Phase conductor break caused by snow accretion on 110 kV overhead power line

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***Abstract*—In the paper we are focused on a 110 kV overhead power line damaged during heavy snowing. Snow accretion on the phase conductor caused increased sag of such a value that it touched the ground. Consequently, more ground short circuits, registered by protecting devices occurred on the energized line. After more automatic power line reenergizing, the line was finally de-energized and the maintenance personnel was sent to the power line route to examine the cause of the line outage. It found out that the conductor melting in the ground short circuit point resulted in the conductor break. In the first part of the paper we represent some theoretical calculations of additional load values on the conductor, which could have produced the conductor sag high enough to touch the ground. We found out that the line longitudinal profile and the tower type enable such kind of event if the additional load for which the line is designed is only slightly exceeded. In the second part we analyze the overhead power line state after the conductor break, and focus on new ground clearances in the damaged conductor section. In this way we get some interesting results regarding safety heights above the obstacles located under the power line.**

I. INTRODUCTION

In the article we give a reconstruction of the 110 kV Beričevo – Kleče OH transmission line condition before and after the conductor break caused by additional snow load. The load occurred on March 5, 2006 in the afternoon hours during heavy snow conditions. In the surroundings of Ljubljana, capitol of Slovenia, disturbances in electricity supply over a larger area were registered by electric distribution companies.

Due to extreme winter weather conditions and additional snow accretion on phase conductors multiple single-pole ground short circuits occurred in the power line span. They caused the conductor mass melting and at last the power line phase conductor final break.

In the first part of the article we give a description of the problem and observations of the maintenance team which tried to eliminate it, with a description of the accomplished maintenance works from their side. In the continuation, in the Chapter Analysis of the power line state, we give a theoretic simulation of additional load on the conductor which might have caused a ground short-circuit as well as a description of the conductor state after its breaking down. With different simulations we tried to arrive at the closest illustration of the real power line state at the given failure. A conductor break is namely interesting from the point of view of safety heights in the damaged section which is being analyzed in the second part of the article. In the last part, within the scope of Conclusions and References, a summary of the analysis results is given.

II. DESCRIPTION OF EVENTS BEFORE AND AFTER THE CONDUCTOR BREAK

On March 5, 2006 at 19.44, after several repeated connections of the power line protection devices, the 110 kV Beričevo – Kleče OH transmission line faced a final outage from the electric power system. Following the intervention of the maintenance teams on duty it was established that due to extreme weather conditions which will be described in the continuation of this text the lower phase conductor broke in the line span between towers no. SM54 and SM55 and caused the line outage.

Fig. 1: Broken conductor on ground. (photo: M.Cernivec)

The additional load on the conductor caused its approaching the ground till final touching. With the power line automatic reenergizing the conductor started melting down and finally broke. Due to mechanical forces caused by the conductor break the conductor slipped out of the suspension clamp installed on the insulator set of the tower no. SM54 for about 6 meters. Further conductor sliding out of the suspension clamp was prevented by a bird cage installed by the clamp which is evident from the Figure 2. This resulted in highly increased sag between towers SM53 and SM54, and the conductor crossing the Sava River in this span not only touched the ground but even sank down under the river water surface. This changed also the sags between the other towers located in front of SM53 and after SM54.

Fig. 2: Conductor sliding out of the suspension clamp. (photo M. Cernivec)

The conductor occupied a good half of the right riverbed. The Sava River which featured an extremely high water level during the period of heavy snows applied additional force on the conductor which provoked additional loads on towers no. SM53 and SM54 with even a risk of their destruction. The task of the team working on site was to eliminate the failure as soon as possible. At tower no. SM54 they firstly dragged the conductor out of water using Unimog maintenance vehicle and provisionally anchored it.

Then they cut out the deformed part of the conductor and replaced it by a new one. The new conductor part which was added together with two compression midspan joints was 20 meters long. The reconstruction was accomplished by the conductor joining and its replacing into the suspension clamp of the insulator set.

According to weather forecasting reports obtained by relevant meteorological institutions the day of March 5, 2006 was supposed to be cloudy with precipitations. In the north-eastern Slovenia it was snowy already in the morning while during the day rain was gradually passing to snow all over the hinterland. In the afternoon, there was heavy snow all over the country while the lowlands of the coast region faced heavy rains. In a short time, up to 30 cm of snow covered the area.

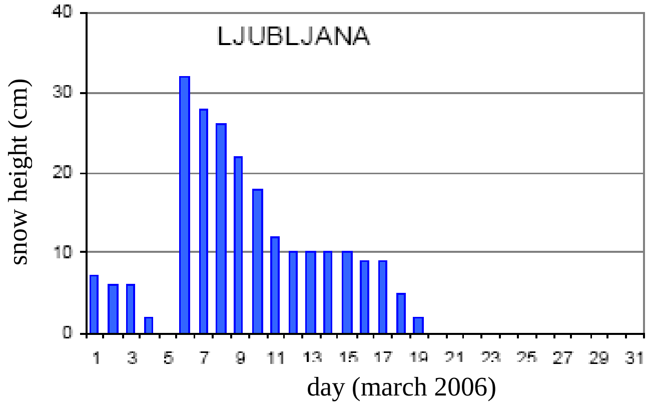

Fig. 3: Daily snow depth in March 2006 [3].

Due to heavy thawing snow many trees were broken and many electric lines were damaged. Along the coast, a south wind - sirocco was blowing which turned to moderate and heavy bora in the afternoon. The fall of temperature caused heavy cooling off. In the morning, the temperatures in central and south Slovenia reached up to 14 °C, while in the evening they fell down and reached from -2 to 3 °C.

Fig. 4: Low voltage network under snow cower on 5. March 2006. (photo B.Zemljaric)

III. ANALYSIS OF THE POWER LINE STATE

A. Reconstruction of the power line state at ground short-circuit

The chapter gives a reconstruction of the additional snow load size which resulted in the power line conductor touching the ground. The snow load foreseen by the simulation was supposed to be only on the damaged span between towers SM54 and SM55. The section of the longitudinal profile encompassing the point of the conductor touching the ground is given in Figure 5.

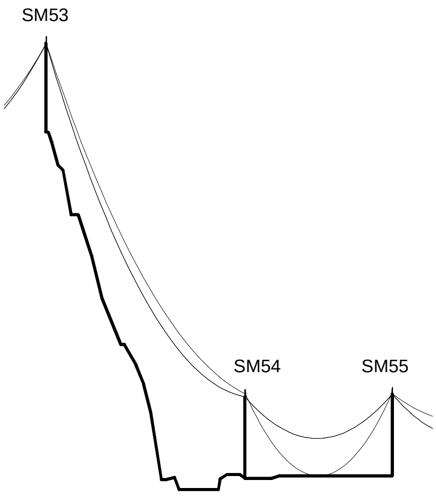

Fig. 5: Longitudinal profile between SM53 and SM55.

The upper catenary gives the position of the upper conductor in normal operating conditions while the lower catenary gives the position of the conductor at its touching the ground. The conductor safety height above the ground was around 8 m. Since no data regarding additional load on the conductors during the event were available, two options were simulated:

-continuous load on the complete span, and

-continuous load only on 1/3 of the span.

In the first simulation of the conductor touching the ground we considered the actual state of sag and the conductor tension stress of 8.7 daN/mm^2. In the iterations, additional load up to the one needed for the conductor touching the ground was considered. The ACSR 240/40 conductor design tension stress is 9daN/mm^2; however, during the power line operating years it decreased to 8.7 daN/mm^2 due to non elastic elongations. This was calculated from the difference of sags between the reconstructed over-tensioned conductor and an old undamaged conductor from another system, this being around 0.5 m.

The section of the power line limited by two tension towers is 2000 m long and contains 6 straight line supports. The configuration of the observed section is quite agitated since the line steeply climbs up from a lowland part and then re-falls down to the lowlands where the section terminates.

The Table I gives the values of additional load along the whole span and at different air temperatures ranging from -2ºC to +3ºC. As it is evident, the temperature does not basically affect the size of the calculated additional load. Considering weather conditions which were ruling on site during the conductor deformation and which are represented in the continuation of this text, the basic starting point of temperature is that of 0ºC.

TABLE I.
TABLE OF ADDITIONAL LOAD FACTORS AT DIFFERENT TEMPERATURES

Temperature	Additional load between SM54-SM55
(ºC)	(daN/m)
-2.0	2.43
1.0	2.40
0	2.37
1	2.36
2	2.34
3	2.31

Additional load at which the conductor touches the ground if it is additionally loaded only in the observed span while in the other spans there is no additional load, at a temperature of 0ºC which was simulated by SagSec computer program, amounts to 2.37 daN/m. It has been established that at lower air temperatures and with the same conductor sag the additional load factor increases, and vice-versa. If the load is represented by the conductor coat thickness, in case of light snow with specific weight of 0.6 kg/dm^3 this achieves around 3 cm which means that the full diameter of snow on the conductor is around 8 cm.

An unofficial measurement of snow specific weight made by the author of this article himself on the day of the conductor failure and at a temperature of –2°C achieved around 0.2 kg/dm^3, while two days after snowing and at a temperature of +3°C the specific weight of snow reached 0.47 kg/dm^3. This means that due to smaller specific weight the coat could have reached a thickness of 5.5 cm at a specific weight of 0.2 kg/dm^3 and the external diameter of snow was so 17.9 cm.

In the second simulation made in the same weather conditions the span between SM54 and SM55 was divided into three thirds. The load was simulated only on 1/3 of the central sub-span. The continuous one-third load was simulated by five points in the central sub-span, see Figure 6. By iterative addition of constantly applied same parts of load in the previously mentioned points it has been established that at the moment when the conductor reaches the ground this load achieves 77.5 daN. The calculation result is given in Table II.

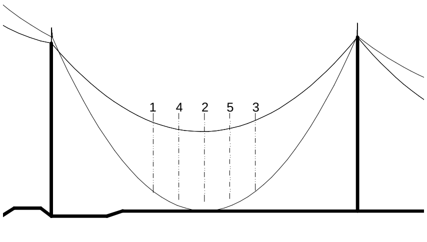

Fig. 6: Additional load points in second study case.

The results show that an additional load smaller for 10 kg and applied in the previously mentioned points of the conductor decreases the sag for around 63 cm. The table also gives that in case of a simulation of an unequal load in the span the conductor reaches the ground at a minimally increased load.

TABLE II
TABLE OF ADDITIONALLY APPLIED LOAD AND DECREASE OF HEIGHT ABOVE GROUND

Additional conductor load applied in five points	Safety height (decreased sag)	Additional load per unit of length
(daN)	(in m)	(daN/m)
77.5	0 (touching of ground)	2.516
67.5	**0.63**	2.192
57.5	1.38	1.867
47.5	2.25	1.542
37.5	3.26	1.217
27.5	4.43	0.893
17.5	5.80	0.568
7.5	7.39	0.243
No load	8.73	0

B. State after the phase conductor break

In this simulation the power line state at the conductor break between SM54 and SM55 and the conductor slipping out of the suspension clamp of the insulator set in the length of 6 m has been analyzed. A bird cage of the aluminum part of conductor prevented further sliding of the same from the clamp. In support of the broken conductor the straight line tower SM54 took over the role of a tension tower. The conductor length extended for around 8 m. The difference of sags due to the conductor length extension in the section is given here below. The most critical sag occurred in the span crossing the Sava River. The conditions are given in Figure 7.

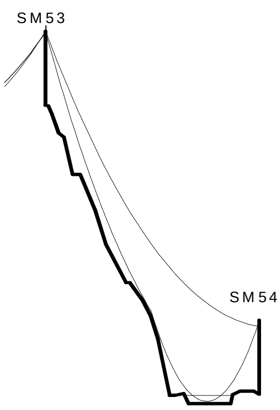

Fig. 7: State of the sag after conductor breaking.

The upper conductor represents a normal state while the lower one gives the state after the conductor breaking when it plunged down into the Sava River with highly increased water level. In this span the power line crosses also a local road which had to be closed temporarily due to the increased sag The conditions, where conductor reach the road and marking them with red ribbon are shown in Figure 8.

Fig. 8: Damaged conductor on the road. (photo M. Cernivec)

In order to simulate the state of the conductor reaching the Sava River a calculated extension of around 8 m of the conductor dragging out of the suspension clamp was required. This is near to the length of 6 m assessed by the maintenance personnel and obtained by their observation of the conductor length from the ground.

After the conductor break, a new equilibrium was established in the reduced section of the damaged conductor between SM45 and SM54. The tower SM54 took over the role of a tension tower, the conductor length in the section increased and as regards normal operating conditions the other insulator sets took a deflective position. This is given in Table III:

TABLE III
INSULATOR SET DEFLECTION

Tower No. (SM)	Deflection in longitudinal direction	Deflection in vertical direction	Deflection
	(cm)	(cm)	(°)
46	-0.3	0	0
47	-2.4	0	1
48	-6.1	0.1	2
49	-12.3	0.4	4
50	-30.6	2.8	10
51	-33.8	3.4	11
52	-37.8	4.2	13
53	-68.2	14.2	23

The Table shows that the biggest deflection occurred at tower no. SM53 while after that, looking towards SM46 at the beginning of the section, the deflection decreased.

Extension of the conductor and deflection of the insulator sets caused a change in sags or safety heights above the ground, respectively. This is why the sags in normal operating conditions of the power line and sags after the conductor break as well as their differences were analyzed. This difference in sags helped us in assessing the safety height decrease. The Table IV gives a presentation of the differences in sags in individual spans.

TABLE IV
SAFETY HEIGHTS IN NORMAL CONDITIONS AND AFTER THE CONDUCTOR BREAK

Tower no. (SM)	sag (0ºC) initial	sag (0ºC) break	Sag difference
	(m)	(m)	(cm)
45-46 (1)	3.25	3.27	2
46-47 (2)	12.57	12.68	11
47-48 (3)	16.04	16.21	17
48-49 (4)	11.21	11.56	35
49-50 (5)	16.70	17.54	84
50-51 (6)	3.09	3.31	22
51-52 (7)	2.85	3.09	24
52-53 (8)	8.73	10.33	160
53-54 (9)	18.67	38.06	1933

As it is evident, the sags increase from the undamaged part to the damaged one. It is interesting that the sags are not essentially increased with the exception of the span located beside the damaged one.

IV. CONCLUSION

Our aim was to analyze and represent the state of the 110 kV power line before and after its conductor break due to additional snow load, and to make a reconstruction of the additional snow load size which caused the lower phase conductor touching the ground. With different simulations we tried to get a real picture of the actual events occurring on the power line.

With assumption that additional snow load occurred only between tower no. SM53 and SM55 the simulation resulted in a conductor load of approximately 2.37 daN/m of snow which corresponded to a coat of around 30 mm of thaw snow of 0.6kg/dm^2 specific weight. In the simulation considering the snow being present only at one third of the span we give a similar result.

After the conductor break and its dragging out of the suspension clamp for 8 m the safety heights in the neighboring spans decreased. The result of the simulated state shows that the safety heights in the section with 9 spans decreased gradually. In the most distant span the break effect was minimal, i.e. around 2 cm, while the maximum effect occurred in the span next to the damaged one and achieved around 160 cm.

V. REFERENCES

[1] [1] Project documentation 'DV 110 kV vstavitev stebra na SM133A' *(110 kV power line, insertion of tower no. SM133A)*, Project No: D345-A025/133A, Design/Folder No: ME01 (August 2003),

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[3] Monthly meteorological report, ARSO, Ljubljana, no.3, vol. 13, March 2006.