Flashover performance of a T-shaped circuit breaker under snow conditions

H. Wieck
STRI AB
Box 707
SE-771 80 LUDVIKA, Sweden
hakan.wieck@stri.se

I. Gutman
STRI AB
Box 707
SE-771 80 LUDVIKA, Sweden
igor.gutman@stri..se

T. Ohnstad
Statnett
Postboks 5192 Majorstua
NO-0302 OSLO, Norway
trond.ohnstad@statnett.no

Abstract – **A most critical situation for a breaker with horizontal breaking chambers covered with snow is when connecting a line to a generator. Depending upon the routines during the synchronizing, the maximum applied voltage can reach 2,5 times the normal phase-to-earth voltage. A 420 kV circuit breaker with two horizontal breaking chambers and parallel grading capacitors was tested at different snow conditions, including natural snow, natural snow collected from the ground and snow produced by snow cannon. The tests included measurements of basic snow parameters and flashover tests with observations by daylight UV camera.**

The most critical parameters for the flashover were the snow bridging over the parallel breaking chamber and capacitor insulator and snow density above 0,3 g/cm^3. The maximum discharge activity leading to flashover can well occur within the synchronizing period when a line is connected to a generator.

I. Introduction

On horisontal insulators the snow often accumulates non-unifomly and in thicker layers than on vertical insulators. While most of the high voltage apparatus insulators are vertical, some circuit breakers (especially at higher voltages) have horizontal or Y-configurated breaker chambers. Therefore, theoretically on such apparatus the risk for flashover due to snow may increase.

The most critical situation for a breaker is the synchronizing period during the connection of a generator to a line. In this case, the voltage over the breaker chamber in open position can for a short period of time reach 2,5 p.u. (compared to normal operating phase-to-ground voltage). A breaker of Y-configuration in Norway has recently flashed over and exploded during synchronizing and at 90 cm snowfall. The amount of snow on such a breaker is illustrated in Fig. 1.

Fig. 1. Snow on breakers after heavy snowfall in Norway, January 2004.

There are very few well-documented observations of flashover performance of insulators under natural snow conditions. It was therefore decided to investigate the risk for flashover over an open breaker under different snow conditions.

The basic snow parameters that affect the insulation performance of snow covered insulators are [1]:

- amount of snow
- volume density of snow
- snow distribution
- volume resistivity
- conductivity of the melted water from the snow
- liquid water content

A flashover mechanism of the insulators covered by snow was summarised in [1]-[2] as follows. The amount of snow accumulated on insulators, snow density and the resistivity of the snow are the major parameters that affect the AC withstand voltage of horizontal insulators. These parameters are influenced by the current flowing in the snow and on the surface of the insulator. The current increases when the density (e.g. packed snow) and the conductivity (e.g. salt snow) increases. Some parts of the snow with higher current density melt earlier due to Joule heating, and such parts may fall down leaving an uneven distribution of snow. This results in an uneven voltage distribution over the insulator. Depending on the resistance of the remaining snow and the length without snow, partial arcs develop over the snow-free gaps and in the worst case a complete flashover may occur.

II. Test object and Test set-up

The tests were performed on a 420 kV circuit breaker with two horizontal breaker chambers with porcelain insulators and grading capacitors in parallel with the breaking elements according to Fig. 2. The breaker was tested in open position. The voltage was applied from a single phase 500 kV test transformer to one element with the other element earthed. For the higher test voltages above 500 kV, the voltage was applied from two transformers connected in opposite phases to each breaker chamber. A resistor was installed between the transformer and the test object to protect the transformer from transients at flashovers. The test set-up is illustrated in Fig. 3. All the tests were performed at the outdoor test site. The testing was monitored with a daylight UV video camera, DayCor II from Ofil Ltd.

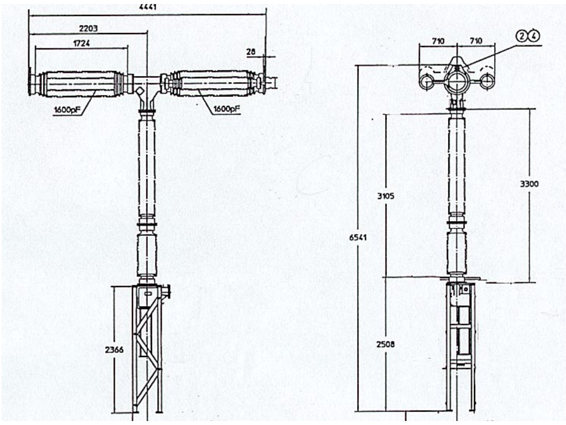


Fig. 2. Test object, a 420 kV circuit breaker with grading capacitors.

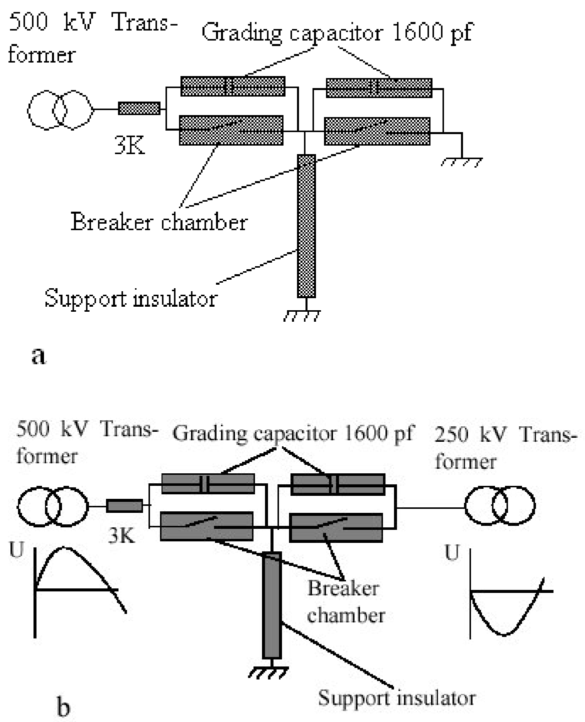


Fig. 3. Test set-up. a) Connection of an element to a 500 kV transformer with the other element earthed. b) Connection to two transformers in opposite phase.

Fig. 4. Snow test conditions, a) natural snow 5 cm height above the sheds, b) snow collected from the ground and piled up on the breaker, snow height 20 cm, c) snow produced by a snow cannon, snow height in average 10 cm, also covering the post insulator.

I. Test method

A. Voltage application

The voltage was increased in steps, first to 242 kV (the maximum operating voltage) and then successively to 485 kV or 630 kV if no flashover occurred before. The highest voltages were applied when the breaker was covered with natural snow.

B. Snow conditions

Three different types of snow have been tested (Fig. 4):

- Natural snow when it was available
- Natural snow from the ground piled on the breaker
- Snow produced from the lake water by a snow cannon

C. Snow and weather parameters

The following parameters were registered:

- Height of snow above the insulator sheds
- The snow and air temperature
- Snow density
- Conductivity of the melted snow
- Discharge activity

II. Test results

A. General

Seven voltage tests were performed in total. An overview of the test results is presented in Table 1. In the first two tests with natural snow the snow did not bridge over the parallel insulators. In these cases the target voltages 485 kV and 630 kV respectively were applied without flashover. In all other cases flashover occurred and was never below the highest phase-to-earth service voltage 242 kV.

TABLE 1
RESULTS OF VOLTAGE TESTS ON A SNOW COVERED 420 KV CIRCUIT BREAKER WITH HORIZONTAL BREAKING ELEMENTS AND GRADING CAPACITORS IN PARALLEL.

Test No.	1	2	3	4	5	6	7
Target test voltage, kV	485	630	485	485	242	630	485
Discharge inception, kV	<242	485	60	55	<242	150	180
Flashover voltage, kV	No FO	No FO	420	360	No FO	327-252[1]	292-403[1]
Type of snow	Natural	Natural	Piled from ground	Piled from ground	Piled from ground	Snow cannon	Snow cannon
Height of snow, cm	5	5	20	20	25-35	10	10
Snow distribution	No bridging	No bridging	Bridging	Bridging	Bridging	Bridging	Bridging
Snow temperature, ºC	-0,4 to 0	-6,7	0	-2,3 to 0	-1 to 0	-3,3	-0,4
Air temperature, ºC	-0,7 to 0	-6	3,5	1	1	-3 to-2	0
Snow density, g/cm^3	0,15[2]	0,10	0,30	0,51	0,46	0,46	0,50
Conductivity of melted water, µS/cm	16	3	3	5	7	46	46

[1] See details in Table 2
[2] 0,27 g/cm^3 after the test

B. Observations during the voltage tests

The discharges were monitored with a daylight UV video camera. The discharges took place mostly close to the insulator ends and also approximately in the middle of the porcelain breaking chamber at the position of the open breaker contacts. If no flashover occurred during the test (tests No. 1 and No. 5), the discharges extinguished after 10-30 min. During the tests when flashover occurred, the discharges increased in irregular way and increased strongly shortly before the flashover. Discharges took place over the gaps in the snow. From the beginning this occurred mostly at the ends of the insulators where the snow cover was the thinnest. Snow melting was observed a few minutes after discharge inception. Sporadically snow shedding occurred after sudden intensive discharges. Snow shedding also always occurred after a flashover. Examples of discharges are illustrated in Fig. 5 and Fig. 6. The effect of snow melting is shown in Fig. 7 where the snow has melted away from the middle part of the insulator over the open breaker contact and also at the end of the insulator.

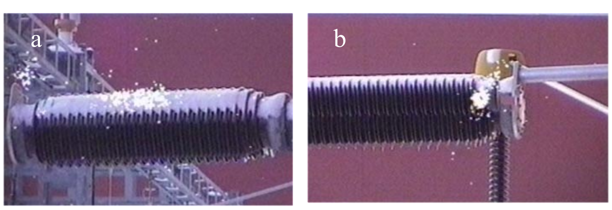
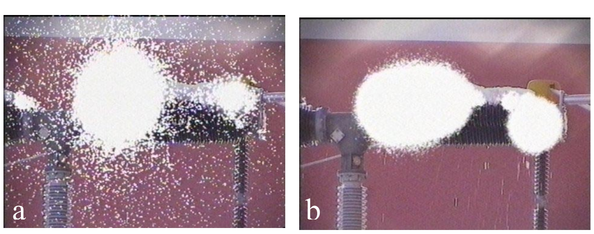


Fig. 5. Discharges recorded with a UV camera during snow test No. 2 at 630 kV: a) discharges over the breaker contacts position; b) discharges at the end of the grading capacitor insulator.



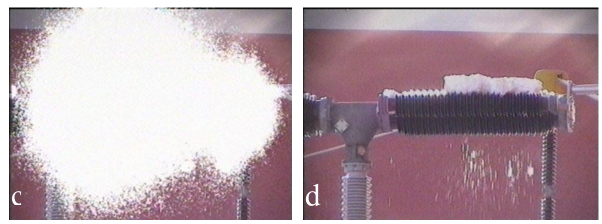


Fig. 6. UV discharge pictures during snow test No. 4 at 360 kV: a) 0,2 s before flashover; b) 0,04 s before flashover; c) flashover; 0,16 s after flashover with shedding of snow.

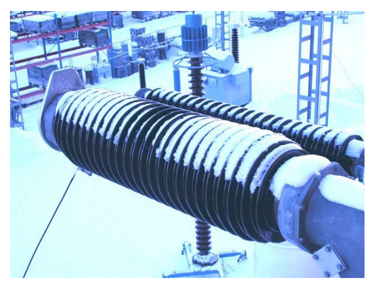


Fig. 7. Effect of snow melting during 130 min. at test voltage 485 kV.

At test No. 5 with application of the constant voltage 242 kV for relatively long time, the discharge activity was correlated with snow melting and the snow distribution on the insulators. The highest discharge activity occurred when the gaps in the snow were short-circuited by arcing. When larger portions of snow had slided off, the gaps became wider and could not be flashed over at the applied voltage. This pattern was also observed at test No.1 at 485 kV. During other tests with stepping up the voltage, this effect was obscured by too short step times on each voltage level.

The influence of the melt water conductivity is only important when liquid water exists in the snow, i.e. when the snow temperature is close to zero. In our tests the start temperature of the snow followed more or less the ambient temperature. Due to the resistive heating of the snow the temperature soon rose up to zero degree. The natural snow in Ludvika, Sweden was very clean and the conductivity of the melted water was below 20 µS/cm.

Snow melting was observed in the form of the drops from the insulators started a few minutes after voltage application. The melting and shedding of snow created gaps in the snow leading to more intense discharges over the gaps that could later on develop into flashovers.

III. Discussion

A. Influence of snow parameters

During the tests with natural snow no flashovers occurred even at 630 kV, which is about 2,5 p.u. for 420 kV voltage class. During these tests both the snow thickness and the snow density were rather small, which were beneficial for the insulation strength [1]. When snow collected from the ground or produced by the snow cannon bridged the parallel insulators of the breaking chamber and the grading capacitor, flashovers occurred far below this voltage. In these cases both the height of the snow cover and the density of the snow were higher than for natural snow. It appears from Table 1 that the flashover occurred below the target voltage when the snow bridged the parallel insulators, the snow height was above 10 cm and the snow density was at least 0,3 g/cm^3. Bridging and larger thickness increased the cross area of the snow. This decreased the total resistance of the snow and increased the snow melt rate. These two parameters, amount of snow leading to bridging and snow density were therefore the most critical for the performed tests.

B. Time to flashover

The intensive discharges over the snow gaps are the starting point for the complete flashover. The discharge intensity increased very fast within only one second before flashover as illustrated in Fig. 6. If no flashover occurred, the discharges extinguished due to further melting and shedding of snow. This indicates that there is a maximum risk for flashover during a certain time after the voltage application. Based on the flashover data obtained in these tests, this time varied from six seconds to one minute. Comparison with actual synchronizing times indicates that there could be enough time for flashover during the synchronizing period.

C. Flashover voltage data

The flashover voltages are compiled in Table 2.

TABLE 2
FLASHOVER VOLTAGES FOR DIFFERENT SNOW CONDITIONS ON A SNOW COVERED 420 KV CIRCUIT BREAKER

Test No.	3	4	5a	5b	6
Snow type	Piled from ground	Piled from ground	Snow cannon	Snow cannon	Snow cannon
Snow distribution	Clean support	Clean support	Snow on support	Clean support	Clean support
Flashover voltage, kV	420	360	525	413	393
	420	360	375	336	393
			353	327	403
			345	353	346
			380	335	343
First flashover stress, kV/m	122	104	152	120	114

It is most probable that the first flashover voltage in test series on snow covered insulator will be higher than the consequent flashover voltages. A possible explanation is that under the influence of resistive heating from leakage currents and discharges the snow changes. It melts and slides off leaving a more non-uniform snow cover.
The implication of this observation is that the first flashover voltage should be used to estimate the flashover risk during the synchronizing period after heavy snowfall.

The density of the snow piled from the ground and that produced by snow cannon was in the same range. No principal difference in the flashover voltages was found for these two types of snow, although the conductivity of the melt water from the cannon snow was higher. However, the absolute conductivity was small in both cases.

The flashover stress calculated from he flashover voltage is estimated as 100-120 kV/m. Let us estimate how this figure corresponds to the earlier derived formula for the calculation of insulation strength during slow melting of snow [3]:

V (kV/m dry arc) = 1303(ISP$)^{-0,26}$,

where ISP is the product of the ice layer weight (g/cm of dry arcing distance) and the snow layer conductivity (μS/cm).

Using the above formula and the average parameters obtained for the last case, i.e. snow produced by snow canon (5b and 6 in Table 2), the insulation strength (flashover stress) can be estimated as: 1303x(10 cm x 44 cm x 0,48 g/cm^3 x 46 μS/cm $)^{-0,26}$ = 120 kV/m. This corresponds well with the average experimental flashover stress (120+114)/2 = 117 kV/m.

D. Comparison with ice tests

Comparison with earlier performed at STRI tests on ice covered breaker (to be reported at CIGRE-2006) shows that the flashover stresses are about the same for ice and snow with parameters typical for Scandinavian conditions: 100-120 kV/m for snow and about 100 kV/m for ice for the same type of breaker. However, for snow conditions there is no apparent difference if the post insulator is covered with snow or not (in service the post insulator is more often not covered by snow). During snow conditions in Norway, the snow covered mostly horizontal parts of the breaker, see Fig. 1. On a snow covered open breaker the critical flashover occurred over the breaker chambers. This was reproduced in our tests since there was no snow on the post insulator except at one test.

However, most of the flashovers under ice occurred over the T-configuration, i.e. over a breaker chamber and down along the post insulator, when the voltage was connected to a breaking chamber and the other was earthed. This simulates the service case for ice conditions for the breaker, when the ice covered all the insulator structure.

The flashover mechanism for snow is as follows:

Leakage currents in the snow produce snow melting which in turn produces gaps in the snow cover. The discharges are initiated over the gaps, which can propagate over the whole insulation. The horizontal insulation is thus critical for snow conditions.

The flashover mechanism for ice is as follows:

Wet growth of ice produces icicles that are bridging the spacings between the sheds and produce discharges in the gaps between the tips of the icicles and adjacent sheds, which can propagate over the whole insulation. The vertical insulation is thus critical for ice conditions.

IV. Conclusions

- The most critical for the flashover snow parameters are the amount of snow resulting in the bridging of the snow over the breaking chamber and parallel capacitor and snow density above 0,3 g/cm^3
- The maximum discharge activity leading to flashover can well occur within the synchronizing period when a line is connected to a generator
- The flashover stress under snow conditions is approximately the same as under ice conditions when the amount of snow is high enough and the snow density is above 0,3 g/cm^3. This stress is in line with known literature data.
- The flashover mechanism is different for snow and ice conditions. The horizontal insulation is critical for snow conditions, while the vertical insulation is critical for ice conditions.

V. Acknowledgement

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VI. REFERENCES

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