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No. EL/2.2.23 Dated 08.08.2016

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Technical Circular No. RDSO/2016/EL/TC/0136 (Rev'0') dated .08.8.2016

1.0 Subject:
Condition Monitoring of Lightening Arrestors of Electric Locomotives & EMUs.

2.0 Introduction:

High voltage power systems including traction power supply experience over voltages, which are generated through occurrence of faults, switching operations and lightning discharges. The duration of the over voltages vary from a few micro seconds to few seconds depending on the type of surges. Similarly, the magnitude of over voltages varies from 1.5 to 4 times of the normal operating voltages. Under these severe overvoltage conditions, the insulation of the power system/equipment undergoes stresses that could lead to catastrophic failure. Hence, it is imperative that the power system equipments are protected from these over voltages at the time of occurrence. Using a device with variable impedance with respect to voltages can provide the protection of power equipments from over voltages. This kind of overvoltage protection device is connected in parallel to the system/equipment to be protected. An effective Surge Protection Device must satisfy the following conditions:

- Conduct only during over voltages.
- Low power loss under normal operating conditions.
- High energy handling capability.
- High reliability and long life.

Usually, metal oxide (Zinc Oxide) type of Lightning Arrester herein after shall be called as LA is used for protection of system/equipments from overvoltage in Electric Locomotives and EMUs.

2.1 Principle of Operation of Lightening Arrester (LA):

The primary function of a zinc oxide LA is to protect the power equipments from over voltages and to absorb electrical energy resulting from lightning or switching surges and from temporary over voltages. These gapless metal oxide arrestors consist of active part, which is a highly non-linear ceramic resistor, made of essentially zinc oxide. Fine Zinc Oxide crystals are surrounded by other metal oxides (additives). The microstructure of an element of LA is shown in Fig. 1.

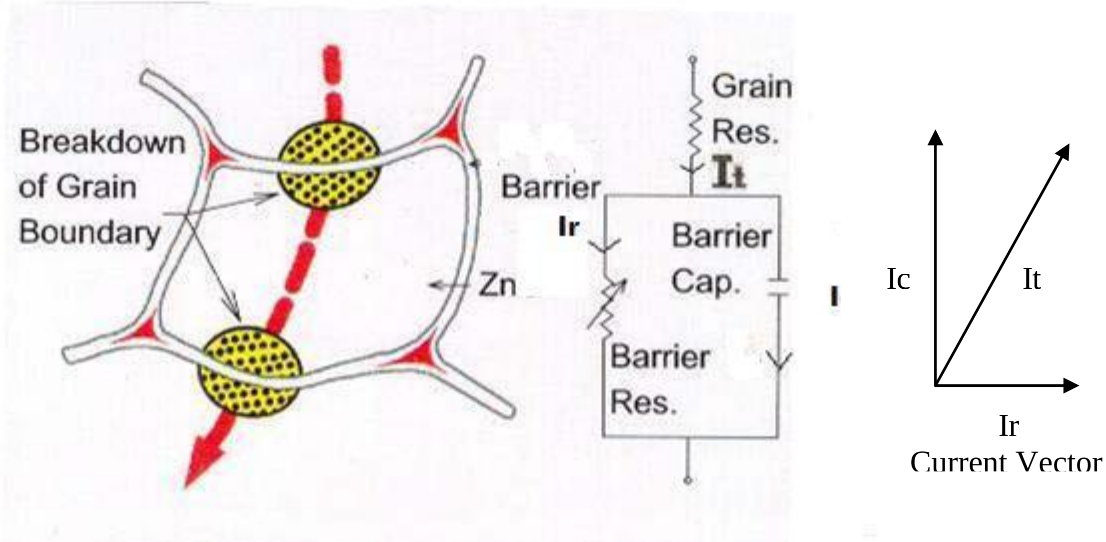

Fig. 1 Microstructure & equivalent circuit

As shown in Figure 1, Zinc Oxide elements are made by mixing Zinc Oxide with small amount of additive materials such as Ba_2O_3. The mixture is, then, granulated, compacted and fired or baked. The equivalent electrical circuit of an LA is a Parallel Combination of capacitance and variable resistance. The current flowing through LA is the total leakage current (It) having capacitive leakage current (Ic) and resistive leakage current (Ir) components. Normal operating voltages cause ageing of Zinc Oxide elements/blocks whereas Switching/Lightning over voltages may cause overloading of all or part of the Zinc Oxide blocks. Due to various electrical stresses, the granulated layers/barriers break down causing the conduction. The increase in the voltage stresses on healthy granulated layers results in the higher resistive leakage current (Ir) amounting to higher total leakage current in LA.

2.2 Energy Handling Capacity and Thermal Stability of ZnO Arrester:

The application of ZnO ceramic elements for over voltage protection also calls for energy handling capacity which is defined as Energy E= V x I x t. The energy handling capacity of the commercial ZnO arresters is in the order of 150 Joules/cm^3. The Energy absorption and dissipation being dependent on this specific energy handling capacity, the energy discharge of Zinc Oxide Block is basically dependent on its volume. The rated voltage of Zinc Oxide element is proportional to the height. The energy level increases with the increase in area of the Zinc Oxide block. Concept of thermal behaviour of ZnO arrester is an important application consideration. Thermal capability of a design takes advantage of overvoltage capability. The thermal capability of ZnO arrester depends on the assembly structure of the arrester. As long as the heat generated from the Z_nO elements due to continuous operating voltages and surges is less than the thermal power dissipation of the housing, the elements will remain in an undamaged condition, capable of performing their protective function.

2.3 Important Definitions:

2.3.1. **Arrester discharge current**
The current that flows through an arrester resulting from an impinging surge.

2.3.2**. Arrester discharge voltage**
The voltage that appears across the terminals of an arrester during the passage of discharge current,

2.3.3. **Lightning overvoltage**
The crest voltage appearing across an arrester or insulation caused by a lightning surge.

2.3.4**. Maximum continuous operating voltage (MCOV) rating**
The maximum designated root-mean-square (rms) value of power frequency voltage that may be applied continuously between the terminals of the arrester.

2.3.5. **Rated Voltage**
The rated voltage is the maximum power frequency voltage that is applied in the operating duty test for 10 seconds.

2.3.6**. Standard lightning impulse**
The wave shape of the standard impulse used is 1.2/50 μA.

2.3.7. **Temporary overvoltage**
An oscillatory overvoltage, associated with switching or faults (for example, load rejection, single-phase faults) and/or nonlinearities (ferro-resonance effects, harmonics), of relatively long duration, which is undamped or slightly damped.

3.0 Background:

In view of above, it may be concluded that Gapless LA is one of the most vital devices used to protect the power equipments of an electric locomotives/EMUs such as transformers etc. against over voltages including lightning surges. Failures of gapless surge arresters on 25 KV conventional electric locomotives/EMUs are cause of concern for IR as these failures not only leading to failure of locomotive on line but also resulting tripping of circuit breaker of feeding sub-station. Moreover, bursting of porcelain lightning arresters can have damaging consequences like damaging nearby equipments due to blowing away of porcelain chips with great force

The following major reasons have been identified for LA failures:
1. Ingress of moisture through sealing system/gasket leading to degradation/flash overs of Zinc Oxide blocks.
2. Accelerated ageing/degradation of Zinc Oxide blocks possibly due to manufacturing defects.

Presently there is no maintenance guideline available to Zonal Railways on preventive maintenance of LAs provided on Electric Locomotives/EMUs. Therefore, it is essential that the health/condition of the LAs provided on Electric Locomotives/EMUs is to be monitored at a regular interval.

The Maintenance Instruction No. TI/MI/0041 Rev. 1 for condition monitoring of Lightening Arresters for TRD application has already been issued by T.I.Dte of RDSO in 2010. Based on above, this Technical Circular for condition monitoring of LA is being issued.

3.1 Conditions monitoring of Lightening Arrestor:

As per the international norms, various techniques are available for the health monitoring of LAs in service. Some of the techniques are mentioned below:

a. Insulation Resistance measurement.
b. Total leakage current measurement.
c. Third Harmonic Resistive Leakage Current (THRC) monitoring.

3.1.1 Insulation Resistance measurement:

The health of an LA may be monitored by periodically measuring the Insulation Resistance (IR) by using 1000V meggar. Usually, the allowable range of IR value for LA should not be less than 1000 Mega Ohms. The measurement of IR value of an LA apparently gives an indication of degradation due to ingress of moisture. The measurement of Insulation Resistance of LA does not provide any significant information about the health/degradation of metal oxide elements while in service. **The insulation resistance of an LA may remain high even though the LA might be on the verge of failure due to various reasons including the ingress of moisture**. Hence, the value of IR of an LA cannot be taken as a criterion for accurate monitoring the health of an LA.

3.1.2 Total leakage current Measurement:

In normal service, the Metal Oxide Lightning Arrestors are exposed to different kinds of stresses such as the normal operating voltage, temporary overvoltages, switching overvoltage, lightning overvoltages and external pollution. All these stress, separately or together in different combinations, may cause an increase in the resistive component of the continuous leakage current through the arrester. This increase may exceed the critical limit and cause arrester failure, if ZnO blocks are cracked or punctured due to overvoltages or if some special fault situations that cause high temporary overvoltages have occurred in the network. In addition, general ageing may also be the reason for increased leakage current and often accelerated due to pollution on the arrester housing. Thus, the measurement of leakage current flowing through LA under normal situations gives the information about the real operating condition of an LA, which may help to:

- Prevent arrester failures by replacing aged arresters before breakdown.
- Increase the safety of the other equipments.
- Avoid disturbances in the electric power supply.
- Reduce the risk for damages to other equipment due to arrester failures, for instance transformer bushings.

However, the total leakage current measurement does not indicate the severity of degradation of Zinc Oxide elements as the resistive current (Ir) is only 15-25% of the total leakage current. Hence, a sharp increase in resistive current due to degradation/ageing of Zinc Oxide blocks does not affect the total leakage current considerably.

Therefore, practically no real time system for monitoring the health of LAs of electric Locomotives/EMUs exists on Indian Railways. Even, if the measurement of total leakage current is monitored, then also a database is required to be built up by the Railways in order to prescribe a threshold limit for various make of LAs for taking the decision of replacing the LA.

3.1.3 Third Harmonic Resistive Leakage Current (THRC) Measurement:

As discussed above, the measurement of total leakage current flowing through an LA under normal conditions is also used as one of the health monitoring techniques. However, the total leakage current measurement does not indicate the severity of degradation of Zinc Oxide elements. The higher resistive leakage current may ultimately bring in the LA to thermal instability and may result in complete failure/breakdown of the Arrester. Hence, the resistive leakage current is the true indicator of health of an LA in service.

3.2 Why measurement of Third Harmonic Resistive leakage Current (THRC) is necessary:

A voltage-current characteristics of a typical metal oxide LA when a sinusoidal voltage is applied to it, is shown in Fig 2 :

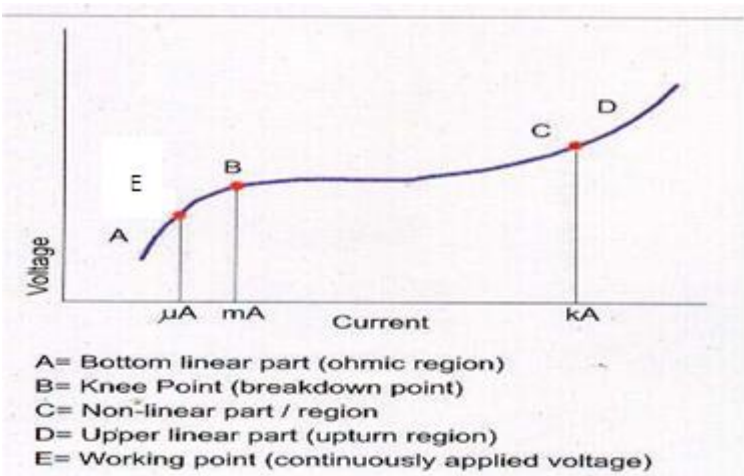

Fig. 2 Voltage – Current Characteristics

The nonlinear characteristics of Zinc Oxide blocks, then introduce a third harmonic resistive current in the leakage current. This current component is therefore generated by the arrester itself and will be an indicator of changes in the non-linear characteristics of Zinc Oxide blocks for a period of time due to ageing phenomenon. The resistive current consists of fundamental, third harmonic, fifth harmonic and seventh harmonic components etc. The harmonic contents depend on the magnitude of the resistive current and on the degree of non-linearity of the voltage current characteristics of zinc oxide blocks. Further, the harmonic contents also are the function of temperature of LA. The third harmonic is the largest harmonic contents of the resistive current and most commonly used for monitoring purposes. In addition to the above, the harmonic contents in operating voltage also increase the harmonic contents in the leakage current.

The system harmonics will interfere with the harmonics generated by the arrestor itself. This implies that with the presence of harmonics contents in the system voltage, if any, cannot be ignored for the purpose of evaluation of the resistive leakage current. In other words – if the harmonic contents of the system voltage are ignored, then it will not be known if an apparent increase in the third harmonic resistive leakage current (Ir) is really due to ageing phenomena of the arrester or it is a 'false' increase due to varying harmonic contents with time. Thus, it is necessary that a measurement of third harmonic resistive current duly compensated for third harmonics present in the system be made for monitoring the health of an LA in service. Further, it is not only the measurement of third harmonic resistive current for one time, but also a data base for this resistive leakage current are to be built up for monitoring the periodical changes due to normal/abnormal ageing phenomena. Sudden rise in third harmonic resistive current or very high value of third harmonic resistive current indicates degradation of Zinc Oxide blocks and calls for corrective actions required to be taken in advance in order to prevent a catastrophic failure of LA in service.

Thus, it is recommended that Railway should go for a periodical measurement of third harmonic resistive leakage current through LA in service. Also to get rid of effect of system harmonics on measurement it is desirable that the measurement of third harmonic current to be done on shop floor.

4.0 Condition monitoring of LA provided on Electric Locomotives/EMUs:

As already explained in the previous para that third harmonic resistive leakage current is important for evaluation of the performance of LA in service. Depending on the value and trend in rise of third harmonic resistive leakage current, a decision can be taken either for close monitoring or for replacement of an LA. Various kinds of instruments are now available in the market, which can be used for measurement of third harmonic resistive leakage current flowing through an LA under normal working conditions. A Testing Set up for the measurement of third harmonic leakage current should be developed by Electric Loco sheds/EMU car sheds. Insulation Resistance is also required to be measured with the help of 5.0 kV equipment.

In order to measure insulation resistance and third harmonic resistive leakage current, it is recommended that LA to be taken out from the locomotive during AOH/TOH and measurement should be done as follows:

4.1 Measurement of Insulation Resistance: The insulation resistance is measured with the help of 5.0 kV equipment. IR value of lightning arresters should be measured during annual maintenance and it should be above 1.0 G ohms.

4.2 Measurement of Third Harmonic Resistive Leakage Current (THRC):

4.2.1 Testing Set up:

In order to measure third harmonic leakage current, following instruments are needed.

1. Controlled HV source
2. High Voltage Chamber
3. Insulated base for mounting LA
4. Instrument needed to measure third harmonic current
5. Interconnecting cables
6. PT Unit and
7. CT unit

As the measurements are to be taken on the shop floor, a test set up need to be developed. The Test up consists of a High Voltage source installed in a high voltage area. The control panel to apply high voltage shall be installed outside high voltage area for the safety of operating personnel. All the precautions needed for operation of High Voltage 25 kV and above shall be ensured. The insulated base to mount LA required to be fixed in side High Voltage area. The instruments needed for measuring third harmonic current shall be installed outside high voltage area. Other equipments shall be connected as shown in Figure3. The HV equipment used in VCB HV testing (40 kV for 10 seconds) may also be used if it can provide 34 kV voltage for sufficient time required during testing and other equipments may be arranged however it may be noted that HV equipment is able to give proportional PT output as shown in figure given below:

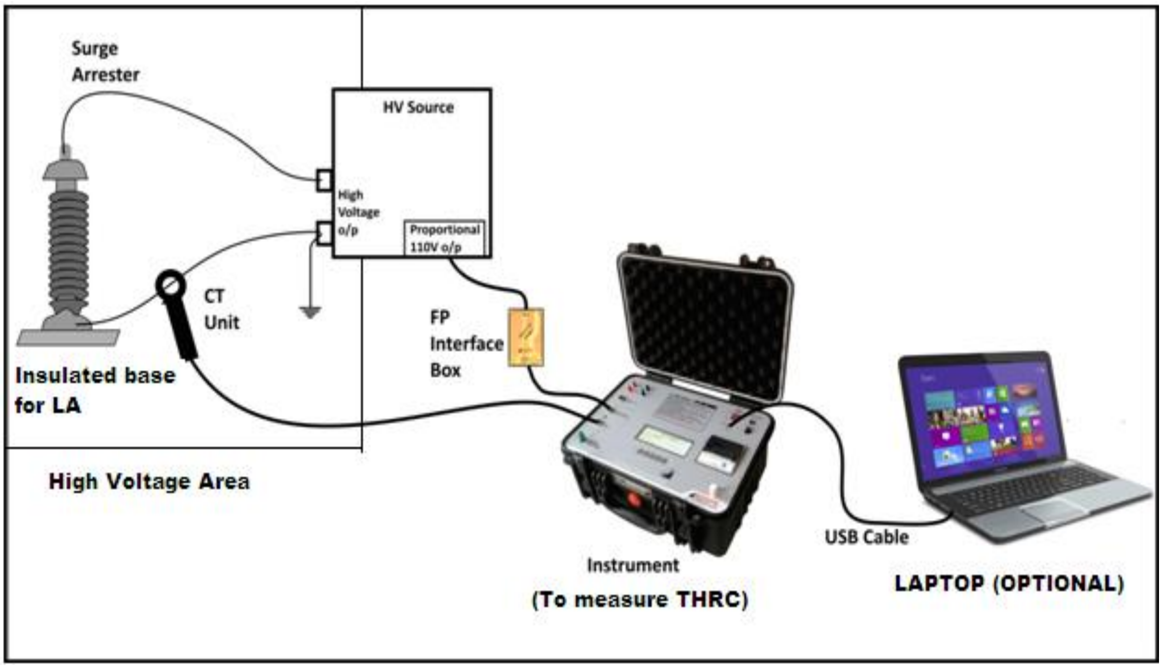

Figure-3: Test Set up for measurement of third harmonic leakage Current

4.2.2 Measurement method of third harmonic leakage current: The measuring instruments to be connected as shown in the figure-3. Apply Maximum continuous operating voltage (MCOV) as 34 kV from the HV control panel and record the readings of the currents i.e. total leakage current, resistive leakage current and Third Harmonic Resistive Leakage Current. The record of measurement shall be kept as per **Annexure-I.** It may be noted that assessment of resistive component of leakage current is a very sensitive measurement due to its small value (few micro amperes) and its dependence on Voltage harmonics and temperature. Every reading recorded is also accompanied by the Voltage. The measurements should be taken preferably under dry climatic conditions to avoid interference with surface leakage currents.

The calibration of the equipment to be kept up to date. The readings recorded should be carefully examined for consistency of results e.g. very high leakage currents or wide variations in repeated measurements needs cross verification.

5.0 Analysis of Results:

The value of resistive leakage current and Third Harmonic Resistive Leakage Current recorded during the measurement are to be analysed and a data base is to be developed (LA make wise) so that a threshold/critical value of Third Harmonic Resistive Leakage Current can be decided for taking the corrective actions for LAs in service.

A comparative study of results shall indicate the deterioration in the condition of LA. Based on the data of measurements received from Zonal Railways for 42 kV LA of TRD application, it is suggested that LA's with third harmonic resistive leakage currents in between 350-500 µA should be closely monitored and beyond 500 µA should not be permitted & should be removed from service. As, these values are not available presently for Locomotives/EMUs hence based on the experience of Zonal Railways these values may be further reviewed in consultation with RDSO.

6.0 Instruments Used:

Though instruments used in the measurements such as high voltage source and insulation resistance tester are quite common and are generally available, the availability of indigenous third harmonic leakage current measuring instruments are limited. While planning for procurement, Railways should clearly indicate their requirement. **It may also be noted that the measurement is temperature sensitive and is affected by harmonics present in the HV voltage applied. Therefore, the instrument purchased for third harmonic leakage current measurement should have facility for automatic temperature compensation i.e. there should not be any effect of temperature on measured values. Also, the output of HV source should be pure sinusoidal.** If the different equipments are purchased from different sources it shall be ensured that all the equipments are compatible with each other else total measuring set up may be purchased from one source. The probable source's addresses are given below however these sources shall not be considered as approved sources of RDSO. The availability of other sources may also be explored by Zonal Railways:

Address1:	**Address2:**
SCOPE T&M Pvt Ltd. 402, Aurus Chamber Annex-A, S. S. Amrutwar Marg, Worli Mumbai, India Phone No. 022-43444244 Fax No. : 022-43444242 Email: marketing@scopetnm.com	M/s Myriad Industrial solutions Ltd. A-401, Mini Garden, Mandapeshwar Road, Dahisar, West Mumbai (India) Mob No. 08042753938, 8454940731 9869260731. Website: http://www.myriadindustrialsolutions.co.in/

7.0 Additional maintenance practices to be followed:

It has also been reported by some of the loco sheds that the point at which HV is connected on LA is found rusted and this may result in moisture ingress inside the surge arrestor. In order to avoid the same it is recommended that after tightening, the connection point may be applied with RTV compound and after that a thin layer of silicon grease may also be applied to avoid rusting.

8.0 References:

(i) "A REPORT ON CONDITION MONITORING OF LIGHTNING ARRESTERS" by Mr. Nasim Uddin, CELE, North Central Railway, Allahabad.
(ii) TI/MI/0041 Rev. 1 dated 8-4-10; Maintenance Instruction on conditioning monitoring of lightning arresters Revision-1issued by T.I.Dte./RDSO.
(iii) IEC 60099-5 Ed 2.0, Part-5; Surge Arrestors-Selection and Application recommendations.

(A. K. Shukla)
for Director General/Elect.

Encl: As above
Distribution: As per standard mailing list.

Annexure-I

S. No.	Loco No	Date of Measurement	S. No. of LA	Make and Type of LA	year of manufacturing of LA	Voltage at the time of measurement	Insulation Resistance	Total Leakage current I_{total}	Resistive Leakage Current Ir	Third Harmonic Resistive Leakage Current I_{3t}