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Switching Impulse Flashover Tests and Analysis for 765kV Jumper V-strings with Damaged Insulators

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Abstract – The 765kV transmission line will be maintained by live-line works for efficient operation. In order to maintain the 765kV transmission lines safely by live-line works, lineman has to know switching impulse flashover characteristics of the jumper V-strings with damaged insulators in advance. In order to know the flashover characteristics this paper carried out experimental flashover mockup tests for jumper V-string with damaged insulators in the outdoors. And it suggests flashover characteristics of the 765kV jumper V-strings also. The results will be used in estimating the safety of live working for 765kV transmission lines.

Keywords: Switching impulse, Live line working, Jumper V-string

1. Introduction

The insulator or insulator set is very important transmission equipment that provides electric insulation in transmission lines. In most cases of live line work, damaged insulators are replaced, and linemen approach the insulator sets to replace the damaged insulators. If the insulators in an insulator set are damaged, the insulation performance of the damaged insulators deteriorates, and the insulator string with degraded insulation performance may put the linemen in a dangerous situation. Therefore, in performing live line work, it is very important to identify the flashover characteristics of the insulator strings by insulator damage type. Besides, criteria or technical grounds are required for the transmission line operation when bad insulators appear in the insulator sets in 765kV transmission lines. At that time, it is important to identify the number of bad insulators and their insulation characteristics by position [1].

In the 765kV transmission line maintenance process, the most influential overvoltage phenomenon for linemen is the switching impulse voltage, which appears in the circuit breaker switching operation. The electric safety of the linemen during live line work mostly depends on avoidance of the flashover caused by the switching impulse voltage. Eventually, the electric flashover characteristic that must be considered in connection with live line work refers to the characteristic of the flashover due to the switching impulse voltage [2].

This study experimentally analyzed the switching impulse flashover characteristics of the jumper V-string that is installed to connect the jumper to strain towers in 765kV transmission lines by insulator damage type, and presents the test results.

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2. Test and Results

2.1 Test overview and preparation

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2.2 Abstract and keywords

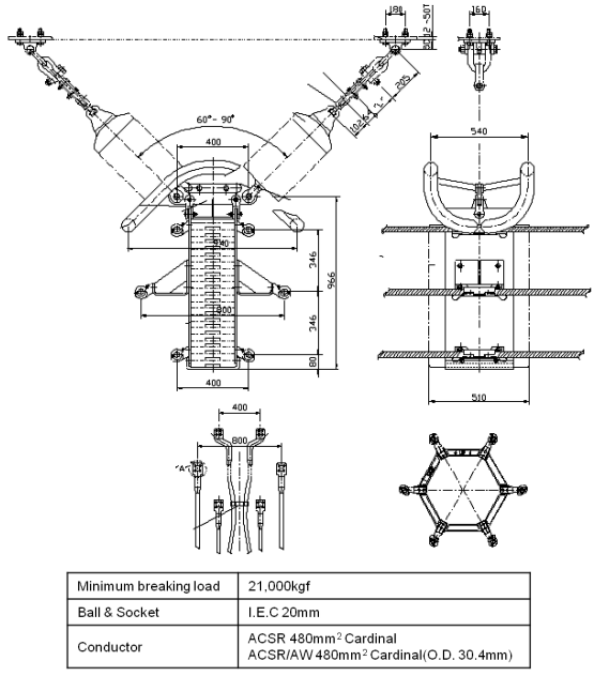
Unlike in the case of the suspension insulator string sets, the test becomes very complicated if the actual insulators of the jumper V-string are damaged for testing, as with the tension insulator strings. In addition, the jumper V-string is too large to test indoors. Therefore, the flashover characteristic of the jumper V-string with damaged insulators was simulated by short-circuiting the insulators using wires.

In the impulse test site in the KEPCO PT Center in Gochang, a test tower was used for the jumper V-string test in the actual 765kV scale. The following were prepared for the test.

<Test equipment for the jumper V-string test>
· Insulator set: One jumper V-string set for the clean area (Fig. 1)
· Insulators for the jumper V-string: 210kN suspension insulators – 38 x 2 strings
· Six jumper spacers for maintaining the jumper sub-conductor space
· Two strain insulator sets for supporting six-conductor bundles

· ACSR 480mm^2 Cardinal wire: 500m or longer
· 250 or more standard suspension insulators for the strain insulator set for supporting two wires
· Other devices and tools for wiring six-conductor bundles

As shown in Fig. 2, the jumper V-string for the six-conductor bundles in the actual 765kV scale was installed together with the strain insulator set.



Minimum breaking load	21,000kgf
Ball & Socket	I.E.C 20mm
Conductor	ACSR 480mm^2 Cardinal ACSR/AW 480mm^2 Cardinal(O.D. 30.4mm)

Fig. 1. 765kV Jumper V-string for the tests

Fig. 2. Installation of the 765kV jumper V-string

The conditions of the jumper V-string on the test tower were as follows.
· V angle of the jumper V-string: 62°
· Jumper depth: 5.750 mm
· Insulator string length: 146 mm x 38EA = 5,548 mm

In the installation condition, the 50% switching flashover characteristic was examined by insulator damage type and live line work type.

2.2 Test conditions

The number of insulators to be short-circuited had to be determined to simulate the insulator damage by short-circuiting the insulators. As shown in Table 1, 3, 5, and 10 insulators were short-circuited. Unlike with the suspension or strain insulator strings, the case with two short-circuited insulators was not tested because it was not significant,

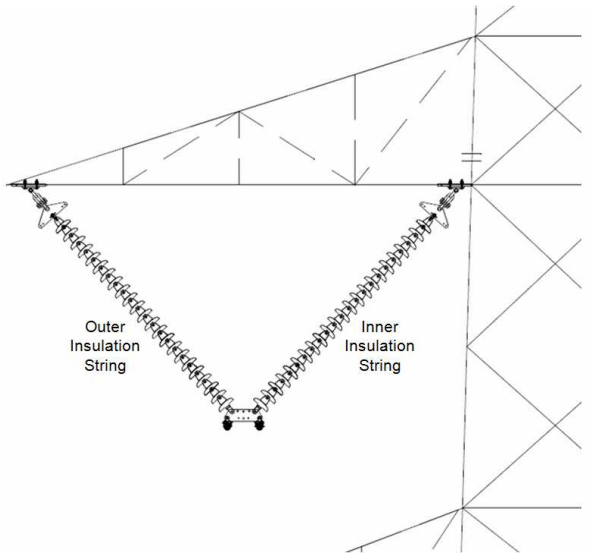


Fig. 3. 765kV Jumper V-string

Table 1. Conditions for short-circuit test

Item	Number and Position of the Insulators
Number of short-circuited insulators (N)	3, 5, and 10
Position of short-circuited insulators (L)	0, 5, 10, 20, and 30
Short-circuited insulator string position	Applied only to one string of two Strings (Inner insulator string)

Table 2. Test conditions for the jumper V-string with damaged insulators

Test Number	Test Case		
	L	N	Position
Test 1	0	0	Normal state
Test 2	0	3	Lowest position
Test 3	0	5	
Test 4	0	10	
Test 5	5	3	
Test 6	5	5	
Test 7	5	10	
Test 8	10	3	
Test 9	10	5	
Test 10	10	10	
Test 11	20	3	
Test 12	20	5	
Test 13	20	10	
Test 14	30	3	
Test 15	30	5	
Test 16	0	3	Highest position
Test 17	0	5	
Test 18	0	10	

considering that two and three suspension or strain insulators have almost the same 50% switching flashover voltages. In addition, two damaged insulators do not matter much in terms of transmission line operation.

The test type was determined based on the test methods in Table 1, and shown in Table 2. When the arcing rings and horns were properly installed, three, five, and 10 insulators were short-circuited from the lowest insulator of the insulator string, their positions were varied, and the changes in the flashover characteristic were examined.

In addition, the position at which the damaged insulator would be simulated in the jumper V-string had to be determined. That is, either the inner or outer insulator string had to be chosen. In this study, it was assumed that the damaged insulators were in the inner insulator string. This was because the damage to the inner insulator string was likely to cause more severe risk.

2.3 Test and analysis

According to the preceding descriptions, the flashover characteristic test was performed by applying the switching impulse flashover voltage to the jumper V-string set. Table 3 shows the 50% switching impulse flashover voltage obtained by short-circuiting the insulators.

Fig. 4 shows the changing trend of the 50% switching impulse flashover voltage by the number of insulators and damaged insulator positions. The graph reveals the following.

As in the case of the suspension and strain insulator strings, the 50% switching impulse flashover voltage did not change much from that in the normal state when five or fewer insulators were damaged.

When 10 insulators were damaged, the flashover voltage was much lower than that in the normal state. As the damaged insulator position was closer to the ground, the flashover voltage was higher.

Table 3. 50% Flashover voltage for the jumper V-string with damaged insulators

Test Number	50% Switching Impulse Flashover Voltage (kV)	Standard Deviations (%)
Test 1	1,629	5.3
Test 2	1,622	2.5
Test 3	1,592	5.2
Test 4	1,390	5.3
Test 5	1,610	3.8
Test 6	1,582	4.4
Test 7	1,202	2.0
Test 8	1,616	2.5
Test 9	1,601	1.3
Test 10	1,297	8.7
Test 11	1,631	4.4
Test 12	1,608	1.9
Test 13	1,494	2.4
Test 14	1,621	2.1
Test 15	1,577	2.3
Test 16	1,631	8.0
Test 17	1,629	8.9
Test 18	1,480	2.1

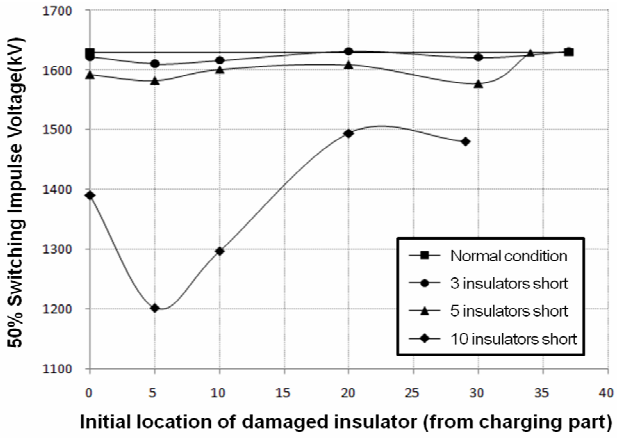


Fig. 4. 50% switching impulse flashover voltage according to the position of the damaged insulators

Considering the test results, it seems that linemen can approach the line and perform live line work if five or fewer insulators are damaged.

2.4 Flashover phenomenon analysis

In the preceding section, the flashover phenomenon was tested and the results were obtained. The test analysis results can be summarized as follows.

2.4.1 Flashover in Test 2

In this test, three insulators from the lowest part of the insulator set (the live part) were short-circuited (Fig. 5). The resulting flashover voltage was similar to that in the normal state. As in the normal state, the flashover occurred between the arcing ring and the arcing horn of the strain insulator set. The flashover also occurred three times between the arcing ring of the jumper V-string and the tower arm.

Fig. 5. Mockup for Test 2

2.4.2 Flashover in test 3

In this test, five insulators from the lowest part of the insulator set (the live part) were short-circuited (Fig. 6). The resulting flashover voltage was 1,592 kV, which was slightly less than 1,629 kV in the normal state. Approximately 70% of the flashover occurred between the arcing ring and the arcing horn of the strain insulator set, as in the normal state. The remaining 30% occurred between the arcing ring of the jumper V-string and the tower arm.

Fig. 6. Mockup for Test 3

2.4.3 Flashover in Test 4

In this test, 10 insulators from the lowest part of the insulator set (the live part) were short-circuited (Fig. 7).

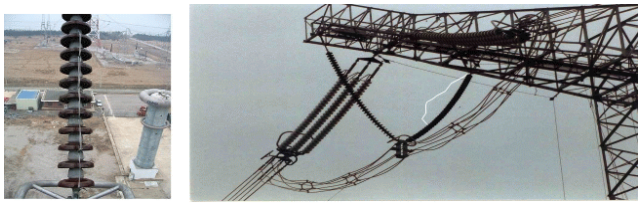


Fig. 7. Mockup for Test 4

The resulting flashover voltage was 1,390 kV, which was much less than that in the normal state. As for the flashover path, almost all the flashovers occurred through the short-circuited insulators to the tower arm.

2.4.4 Flashover in test 5

In this test, three insulators from the fifth insulator up from the lowest insulator of the inner insulator string were short-circuited. The resulting flashover voltage was 1,610 kV, which was almost the same as that in the normal state. Approximately 50% of the flashover occurred from the short-circuited insulator string, and the remaining 50% occurred from the strain insulator set.

2.4.5 Flashover in test 8

In this test, three insulators from the 10th insulator up from the lowest part were short-circuited. The resulting flashover voltage was 1,616 kV, which was almost the same as that in the normal state. This indicates that the flashover voltage will not be affected even if three insulators in the middle of the insulator string are damaged. As for the flashover path, the flashover occurred alternately from the strain insulator string and the jumper V-string set.

2.4.6 Flashover in test 9

In this test, only the number of short-circuited insulators increased to five, in the same condition as in the preceding test. The resulting flashover voltage was similar to that with the three short-circuited insulators, and did not differ much from that in the normal state. As for the flashover path, approximately 90% occurred from the arcing ring of the jumper V-string set through the short-circuited insulator string (Fig. 8).

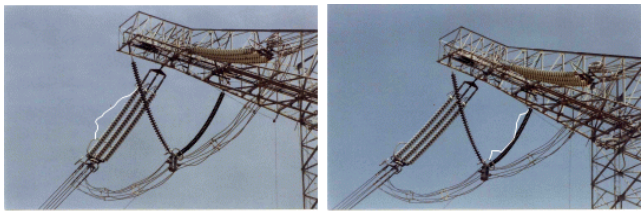


Fig. 8. Mockup for Test 9

2.4.7 Flashover in Test 10

In this test, 10 insulators from the 10th insulator from the lowest part were short-circuited. The resulting flashover voltage was 1,297 kV, which was much lower than that in the normal state. Most of the flashover occurred through the short-circuited insulator string. This indicates that when 10 insulators of the insulator string are short-circuited, most of the flashover occurs through the insulator string.

2.4.8 Flashover in Test 11 and 12

In Test 11, three insulators from the 20th insulator up from the lowest part were short-circuited. The resulting 50% switching impulse flashover voltage was 1,631 kV, which was similar to that in the normal state. Most of the flashover occurred through the strain insulator string, but also occurred twice between the jumper V-string set and the tower arm.

In Test 12, two more insulators were used to short the circuit. The resulting 50% switching impulse flashover voltage and the flashover path were similar to those in Test 11.

3. Conclusion

In this study, the switching impulse flashover characteristic of the jumper V-string for the 765kV insulator set was tested by insulator damage type, and the 50%

switching impulse flashover voltage and flashover characteristic were examined to estimate the danger of live line work on very-high-voltage transmission lines arising from insulator damage and to safely maintain the transmission lines. The jumper V-string had a trend similar to that of the suspension or strain insulator strings [3]. The 50% switching impulse flashover voltage did not greatly decrease when five or fewer insulators were damaged from each insulator string, and in some cases, it was similar to that in the normal state.

It is expected that the test and results data from this study will be very helpful as important operations data in determining the necessity and frequency of maintenance in operating 765kV transmission lines.

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