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**Asset Management of Power System****Real-time Monitoring of a Lightning Arrester using online Partial Discharge (PD) Measurement and its Correlation with Third Harmonic Leakage Current Analysis****Umesh SONI\*****ERDA****India**[umesh.soni@erda.org](mailto:umesh.soni@erda.org)**Anil KHOPKAR****ERDA****India**[anil.khopkar@erda.org](mailto:anil.khopkar@erda.org)**SUMMARY**

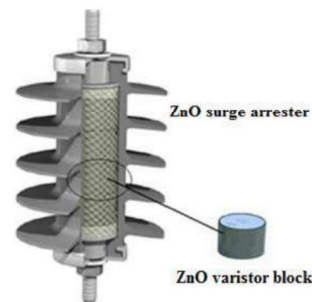
Over voltage in power system is frequent phenomenon apart from continuous operating voltage. Equipment connected in the power system must be protected from such overvoltage arises due to lightning stroke and switching operations. Metal oxide surge arresters (MOSAs) are connected to protect power system equipment against overvoltage. MOSA consists of zinc oxide (ZnO) blocks encased in ceramic or polymer housings. MOSA degrades due to ageing effect under continues operating voltage, pollution effect, heavy lightning current discharges. Degradation of MOSA results in unreliable operation and further it leads to system failure. Voltage-current (V-I) characteristics and residual voltage of MOSA also effects due to degradation. Higher leakage current flows through the degraded MOSA which increases its temperature which results in reduction of ZnO resistance and further increase leakage current. Finally results in thermal runaway condition which is basic cause of MOSA failure. Hence, condition monitoring of MOSAs is critical to ensuring optimal performance and maintaining a stable, uninterrupted power supply. Online and offline diagnostic methods are utilized to assess the condition of MOSAs. Offline techniques are not preferred much as it need system shutdown and hence online methods are more popular. Among these, measurement of resistive current component of leakage current derived from the third harmonic resistive current is considered a reliable indicator of MOSA ageing. However, certain limitations, such as the CT window diameter and the height of the lightning arrester (LA), make these measurements impractical in some cases. This study explores the impact of ageing on third harmonic resistive current (THRC) characteristics through accelerated ageing tests on ZnO blocks, comparing the results with partial discharge measurements in the laboratory. Online partial discharge monitoring proves to be an effective tool for evaluating the health of MOSAs. Various measurements were conducted for different LA ratings before and after accelerated ageing, establishing a correlation between online PD monitoring and the third harmonic resistive current in LAs. In this paper results of comparative results of THRC and online partial measurement of MOSA has been discussed.

**KEYWORDS**

Metal Oxide Surge Arresters, Overvoltage, Zinc oxide, Third harmonic, resistive leakage current, Total leakage current, Partial Discharge.

## 1. INTRODUCTION

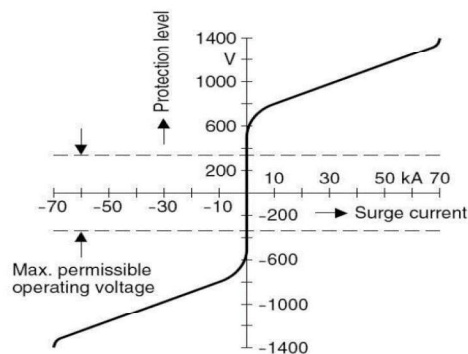
A metal oxide surge arrester (MOSA) is composed of an active part that provides a nonlinear response to electrical stresses, as well as a housing that protects the active part of the surge arrester. Active parts of the arrester consist of metal oxide column (ZnO) supported by structures. Metal oxide pillars are formed by stacking small metal oxide spheres on each other. The amount of metal oxide particles accumulated on that stack determines the arrester's resistance. Thus, the endurance of the arrester is directly related to the height of the ZnO column. Especially in high demand, multicolumn processes are used to produce raw materials. It involves joining two or more frames in parallel or series, depending on the need for high strength or resilience. A protective housing is placed on the metal oxide column to protect the product from external elements such as dirt, moisture, pollution, and dust. This housing ensures adequate creepage distance and mechanical strength. Structures are usually made of two materials: porcelain and silicone rubber. The diagram of the internal and external structure of the Metal oxide surge arrester is given in Figure 1.



**Figure 1: Metal oxide surge arrester inner and outer structure**

Surge arresters are used to protect electrical equipment from overvoltage or lightning. According to the IEC standard 60099-4, also related to discharge voltage is  $U_{res}$  (residual voltage), which must be kept in mind as a primary objective. The number of voltage peaks at which the surge arrester can withstand power frequency overvoltage is decreased, and this results in reduced capacitance to be able to withstand such types of energy. Surge arresters form the critical line of defense at every substation. These are connected in parallel to electrical equipment to be protected, such as transformers. They redirects lightning over voltages to earth & protecting the main equipment.

For the performance curve of the one-pole (gapless) surge arrester varistor, refer to Figure 2.



**Figure 2 : V-I Characteristic Curve of Gapless Surge Arrester Varistor on a Linear Scale**

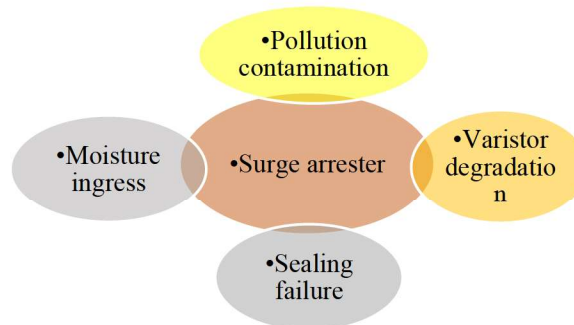
## 2. FAILURES IN MOSA

Numerous studies have been carried out to assess the condition of surge arresters during service. Analysis has focused on the Total Harmonic Resistive Current (THRC) and Partial Discharge (PD) in Metal Oxide Surge Arresters (MOSA). While various aging mechanisms of MOSA are well-documented, there is limited understanding of the underlying factors driving these phenomena. The aging of these arresters is primarily influenced by continuous operating voltage, moisture, humidity, mechanical housing damage, thermal stresses, lightning strokes and pollution levels. Currently, researchers have reached a consensus on the factors contributing to their aging.

This study employs leakage current measurements to assess the current state of ZnO surge arrester deterioration and partial discharge, revealing moisture within its internal structure. Furthermore, the UHF and HFCT techniques are utilized to identify and visualize hot spots in the varistor blocks of the arresters. The proposed technique is useful to identify the healthiness of MOSA.

### Factors Affecting the Performance of the MOSA:

The critical factors affecting the performance of MOSA has been shown in figure 3.



**Figure 3: Factors affecting the performance of polymer-housed arrester**

Moisture intrusion into the arrester appears to be one of the problem areas. This moisture intrusion causes an increase in the resistive part of the arc impedance, subsequently promoting thermal instability across the arrester where the device cannot work and, hence, insufficient arrest. A commonly cited explanation is that moisture ingress into the porcelain housing is the overriding cause of surge arrester failures. Pollution also significantly affects the deterioration of a surge arrester, mainly when accompanied by the humidity input. Moisture ingress is the main reason for high-voltage equipment aging. Moreover, surge arrester reliability requires an appropriate diagnostic tool that can adequately detect the presence of any internal moisture. Impurities intruded into the surge arrester can cause moisture condensate, the protection level to change, and energy dissipation capacity to decrease. As time passes, the resistive portion of current loss increases slowly with the aging of the surge arrester, which causes poor thermal stability to a certain extent and even leads to an incomplete fault. Previous work indicated that the arrester with moisture uptake led to a slight increase in current leaking, which was usually in mA. This, in turn, may cause the zinc-oxide (ZnO) varistor elements to overheat, which could lead to a thermal runaway condition that could subsequently cause the ZnO varistor in the arrester to rupture. When the arrester fails, it cannot work as it should regarding electrical

surges or over voltages. This allows moisture to enter the housing or the arrester to seal. Moisture will lead to overheating and, therefore, partial discharges and, as a consequence, a significant increase of resistive current leakage and its harmonic components in varistor blocks. This would remove the thermal connection to, and may result in the decay of ZnO varistor element. The spirit of power companies are looking at monitoring and improving their Arresters to minimize these potential issues [5]. This may cause the ZnO varistor element to become thermally away and deteriorate. To reduce these potential problems, power companies are focusing on monitoring and enhancing their arresters. Electrical State of Varistor - Degradation: ZnO varistors should undergo periodic testing or continuous monitoring throughout their operational life to determine if any degradation has occurred. Findings indicate that electrical stresses, such as dry-band discharges and leakage currents, are the primary contributors to these issues. Monitoring will be carried out on the same arrester, where signs of erosion have also been observed. The third harmonic resistive leakage current is currently the only method used to assess the health of metal oxide surge arresters. However, relying solely on this method has several limitations: In some cases the THRC is not feasible due to the size restraint of the grounding path of MOSA. There is a need for alternative or complementary methods to improve diagnostic accuracy and reliability.

### 3. ONLINE TOOLS FOR LIGHTNING ARRESTER CONDITION MONITORING

Leakage current measurement is one of the most prevalent techniques for evaluating the health of ZnO surge arresters. These measurements are carried out using a range of online and offline methods. While resistive leakage current plays a key role in arrester diagnostics, the total leakage current, combined with the third harmonic component passing through the arrester, is typically employed to assess arrester aging. It is essential to consult the manufacturer before adding a third harmonic or damping resistor to any arrester [7]. Insulation breakdown, aging, and failure of ZnO arresters are primarily caused by moisture ingress and surface contamination. As the insulation deteriorates, leakage currents increase, potentially leading to damage in the zinc blocks. Therefore, it is crucial to monitor the condition of surge arresters during operation to prevent prolonged outages and reduce time-consuming maintenance efforts. The cause of the insulation breakdown, aging, and loss of ZnO arresters is because the ZnO arrester is directly affected by moisture ingress and wet surface contamination. Degradation of the insulation increases leakage currents, which can damage the zinc blocks. As such, it is important to track the status of the surge arresters whilst in operation to minimize extended outages and long-winded maintenance activities. The methods for leakage current measurement has been shown in figure 4. [7]

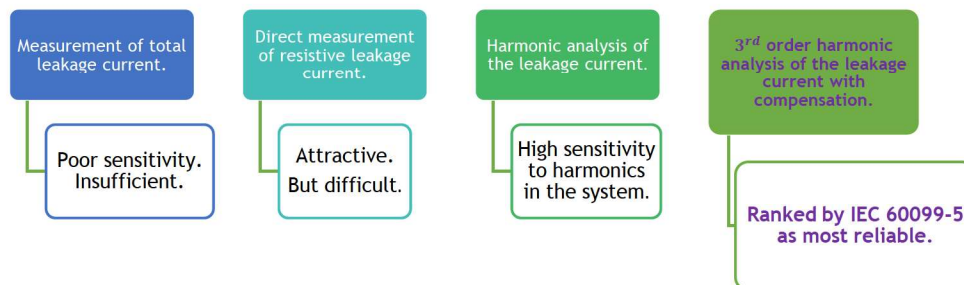


Figure 4: Methods for current leakage current measurement

**Third Harmonic Resistive Leakage Current Measurement with System Harmonic Compensation (IEC 60099-5-B2):**

When arrester is in service, the non-linear voltage-current characteristics of the metal-oxide used within the arrester generate harmonics in the leakage current. Among these, the resistive current of the arrester distorts the primary third-order harmonics. The magnitude of the third-order harmonics in the leakage current serves as a confirmation of the resistive current. Furthermore, the resistive element varies based on the applied voltage and temperature. [1] The supply harmonics may introduce very large error in the THRC measurement & it is important to compensate the supply harmonics to get the accurate result of third harmonic component. As per IEC 60099-5 the B2 method is utilized for this measurement which compensate for the any system voltage harmonics & ultimately provides the accurate measurement of third harmonic component. THRC measurement is the only technique available for monitoring the LA.

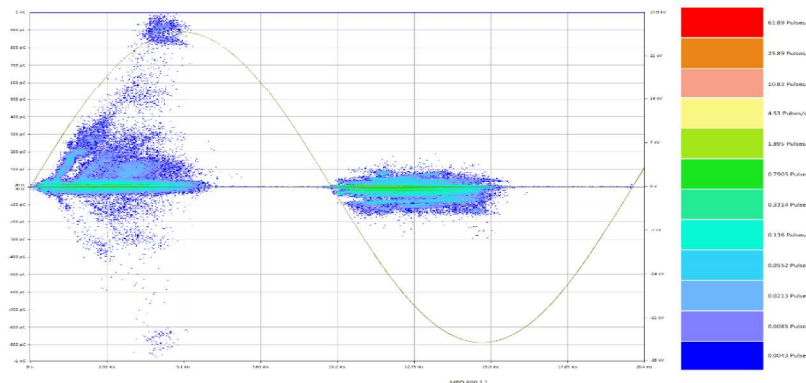
High voltage lightning arresters plays the vital role in electrical power network. For the power system reliability & safety, condition of the lightning arrester should be well maintained to avoid any damage to power equipment. In certain cases, it is not feasible to measure the leakage current using a clamp-on current meter. Therefore, it is crucial to correlate the THRC data with other tests to enhance confidence in the measurement. With co-relation with other measurement technique, more confidence in obtain results of current monitoring technique will established [7].

In presence of moisture, pollutants and other contaminant LA are aged at much faster rate. In this paper 18 kV LA samples LA samples were taken for study in house. 18 kV sample were conditioned in the salt/fog chamber with salt solution for 14 days and measurement were carried out at different voltage level on these sample before and after ageing for both by third harmonic leakage current & online partial discharge measurement along with laboratory partial discharge measurement. Also field measurement of 400 kV LA were done for online partial discharge & third harmonic current measurement were done simultaneously & same has been discussed in case study.

**4. CASE STUDIES:**

**Case Study 1:** Two samples A & B of 18 kV samples were tested after accelerated ageing to co-relate the resistive current from third harmonic to partial discharge measurement. The result of both the lightning arrester are as follows.

Sample 1



**Figure 5 PRPD pattern of partial discharges observed**

The LA shows the gradual increase in Partial discharge activity with voltage. It observes maximum of around 725 pC at 18 kV

- HFCT PD level & THRC also increasing with increase in PD

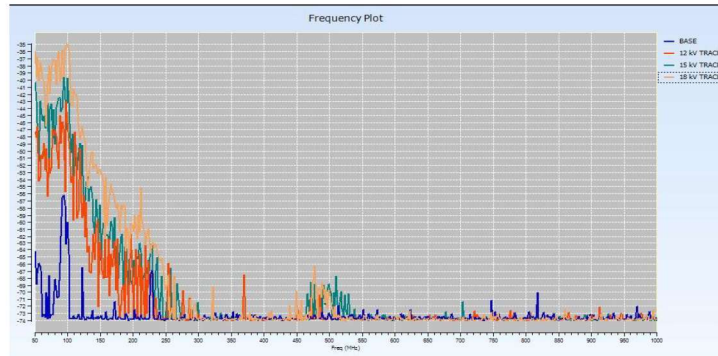


Figure 6 HFCT measurement on the LA

Table 1: Comparison of THRC and PD value

Voltage (kV)	Resistive Current from THRC ( $\mu\text{A}$ )	Partial discharge (pC)
12	20.6	120 pC
15	36.3	250 pC
18	143.5	725 pC

Sample 2

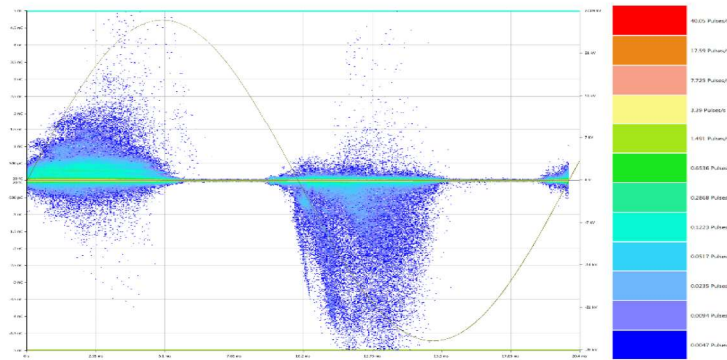


Figure 7 PRPD pattern observed

This LA also LA shows the gradual increase in Partial discharge activity with voltage. It observes maximum of around 4600 pC at 18 kV, HFCT PD level & THRC also increasing with increase in PD

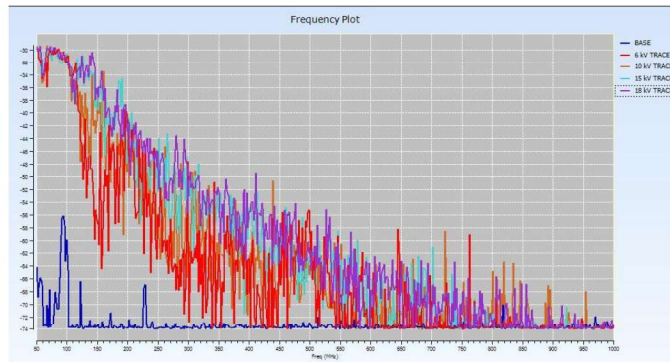


Figure 8 HFCT measurement on LA

Table 2: Comparison of THRC and PD value

Voltage (kV)	Resistive Current from THRC ( $\mu$ A)	Partial discharge (pC)
6	42.5	415 pC
10	66.3	1800 pC
15	158.6	4000 pC

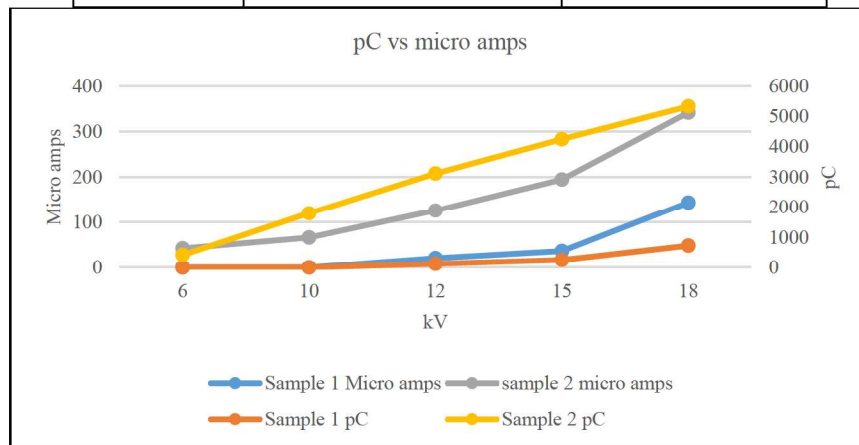
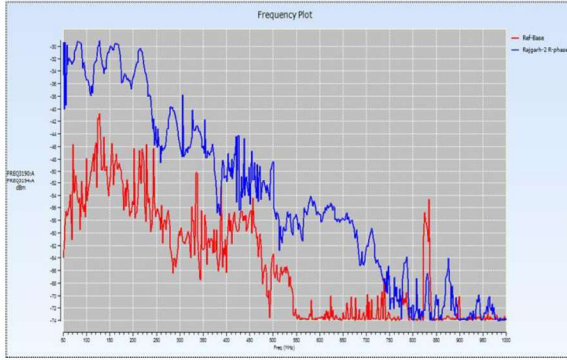


Figure 9 Comparison of Electrical PD & resistive current with voltage

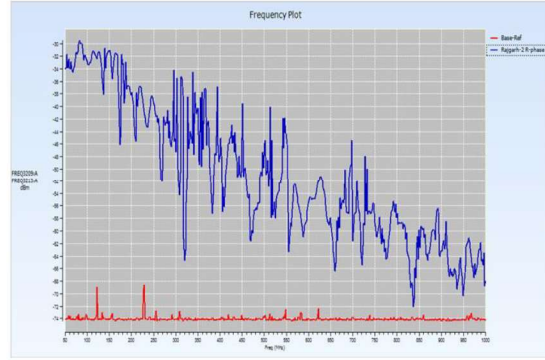
### Case Study 2: Lightning arrester at 410 kV line

Measurement for live switchyard were taken for 410 kV system for RFI, HFCT & third harmonic current for various LA & result tabulated are as below.

Line 1:



**Figure 10 RFI of R-phase of line 1**

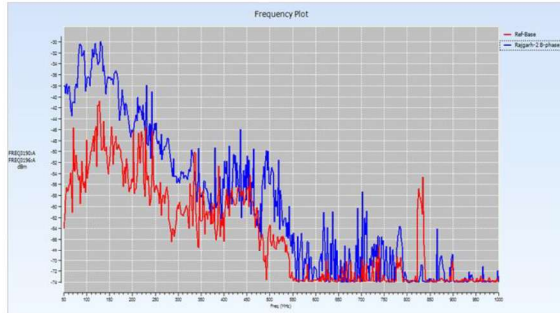


**Figure 11 HFCT of R-phase of line 1**

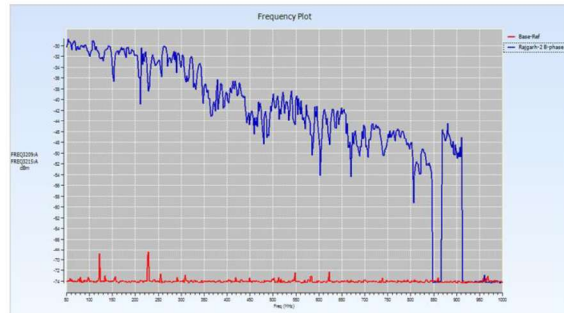
The resistive leakage current from third harmonic component is 195.3  $\mu\text{A}$ .

From the above measurement it has been seen that the HFCT measurement is more sensitive to third harmonic current value in comparison of the RFI measurement, however RFI measurement also gives good idea about the presence of discharges in conjunction with the third harmonic current measurement.

Line 2:



**Figure 12: RFI of Line 2 B-phase**

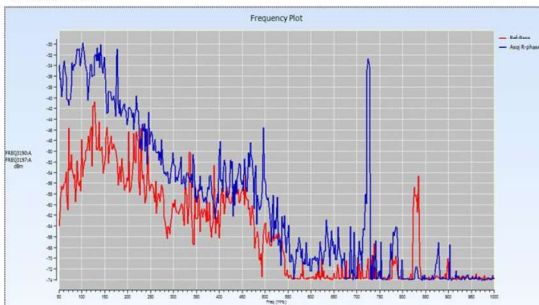


**Figure 13: HFCT of line 2 B-phase**

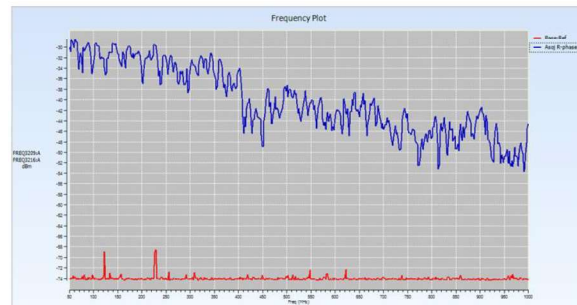
The resistive leakage current from third harmonic component is 280.2  $\mu\text{A}$ .

From the above measurement it has been seen the amplitude of both RFI & HFCT are sensitive to the amplitude of the third harmonic current measurement. Also it has been seen that higher amplitude of  $I_r$  affects the higher frequency range while measurement of discharges through the RFI & HFCT measurement of the LA. Discharges through the NL camera were tried to measure along with the RFI & HFCT, however presence of grading ring may affected the measurement & no visible discharges were measured.

Line 3:



**Figure 14 Line 3 R-phase RFI**



**Figure 15 Line 3 R-phase HFCT**

The resistive leakage current from third harmonic component is 213.8  $\mu\text{A}$ . From the above three cases it has been evident that the HFCT & RFI measurement can effectively give the indication related to the discharge activity which may be resulted due to ageing of the LA & can be helpful in predicting the condition of LA alongside the third harmonic current measurement of the lightning arrester.

### 5. CONCLUSION:

From the accelerated ageing of the lightning arrester, it is found that after accelerated ageing LA gives the higher resistive current from third harmonic component along with the other PD measurement. Field measurement of 400 kV lightning arrester shows that the good co-relation can be drawn with online partial discharge measurement & third harmonic current measurement. It is also evident from the field measurement that online partial discharge measurement using HFCT is more sensitive as compare to online PD measurement by RFI technique as there is large increase in amplitude of HFCT measurement compare to the RFI measurement. Hence it is advisable to utilised the online partial discharge measurement technique along with the third harmonic current measurement for condition monitoring of LA. Online real time partial discharge technique will be more useful where the physical limitation restrict the THRC measurement. Also this technique can be utilized as supplementary to confirm the condition of lightning arrester when measurement done with the THRC shows the ageing in the lightning arrester.

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