Electric Power Systems Research 139 (2016) 146–152

Contents lists available at ScienceDirect

Electric Power Systems Research

journal homepage: www.elsevier.com/locate/epsr

Experimental and analytical investigation of the effects of single and multiple simulated lightning impulse currents on Metal-Oxide arrester blocks

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ARTICLE INFO

Article history:
Received 31 March 2015
Received in revised form 9 October 2015
Accepted 26 November 2015
Available online 6 January 2016

Keywords:
Metal-oxide arrester blocks
Single impulse current
Multiple impulse current
First and subsequent stroke
Interval continuing current
Energy absorption

ABSTRACT

In order to evaluate the performance of distribution network surge arresters more realistically, experimental and analytical investigation of the effects of single and multiple simulated lightning impulse currents on metal-oxide arrester blocks are carried out. Based on the analysis of existing test considerations, the 8/20 μs, 2 ms, 18/40 μs, 30/80 μs, 90/200 μs and 10/350 μs waveforms are used in single impulse current tests. In the multiple simulated lightning impulse currents tests, the first stroke is represented by 10/350 μs current, two subsequent strokes are represented by steep impulse current. The 2 ms rectangular impulse current is used to simulate the continuing current between stroke intervals. The test results on arrester blocks show that the 10/350 μs impulse current is more severe than the 30/80 μs and 90/200 μs waveform current for high lightning duty test under the same total absorbed energy condition. The surface flashover is an especial failure type under multiple simulated lightning impulse current tests, in the test current amplitude range. In the tested impulse interval time range, the time interval between strokes and the sequences of applying simulated impulse currents have almost no influence on the test results. Adopting larger ZnO block volume is an effective countermeasure both under single and multiple simulated lightning impulse currents.

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1. Introduction

Installing the metal-oxide arresters is an effective lightning protection countermeasure for power distribution lines. For example, the distribution arrester installed in Guangdong Power Grid reaches 0.49 million phases till the 2010s [1]. The current limiting arcing horns in Chubu Electric Power Co. reaches a total of approx. 5 million units [2]. The huge number and wide range installation of the distribution network surge arresters proposed the problems of maintenance, life assessment and assets management to the operators [1]. Lightning observation data show that more than 70% of the lightning ground flashes have multiple strokes [3]. The operating experience show that lightning stroke is still the major reason of distribution arrester failures. For example, more than 75% of the 10 kV distribution arrester failures in Zhujiang Electric Company attribute to lightning strokes [4]. The operating experience in American also shows that the multiple lightning strokes are the main cause of distribution arresters failures [5]. IEEE Std. 1410 [6] suggest that the assessment of arrester energy absorption capability need to take the effects of multiple lightning strokes into consideration.

The IEC [7–9] and IEEE [10] metal-oxide arrester standards take the nominal discharge current (8/20 μs), high current (4/10 μs) and rectangular (2 ms) impulse as the lightning current discharge capacity testing impulse for the nominal distribution line arresters, take 30/80 μs current impulse test for high lightning duty arresters, and 90/200 μs [11] or approximate sinusoidal impulse waveform with 200 μs duration to consider the effect of multiple lightning strokes. In the development of the distribution line metal-oxide arresters, only the single impulse current withstand test is taken into consideration [2,12]. Only the line arresters developed for the 138 kV transmission line did the multiple impulse voltage test to validate its capability for multiple lightning stroke protection [13]. The multiple impulse current experimental and analytical researches on distribution arresters had been carried out by Darveniza et al. [14–16], Lee et al. [17] and Haryono et al. [18]; the results

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http://dx.doi.org/10.1016/j.epsr.2015.11.017
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show that the multiple impulse tests are more severe than the typical high current (4/10 μs) and rectangular (2 ms) impulse tests, and the multiple impulse current tests are more realistic than single impulse current tests in the evaluation of the performance of distribution arresters. The main insufficiencies of pervious researches include,

(1) The 8/20 μs waveform used in most multiple impulse current tests could not represent the typical lightning current waveform of practical lightning. As the basis of single and multiple lightning impulse current tests, the parameters related to the discharge current of distribution surge arresters due to natural lightning stroke need further investigation.
(2) The effect of single impulse current on arrester such as 30/80 μs, 90/200 μs and 10/350 μs waveform have not been compared with the effect of multiple impulse current tests.
(3) For different waveform of multiple impulse current tests, only two rectangular impulse currents [11], 8/20 μs + 4/10 μs or 8/20 μs + 4/10 μs + rectangular impulse currents [19], 28/53 μs + 10/25 μs impulse currents [20] were used.

Therefore, in order to evaluate the performance of distribution line arresters more realistically, multiple impulse currents more approximate to the natural lightning stroke need to be used.

In this paper, the effects of single and multiple simulated lightning impulse current on metal-oxide arrester blocks used for distribution line arresters are investigated and the test results are compared. The latest quadruple impulse current generator developed by Shanghai Jiao Tong University is adopted for the tests. The effects of arrester block dimension, interval time between impulse currents, the sequences of impulse currents and the amplitude waveform of impulse currents are investigated.

2. The analysis of selection criterions for single and multiple impulse test parameters

The discharge current observations of distribution arresters due to lightning strokes are the fundamental parameters of waveform, amplitude and time interval of single and multiple simulated lightning impulse current on metal-oxide arrester blocks. As shown in Fig. 1, it is clear that the discharge current waveform of distribution line arresters due to natural lightning subsequent stroke measured by P.P. Barker et al. [21] is different from the typical 8/20 μs waveform used in previous standard tests [7–10]. The observations of lightning discharge current on distribution arresters are summarized in Table 1.

The test impulse current waveforms used for simulating natural lightning stroke more realistically in IEC [27] and SAE [28] standards could be summarized as four typical types: first return stroke, subsequent return stroke, continuing current of interval stroke and long continuing current at the end of the flash. The measured discharge current of distribution line arresters due to continuing current of interval stroke could reach 2 kA for 2 ms [23].

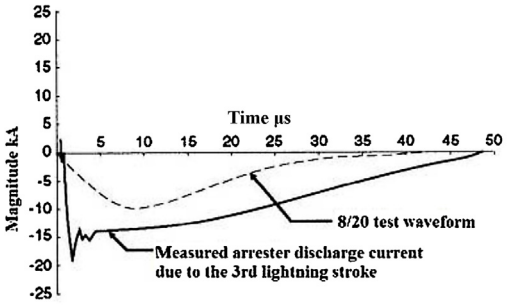

Fig. 1. The discharge current waveform of distribution line arresters due to natural lightning subsequent stroke [21].

Based on the existing researches, there is no measured or analytical report of distribution line arresters due to long continuing current (200~800 A, lasting 0.2~1 s), so it is not taken into consideration in this paper.

Based on the summary of lightning discharge current observations on distribution arresters and test standards, the following results are obtained,

(1) The impulse current waveforms 4/10 μs, 8/20 μs and 18/40 μs could represent the median value of lightning discharge current. The 30/80 μs, 90/200 μs and 10/350 μs could represent the most serious wave tail condition, and the 2 ms square wave could represent the discharge current due to continuing current of lightning interval stroke. The steep impulse current with front time less than 1 μs could represent the discharge current due to subsequent stroke.
(2) The 5 kA and 10 kA amplitude of 8/20 μs nominal discharge current used for typical 10 kV distribution arresters could represent most of the discharge current amplitude.
(3) Most of the lightning discharge current of distribution arrester is double to triple multiple component current, so the quadruple impulse current tests could cover this condition.

3. The equipment and method used for the experiment

3.1. The Multiple Impulse Current Generator

Based on the above investigation, a Multiple Impulse Current Generator (MICG) is developed by High Voltage Testing Equipment R&D Center of Shanghai Jiao Tong University. The circuit schematic of the MICG is shown in Fig. 2.

The Multiple Impulse Current Generator contains four independent impulse current generators. The generator used for the simulating of the first return stroke current could output 10/350 μs, 30/80 μs or 90/200 μs waveform. The two same generators used for the simulating of the subsequent stroke could output steep impulse current with front time less than 1 μs. The 2 ms rectangular impulse current generator is adopted as continuing current

Table 1
The observations of lightning discharge current on distribution arresters.

Observation place	Samples	Observation instruments	Amplitude (kA)		Front time (μs)		Wave tail (μs)	
			Max	Median	Min	Median	Max	Median
Japan [22]	4117 phases	Magnetic link	1	0.2	–	–	–	–
America [23]	–	Current diverter	40	4.1	–	–	–	–
South Africa [24]	281 phases	Current diverter	<1	–	–	–	–	–
Japan [25]	3 phases	Current diverter	<3	–	–	–	50	–
Japan [22]	35 phases	Rogowski coil	1.5	0.3	–	–	–	–
Canada [26]	176 phases	Current diverter	3.79	0.227	0.3	4	200	25
America [21]First strokes	219 phases	Current diverter	28	0.4	0.5	3	220	22
America [21]Subsequent strokes	109 phases	Current diverter	20	0.5	<0.5	0.5	45.9	9.8

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