Span sensitivity to snow accretion and snow shedding in an overhead line tension field

Borut Zemljaric,
IBE, Consulting Engineers
Hajdrihova 2, 1000 Ljubljana, Slovenia, borut.zemljaric@ibe.si

Janez Jakse,
Mozanca 16, 4205 Predvor, Slovenia

Abstract - **Like in the other parts of Europe in Slovenia as well the distances between phase conductors and a ground wire in the middle of the span are designed according to their disposition and sags. Field experiences show that during periods of snow some lines can be exposed to short circuit events if upper and lower conductors lie in a vertical disposition. In this paper we would like to clarify why such short circuit events occur if the line is designed according to national legislation. A basic study of the line geometry and a calculation of static conductors' sags for different loading cases showed us that some spans were more vulnerable to snow accretion and snow shedding. We considered different conductor types hanged in multi span tension fields with different span lengths. Then we implemented different load cases and calculated sags in those tension fields. The results confirmed our expectations that some spans were more vulnerable to snow shedding than the others in a non-linear way.**

Key words: transmission lines, snow shedding, snow accretion, icing, span, conductor

I. INTRODUCTION

The majority of the Slovenian 110 kV grid consists of double circuit lines with vertical configuration of cross-arms. Most of the towers' upper and lower cross-arms are of the same length while the central one is longer. The distances between phase conductors and a ground wire in the middle of the span are designed according to the Slovenian national regulation. Like in the other parts of Europe, the distances between conductors are based on their disposition and sags [1].

Field experiences show that during periods of snow some overhead lines are exposed to short circuit events if upper and lower conductors lie in a vertical disposition. After several analyses a new solution was made. In order to prevent short circuits between phases a rearrangement of conductors' disposition by 'V' insulators strings on the tower was performed in a way that no conductor laid in a vertical disposition. The results from the field were promising, i.e. in the next two years the overhead line operated without disturbances. Up to now, two overhead lines were modified.

In this paper we would like to clarify why the short circuit events occur if the line is designed according to national legislation. According to the national legislation the overhead transmission line static and the tower head geometry are designed to bear maximal loads on the conductors. A basic study of the line geometry and a calculation of static conductors' sags for different loading cases showed us that some spans were more vulnerable to snow accretion and snow shedding [3]. We expanded these calculation approaches more systematically and generally. We considered different conductor types hanged in multi span tension fields with different span lengths. Then we implemented different load cases and calculated sags in the tension field.

The results confirmed our expectations that some spans were more vulnerable to snow shedding than the others in a non-linear way. In future we will reflect on phase span sensitivity, which should be considered when compact towers' lines with vertical conductors' disposition are designed in snowy areas.

II. CALCULATION METHOD

In order to reach the goals described in the previous chapter a four-step method was applied. The first step consists of the conductor type selection where some of the most common conductors are used. Types are chosen in the way to get the most used range of conductor's diameters and comparative values between American and European standard conductors. Table 1 gives basic technical parameters of five conductors' type which were used in the calculation.

Table 1: Conductors' parameters

No.	Conductor	Diameter	Unit Weight	Similar conductor by EN standard
		(mm)	(N/m)	
1.	Cardinal	30.38	17.9	490/65 ACSR
2.	Bison	26.97	14.2	380/50 ACSR
3.	Hawk	21.79	9.6	240/40 ACSR
4.	Oriole	18.82	7.7	185/30 ACSR
5.	Ostrich	17.27	6.0	150/25 ACSR

In the second step additional load value was determined. According to the national legislation the overhead transmission line is static and the tower head geometry is designed to bear maximal normal load on the conductors. The load is calculated as per equation (1)

$$g_a = k1{,}8\sqrt{d} \qquad (1)$$

where d is a conductor diameter given in mm, and k is a load parameter. They represent a load factor on the line and could be 1, 1.6, 2.5 or more. In principle, with this load being present on the conductors, the tower vertical distances between lower und upper conductors should satisfy, if on the observed span additional load is present and on the other spans there is no load. Figure 1 represents a typical tower top with vertical disposition of upper and lower conductors.

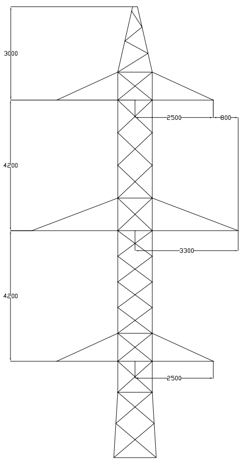

Figure 1: Tower top type Nb/h

However, field experiences obtained on the overhead line show that most problems occur during snowing and shortly after it. It can also be affirmed that the wet snow external diameter exceeded the designed one.

So, additional loads of different thicknesses were calculated for five conductors, and a mean value corresponding to the load thickness was determined and labeled from I to VI. Table 2 gives the average loads and labels applied. Snow specific mass used in calculations is $0.6 kg/dm^3$.

Table 2: Conductors' additional loads (in N/m)

No	Conductor	Diameter	Load thickness (mm)					
		(mm)	10	20	30	40	50	60
1.	Bison	26,97	6,97	17,71	32,22	50,50	72,55	98,37
2.	Cardinal	30,38	7,61	18,99	34,14	53,06	75,75	102,2
3.	Hawk	21,79	5,99	15,76	29,29	46,59	67,66	92,51
4.	Oriole	18,82	5,43	14,64	27,61	44,35	64,86	89,14
5.	Ostrich	17,27	5,14	14,05	26,73	43,18	63,40	87,39
Averge additional load (N/m)			**6**	**16**	**30**	**48**	**69**	**94**
Label			**I**	**II**	**III**	**IV**	**V**	**VI**

The third step consists of the overhead line determination. Generally, the span length was varied from 150m to 400m, the number of spans from 3 to 7 in the tension field, the conductor tension was varied as well.

The fourth, final step consists of a definition of shedding and clinging cases which were basically used for calculation and analyses. By combination of different cases the most unfavorable state of the overhead line can be found. Basic idea of work is given in Figure 2.

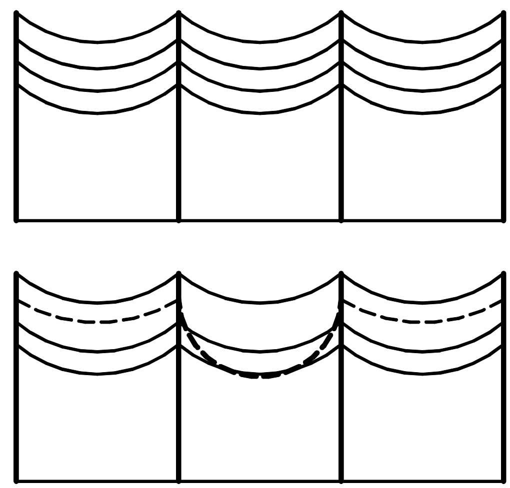

Fig 2: Three span tension field

III. SNOW SHEDDING AND CLINGING CASES

In general, 33 snow shedding cases and conditions on the tension fields were predicted and calculated. See Table 3 for detail information. These cases can be summarized into the following subgroups:

I. - after the line snow shedding, snow, this is additional load, exists only in one span (cling).

{a.} In cases 1-3 we observed snow cling in one span, in tension fields which consist of 3, 5 or 7 spans; all 5 conductors and the spans were varied from 150 m to 400m by a 50m step. The goal was to find out what was the general difference caused by the conductor types, length of spans and number of spans.

{b.} In cases 4-7 we observed hawk and cardinal conductors in 3 and 5 span tension fields with line inclination of 4°and 9°, in the entire range of spans. The goal was to determine influence of the line inclination to sag difference.

{c.} In cases 8-11 we observed a hawk conductor in condition of lower tension stress, all the other parameters were the same as in cases 1-3. We tried to find out what was the influence of the conductor stress to sag.

{d.} In cases 12-22 we observed a hawk conductor in a 3 span tension field. The lengths of spans in the tension field were unequal in the way; 2a/3, a, a; a, 2a/3,a; 2a/3, 2a/3, a; a/2,a, a; a, a/2, a, a/2,a/2,a where the span a was 150m or 250m long. A similar case was repeated within a 5 span tension field. The goal was to determine influence of different span lengths to sag difference.

{e.} In case 23 we observed a hawk conductor hanged on a 0.3m long insulator, which simulated a post line insulator. The influence of the line length insulation to the conductor sag difference was determined.

II. - After the line snow shedding only one span remains without snow; on all the other spans snow, i.e. additional load exists (shedding).

{f.} In cases 24-25 we observed hawk and cardinal conductors and the spans were varied from 150 m to 400m by a 50 m step. The goal was to find out what was the general difference caused by conductor types, length of conductor spans and number of spans.

{g.} In cases 26-27 we observed a hawk conductor in condition of lower tension stress; all the other parameters were the same like in the previous case. We tried to find out what was the influence of the conductor tension to sag differences.

{h.} In case 28-33 we observed a hawk conductor in a 3 span tension field. The lengths of spans inside the tension field were varied. The goal was to determine the influence of different span lengths to sag difference.

Table 3: Additional details about analysed cases

No.	Case name	Load type	Disposition	Span	Conductors	Tension N/mm^2
1.	A	cling	3 spans	a, a, a	All	90
2.	B	cling	5 spans	a,a a,a, a	All	90
3.	C	cling	7 spans	a, a, a, a, a, a, a	All	90
4.	Da	cling	3 spans, 9°inclination	a, a, a	Hawk, Cardinal	90
5.	Db	cling	3 spans, 4°inclination	a, a, a	Hawk, Cardinal	90
6.	Ea	cling	5 spans, 4°inclination	a, a, a, a, a	Hawk, Cardinal	90
7.	Eb	cling	5 spans, 9°inclination	a, a, a, a, a	Hawk, Cardinal	90
8.	F	cling	3 spans	a, a, a	Hawk	80
9.	G	cling	5 spans	a,a,a, a, a	Hawk	80
10.	H	cling	7 spans	a, a, a, a, a, a, a	Hawk	80
11	R	cling	5 spans	a, a, a, a, a	Hawk	70
12.	Ia1	cling	3 spans	2/3a, a, a	Hawk, Cardinal	90
13.	Ia2	cling	3 spans	a, 2/3a, a	Hawk, Cardinal	90
14.	Ia3	cling	3 spans	2/3a, 2/3a, a	Hawk, Cardinal	90
15.	Ib1	cling	3 spans	1/2a, a, a	Hawk, Cardinal	90
16.	Ib2	cling	3 spans	a, 1/2a, a	Hawk, Cardinal	90
17.	Ib3	cling	3 spans	1/2a, 1/2 a, a	Hawk, Cardinal	90
18.	Ja1	cling	5 spans	2/3a, a, a, a, a	Hawk	90
19.	Ja2	cling	5 spans	a, 2/3 a, a, a, a	Hawk	90
20.	Ja3	cling	5 spans	a, a, 2/3 a, a, a	Hawk	90
21.	Ja4	cling	5 spans	2/3a, 2/3 a, a, a, a	Hawk	90
22.	Ja5	cling	5 spans	a, 2/3 a, 2/3 a, a, a	Hawk	90
23.	P	Cling	3 spans	a, a, a	Length of insulator string 0.3m, 100N	90
24.	Ka,b	shedding	3 spans, horizontal	a, a, a	Hawk, Cardinal	90
25.	La,b	shedding	5 spans	a, a, a, a, a	Hawk, Cardinal	90
26.	N	shedding	3 spans	a, a, a	Hawk	80
27.	O	shedding	5 spans	a, a,a,a, a	Hawk	80
28.	Ma1	shedding	3 spans	2/3a,a,a	Hawk	90
29.	Ma2	shedding	3 spans	a, 2/3a, a	Hawk	90
30.	Ma3	shedding	3 spans	a, a, 2/3a	Hawk	90
31.	Mb1	shedding	3 spans	1/2a, a, a	Hawk	90
32.	Mb2	shedding	3 spans	a, 1/2a, a	Hawk	90
33.	Mb3	shedding	3 spans	a, a, 1/2a	Hawk	90

IV. CALCULATION RESULTS

All calculation results got by SagSec (Power Line Systems, Inc.) program were summarized in tables and presented in figures in order to get a possibility of comparing and analyzing the cases. The summarized results by sub cases are:

{a} Figure 3 represents sag differences obtained by variations of additional load in a cling span. It is obvious that by increasing the cling load the sag increases. The sag increases significantly also with the span length. This means, that if the line design is predicted to level III load with more load on the line cling, let us say value V, the sag will be bigger and a possibility of short circuit will exist.

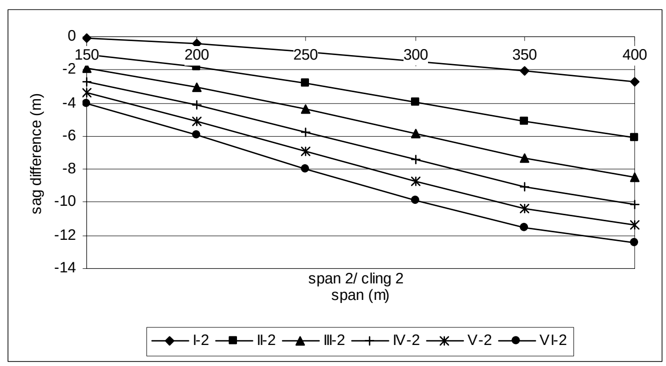

Fig.3: Sag differences for a hawk conductor in the second span with different cling load in a 3 span tension field

In Figure 4 the sag difference is compared to level III additional load for all analysed type conductors. The conductors with lower diameter are more exposed to sag differences, because the average additional load on them is bigger. But it is interesting that in spans of over 300 m length the sag difference starts to converge to the same value. We can conclude that by increasing the conductor diameter a decrease of the additional load influence on the conductor can be reached.

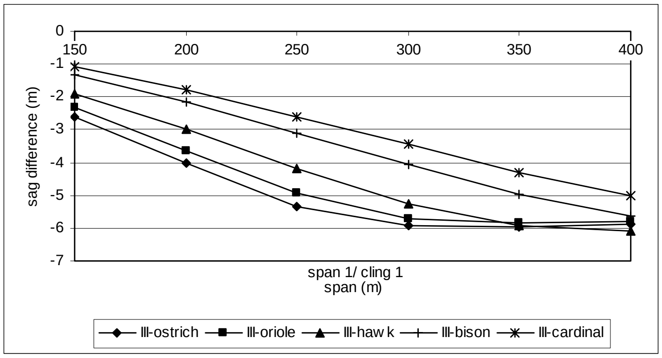

Fig. 4: Sag differences for all conductor types in the 1st span and cling load in the 1st span in a 3 span tension field

By comparing sag differences in spans with location of additional load cling it can be seen that the most unfavorable case occurs by the additional load clinging in the central span of the tension field. The span number in a tension field has no mayor influence to the sag values. The relations are presented in Figure 5.

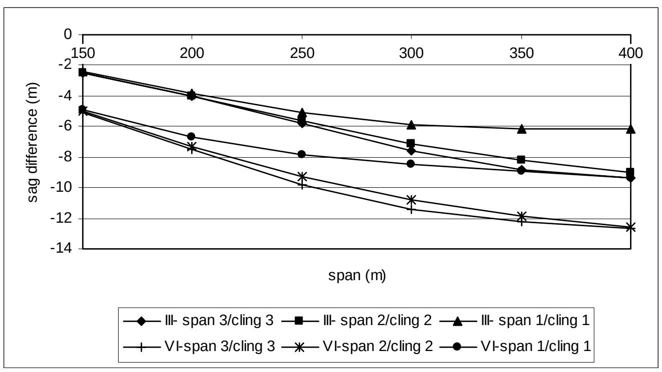

Fig.5: Sag differences for a hawk conductor in the 1st, 2nd, 3rd span with two levels of additional cling loads in a 5 span tension field

Taking into account a corresponding conductor jump in the neighboring spans the most unfavorable case always occurs when the additional load exists in the second span of the tension field. The sag difference increases with the span length. The calculation results are presented in Figure 6.

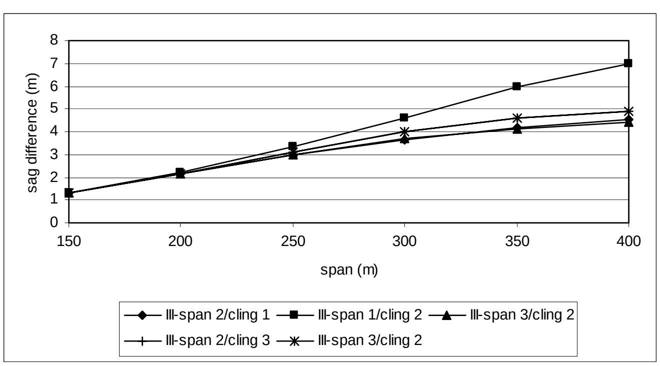

Fig.6: Sag differences for hawk conductor in the neighboring spans of the 1st, 2nd, 3rd span with additional load in a 5 span tension field

{b} Simulating the line route on a hilly terrain a linear line inclination in 4° and 9° was taken into account; it gave us a very small sag increase. We concluded that the line inclination had no influence to the sag differences. So, all the other conclusions about sags are the same as in case of a horizontal line route.

{c} Figure 7 gives sag differences in the first and in the second span for a hawk conductor in a 5 span tension field for three different conductor tensions. The sag differences are small, so the conclusion is that the conductor tension has no mayor influence to the conductor sag differences. It is interesting that by increasing the span length the sag difference alternates. In the showed case the sag difference alternates at 350m.

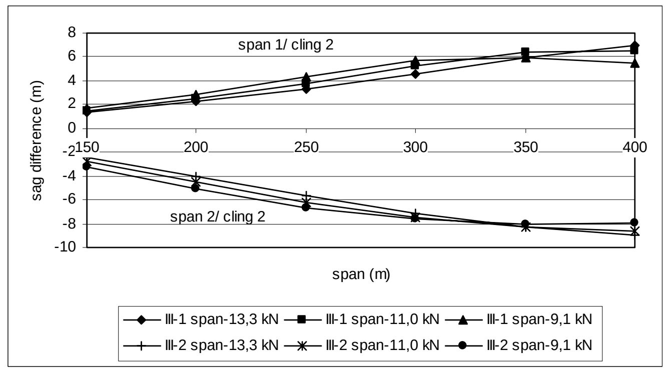

Fig. 7: Sag differences for a hawk conductor in spans 1 and 2, cling load in the 2nd span, with different conductor tension in a 5 span tension field

{d} In this case different combinations of span lengths in a three span tension field were used in calculations. It can be concluded that the sag difference doesn't exceed the values obtained at equal span length tension field. Inside the tension field the highest sag differences are obtained within cling neighboring spans with a longer span. In this combination longer spans are more vulnerable than the shorter ones. Figure 8 gives sag differences in all thee spans and cling additional load in the second span.

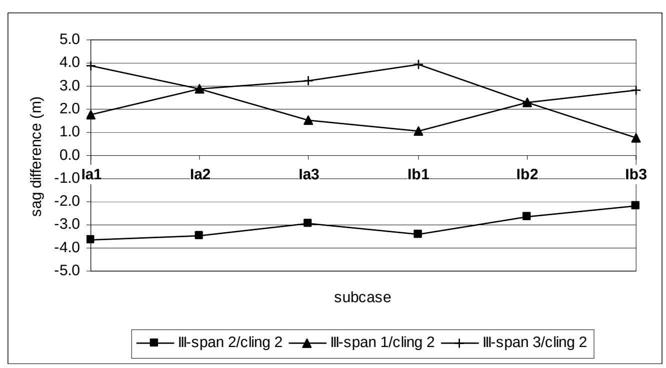

Fig.8: Hawk conductor in case of different combinations of span lengths and clinging in a 3 span tension field

{e} The insulator length has big influence on the conductor sag difference. Figure 9 gives the calculation results for the insulator length of 0.3m. This length simulate line post insulators. Comparing the results with Figure 3, where the insulator length of 1,5m was assumed, the span difference of approximately 2.5m at 250m span length and of 5m at 400m span length taking into account the worst load case VI level, is observed.

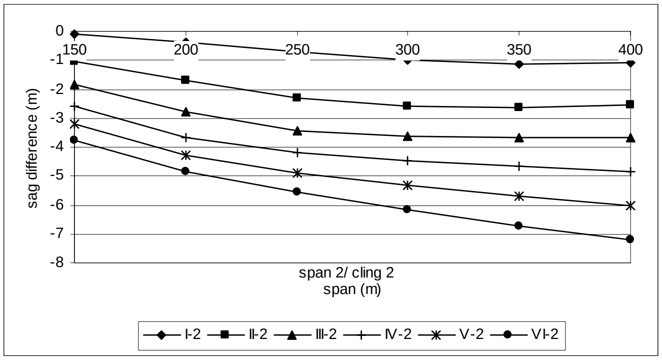

Fig.9: Sag difference for a hawk conductor in the second span with different cling load in a 3 span tension field and with insulator length of 0.3m.

{f} In the next cases we assume additional load in the whole tension field except in one span marked with shedding. The analysis shows that the line behavior is similar to the reverse case of clinging. The values of sag differences are slightly higher than in case {a}. This can be observed by comparing the conductor tension curve of 13,3kN in Figure 10 and in Figure 7.

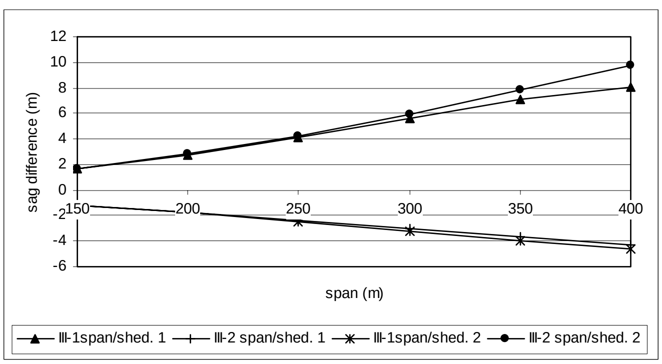

Fig. 10: Sag difference for a hawk conductor in spans 1 and 2, with shedding load in the 1st or 2nd span in a 5 span tension field

{g} Comparing Figure 11 which gives a hawk conductor in the first two spans of a 5 span tension field with two conductor tensions, with Figure 7 it can be seen that in this case of observing the shedding effect the lower tension has an increased but still small influence on the sag difference.

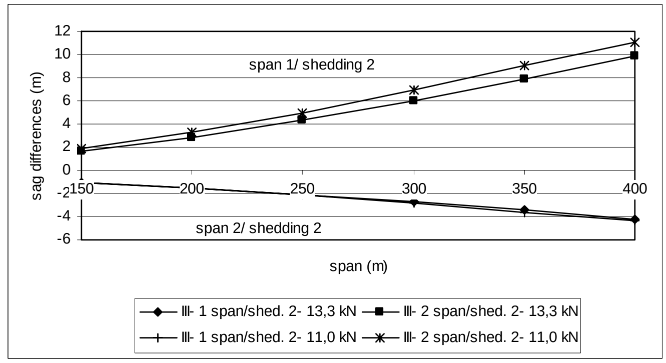

Fig. 11: Sag difference for a hawk conductor in the 1st and in the 2nd span, shedding load in the 2nd span, with different conductor tension in a 5 span tension field

{h} This is a reverse case in comparison with the one given in Figure 8. Also in this case different combinations of span lengths in a three span tension field were used in calculations. We can say again that a longer span is more vulnerable to sag difference than a shorter one. Figure 12 shows sag differences in all thee spans, and shedding additional load in the second span.

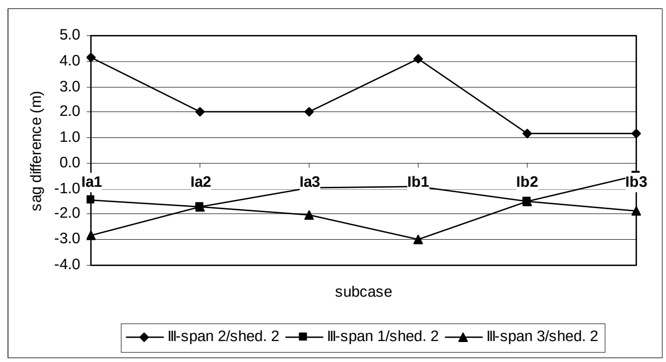

Fig.12: Hawk conductor in case of different combinations of span lengths and shedding in a three span tension field

V.CONCLUSION

With a shortened presentation of calculation results given in this paper we tried to clarify one of the mechanisms of short circuit events occurring due to snow shedding and clinging effects. We believe that the reason lies in the unequal span snow sheddings in the overhead line tension fields. The 'right' combination can easily cause conductors touches, and consequently - short circuits.

In the analyses we focused on a static calculation of sag conductors. In the summary, 33 cases were analysed. Cases include different values of snow additional load, diferent conductor types, from small to increased diameter values, different shape of tension fields, tension of conductors etc.

The conclusions can be summarized as follows:

- High diameter conductors are less vulnerable to additional load,
- With increasing the span length the sag difference increases as well,

- Conductor tension has a very small influence on the conductor sag difference,
- The first span near the tension tower has a biggest sag difference when the load exists in the second span,
- Observed from the sag amplitude the most vulnerable is the central span of the tension field,
- Number of spans in a tension field has no influence on the sag values,
- In case of different span lengths in one tension field the longer spans are the most vulnerable,
- In sag difference issues the length of suspension insulators plays a very important role.

The above conclusions can serve to the overhead line designers in their better estimation and decision making regarding additional loads on the overhead lines. Due to probabilistic nature of snow shedding, balancing between the OH line design cost and operational security will still remain a problem in practice. But with careful design of tower heads and being aware of the fact that more load than usually foreseen can exist and will definitely be a case during snow periods, the number of short circuit events due to snow shedding can be decreased to the smallest possible one.

VII. REFERENCES

[1] F. Kiesling, P. Nefzger, U. Kaintzyk, “Freileitungen,” 5 ed. Springer, 2001, pp. 153-161

[2] G. McClure, M. T. Harash, J. Jakse, “Numerical modeling of snow-shedding effects on a 110 kV overhead power line in Slovenia,” in Proc 2001 Sloko Cigre, pp.22.31-22.37

[3] B. Zemljaric, “Feasibility study of setting V strings to prevent interspan contacts at snow shedding effects (Študija možnosti montaže V verig na daljnovod s ciljem preprečitve medfaznih stikov pri neenakomernih odpadih snežnih oblog z vodnikov),” IBE, Ljubljana, Slovenia, The. Rep. D295.1-A572/088A, July 2004