

Eskom's unique type test requirements for lightning surge arrester ground lead disconnectors



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1 Introduction

Lightning surge arresters are widely used by utilities to protect transformers and other equipment on medium voltage (MV) distribution lines. It is common practice to fit these arresters with ground lead disconnectors (GLDs).

The function of the GLD is to disconnect a failed arrester from the network, before a permanent earth fault occurs.

International specifications tend to focus mainly on the arrester, neglecting the GLD. The specified requirements do not adequately cover the performance, duty and reliability of the GLDs.

Specific problems experienced by Eskom in recent years include: lack of co-ordination with earth fault protection settings, operation of the GLD when the arrester is not damaged, failure of the GLD to operate when it is suppose to operate, as well as deterioration of the GLD due to weathering of the unit over time.

These problems had significant impact on Eskom's reliability of supply. Eskom was therefore compelled to reassess the international test requirements for GLDs. Significant deficiencies were identified and six additional test requirements have been developed by Eskom to ensure that future products will be suitable for application on the Eskom network.

The paper starts off with a discussion on the basic operation of a GLD and the international test requirements for GLDs. Eskom's recent field experiences with GLD's are then examined and the subsequent changes to the type test requirements are discussed.

2 Basic workings of a GLD

The most commonly used GLD design consists of a spark gap, a resistor and a blank cartridge. The basic circuit diagram of such a GLD is indicated in

Figure 1.

The resistor provides a path through the GLD for the arrester's leakage current. Most designs use standard, 22 k Ω , film resistors (i.e. the type used in electronic circuits). The cartridge is a standard 0.22, blank cartridge. The blank cartridge will ignite when enough heat is generated in the GLD. The resulting explosion provides the mechanical force that is required to disconnect the earth connection from the arrester.

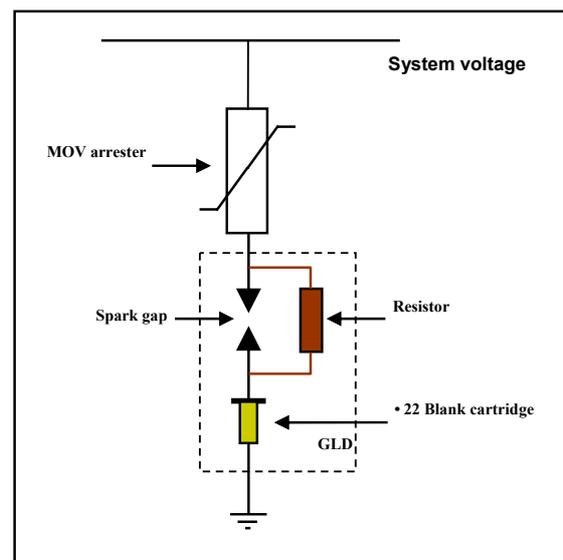


Figure 1 – Circuit diagram of a typical GLD

To explain the operation of a GLD it is necessary to look at the following four conditions:

2.1 Healthy arrester under power frequency conditions

The GLD resistor is connected in series with the arrester's metal oxide varistor (MOV) blocks which result in a voltage divider circuit. Under normal power frequency conditions, the resistance of the MOV blocks is very high in comparison to the resistance of the resistor. The majority of the system voltage is therefore dropped across the MOVs and the voltage across the resistor remains below the flashover voltage of the spark gap. Leakage current in the order of 300 micro-ampere will constantly flow through the

MOVs, the resistor and the cartridge. The associated energy is however too low to generate enough heat to ignite the cartridge. The arrester and GLD can therefore remain in this state indefinitely.

2.2 Failed arrester under power frequency conditions

If a power frequency overvoltage condition occurs that exceeds the temporary overvoltage capability of the arrester, the MOVs will fail. The MOVs normally fail short-circuit, which means that the full system voltage will suddenly appear across the resistor and spark gap. The spark gap will therefore flash over and the system's earth fault current will flow through the GLD. Enough heat will be generated instantly and will ignite the cartridge, thereby disconnecting the earth tail from the arrester. The arrester and the GLD will be permanently damaged and will have to be replaced as soon as possible.

2.3 Healthy arrester under transient conditions

When the arrester is subjected to a transient overvoltage, as in the case of a lightning surge, the resistance of the MOV's will temporarily reduce to a very low value in comparison to the resistance of the resistor. The voltage across the resistor and the spark gap will rise and the spark gap will flashover. Surge current will flow through the arrester and the cartridge for a short time. Once the overvoltage condition passes the MOV resistance return to a very high value again, the voltage across the gap reduce and the arc across the gap is quenched. Not enough heat is generated to ignite the cartridge due to the very short duration during which the surge current flows through the GLD. The arrester and GLD therefore return, undamaged, to the same state in which it was before the surge condition.

2.4 Failed arrester under transient conditions

If the surge energy exceeds the energy capability of the arresters, the MOV will fail. The surge current will be followed by power frequency follow-through current. Enough heat will be generated instantly to ignite the cartridge, thereby disconnecting the earth tail from the arrester. The arrester and the GLD will be permanently damaged and will have to be replaced as soon as possible.

3 International specifications

The two main international specifications for surge arresters are IEC 60099-4 [1] and IEEE C62.11 [2]. The following test requirements are specified in the IEC specification, the IEEE requirements are however almost identical.

3.1 Time versus current curve test

Power frequency voltage is applied across the GLD until it operates. The duration to first movement of the GLD is recorded. This

procedure is conducted at three current levels: 20 A, 200 A and 800 A.

The recorded operating time at each current level is plotted to provide the GLD's operating curve, as indicated in Figure 2.

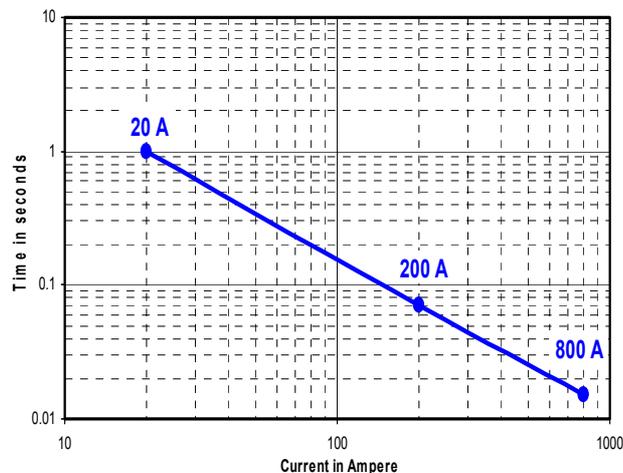


Figure 2 – GLD operating curve

3.2 Long duration current impulse test

The arrester and GLD are subjected to a series of eighteen long duration current impulses (2000 μ s square wave, peak current > 250 A).

3.3 Operating duty test

The arrester and GLD is subjected to a series of twenty lightning current impulses (10 kA, 8/20 μ s) and two high current impulses (100 kA, 4/10 μ s).

3.4 Discussion

The purpose of the first test is to establish the operating time of the GLD at different current levels.

The aim of the second and third tests is to simulate transient conditions that the arrester and GLD could be subjected to when in service. The arrester is required to withstand these impulses. The GLD should also withstand these impulses without operating, because the GLD should only operate in the case of an arrester failure.

4 Field failures

Compliance with the above mentioned test requirements are strictly enforced on all arresters applied on the Eskom network. However, large numbers of GLD maloperations have been reported in recent years.

The majority of these maloperations can be grouped into two categories:

- GLDs that do not operate when the arrester fail, examples are shown in Figure 3.
- GLDs that are too sensitive, i.e. the GLD operates prematurely on an arrester that is still in a good condition. An example is shown in Figure 4.

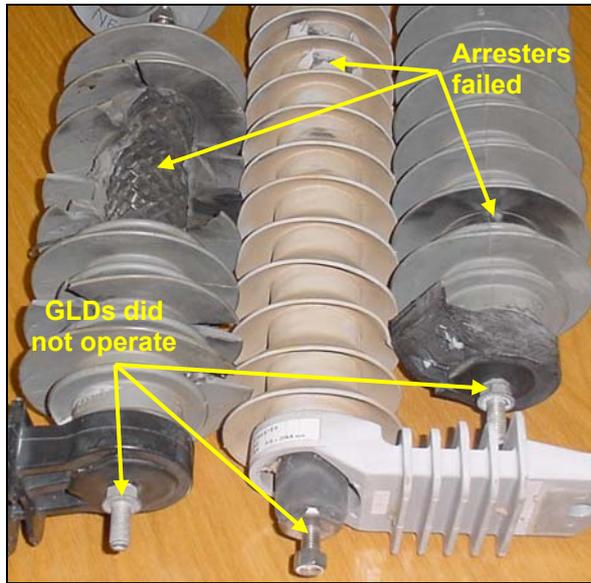


Figure 3 – The GLDs did not operate when the arresters failed

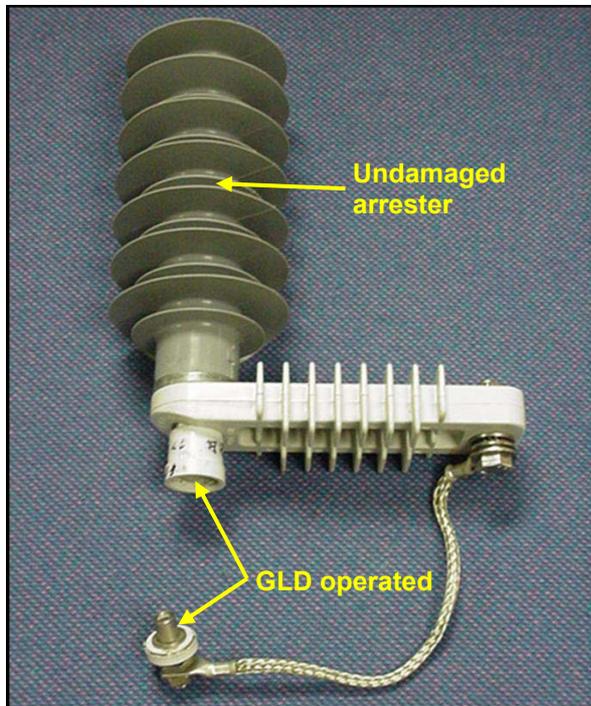


Figure 4 – Premature GLD operation

4.1 GLDs that fail to operate

The investigation revealed that these maloperations occurred, because the GLD operating curves do not grade with the upstream protection. It was found that a loss of co-ordination can occur between the operating time of the GLD and the sensitive earth fault (SEF) setting at the upstream protection device.

The purpose of the GLD is to remove a failed arrester from the network, before the subsequent earth fault is permanently cleared by upstream protection. The GLD should therefore ensure that an arrester failure does not affect the rest of the network due to a permanent outage. Loss of co-ordination between the GLD and the SEF protection defeats the object, because the upstream breaker clears the earth fault before the

GLD can operate.

According to Eskom's settings philosophy for rural feeders [3], SEF pick-up settings are set between 3 A and 6 A. The time-current characteristic is a definite time characteristic with the trip delay set between 3 s and 15 s. A typical SEF setting has a pick-up of 5 A and a trip delay of 5 s. The SEF setting range is illustrated in Figure 5.

The GLD operating characteristic curves of the arresters that were most commonly used by Eskom at the time are shown in Figure 5.

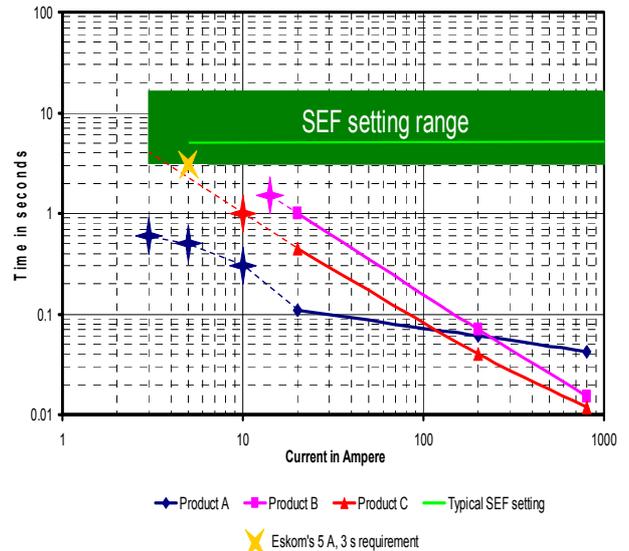


Figure 5 - GLD operating curves

According to these operating curves the GLD's of all three makes will operate faster than the SEF element for earth fault currents of 20A and higher. The GLD operating times below 20A were however not readily available, because the international specifications only require the test to be conducted at 20A, 80A, 200A and 800A. The manufacturers were approached to provide operating times at lower currents. These operating points are indicated in Figure 5 with the 'star' symbols.

Product A grades with the SEF settings in all cases. A straight-line extrapolation (dotted line) suggests that product B will start to lose co-ordination below 4 A. The manufacturer of product C indicated that it will not operate at all for currents below 15 A. These findings correlated well with maloperations that were reported from the field.

Eskom therefore decided to amend the requirements of the time versus current curve test. It is now specified that the GLD operating time must also be recorded at 5 A and it must be faster than 3 s.

The GLD operating curves for products A, B and C, after implementation of the amended requirements, are shown in Figure 6. The operating times for products B and C are notably faster.

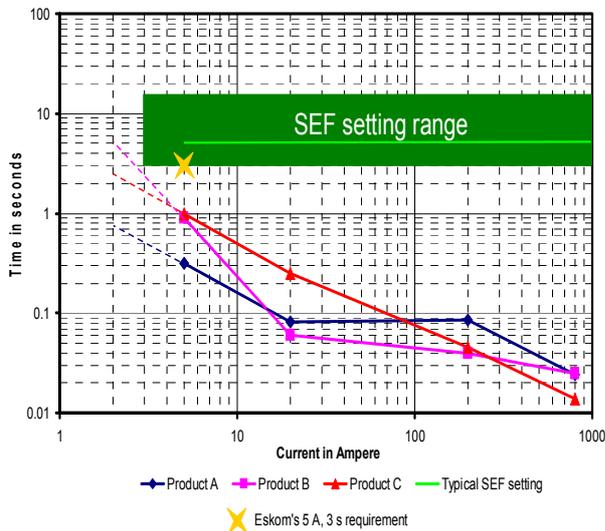


Figure 6 – New GLD operating curves

4.2 Premature GLD operation

The investigation revealed that the premature GLD operations occurred during lightning storms, predominantly in areas with high lightning ground flash densities. It was therefore necessary to investigate whether the specified type tests adequately simulate the lightning conditions that the arrester will be subjected to on a distribution network.

The effective duration of an impulse is defined as the difference between the tail time and rise time of the impulse, as detailed in clause 8.1. The effective duration of typical lightning impulses [4], [5] is between approximately 30 μ s and 120 μ s. The effective durations of the three test impulses specified in IEC 60099-4 are however 6 μ s, 12 μ s and 2000 μ s respectively. The differences in the effective impulse current durations are illustrated in Figure 7.

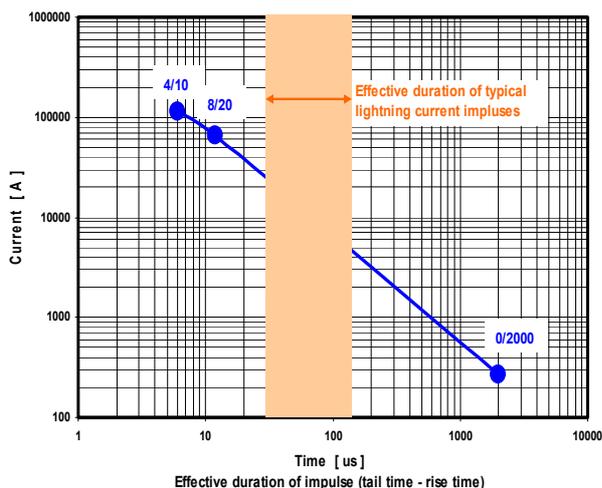


Figure 7 – GLD current impulse test points in accordance with IEC 60099-4

The effective duration of the standard specified test impulses do not correlate well with the effective duration of typical, natural lightning impulses. The IEC type tests therefore do not provide a good indication of a GLD's withstand capability for typical lightning impulses.

Additional current impulse withstand tests with an effective impulse duration of between 30 μ s and 120 μ s are required.

All the premature GLD operations occurred with one specific make and model of arrester and GLD, dubbed 'product X' for the purpose of this paper. Product X complied fully with all the type test requirements of IEC 60099-4. It was therefore suspected that the operating characteristic of the unit is too sensitive in the zone of typical lightning impulses. The particular arrester and GLD were subsequently subjected to two additional current impulses with 15/350 μ s and 30/80 μ s wave shapes, the results are illustrated in Figure 8.

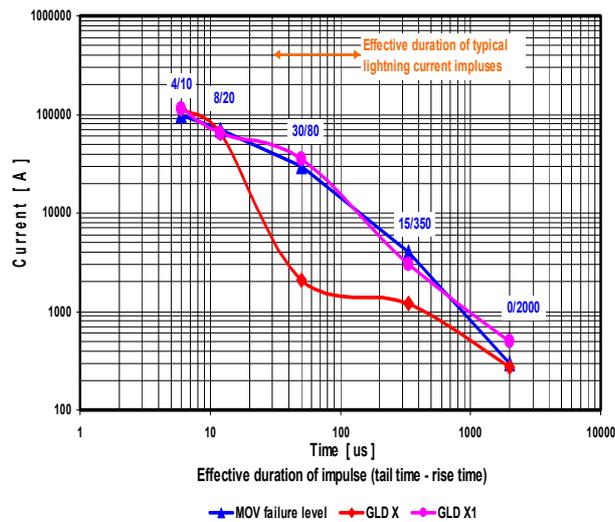


Figure 8 – MOV failure level versus transient operation curve of GLD

The MOV failure level indicates the amplitudes at which the MOV blocks of arrester X will fail for each of the wave shapes specified by IEC 60099-4, as well as for the two additional wave shapes.

The 'GLD X' curve shows the current impulse withstand values of GLD X and can be described as the transient operating curve of the GLD.

In principle the GLD should only operate once the arrester failed. The MOV failure level of the arrester should therefore be located below, or at least very close to, the transient operating curve of the GLD. It is clear from Figure 8 that this is not the case, especially in the range of typical lightning impulses. For a 30/80 μ s impulse the GLD X will operate at 2 kA, whereas the MOV will only fail at about 30 kA. The GLD is more sensitive than the arrester at these wave shapes, which explains the maloperations that occurred on the network.

Manufacturer X subsequently designed a new less sensitive GLD, GLD X1. The transient operation curve of GLD X1 is also indicated in Figure 8 and it can be seen that it grades well with the MOV failure level of arrester X.

The transient operating characteristics of GLDs X and X1 were also benchmarked against GLDs from other manufacturers that have been

successfully utilised on the Eskom network for a number of years. The results for 30/80 μ s current impulses are illustrated in Figure 9.

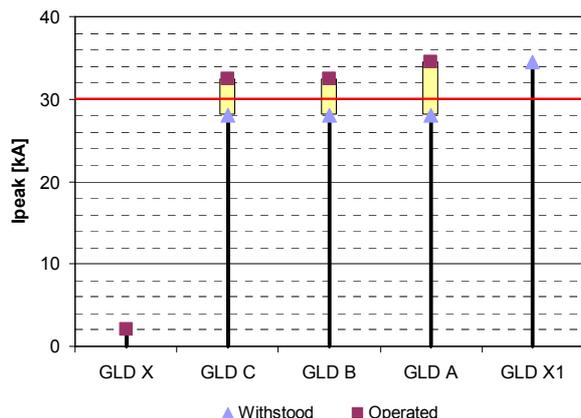


Figure 9 – Benchmarking of current impulse withstand values for a 30/80 μ s wave shape.

The withstand value of GLD X was found to be significantly lower than that of products A, B and C. The withstand value of the redesigned GLD X1 is much closer to the other models and is even slightly less sensitive.

5 Eskom's new GLD test requirements

The field failures and investigations that followed brought to light the fact that the requirements of the international specifications for GLDs do not adequately cover performance, duty and reliability of GLDs

The following additional test requirements were therefore added to Eskom's specification for distribution class surge arresters, SCSSCAAN5 [6].

These tests do not only focus on the failure modes that were discussed in the previous two sections. Additional possible failure modes were identified and test requirements were formulated to also cover it.

Three of the main surge arrester manufacturers, on the international market, comply currently with Eskom's amended test requirements.

5.1 Time versus current curve test

The GLD operation curve has to grade with the SEF settings. It is therefore specified that in addition to the standard requirements of IEC 60099-4 the operating time shall also be obtained at 5 A and it must be ≤ 3 s.

5.2 High lightning duty current impulse withstand test

The investigation proved that the sensitivity of a GLD is not necessarily linear across the whole spectrum of possible transient impulse wave shapes. It is for that reason necessary to ensure that the current impulse withstand capability of the GLD is sufficient for typical lightning wave shapes.

It is therefore specified that GLDs are subjected to two consecutive 30/80 μ s current impulses

with a minimum peak value of 30 kA.

5.3 Repetitive surge withstand ability test

The arrester and GLD are subjected to a large number of impulses over its service life as a result of induced surges. These repetitive surges can erode and damage the internal components of the GLD to such an extent that the operating characteristics of the GLD are altered.

In a paper by Geldenhuys and Theron [7] it is shown that small surges with slow rise times is the most severe duty that a GLD can be subjected to. It is further shown that the number of such impulses that a GLD will experience in its life on the South African network is in the order of a thousand impulses.

A test is required to confirm that a GLD is capable of withstanding a large number of low amplitude surges with slow rise times. The repetitive surge withstand test was formulated for this purpose.

GLDs are subjected to a thousand consecutive voltage impulses. The amplitude of the impulses must exceed the spark over value of the GLD's internal gap by 120%. The impulses must have a virtual front time of 5 μ s to 10 μ s and the tail time should be long enough to ensure that sparkover occur across the GLD's internal gap. The thousand impulses are applied consecutively with a 50 s to 60 s interval between impulses.

5.4 Thermal pre-conditioning and water immersion test

It is critical that the GLD is hermetically sealed for its entire service life. A moisture ingress test is specified in IEC 60099-4, but it is only required on the arrester. The Eskom specification requires that this test also be conducted on the GLD. The aim of this test is to first thermally age the GLD and then to confirm that the GLD remains sealed.

The moisture ingress test consists of three parts; thermal, mechanical pre-conditioning and water immersion. GLDs should be subjected to the thermal preconditioning and water immersion parts of the test. The mechanical part of the test is not required on the GLD.

The GLD is subjected to specific thermal variations consisting of two 48 hour cycles of heating and cooling, conducted in air. The thermal pre-conditioned samples are then subjected to the water immersion test.

The water immersion test essentially requires that the GLD is boiled in salt water for 42 hours and thereafter cut open to verify if any moisture ingress occurred

5.5 GLD resistance measurements

The pass criteria in the IEC specification simply require that the GLD does not operate when subjected to the current impulse tests. It is however possible that the GLD's internal resistor

failed short-circuit during the test. The spark gap will therefore be permanently bridged-out and the GLD will never operate.

The Eskom specification consequently specifies that the resistance of the GLD be measured across its terminals before and after each of the standard impulse tests, as well as before and after the additional tests that are specified by Eskom. The resistance should not change by more than 5 %.

It is further recommended that carbon composition resistors, rather than film resistors, be utilised for GLDs. The surge performance and ageing of carbon composition resistors are believed to be superior.

5.6 Operation verification test

Besides the resistor, the other sub-components of the GLD can also be damaged during the impulse tests. In order to ensure that the GLD is still in a working condition after being subjected to each impulse test, it is specified that the actual operating time of the GLD be measured. The requirement for an operating time of less than 3 s for a 5 A current is arguably the most arduous in the power frequency domain.

The new specification requires confirmation that the operating time of the GLD at 5 A is still less than 3 s, after completion of each of the impulse tests.

6 Conclusion

International specifications for surge arresters focus mainly on the arrester, neglecting the GLD. The specified requirements do not adequately cover the performance, duty and reliability of the GLDs.

Eskom developed the following six additional test requirements to confirm that GLDs are suitable for application on the Eskom network:

- Time versus current curve test
- High lightning duty current impulse withstand test
- Repetitive surge withstand ability test
- Thermal pre-conditioning and water immersion test
- GLD resistance measurements
- Operation verification test

7 References

- [1] IEC 60099-4, Surge arresters — Part 4: Metal-oxide surge arresters without gaps for a.c. systems.
- [2] IEEE C62.11, IEEE Standard for metal-oxide surge arresters for alternating current power circuits.

- [3] DISSAGAAQ0, Eskom distribution standard, Part 4, Section 8, Rural reticulation protection: Network philosophy.

- [4] RB Anderson, AJ Eriksson: "Lightning parameters for engineering applications." Electra No. 69 p 65-102, 1980.

- [5] RH Golde: Lightning. 1977

- [6] DISSCAAN5 Rev.4, Eskom specification for distribution class surge arresters without spark gaps.

- [7] HJ Geldenhuys, DR Theron: "Lightning surge arrester ground disconnecting link." IX International symposium on lightning protection. Foz do Iguaçu, Brazil. Nov 2007

8 Definitions

8.1 Effective impulse duration: For the purpose of this paper the effective impulse duration is estimated as the difference between the virtual time to half value on the tail of an impulse and the virtual front time of an impulse, i.e. $T_2 - T_1$.

8.2 Tail of an impulse: The part of an impulse which occurs after the peak. [1]

8.3 Virtual origin of an impulse: The point on a graph of voltage versus time or current versus time determined by the intersection between the time axis at zero voltage or zero current and the straight line drawn through two reference points on the front of the impulse. For current impulses the reference points shall be 10 % and 90 % of the peak value.

8.4 Virtual front time of an impulse (T_1): The time in microseconds equal to 1,25 multiplied by time in microseconds for the current to increase from 10 % to 90 % of its peak value. [1]

8.5 Virtual time to half value on the tail of an impulse (T_2): The time interval between the virtual origin and the instant when the voltage or current has decreased to half its peak value. This time is expressed in microseconds. [1]

8.6 Wave shape (T_1/T_2): The shape of a voltage or current impulse is defined by the virtual front time (T_1) and the virtual time to half value on the tail (T_2) and is indicated as T_1/T_2 .

9 Abbreviations

9.1 GLD: ground lead disconnecter

9.2 IEC: international electrotechnical commission

9.3 IEEE: institute of electrical and electronics engineers

9.4 MOV: metal oxide varistor

9.5 MV: medium voltage

9.6 SEF: sensitive earth fault