The Testing Of High Voltage Silicon Carbide Lightning Arresters

Ass Lect. Arkan A. Hussein

University Of Tikrit / Engineering College / Electrical Engineering Department

ABSTRACT

The majority of high voltage gapped silicon carbide lightning arresters on transmission and sub transmission systems have been in service for over 10 years. A testing program is required that can accurately and efficiently determine the condition of these high voltage arresters. The essential theory of silicon carbide arresters was investigated, focusing particularly on arrester construction, performance and the unique characteristics of high voltage arresters. The effectiveness of available testing procedures was then evaluated and a set of tests selected, based on their expected performance, their ability to assess all facets of arrester behavior, the ease with which they could be completed in the available laboratory and their possible application to in-field testing. The testing program implemented consisted of a series of procedures including the lightning impulse sparkover voltage test, power frequency sparkover voltage test, power frequency withstand test, AC and DC leakage current measurements, 5 kV insulation resistance test, and finally a non-standard current impulse test. The tests were performed on a set of 6 arresters rated at 33 and 132 kV and a set of 5 arrester sections. The results of the investigation verified the effectiveness of the selected procedure with a consistent and accurate assessment of arrester condition obtained for all arresters under test. All arresters exhibited satisfactory performance in the selected tests, indicating that high voltage gapped silicon carbide arresters are more durable than those used on distribution systems.

Key Word : Lightning Arrester , silicon carbide Arrester , high voltage arrester

1. INTRODUCTION

The primary function of an electrical transmission/distribution system is to transfer electricity from the generators to the end users. In today's competitive electricity market consumers expect a continuous, reliable supply of cheap electricity. Crucial to system reliability is an effective protective network.

The role of the protective network is to safeguard the system from the effects of "electrical overstress" or Surges. Electrical overstress is any current or voltage waveform on the system that exceeds normal operating specifications and may be in the form of:

- power frequency over-voltages (usually associated with faults on adjoining phases).
- switching transients.

- lightning over-voltages.
- electro-magnetic pulses [1].

Irrespective of the source of overstress, the protective network is required to protect the system by either dissipating the lightning energy before reaching, or diverting it from the power system component being protected.

Although protective devices are generally classified as either series or shunt devices, in high voltage systems protection is invariably provided by shunt devices. The basic characteristics of a shunt protective device are that they “must act as an insulator, conducting at most a few mA at normal system voltage, change to a relatively good conductor capable of carrying kA, with discharge voltage lower than the voltage withstand of the protected equipment and extinguish or clear current flowing through the arrester after the lightning has been dissipated” [2]. An “arrester” or “lightning arrester” is the term commonly to describe a device that meets these requirements.

The use of arresters on power systems dates back to 1892 [2]. The earliest protection was provided by a simple spark gap. Unfortunately this sparks over erratically and so does not provide a consistent level of protection. Nor is a simple spark gap capable of clearing power follow current itself.

From 1908 the level of protection available was improved somewhat with the utilization of non-linear resistors based on the puncturing and reforming of a metallic film. The oxide film arrester was developed soon after this (about 1920) and remained in service at distribution levels until as late as the 1950’s [2].

The gapped silicon carbide (SiC) lightning arrester, however, provided the first true sophisticated over-voltage protection. Originally developed in the 1930’s, the basic gapped silicon carbide lightning arrester was upgraded from approximately 1954 onwards to make use of active gap phenomena and remained the most common protective device against electrical overstress until the development of the metal oxide or zinc oxide lightning arrester in 1976.

Although metal oxide (ZnO) lightning arresters have all but replaced gapped silicon carbide lightning arresters in distribution systems, SiC lightning arresters are still the most common form of protection on sub-transmission and transmission level systems. It is estimated that there are tens of thousands of SiC lightning arresters still in service today [3]. At higher operating voltages (33kV and above), the cost of replacing these devices is significant. Similarly the more rugged construction of these arresters means many are still working adequately. The expense and inconvenience associated with replacing all these arresters cannot be justified when, for the most part, the systems are functioning correctly.

2. LIGHTNING ARRESTER THEORY

It is necessary to understand the basic characteristics of the arresters being tested. Knowledge of their construction and behaviour will allow a more effective program to be developed.

2.1 Lightning Arresters

In electrical systems a lightning arrester or lightning diverter is defined as “a device designed to protect electrical apparatus from high transient voltages and to limit the duration and frequently the amplitude of the follow current” [4].

Depending upon the magnitude of the system’s operating voltage and the nature of the overstress present on the system, an arrester may be a diode, a spark gap, or even the traditional silicon carbide or zinc oxide arrester.

In [5] the ideal requirements for a shunt protective device or arrester used in electrical systems are defined as follows.

a) The device should not usually flashover for power frequency over-voltages.
b) The volt-time characteristics of the device must be below the withstand voltage of the protected apparatus or insulation.
c) It should be capable of discharging high energies contained in lightnings and recover insulation strength quickly.
d) It should not allow power frequency follow-on current to flow.

The earliest form of shunt protection was provided by a simple spark gap that flashed over once the voltage across the device exceeded the spark-over level [2]. Although providing some protection, the spark gap had a number of disadvantages. The scatter in flashover voltages was large and unpredictable presenting a large failure risk to the device being protected. Similarly, once the spark gap was “tripped”, the spark gap became a line – ground short with little or no ability to quench the follow current.

2.2 Gapped Silicon Carbide Lightning Arresters

The first device to truly comply with the requirements of shunt protection equipment was the gapped silicon carbide lightning arrester. Developed in 1930, [2] the silicon carbide gap-type arrester is defined as any arrester having one or more silicon carbide non-linear resistor blocks connected in series with a single or multiple spark gap(s) [4].

The entire assembly is housed in a watertight porcelain casing. A basic representation of a silicon carbide gap-type lightning arrester is shown in Fig 1 .

The characteristic response of a gapped silicon carbide arrester to an over voltage is shown in Fig 2.

When a lightning voltage V_i exceeds the sparkover voltage, V_s, of the arrester, the spark gaps break down allowing a discharge current, i_d, to flow through the arrester maintaining a voltage, V_d, across it [6]. During operation the non-linear blocks limit the follow current, which the gaps intercept, restoring the arrester to original condition [7].

2.2.1 Silicon Carbide Blocks

One of the principal components of the gapped silicon carbide lightning arrester is the silicon carbide non-linear resistive blocks. The operation of the blocks can be generalised as that of a standard non-linear component given by:

$$I = kV^{\alpha}$$

where

I = discharge current

V = applied voltage across the element

and k and α are constants whose value depends upon the material and dimensions of the non-linear resistive element [8].

For silicon carbide blocks, α is usually in the range of 2 to 6. This is not high enough to ensure that the resistive blocks will not conduct significant current at normal operating voltages. They must be used in series with a spark gap to ensure they conduct only when the sparkover voltage of the series gap(s) is exceeded.

The blocks themselves consist of a composite of silicon carbide, graphite, and clay, fired into a hard ceramic matrix [5]. Although their non-linear properties have been used since the 1930's the precise mechanism of the non-linearity was never clearly established. It was suggested by Holm that the non-linear mechanism is primarily the result of the negative temperature coefficient of the resistance of silicon carbide [9].

2.3 High Voltage Lightning Arrester

One of the principal advantages of gapped silicon carbide lightning arresters is that their protective capabilities are directly proportional to the number of spark gaps and nonlinear resistors that are used in their construction. It is possible to make high voltage arresters by directly combining a number of arresters rated at lower voltages in series.

2.3.1 Shunt Grading Resistances

A problem can occur however when a series of gaps is subjected to a potential below sparkover voltage. A non-uniform electric field can be created that produces a voltage distribution such that the potential across the line end gap is greater than that across the gap nearest the grounding point. The first gap may sparkover before the remaining gaps reach sparkover voltage. The remaining gaps will then discharge consecutively, from the line end downwards, reducing the overall sparkover of the series gaps [7]. This problem becomes more severe as the voltage rating, and thus the physical height, of the arrester increases. A common solution to this problem is to place grading resistors in parallel with the spark gaps as shown in Fig 3.

3. ARRESTER TESTING TECHNIQUES

3.1 Introduction

The purpose of this investigation is to develop a testing program that will allow accurate diagnosis of the condition of gapped silicon carbide lightning arresters still in use on high voltage electrical systems. The test procedure should be able to be completed quickly and easily without need for disconnecting the arrester from the power system. Once the condition of the arrester has been assessed appropriate action, such as replacing the arrester if performance is significantly degraded, can be taken. Implementing such a program should also reduce system-operating costs by ensuring that arresters are replaced only when needed and damage from arrester failure is minimized.

The specific goal of this Work is to determine the condition of various gapped silicon carbide lightning arresters removed from service in a high voltage power system. By using a number of traditional laboratory tests combined with visual inspection and novel testing procedures, a comprehensive and accurate measure of arrester condition can be obtained.

By compiling the results of these tests and comparing the response of arresters to each test, it is hoped that the most informative test procedures can be determined, allowing complete arrester condition to be determined from, at most, 2 or 3 tests. It may then be possible to adapt these tests to an in-field situation so that on-line assessment of the arresters can be performed.

3.2 Test Procedure Classification

Although there are a large number of standard arrester test procedures the majority of these tests can be classified as either:

1. common tests
2. specialized diagnostics tests
3. development tests with more specific applications that could be as used a test, with some refinement of procedure.

3.3 Test Selection

3.3.1 <u>Selection Criteria</u>

The prior performance of testing techniques is just one of the criteria used in the selection of the testing procedures applied in this investigation. The criteria used in selecting the tests performed included considering:

1) the tests' ability to test all facets of arrester performance.

The chosen tests should assess all areas of arrester performance including both response to electrical over-stress and behaviour in standard operating conditions.

2) the tests' capacity to test all components of the arrester itself.

The selected tests should also examine the performance of all the major components of a lightning arrester, including the spark gaps, the non-linear resistive blocks and the gap-grading resistor where present. It is essential that the tests are responsive to degradation resulting from moisture ingress as this is by far the most common cause of arrester failure, as found in studies [11], [12] and [13].

3) the ability to complete the selected tests on available equipment.

There is little point in selecting a test that cannot be performed on the equipment available at the university.

Impulse current testing and operation duty cycle testing place both high current and high voltage demands on test equipment so are usually performed only on pro-rated sections of arresters. Tests such as these may not be applicable to a set of complete high voltage arresters.

4) the stress placed on the arrester during the testing process.

A test that damages the arresters is of little real value as it will distort the results of the test itself and may prevent accurate measurement from being collected from the remaining tests. For example, multi-pulse testing, although a more accurate representation of a true lightning incident, may cause significant damage to aged SiC blocks [14].

5) the availability of comparative test results.

It is much easier to make an accurate assessment of arrester condition if manufacturers' data describing expected results in the selected tests are also available. This is particularly important in an investigation of this nature where the sample size is somewhat limited.

6) the application of the selected test procedures to field testing.

One of the aims of this investigation is the development of a testing regime that can be used to diagnose the condition of an arrester in field.

3.4.2. Testing Program

Given the criteria outlined previously, the tests selected were:

- standard lightning-impulse sparkover voltage test .
- dry power frequency sparkover voltage test .
- dry power frequency withstand test .
- AC leakage current test .
- 5 kV insulation resistance test .
- DC leakage current test.
- Impulse current test.

Together these tests will provide an accurate assessment of overall arrester condition[4,11].

Spark gap performance under over-stress and normal operating conditions is assessed by the standard lightning-impulse sparkover voltage test, dry power frequency sparkover voltage test and dry power frequency withstand test. AC/DC leakage current and 5 kV insulation resistance measurements assess the condition of grading resistors if present and also provide a gross assessment of spark-gap condition. A gross measure of the integrity of the non-linear resistive blocks is provided by a non-standard impulse current test.

4. EXPERIMENTAL PROCEDURE

4.1 Test Samples

The high voltage gapped silicon carbide arresters available for testing are described as:

Lightning Arrester

Station Type (Class 10kA)

Rated 30 – 210 kV

Self supporting – 110mm diameter active parts (spark gaps and valve resistors),Their general construction is illustrated in Fig 4.

The test sample contained a total of 11 arresters, consisting of 6 complete arresters and 5 arrester sections. The details are shown in the tables 1 . The first table outlines the complete arresters available for testing whereas the second table contains arresters, which although in self-contained packages, are actually sections of a larger arrester.

4.2 Standard Lightning Impulse Sparkover Voltage Test

The purpose of the standard lightning impulse sparkover voltage test was to assess the ability of the arrester, in particular the spark gaps, to appropriately deal with steeply rising waveforms used to approximate lightning incidents.

The standard voltage waveform used to represent a lightning incident is the 1.2/50μs voltage impulse. In this test lightning impulses were produced by a three stage impulse generator shown in Fig 5 .

where

R_1`=2Ω □R_1`` = 164 Ω , □R_2 = 680 Ω , C_1` = 40 nF , C_2 = 2000 pF

leading to an effective front resistance, R1, of approximately 289Ω.

The procedure was strictly adhered to when testing arresters A–C, the 33 kV arresters. Five lightning impulses of both positive and negative polarity were impressed across the lightning arresters. Arrester response was noted.

In accordance with the standards, the lightning impulse applied to arresters A-C had a

prospective peak of 106 kV. The applied impulse was found to have a front time of 1.25μs and a half time of 46.67μs, values well within the tolerances specified by the standards.

As it was not possible to estimate the expected maximum standard impulse sparkover voltage for the arrester sections, the test procedure was modified to determine the minimum standard lightning impulse sparkover voltage for the given section.

For both the 33 kV rated arresters and the arrester sections an arrester sparkover was distinguished from a “withstand” by the characteristic waveform produced. The waveform produced on sparkover was easily distinguishable from the standard 1.2/50 impulse waveform measured when the arrester remained an open-circuit.

A similar technique to that show above was used to determine minimum standard

lightning impulse sparkover for the 132 kV rated arresters.

4.3 Power Frequency Sparkover/Withstand Voltage Test

The purpose of these tests was to verify the ability of the arresters’ spark gaps to withstand power frequency voltages. The circuit in Fig 6 was used to complete the power frequency tests.

All power frequency tests on the 132 kV rated arresters were performed with the grading ring removed.

4.4 AC Leakage Current Measurement

The AC leakage current measurement was a non-standard test used to gain a gross indication of arrester condition. Although the test provides a reasonable indication of overall arrester degradation , its primary purpose is to test the condition of the gap grading resistors under power frequency voltages. The experimental set-up used for leakage current measurement is as shown in Fig 7 .

4.5 5kV Insulation Resistance Test.

The 5kV insulation test as shown in Fig 8 is a commonly used and often effective measure of the integrity of the arrester’s internal components. In this investigation it provided an important contrast to AC leakage current measurements. By measuring the current flowing through an arrester under the application of a large DC voltage (in this case 5 kV), the internal resistance of the arrester can be determined. This test is particularly useful for determining the condition of arresters that do not contain resistively graded gaps when the main connection between spark-gap electrodes would be formed by corrosion on the electrodes. A low value of internal resistance would indicate significant internal corrosion.

4.6 Current Impulse Testing

An important constraint placed on high voltage testing is the limitation of the plant to supply the required power to complete a given test.

Although standard current impulse/withstand tests exist, the available test equipment does not have the necessary
power capability to complete them on the high voltage silicon carbide lightning arresters.

A gross measure of block integrity was attained, however, by measuring the voltage and current waveforms produced when a voltage impulse with prospective peak significantly above sparkover voltage was applied to the arresters. The experimental set-up for this test is similar to that of the lighting impulse test.

5. RESULTS

5.1 Lightning Impulse Sparkover Voltage

The result for lightning impulse sparkover voltage is shown in table (2)

5.2 Power Frequency Measurements

The result for power frequency sparkover test shown in table (3) and the result of power frequency withstand voltage is shown in table (4)

5.3 AC Leakage Current Test

The result for AC leakage current shown in table (5).

5.4 DC Resistance

As noted in the details of experimental procedure all measurements were made with the applied voltage of 5064 V. The only measurements not taken at that level were those in which the measured resistance was so low that the current flow through the arrester would have exceeded the rating of the megger. In that case the voltage applied was merely that required to produce a DC current of 1 mA through the arrester. The result shown in table (6).

5.5 Impulse Current Measurements

A full listing of observed voltage and current waveforms for each arrester is shown in table (7) . Although a number of impulses were applied to each arrester for each circuit configuration the consistency between the measurements was good enough that any one of the recorded waveforms could be used to represent the behavior of the arrester under those specific test conditions. The measured currents are given as a function of the front resistance of the impulse generator, R1.

6. DISCUSSION OF RESULTS

6.1 Lightning Impulse Sparkover Voltage Test

The most obvious conclusion that can be drawn from the results is that all complete arresters would be considered to have satisfactorily passed the standard lightning impulse sparkover test as defined in [4]. For arresters A-C no further information can be drawn from the test results. Having followed the procedure defined in [4] exactly, it is not known whether the arresters would still meet guaranteed behavior defined in the manufacturer's datasheets, highlighting the limitations of the standard testing procedure. From results obtained for arresters D–F, however, it is possible to conclude that the arresters' performance exceeds not only the required level of performance defined in [4] but also the guaranteed performance set by the manufacturer. In fact, the standard lightning impulse sparkover voltage was found to exceed even the expected 50% sparkover level of the arresters. If anything the arrester sparkover voltages could be considered a little low, with minimum sparkover voltage approximately equal to 1.9 p.u. rather than the more standard range of 2.2 – 2.8 p.u. In either case it would seem that the arrester's impulse sparkover behaviour has degraded little, if at all, over it's operating life.

6.2 Power Frequency Testing

The test results showed that all complete arresters tested exceeded the minimum sparkover voltage specified in both the Australian standards [4] and the manufactures data sheets. Again one would have to conclude that the arresters are still performing adequately when subjected to power-frequency voltages. When examining the results produced by arresters D-F, it was observed that arrester D had both the highest power frequency sparkover voltage and highest lightning impulse sparkover voltage. Similarly arrester F had the lowest sparkover level for both power frequency and lightning impulse voltages. These results are consistent with the nature of the two tests. Both tests examine spark-gap strength so it would be expected that an arrester with a slightly larger gap structure would have both comparatively high impulse and power frequency sparkover voltages.

It was also noted that the power frequency sparkover voltage for arresters D-F was larger than the corresponding lightning impulse sparkover voltages. The power frequency sparkover voltage of the arrester sections was also measured where possible. It was found that significant current flowed through arresters H and J3 the instant any voltage was applied across them, further evidence that the arresters are made of resistive blocks only.

6.3 5 kV Insulation Test.

The main issue in this test was determining what level of internal resistance should be set as the minimum level for functional arrester behaviour. In [11] it was suggested that internal resistance of a sound arrester should be greater than 2000MΩ .

Although the spread between measurements was greater than in previous experiments,

arresters A–C still had a reasonably consistent internal resistance of approximately 10

GΩ. Although this suggests that there is very little internal degradation it does seem rather large for arresters with resistively graded gaps. In order to check the actual resistance, a number of gap-grading resistors were measured with a multimeter. Each grading resistance was found to have at least 20M□□of resistance so the total measured value is probably reasonable and indicative of standard behavior.

The internal resistance of arresters D – F, however, was found to be much lower than

arresters A-C . It is difficult to explain the great difference between internal resistance for arresters A-C and D-F. Both series of arresters used what seemed to be very similar looking gap grading resistors yet the measured resistance of the individual arresters differed significantly. The other problem was explaining the very large measured resistance of the arrester sections. The measured resistance of arrester sections was in some cases an order of magnitude larger than that measured for arresters A–C and is up to 1000 times as large as the resistance of arresters D–F. A possible explanation for this phenomenon is that the grading resistors are made material of similar appearance with significantly different electrical properties. Alternatively, the discolouration on the end faces of some of these resistors could be an insulating surface layer that significantly alters the properties of the resistors.

Finally it was noted that both arrester H and J1 and the ground-side arresters from the multi-unit arrester all had much lower resistance than the other arresters, presenting another clear indicator that these arresters are probably un-gapped and consist only of valve blocks. It was pleasing to see these suppositions vindicated when the internal components of the arresters were examined.

Although the DC leakage current flowing through the arresters was also recorded there is little point in reviewing the results, as they are merely another representation of the results obtained in the 5 kV insulation test. The DC leakage current was determined by :

$$I_{DC} = \frac{5kV}{R_{arrester}}$$

The main purpose of recording DC leakage current was to provide a point of comparison with AC leakage current measurements and allow the internal capacitance of the arresters to be calculated.

6.4 AC Leakage Current Measurements

Although this test is a commonly used technique for metal oxide lightning arresters, it is rarely used for silicon carbide lightning arrester. This causes some problems in that it is difficult to determine an acceptable level of leakage current

If the maximum acceptable leakage current at rated voltage was set at 600μA, however, all the complete arresters tested would have to be considered as defective. This would be inconsistent with previously obtained test results. The consistency between measurements of arresters with the same voltage rating also suggests that the measured leakage current levels are acceptable and that the 600μA leakage current threshold is not applicable to these arresters.

It was somewhat surprising to see that AC leakage flowing through arresters A-C was larger than that flowing through arresters D-F. The comparative order of these measurements was the reverse of that obtained when DC leakage current was considered. A possible explanation is that the internal capacitance of arresters A-C may be appreciably larger that that of the arresters D–F allowing a much larger portion of capacitive current to flow through arresters A-C for a given voltage. This correlates well with the estimated value of internal capacitance, lending further support to the supposition that AC leakage current is dominated by capacitive leakage current.

6.5 Current Impulse Testing

The current impulse test was unique in that it was the only test in which the quantitative measurements were of far less importance than the qualitative measure of overall arrester behaviour. Although measurements of the peak current impulses flowing through the arresters were collected, the most important results of the test were the actual voltage and current waveforms produced across the respective arresters by the standard and non-standard current impulses.

The peak current was measured at the peak of the wave front of the current impulse waveform. The measured voltage/current waveforms were almost identical amongst a series of arresters with constant rated voltage. The tails of the waveforms were almost identically matched and the only perceptible sources of difference were the magnitude of the wave front peak and amount of ringing of the top the current impulse.

Overall, none of the arresters tested showed any evidence of block flashover. The tail of both the current and voltage waveforms appeared to decay smoothly indicating a controlled discharge of current through the non-linear blocks.

7. CONCLUSIONS

As stated previously the purpose of this investigation was to develop a testing regime that could accurately assess the condition of aged high voltage gapped silicon carbide lightning arresters. By developing a test program consisting of both standard and non-standard tests it was verified that the developed testing regime could effectively determine the condition of the aged gapped silicon carbide arresters. The tests produced consistent results, verifying the satisfactory performance of all arresters. It was found that the complete arresters had suffered little degradation throughout their service life with their measured performance It is believed that this research demonstrates that the procedure undertaken represents a satisfactory, if somewhat laborious, program capable of determining the condition high voltage gapped silicon carbide lightning arresters.

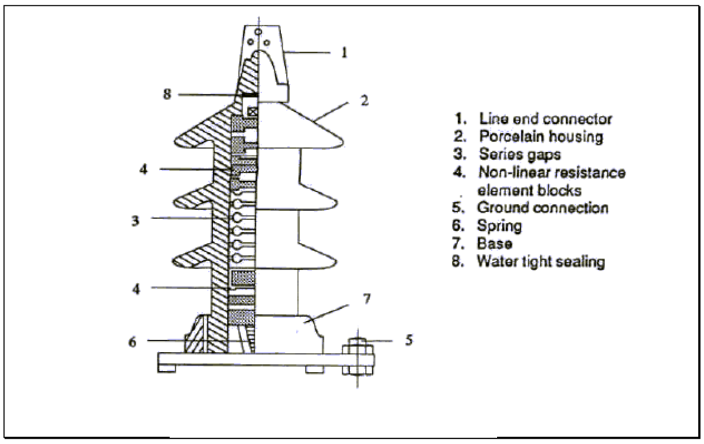
The results of this investigation also indicate that high voltage silicon carbide lightning arresters can maintain adequate operational performance over a long service life. Satisfactory test results, coupled with little visible evidence of significant internal degradation suggest that these arresters are highly durable, perhaps far more so than distribution level arresters of similar construction. It is possible that high voltage silicon carbide lightning arresters can be left in service with a reasonable expectation that they will continue to operate as required, even though they may have already been in service for an extended period of time.

8. Reference

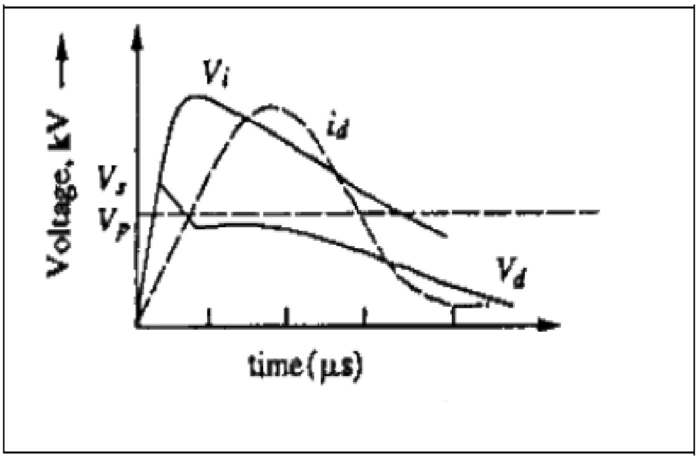
1. Standler-RB, Protection of Electronic Circuits from Over-voltages, John Wiley and Sons, 1989.
2. akshaug E.C., "A brief history of AC Lightning Arresters", IEEE Power Engineering Review, August 2001.
3. Allen-EJ; Nesbitt-JS, "New instrumentation for lightning arresters", Transmission-and-Distribution. Vol.24, no.7; July 1972; p.66-9
4. Australian Standard AS 1307.1 - 1986, Lightning Arresters (Diverters) Part 1 - Silicon Carbide Type for A.C. Systems, Standards Association of Australia, North Sydney, NSW
5. Mitchell-J, Shewchun-J, "High-current characteristics of silicon carbide varistors." Journal of Applied Physics, Vol 42, No.2, Feb 1971, pp 889-92
6. Naidu-MS; Kamaraju-V, High Voltage Engineering, The McGraw-Hill Companies, Inc, USA, 2000.
7. Beck-FW, Lightning Protection for Electric Systems, McGraw-Hill, New York, 1954
8. Ueno-E, "Varistor applications expand", JEE-(Journal-of-Electronic-Engineering). Vol.16, no.156; Dec.1979; p.53-7
9. Holm-E, "Contribution of the Theory of the Silicon Carbide Contact", Journal of Applied Physics, Vol.23, No.5, May 1952, pp509-17
10. Jones-HF, Garrard-CJO, "The design, specification and performance of high-voltage lightning diverters." The Institution of Electrical Engineers, Proceedings of the Institution, Vol 97, Part II, No 57, June 1950.
11. J.Mcdonald ," The Diagnostic testing of high voltage silicon carbide surge arrester" , University of Queensland , October 1999, p 13-26.
12. Lat-MV, Kortschinski-J, "Distribution Arrester Research" IEEE-Transactions-

on-Power- pparatusand-Systems. Vol. PAS-100, no.7; July 1981; p.3496-3505.

13. Gaibrois - GL. Lightning current magnitude through distribution arresters. IEEE Transactions on Power Apparatus and Systems, pp 1563-1573 July/Aug 1971.
14. Darveniza-M; Mercer-DR, "The effects of multiple stroke lightning on distribution transformers, fuses and arresters", Electric energy conference 1991: power for developing areas: Darwin 10-13 June 1991: preprints of papers. p126-129.



Fig(1) Gapped Silicon Carbide Lightning Arrester



Fig(2) Characteristic response of a silicon carbide lightning arrester

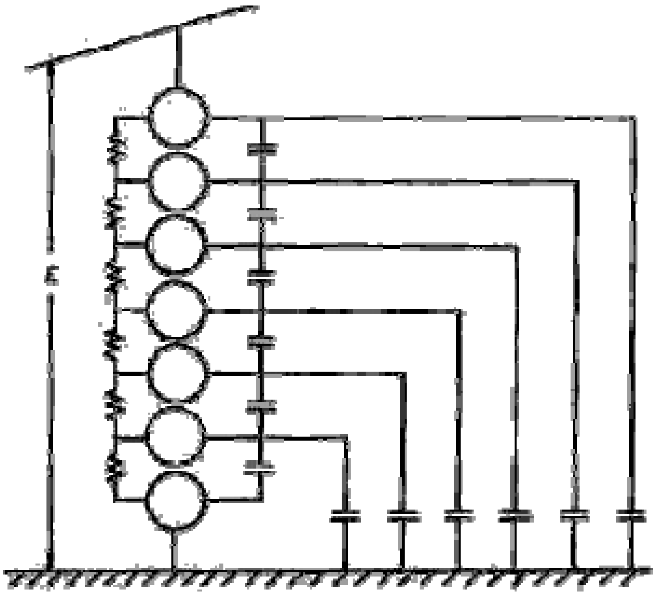


Fig (3) Gaps shunted by grading resistance

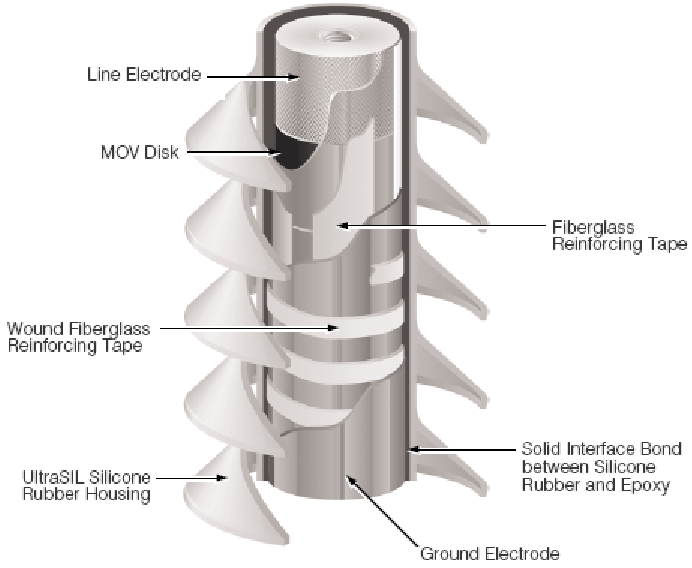


Fig (4) Transmission Line lightning Arrester Construction

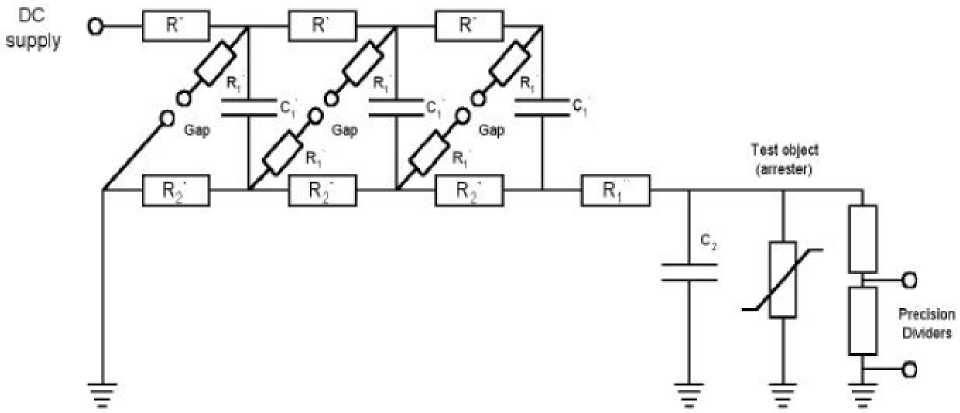


Fig (5) Three – stage impulse voltage generator

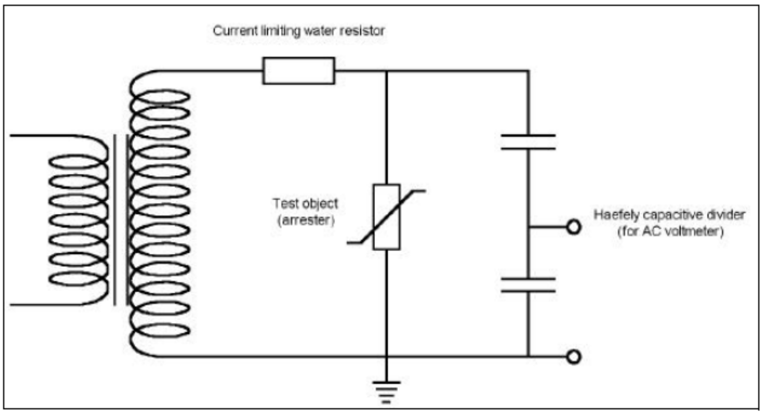


Fig (6) Power frequency voltage tests - experimental set-up

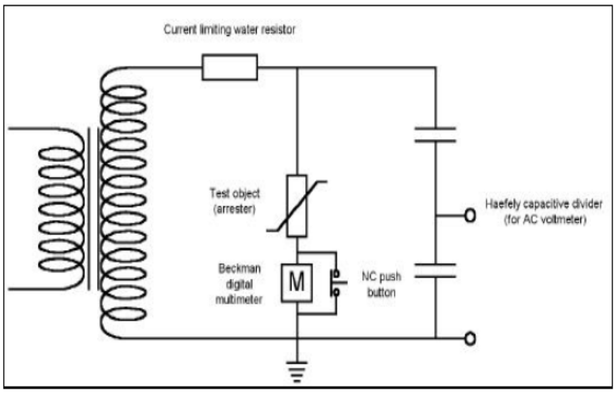


Fig (7) AC leakage current measurements - experimental set-up

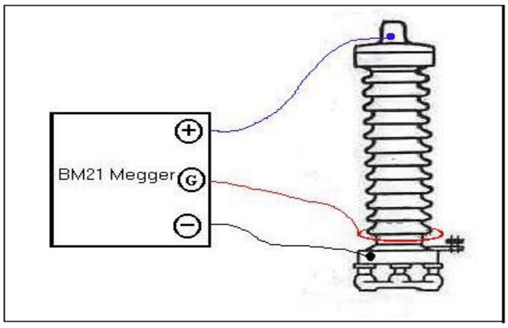


Fig (8) Megger Connection s

Table 1 Complete high voltage gapped silicon carbide lightning arresters

Lable	Manufacture	Rated Voltage(Kv)	Class	Frequency (Hz)
A	KEMA	33	10kV	50-60
B	KEMA	33	10kV	50-60
C	KEMA	33	10kV	50-60
D	KEMA	132	10kV	50
E	KEMA	132	10kV	50
F	KEMA	132	10kV	50
G	KEMA	132	10kV	50
H	KEMA	132	10kV	50
J1	KEMA	132	10kV	50
J2	KEMA	132	10kV	50
J3	KEMA	132	10kV	50

Table (2) Lighting impulse test

Arrester	Voltage Rating(KV)	Measured Lighting impulse sparkover voltage (KV)	Maximum Lighting impulse sparkover voltage (KV)	Guaranteed Lighting impulse sparkover voltage (KV)	
				50%	100%
A	33	<96	96	82	94
B	33	< 96	96	82	94
C	33	< 96	96	82	94
D	132	270	352	270	311
E	132	254	352	270	311
F	132	243	350	270	311
G	-	166	-	-	-
H	-	-	-	-	-
J1	-	184	-	-	-
J2	-	151	-	-	-
J3	-	-	-	-	-

Table 3 Power frequency sparkover voltage summary

Arrester	**Average measured power frequency sparkover (KV)**	**Minumim measured pf sparkover (KV)**	**Guaranted minuimum power frequency sparkover**	**Minimum pf sparkover (kv)**
A	**63**	**62**	**58**	**52**
B	**64**	**61**	**58**	**51**
C	**61**	**60**	**58**	**50**
D	**265**	**263**	**238**	**198**
E	**258**	**257**	**238**	**198**
F	**256**	**256**	**237**	**196**

Arrester Section				
G	158	155	-	-
H	-	-	-	-
J1	157	154	-	-
J2	140	138	-	-
J3	-	-	-	-

Table 4 power frequency voltage withstand test

Arrester	Applied Voltage (KV)	Test Duration (s)
A	60	60
B	60	60
C	60	60
D	198	60
E	198	60
F	198	60
Arrester Section		
G	79	60
H	N/A	60
J1	70	60
J2	70	60
J3	N/A	60

Table 5 AC leakage current measurements

Arrester	Applied Voltage (KV)	Leakage Current (μA)
A	33	766
B	33	763
C	33	744
D	132	745
E	132	735
F	132	765
Arrester Section		
G	80	62
H	N/A	N/A
J1	70	174
J2	70	113
J3	N/A	N/A

Table 6 5kV Internal resistance measurements

Arrester	Average resistance (GΩ)	Leakage Current (μA)
A	10.9	0.375
B	10.17	0.414
C	8.55	0.482
D	0.28	22
E	0.28	22
F	0.277	22.2

Arrester Section		
G	181	0.0289
H	0.000352 at 542v	>999 at 542
J1	79	0.59
J2	27	0.236
J3	0.00035	>999 at 520

Table 7 Impulse Current measurements

Arrester	Average Peak Current (A)		
	R_1=298Ω	R_1=125Ω	R_1=0Ω
A	1990	2177	-
B	1821	2623	-
C	1802	3319	-
D	466.3	1014	3556
E	518	1306	4110
F	488	1139	3904
	Arrester Section		
G	3363	3938	-
H	N/A	N/A	N/A
J1	2591	4351	-
J2	3158	3910	-
J3	N/A	N/A	N/A