kV MOSA

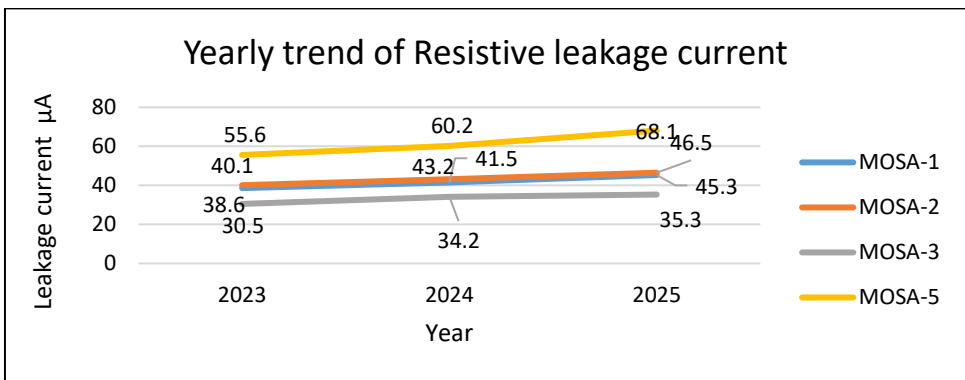


Figure 6: Yearly trend of measured resistive leakage current for 220 kV MOSA

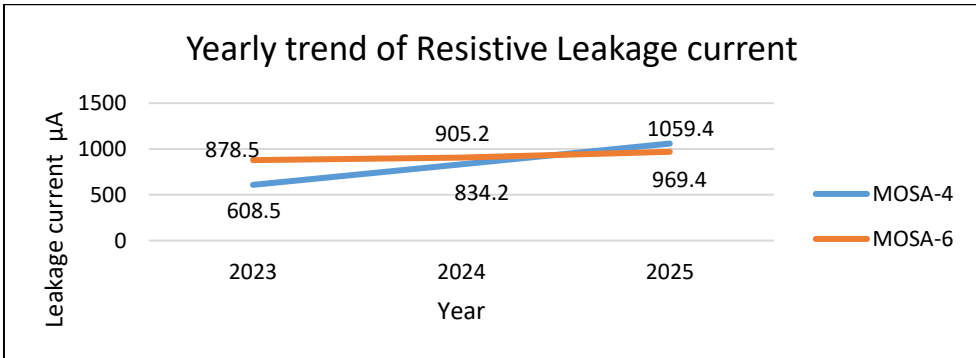


Figure 7 : Yearly trend of measured resistive leakage current for 220 kV MOSA

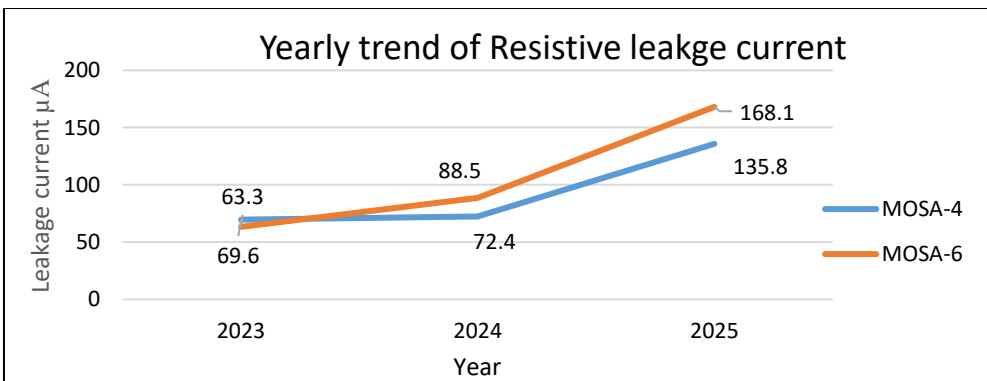


Figure 8 : Yearly trend of measured resistive leakage current for 220 kV MOSA

It can be seen that the variation in total leakage current for MOSA-4 has been observed from 608.5 μA to 1059.4 μA i.e. 74.1 %. Whereas variation in resistive leakage current from MOSA-4 has been observed from 69.6 μA to 135.8 μA , i.e. 95.1 %. Similarly, variation in total leakage current for MOSA-6 has been observed from 878.5 μA to 969.4 μA i.e. 10.3 %. Whereas variation in resistive leakage current from MOSA-6 has been observed from 63.3 μA to 168.1 μA , i.e. 165.1 %. Hence, it has been seen that the resistive component of leakage current is more sensitive health indicator of MOSA. Variation in total leakage current from first measurement to last measurement has been shown in figure 9. Variation in resistive leakage current from first measurement to last measurement has been shown in figure 10.

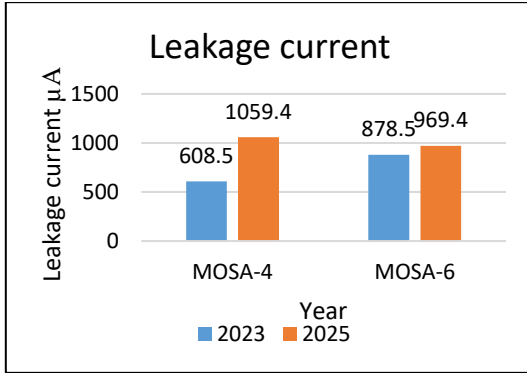


Figure 9: Variation in total leakage current

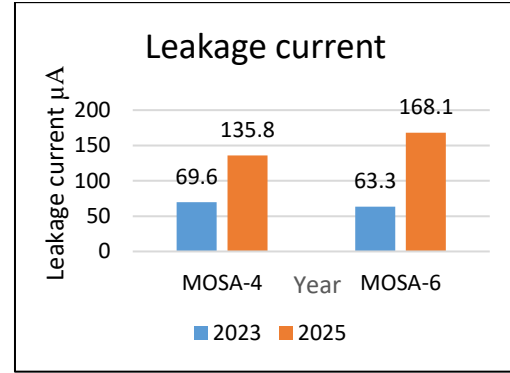


Figure 10 : Variation in resistive current

5.2 Analysis of obtained results of 132 kV MOSA:

The measured leakage currents of MOSA installed in 132 kV system has been investigated for consecutive three years. Magnitude of measured total leakage has been given in table 3. Magnitude of resistive leakage current component has been given in table 4.

Table 3: Measured leakage current of 132 kV MOSA

	Total leakage current		
	2023	2024	2025
MOSA-1	350.1	365.6	386.8
MOSA-2	361.2	365.5	372.2
MOSA-3	295.2	318.4	330.3
MOSA-4	333.4	465.4	495.5
MOSA-5	305.5	435.5	465.6
MOSA-6	560.6	610.5	666.6

Table 4 : Measured leakage current of 132 kV MOSA

	Resistive leakage current		
	2023	2024	2025
MOSA-1	40.5	53.3	63.4
MOSA-2	43.5	47.3	50.5
MOSA-3	44.5	53.4	60.1
MOSA-4	40.7	65.5	123.4
MOSA-5	59.6	55.6	138.5
MOSA-6	65.1	80.3	89.4

There is no variation found in amplitude of measured total leakage current for MOSA-1, MOSA-2, MOSA-3 and MOSA -6. There is no variation found in amplitude of measured resistive current for MOSA-1, MOSA-2, MOSA-3 and MOSA -6. So all these MOSAs were found healthy. Yearly trend of total leakage current and resistive leakage current has been shown in figure 11 and figure 12 respectively.

For MOSA -4, amplitude of measured total leakage current increased from 333.4 μAp to 465.4 μAp after one year. Amplitude of the resistive leakage current increased from 40.7 μAp to 65.5 μAp after one year. Since, there is no large increment observed MOSA-4 declared as healthy. But after one year measured amplitude of total leakage current increased from 465.4 μAp to 495.5 μAp . Also, amplitude of measured resistive leakage current increased from 65.5 μAp to 123.4 μAp . As there was large increment observed in resistive leakage current, it was suggested to repeat the measurement after three months. There was no increased trend observed after three month measurement hence, it was advised to clean the MOSA and keep the MOSA in service and observed resistive current trend after one year.

For MOSA -5, amplitude of measured total leakage current increased from 305.5 μAp to 435.5 μAp and measured resistive leakage current was nearly same. Hence, MOSA-5 was declared as healthy. After one year measured amplitude of measured total leakage current increased from 435.5 μAp to 465.6 μAp . Also, amplitude of measured resistive leakage current increased from 55.6 μAp to 138.5 μAp . Since, there is large increment observed in resistive leakage current, it was suggested to repeat the measurement after three months. Measured total leakage current after three month was 765.5 μAp and resistive leakage current measurement was 178.1 μAp . Since, there is continuous increased trend observed in restive leakage current, it was advice to replace the MOSA -5. Yearly trend of measured total leakage current and resistive leakage current has been in shown in figure 13 and figure 14 respectively.

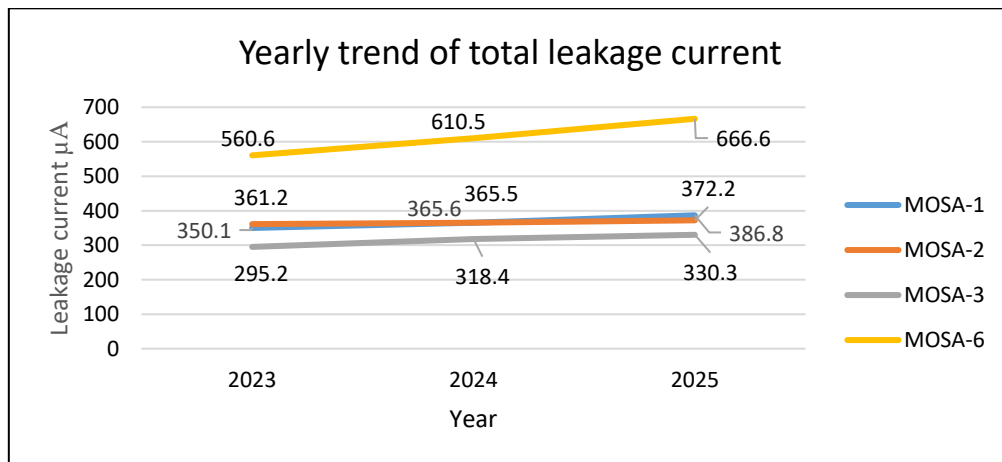


Figure 11 : Yearly trend of measured total leakage current for 132 kV MOSA

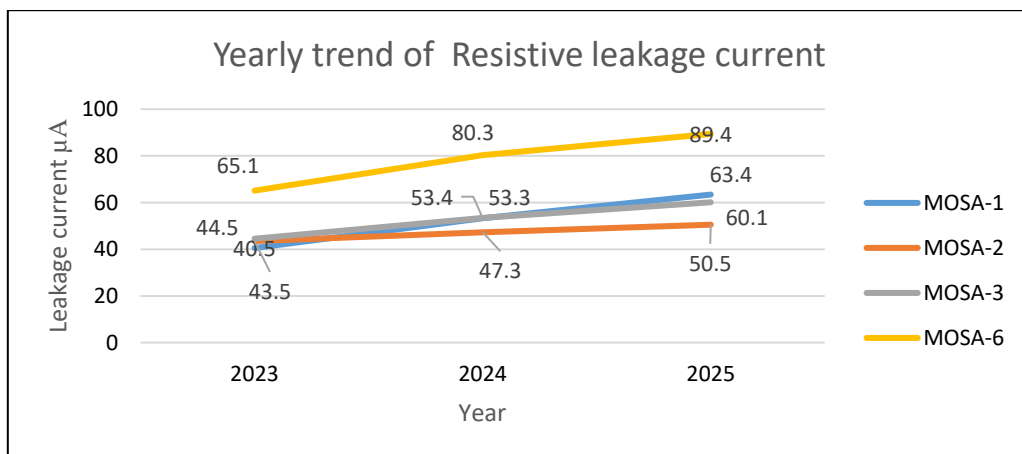


Figure 12: Yearly trend of measured resistive leakage current for 132 kV MOSA

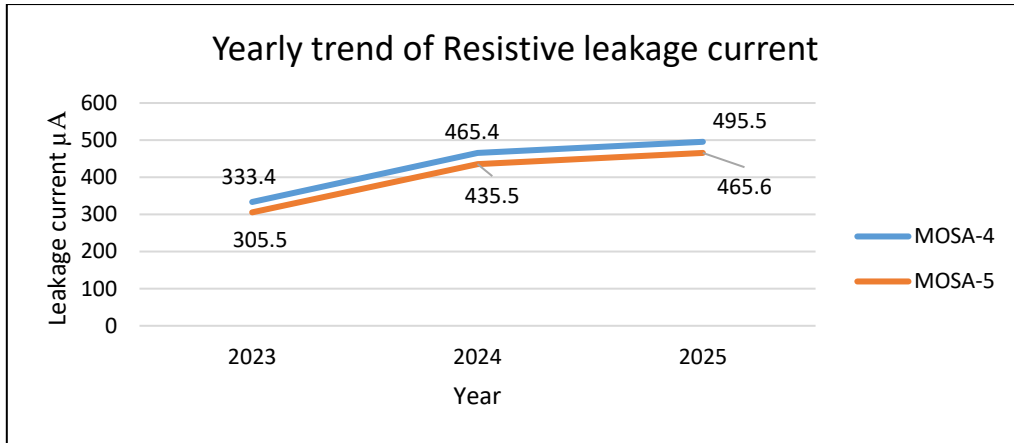


Figure 13: Yearly trend of measured resistive leakage current for 132 kV MOSA

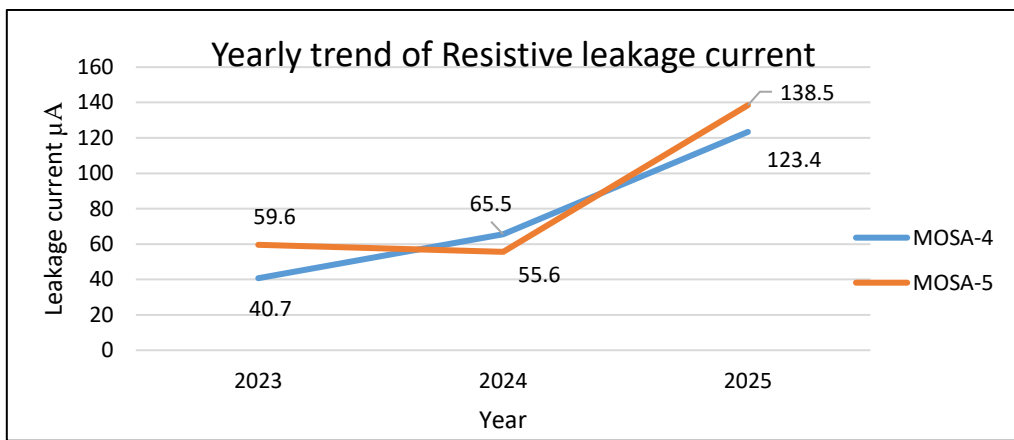


Figure 14: Yearly trend of measured resistive leakage current for 132 kV MOSA

It can be seen that the variation in total leakage current for MOSA-4 has been observed from 333.4 μA to 495.5 μA i.e. 48.6 %. Whereas variation in resistive leakage current from MOSA-4 has been observed from 40.7 μA to 123.4 μA , i.e. 203.2 %. Similarly, variation in total leakage current for MOSA-6 has been observed from 305.5 μA to 465.6 μA i.e. 52.4 %. Whereas variation in resistive leakage current from MOSA-6 has been observed from 59.6 μA to 138.5 μA , i.e. 132.4 %. Hence, here also, we can see that the resistive component of leakage current is more sensitive health indicator of MOSA. Variation in total leakage current from first measurement to last measurement has been shown in figure 15. Variation in resistive current from first measurement to last measurement has been shown in figure 16.

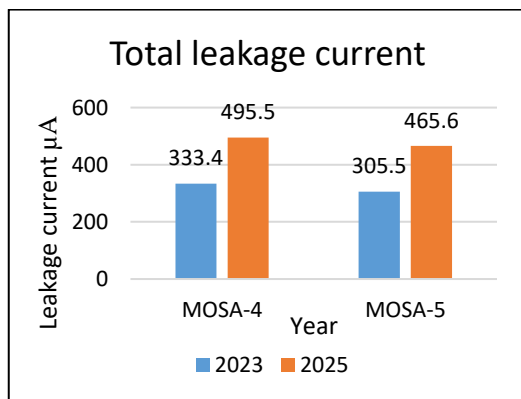


Figure 15: Variation in total leakage current

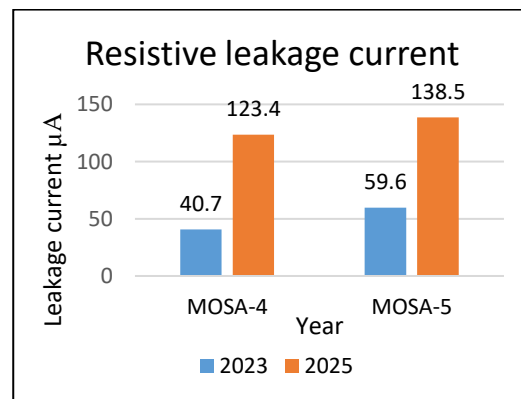


Figure 16: Variation in resistive current

6. Conclusion:

Health verification of MOSA is an important activity for the utility. Measurement of I_T i.e. total leakage current and measurement of resistive current i.e, I_R both are important to ascertain the healthiness of the MOSA. Yearly measurement of leakage current is advisable to monitor the trend analysis. Increased trend in resistive leakage current indicates the degradation of MOSA, so when there is increased trend observed on resistive leakage current it must be closely monitored and frequency of measurement should be done quarterly and if trend found increased then MOSA must be replaced, to avoid its failure.

7. References :

- [1] S. Mohammed Arshad, Asanka S. Rodrigo, “Modified phase shifting of leakage current to condition monitoring of metal oxide surge arresters in power system.” *Mortuwa Engineering Research Conference (MERC on)*, 978-1-5386-4417-1/18, 2018, IEEE pp 300-305. 2018.
- [2] Anil S. Khopkar and Umesh N. Soni, “Technique for Online Condition Monitoring of Surge Arrestors”, *World Academy of Science, Engineering and Technology International Journal of Electrical and Computer Engineering*, Vol:18, No:7, 2024. Pp 140 to 145, International Scholarly and Scientific Research & Innovation 18(7) 2024.
- [3] Z. Abdul Malek, Novizon Yusoff, Mohd Fairuz and Mohd Yousuf, “Filed Experience on Surge Arrester Condition monitoring – Modified Shifted Current Method”. *UPEC 2010*, 31st August – 3rd Sept. 2010.
- [4] Abdullah Munir, Z. Abdul Malek and Rai Naved Arshad, “Resistive component extraction of leakage current in metal oxide surge arrester: A hybrid method”, *Elsevier Journal, Measurement* 173 (2021) 108588.
- [5] Anil S. Khopkar and Kartik S. Pandya, “ Advance technique for online condition monitoring of surge arresters”, *Bulletin of Electrical Engineering and Informatics Vol. 14, No. 4, August 2025*, pp. 2526~2536 ISSN: 2302-9285, DOI: 10.11591/eei.v14i4.9457
- [6] Surge Arresters – Selection and Application Recommendation”, *IEC Standard 60099-5*, 2013.
- [7] Surge Arresters – Metal oxide surge arresters without gaps for a.c. systems, *IEC Standard 60099-4*, 2014.