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The Survey and Analysis on Lightning Arrester Failures in Distribution Systems

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Abstract - The conventional SiC-type of lightning arresters in distribution systems has been replaced by ZnO-type because the ZnO-type has characteristics such as outstanding non linearity, high energy absorption capability, surge suppressing performance, and excellent response to abrupt wave. Out of the various types of lightning arrester failures, some which have been often reported could be prevented in advance. Therefore, the preventive countermeasures which can cope with the failures are strongly required. This paper summed up and analyzed the lightning arrester failures which occurred, from 1983 to 1992, in distribution systems in order to provide fundamental data, classified by year, to make countermeasures.

1. Introduction

Nowadays, the increment in load has led to the complication in the distribution systems, the combination of underground and overhead distribution lines, and the various and large-scaled machinery. Therefore, power companies have tried to improve the reliability in service. The 22.9[kV] using multi-grounding systems in distribution is, however, exposed to manifold types of surge due to internal or external causes, and they cause many failures. As one of countermeasures against these surges, the analysis and the examination on them are indispensable to insulation design. The coordinated insulation between a lightning arrester and a protected device is necessary for designing the proper insulation of the systems. The main characteristics of the lightning arresters used with such purposes are; first of all, they have to be operated without interruption under normal condition, second of all, the large current has to be released into the ground and the voltage between both ends of the lightning arrester has to be suppressed below certain value when the surge breaks in the systems, and third of all, the follow current after release has to be also blocked, thus self-restoration is possible.

The lightning arresters used in distribution systems are classified into the gapless type using the ZnO elements and the gap type using SiC elements, and the former is commonly used at present because the ZnO is more excellent in characteristics than the SiC. However, when the lightning arrester failures occur, the temporary or permanent interruption of electric power is expected because the failures spread out. When it comes to this country, the failure rate in lightning arresters reaches about 3 to 9 percent of the whole failure in the systems, and defects in manufacturing are the most in point of cause. Therefore, it is considered to be desirable that the subsequential failures have to be prevented by the perfect analysis to the failures.

2. Main Issues

2.1 The structure of the lightning arrester

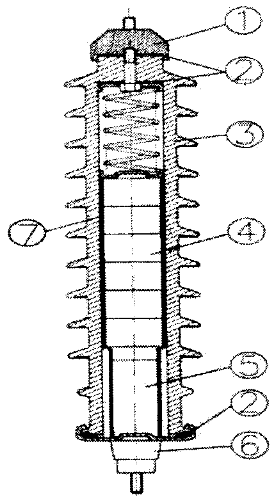

Figure 1.
The structural diagram of lightning arrester ;
① upper cap ② O-ring ③ insulating tube ④ ZnO elements ⑤ spacer ⑥ disconnecting device ⑦ fixing tube or ring

As shown in figure 1, the lightning arrester is generally composed of the piled and sealed units containing series gaps and characteristic elements with non linear resistance, and shield rings are added if necessary. The characteristic elements is valve resistive. The insulating tube is very dangerous because it can be exploded by the continuous follow current when the duty over ensured performance is loaded. To prevent the explosion, pressure relief valve emitting the increased internal pressure is commonly employed.

2.2 Standard for installing a lightning arrester

It is regulated to take the countermeasures against lightning strokes in the area where the ISO Keraunic Level is more than 10 days per year. There are two methods used as the countermeasures, which are lightning arresters and overhead ground wires. In the area where the overhead ground wires are installed, the lightning arresters have to be, in principle, installed with them to suppress the surge. The place where the lightning arresters are to be installed is generally classified into machines, special applications, and overhead distribution lines[1], and the grounding electrodes of the lightning arresters have to be separated by equal or more than 1[m] from that of the overhead ground wires, and connected with the neutral.

2.3 The *status quo* of distribution system failures by lightning arresters

It is surveyed that the number of the installed lightning arresters in distribution systems as of 1998 is about 590 thousand. As shown in Table 1, the lightning failures which have occurred since 1996 reaches 4.4[%](303 failures) in distribution systems.

Table 1 : The *status quo* of distribution system failures by lightning arresters by year

year	'96	'97	after '98	total
units	124	130	49	303
[%]	4.4(compared with the whole system failures)			

2.4 The *status quo* of lightning arrester failures

The cause of lightning arrester failures is generally classified into three. The first cause is the permeation of moisture and the contamination, the second is the temporary overvoltage due to the failure of a sound line, and the last is the want of capability to release the surge. In case of the first cause, the moisture existing in the SiC condenses between the surface of characteristic elements and the air gap, which causes current carrying even at low voltage. If the contamination is added, the flashover may occur at dry spot due to the current on the bushing surface. However, according to the reports, in case of the ZnO, the failures due to moisture is hardly occurred because the heat by leakage current prevents fine moisture from condensing and the ZnO as characteristic elements does not absorb moisture. In second cause, when the failure is due to the temporary overvoltage, there is no problem in the discharge by the voltage because the SiC type has a gap. The ZnO may be, however, damaged by heat avalanche when the heat generated at elements is over that radiated. In the last cause, under the continuous operating voltage, the surge discharging capability of the SiC is 6[kJ/kV], and that of the ZnO is 7[kJ/kV], which means the discharging capability of lightning arresters has a trend to be lowered in long wave length, therefore, the SiC is considered not to be proper. Summing up the lightning arrester failures occurred in actual systems from 1983 to 1992, out of a total of 20279 failures, the number of lightning arrester failures was 882, 4.35[%] in percentage as shown in Table 2 and 3. The number was decreased with time, but the trend is not easy to identify because the number by year is far different. By the way, the failures caused by defects in manufacturing were the most as 38.78[%] in point of the cause, the next was natural ageing, and lightning strokes followed them. Out of these main cause occurring failures, the defects in manufacturing, and the lightning strokes are considered to be prevented by strict tests and continual maintenance, the performance improvement and the grounding technique to optimize behavior of the lightning arrester, respectively.

Table 2 : The cause and the percentage of lightning arrester failures by year

c \ y	'83	'84	'85	'86	'87	'88	'89	'90	'91	'92	total	[%]
na	27	30	20	16	17	12	12	14	18	20	186	21.09
wr	13	5	3	7	10	10	4	1	3	2	58	6.58
ln	22	10	7	12	6	9	10	5	2	13	96	10.88
co	1	1	1			2	2	2		2	11	1.25
ec	8	2	1	3	6	2	12	10	2	9	55	6.24
dm	126	74	2	28	22	13	14	27	15	21	342	38.78
ei	2	3	38	2	2	2				2	51	5.78
nm	5		1	3	5				1	1	16	1.81
af	5	1	1	1		1					9	1.02
ds	3				1	2	1		1	2	10	1.13
db	2	3	1	1	11	5	3		1		27	3.06
etc	2	2	1	1	2		3		1	2	14	1.59
uc	2	1	1	1		1	1				7	0.79
total	218	132	77	75	82	59	62	59	44	74	882	100

※ The original of the acronyms written in Table 1.
na : natural ageing, wr : ageing caused by wind and rain, ln : lightning, co : corrosion, ec : external contact, dm : defect in manufacturing, ei : error in installing, nm : negligence of maintenance, af : secondary affected by the other failure, ds : damaged by snow, db : damaged by brine, etc : et cetera, uc : unknown cause

Table 3 : The *status quo* of lightning arrester failures

year	total	arrester	percent[%]
'83	3,664	218	5.95
'84	3,215	132	4.11
'85	2,819	77	2.73
'86	911	75	8.24
'87	1,893	82	4.33
'88	1,705	59	3.46
'89	1,545	62	4.01
'90	1,606	59	3.67
'91	1,527	44	2.88
'92	1,394	74	5.2
total	20,279	882	4.35

In point of the cause in natural ageing, the failures were mostly occurred by insulation faults and cut leads as shown in Table 4.

Table 4 : The cause and the percentage of lightning arrester failures considered as natural ageing

cause	insulation faults	cut lead	ceramic crack	metal	etc	total
percent [%]	48.4	26.9	11.8	1.1	11.8	100 (93 failures)

2.5 The cause of lightning arrester failures

2.5.1 The failures caused by ill-manufactured lightning arresters

2.5.1.1 The mechanism to the failure

If there is the cause of failures, e.g. the impurities are in the lightning arrester in the process of putting together, the moisture by a loose gasket, the low gasket pressure, and the bad quality in the design of sealing housed to prevent against impurities after installing, the failures may occur even under commercial voltage since the elements are aged and the performance of the discharging gap is lowered, and it cannot be re-sealed when the surge breaks in the lightning arrester. In other words, the breakdown caused by the internal impurities or moisture in lightning arresters leads to the explosion of them.

2.5.1.2 The features of ZnO elements damaged by moisture permeation

Traces left by current which passes through the ZnO element of the lightning arrester damaged by power frequency current were at about 5[㎜] inside from its surface, and the disconnecting device was also damaged[2].

2.5.2 The failures caused by ill-manufactured ZnO elements

2.5.2.1 The mechanism to the failure

When impurities exist in the lightning arrester in the process of assembling the ZnO elements, the electric stress due to the impurities is concentrated. Where the layer of the cement between elements is not uniform, the current is also concentrated even if the overvoltage is low. In the result, both the cases do damage to the ZnO elements, by local heat.

2.5.2.2 The features

When the stress caused by local heat is over the upper limit, there occur cracks in the element, and they deploy with time, therefore, the breakdown of the element occurs.

2.5.3 The failures caused by direct lightning strokes

2.5.3.1 The mechanism to the failure

When the direct lightning stroke current whose current peak is tremendous flows backward to distribution systems, overvoltage caused by surge impedance existing in distribution lines occurs. If the overvoltage is over the critical flashover voltage(125[kV]) of the lightning arresters, breakdown will occur. Generally, putting the surge impedance of the distribution systems at about 400[Ω] to 500[Ω], when the current peak of the direct lightning stroke is 2[kA], induced voltage reaches about 400[kV] to 500[kV].

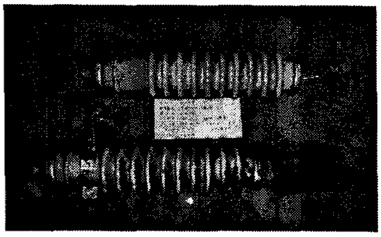

Photo 2.
The lightning arrester damaged by flashover

2.5.3.2 The features

The current wave form of the direct lightning stroke is an steep impulse whose wave front duration is about 1[μs] to 7[μs] and whose time to half value of wave tail takes shorter than 40[μs]. The abrupt wave such as an impulse flashovers along the surface of the ZnO elements of the lightning arrester, and leaves traces on the surface of it[2].

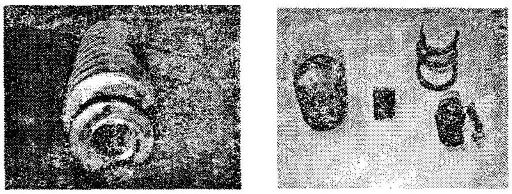

Photo 3.
The lightning arrester damaged by moisture (left) and the destroyed ZnO elements(right)

3. Conclusion

This paper analyzed the failure types of lightning arresters. According to the analysis, the cause of their failures is summed up as the defects in ZnO elements, the moisture permeation in lightning arresters, and the heat avalanche due to the want for capacity in surging. Therefore, the qualitative improvement in reliability to the lightning arrester is required as one of the requirements to reduce the failure rate. To accomplish the improvement, it is indispensible to diagnose their performance synthetically through the tests such as voltage/current withstand test, operating duty test, contamination test, disconnecting device test, and hygroscopic test. It is also considered that the continuous interest and study in the latest style of the lightning arresters, e.g. polymer tubed type(silicon rubber, EPDM, etc.) or VARI-gap type, is required.

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