THIRD HARMONIC LEAKAGE CURRENT MEASUREMENT AND HEALTH MONITORING OF SURGE ARRESTERS-B1 METHOD- QUICK, ACCURATE, SIMPLE & SAFE

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Abstract

Surge arresters are installed on transmission and distribution substations between phase and earth in order to improve the lightning performance and reduce the failure rates. High-energy stresses and housing deterioration are the main factors of degradation and damage of surge arresters. Thus, there is need for testing and monitoring the surge arresters, in order to verify their good condition and their ability to effectively protect the lines.

There are number of methods are available to measure the arresters leakage current like compensation method, harmonic analysis method. The most common method used, is the measurement of the arresters 3rd Harmonic Current as per **IEC-60099-5-B1 due to quick, accurate, simple & safe**, which is an indicator of the surge arrester's condition, since every change, deterioration or damage leads to an increase of the 3rd Harmonic leakage current.

Introduction

What is a Lightning Arrester?

A device used on Power Systems above 1000V to protect other Equipment from Lightning and Switching Surges. Surge Arresters are designed to be insulators for nominal operating voltage, conducting at most a few milli-amperes of current and good conductors when the voltage of the line exceeds design specifications to pass the energy of the lightning strike to the ground.

What exactly does a lightning arrester do?

- It Does not Absorb the Lightning
- It Does not Stop the Lightning
- It Does Divert the Lightning to Ground
- It Does Clamp (limit) the Voltage produced by the Lightning
- It protects Substation Costly Assets such as Transformer, CT, PT, Circuit Breakers etc.

Lightning strikes are the main reason for outages in overhead transmission system. In an effort to maintain high power quality and to avoid damages and disturbances, overhead ground wires and surge arresters are used for the Transmission/Distribution system protection.

A vital aspect of asset management on power systems is understanding the remaining life of a Surge Arrester. Predicting the life of this component while on-line or off-line is an onerous task at best. Testing surge arresters in the field is important on both transmission systems and distribution systems since they are extensively applied in both.

According to IEC60099-5, measurements can carried out on-line under normal service voltage is the most common method. The non-linear voltage-current characteristic of a metal-oxide arrester gives rise to harmonics in the leakage current when the arrester is energized with a sinusoidal voltage. The third harmonic is the largest harmonic component of the resistive current, and it can be used for diagnostic measurements of Surge Arrester.

This 3rd Harmonic Leakage Current measurement as per **IEC-60099-5-B1** for Surge Arrester Assessment is rapidly becoming the method of choice due to **quick, accurate, simple & safe** for arrester users interested in excellent long term maintenance of arresters. This method has been developed for the current generation of Metal Oxide Arresters. This method is the most accurate in predicting the life of an arrester and offers the most relevant data with regard

to the past and present status of the arrester. IEC Standard 60099-5 has an annex devoted to this type of field testing of arresters.

An enterprising product "TAURUS MULTI:ALCL-40" which is designed as per IEC60099-5 B1 method for online 3rd harmonic leakage current measurement on metal-oxide surge arresters can be used for Measuring & Monitoring.

Sensitivity to Arrester Health:

With the proper equipment, this is a highly accurate means of measuring the present state of an arrester's health. Arresters that are in short or long term failure mode will exhibit some increase in 3rd harmonic leakage current long before any other characteristic shows changes.

Informative:

As stated above, the 3rd Harmonics Leakage Current is a definitive characteristic of an arrester's health. This data coupled with an historic set of data is the best possible way in assessing the health of an arrester.

Speed of Use:

With the proper use of portable clamp type test equipment (TAURUS MULTI: ALCL-40) speed of measurement can be increase with safely.

Ease of Use & Safe:

With the proper training any line personnel can use this type of equipment.

Reliable Predictor of End of Life:

The most reliable means of predicting the end of life of an arrester, if historical data is kept on record by routine testing. A trend change in the resistive current (3rd Harmonics Leakage Current) of an arrester is one of the most sensitive characteristic of an arrester's health.

Test While Installed:

This is the preferred state when performing a 3rd harmonic leakage current measurement to confirm the healthiness of the Surge Arrester and keep the data as base line measurement for future analysis.

Maintenance Cost:

No maintenance is necessary, but the equipment must be handled with care.

CT Accuracy:

Measurement tool should be very accurate to provide the reliable results, as the current measurement has to be carried out at micro-amps ranges. Typical Taurus Multi-Surge Arrester (ALCL-40) have quite unique, sophisticated and very high accuracy CT which enables to measure very low range current with minimum resolution of 0.1μA at the accuracy 1.2%.

Induction & Noise Suppression:

Necessity of nullifying the induction & noise is very much mandatory as measurement has to be carryout at substations, where presence of Induction is very much normal. Since, 3rd Harmonic Leakage Current mostly in micro-amps range, which will get affect by presence of Inductions & Noises.

Hence, to work in highly induced substation, the equipment (TAURUS MULTI: ALCL-40) has been designed with triple shielding to nullify the induction/noises & to provide the accurate results.

Special Requirements for IEC-60099-5 B1 Method to achieve optimistic results:

1. ***Measuring 1st Harmonics:***
   a. White paper says if the Total Leakage Current (RMS) and 1st Harmonics (Fundamentals) matches nearly (i.e. rms ~ Fundamental (1st Harmonics)) then there is no harmonics in the system and if huge difference is there it means Harmonics are present in the system.

Reference:

Fundamental vs. Total RMS

A significant advantage delivered by the MCEMAX is the ability to segregate the Fundamental and Total RMS values of voltage and current. Most multi-meters will normally deliver Total RMS, which provides a value similar to our Total Voltage or current value. However, our Fundamental value will always be lower as it represents only the fundamental (working) frequency of the voltage and current. If you have a large differential between fundamental and total then a large amount of distortion is suspect. Poor power quality to a motor delivering design full load may result in a high temperature situation. This is due to the motor working harder than designed to deliver its designed full load. Compare your output horsepower (HP) to your running amps. If the motor is at design full load amps (FLA) and is delivering less than the designed HP, check your fundamental vs. total values of voltage and current. You may find that they are very different.

   b. According to *IEC-60099-5 Section 6: Diagnostic indicators of metal-oxide surge arresters in service: Clause 6.1.6.1.3 Harmonics in the leakage current;* **"The system harmonics is negligible and its influence may be considered"**. This explains that system harmonics are rarely present and its influence on 3rd Harmonics measurement may not be considerable.

IEC- Reference:

6.1.6.1.3 Harmonics in the leakage current

The non-linear voltage-current characteristic of a metal-oxide arrester gives rise to harmonics in the leakage current when the arrester is energized with a sinusoidal voltage. The harmonic content depends on the magnitude of the resistive current and the degree of non-linearity, which is a function of voltage and temperature. As an example, the third harmonic content of the resistive current is typically 10 % to 40 %. The harmonic content can, therefore, be used as an indicator of the resistive current. Typical values of the variations with voltage and temperature of the third order harmonic component are shown in figures 6 and 7.

Another source of harmonics, beside negligible ones, that may considerably influence the measurement of harmonics in the leakage current, is the harmonic content in the system voltage. The capacitive harmonic currents produced by the voltage harmonics may be of the same order of magnitude as the harmonic currents created by the non-linear resistance of the arrester. An example of harmonics in the leakage current caused by system voltage harmonics is seen in figure 4.

   c. Taurus measuring the Surge arrester leakage using B1 method (TAURUS MULTI: ALCL-40) from last 8 years and experienced that 99% transmission Substation has no system harmonics by comparing the Total leakage (RMS) and Fundamental (1st Harmonics).

Minutes of meeting held between M/s. MSETCL & M/s. Taurus powertronics Pvt. Ltd. Bangalore at 400kV RS (O&M) Division Padghe on 23 Aug 2013.

As per letter No. MSETCL/CO/TR(O&M)SE-1/Seminar/10464.
Dtd:-08.08.2013 issued by CE Trans (O&M) MSETCL, M/s. Taurus powertronics Pvt. Ltd arranged field demo of their lightening arrester third harmonic leakage current tester model ALCL-40 At 400/220kV S/s. at padghe .

During first half of demonstration following LA's were tested for total current, third harmonic leakage current and first harmonic leakage current by Taurus kit. The values are tabulated as under.

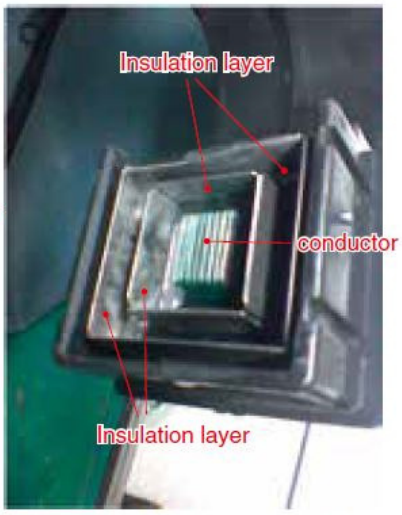
Bay name	phase	Total current (mA)	First harmonic(mA)	Third harmonic(micro Amp.)	It (tong) (mA)
315MVA ICT-1	R-phase	0.889	0.889	83.5	0.85
	Y-phase	0.467	0.464	12.1	0.52
	B-phase	0.434	0.420	12.8	0.4
Babhaleshwar-1	R-phase	0.458	0.455	13.6	0.52
	Y-phase	0.4	0.38	12.2	0.39
	B-phase	1.14	1.155	99.1	1.01

Induction & Noise Suppression: The measurement tool should be well equipped with Induction and Noise Suppression technique to provide the accurate results in the induced zone of Switchyard. As measurement of 3rd harmonic currents is in micro-amps range, the measurement tool should be capable of nullifying the external interferences. The CT used by the typical Taurus Multi-Surge Arrester Tester ALCL-40 (Method-B1) is nullifying the external magnetic field and noise by triple shielding of CT as shown in figure, which lead it to the accurate measure value.

Ordinary

Plane clamp head is easily to become dirty. Magnetic can not coherent with single isolation layer easily.

ALCL-40



Clamp head coherent mutually. Magnetic line is easily to be Conducted.
Double-deck isolation & insulation will not be interfered easily.

2. ***CT Accuracy:*** Measurement tool should be very accurate to provide the reliable results, as the current measurement has to be carried out at micro-amps ranges. Typical Taurus Multi-Surge Arrester (ALCL-40) have quite unique, sophisticated and very high accuracy CT which enables to measure very low range current with minimum resolution of 0.1μA at the accuracy 1.2% for RMS (1% for Harmonics) defending such outer electric noises.

   For example, the comparison list for ordinary & Taurus Surge Arrester Tester CT is as followings:

Range	ALCL-40/-40L	Ordinary Model
Accuracy	1.2%	±5% ±10%
Minimum Resolution	0.1μA	10μA
Influence of Outer Magnetic Fields	Less than 10μA (400A turn/15cm)	Less than 1mA (20A turn/5cm)

Non-Necessity of System Harmonics Compensation for Method-B1 make Testing Safe over Method-B2

During testing of LA with **Method-B1** recommendation are to check Total Leakage Current (RMS) and 1st Harmonics (Fundamentals). If both the reading matches nearly (i.e. rms ≃ Fundamental (1st Harmonics)) then there is no harmonics in the system. As observed from past 8 years with various Utilities 99% both Total Leakage Current & 1st Harmonic are matching, and can proceed to test the 3rd Harmonic leakage current measurement.

If some places both the readings Total Leakage Current (RMS) and 1st Harmonics (Fundamentals) are differ, recommendations are to wait for a while & repeat the test after some time, as mostly harmonics are instantaneous due to switching and go off immediately.

According to *IEEE-519 section 1: Overview;* Harmonics are created in the power system by the end users. Common sources of harmonic in power systems include power electronic converters, arc furnaces, static VAR systems, inverters for distributed generation, ac phase controllers, cyclo-converters, and ac-dc converters (rectifiers) commonly used in switched mode power supplies and pulse width modulated (PWM) motor drives used by user. Which is mostly in towards end user side, not in the transmission/Distribution Substations.

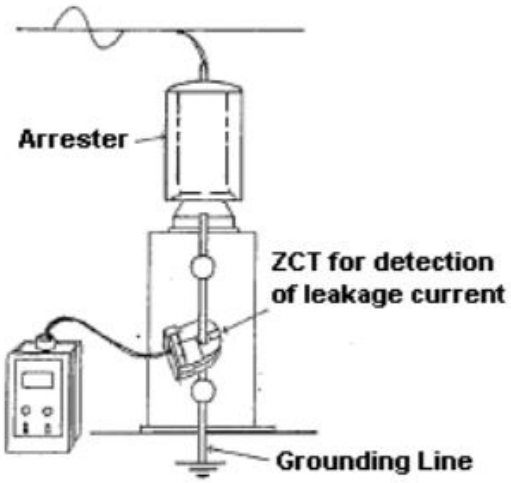
In *IEEE-519 section 1: Recommended Harmonic Limits;* they recommended limit for harmonic distortion only at the point of Common Coupling (PCC). (PCC is usually taken as the point in the power system closest to the user where the system owner or operator could offer service to another user), not for transmission line between substations as there is no source of harmonics.

Also in *IEEE-519 section 1: Recommended Harmonic Limits;* The permissible limit of Harmonics mentioned at PCC point are less than 1%.

According to *IEC-60099-5 Section 6: Diagnostic indicators of metal-oxide surge arresters in service: Clause 6.1.6.1.3 Harmonics in the leakage current;* **"The system harmonics is negligible and its influence may be considered"**. This explains that system harmonics are rarely present and its influence on 3rd Harmonics measurement may not be considerable. (IEC reference paper has been mentioned above at page-4.) As explained above, hence Testing Lightning Arresters with Method-B1 is sufficient for monitoring the healthiness of Lightning Arresters. Due to the non-requirement of compensation probe, **Method-B1 is very safe to use** compare to Method-B2, where compensation probe is require while measurement of Lightning Arresters.

Benefits of Method-B1 over Method-B2			
SL. No.	**Method-B1 (TAURUS MULTI - ALCL-40)**	**Method-B2 (others)**	**Remarks**
1	Ease of use due to portability	Handling complexity due to bulky kit	Method-B1 is comfortable & easy for LA testing
2	User Friendly & Light weight. Speedy & Quick LA testing is possible	Very difficult to connect, heavy weight & complexity in testing due to Compensation Probe. Very Slow & cumbersome to use	Method-B1 is quick. Frequent LA testing is feasible
3	Very Safe to use due to non-requirement of Compensation Probe	Harmonic compensation probe need to connect at surface of Surge Arrester mounting structure, which is quite dangerous. "Hence not safe for the testing personnel".	Method-B1 is safe to use
4	Taurus-LA test kit is having quite unique & sophisticated CT which enables to measure very low range current with minimum resolution of 0.1μA and accuracy 1.2% for RMS defending outer electric noises/interference/induction.	The CT used for the Leakage current measurement by the Method-B2 were having low accuracy, between 5%-10%, due to this the values obtained from them are higher.	Method-B1 is accurate

TESTING METHODOLOGY:



- Insert the plug of CT to the position "CT INPUT" of the instrument body.
- Clamp CT to the Earth wire coming from Surge Arrester to Surge meter/counter, make sure clamp CT before the surge meter.
- Set mode switch to "RMS" position and range switch on 300μA.
- If "OL" sign display on LCD, change the range switch to 3mA.
- Wait for 5sec so that the displayed values get stable and note it down.
- Change the mode switch to "1st H" & "3rd H" and repeat step 5.

Experience of other Utilities

Power Grid Corporation of India Limited (PGCIL) reported that about 200 Lightning Arresters provided on 400 KV and 200 KV side were monitored and results obtained during sample checks are as below:

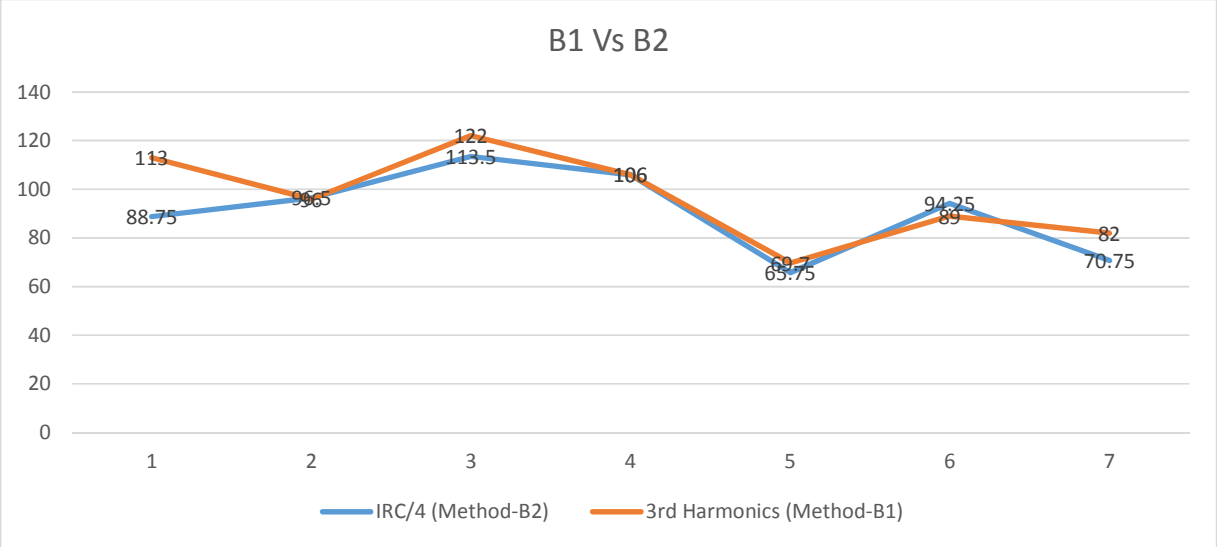
System Voltage	Range of 3rd Harmonic Current* Make A, Method-B1		Range of Resistive Leakage Current* Make B, Method-B2		Remarks
	Normal Range	Abnormal Range	Normal Range	Abnormal Range	
400kV	10-50 μA	100μA & above	30-150 μA	300μA & above	Five surge arresters were showing upto 2100 μA

The value of the third harmonic leakage current was recorded generally in the range of 10-15 micro amperes for new LAs whereas for 12 to 15 years old LAs, the value was in the range of 200-300 micro ampere.

A similar kind of study is also to be made by RDSO/ Railways in order to arrive at a threshold/ critical value of Third harmonic leakage current in order to take necessary corrective actions for those LAs, which are having large third harmonic leakage current.

Details of Taurus Experiments: Method-B1 & Method-B2

Sl No	Bay Name	Phase	B1 Method			B2 Method			Power grid Limit	
			Total RMS	1st harmonics	3rd Harmonics	IRC	IT	IR	IRC/4	3rd Harmonics
			30mA	30mA	300μA	μA	μA	μA	<150μA	μA
1	Padge-II	B	3.44	3.44	113	355	4220	442	88.75	113
2	Padge-I	R	3.56	3.55	96	386	5156	488	96.5	96
3		Y	3.43	3.42	122	455	4945	575	113.75	122
4		B	3.36	3.35	106	424	4766	536	106	106
5	Solapur-I	R	2.61	2.61	69.7	263	3675	314	65.75	69.7
6		Y	2.48	2.48	89	377	3534	460	94.25	89
7		B	2.37	2.37	82	283	3334	345	70.75	82



This experiment has been carried out at POWERGRID site, and concluded that both the readings Method-B1 3rd Harmonics (Direct Instrument reading) & Method-B2 IRC/4 (as per POWERGRID Calculation for Method-B2) are matching for decision making.

Case Studies

1. LA Testing at KPTCL 400kV Substation- Nelamangala;

Bay Name	Phase	THRC Reading	Remarks
Nelamangala – Peenya 2	R	101.6 µA	LA got flash over
Nelamangala – Nittur	R	127.6 µA	LA got flash over

2. LA testing at 220kV Substation- Gadag

Bay Name	Phase	THRC Reading	Remarks
Gadag – Dambal 110kV	B	188µA	LA got flash over

LA got flashover about half an hour after testing.

Conclusion:

As explained earlier, LA is one of the most vital devices used to protect the power equipment's such as transformers etc. against over voltages including lightning surges. Therefore, it is quite imperative that the health/condition of the LAs at Sub-Stations is to be monitored at a regular interval by measuring third harmonic leakage current with the help of measuring instruments **preferably Method-B1 (TAURUS MULTI-ALCL-40) due to quick, accurate, simple & Safe, which enable substation maintenance personnel to do frequent measurement because of portability & ease of use at site.** Further, a database for the third harmonic leakage current for all the LAs (make wise) is to be developed and analysed. A threshold/critical value of third harmonic leakage current is then to be specified based on the database developed over a period of time.

The following practices for maintenance and condition monitoring of LAs in service are suggested:

Sl. No.	Proposed Practices	Periodicity
1	Cleaning of LA housing	Twice in Year
2	Measurement of Third harmonic leakage current through LA	Monthly
3	Measurement of Insulation Resistance (IR) Value of LA at the time of Schedule Maintenance. Usually the IR value should not be less than 1000 M.Ohms.	For the suspected LA as per Third harmonic leakage current data
4	Measurement of Hot Spot by Thermal Camera	For the suspected LA as per Third harmonic leakage current data
5	Preparation of database (LA make wise) for Third harmonic leakage current for deciding the threshold/critical valve for each type of LAs.	Monthly data collection & record
6	Decision is to be taken for either close monitoring or replacement of LAs in service depending on the value/ steep rise/ trend in the rise of Third harmonic leakage current.	Decision as per 3rd Harmonic Leakage current reading

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