COMPACT TOWERS WITH POST-LINE INSULATORS DESIGNED FOR SNOWY AREAS

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Abstract: One of the options for narrowing the overhead-line corridor is to use armless insulation constructions, like post-line insulators or brace-insulator assemblies. For the first time in Slovenia, compact towers with post-line insulators at the 110-kV level have been studied. The presented overhead-line route is in an area where snow events can occur during the winter. A post-line insulator with its base rigidly attached to the support structure should withstand unbalanced loads and the bending stress inside the insulator's fiberglass core. To determine the right properties for the mechanical insulator, the line design should take into account the local standards, the designer's experiences and, if it is available, the local metrological data from the line route. The variation of the major parameters − like snow quantity, unequal snow accretion, conductor size, insulator lengths and freedom of movement in the conductor's attaching point on the compact-tower design and the post-line insulator − will be presented. From our experiences the demands relating to the EN 50341 standard are discussed.

1. INTRODUCTION

Our goal is to present the difference between the longitudinal forces obtained from different traditional and flexible static calculation approaches. In the tension-field model for suspension towers, three different input data were given, i.e., M I, M II and M III, for the same presented line.

2. RESULTS AND DISCUSSION

Poorly defined load factors in the NNA standards, which have to be taken into account in the design stage, can be very confusing to the line designer. Also, they can be a limiting factor when using a new material in practice. Today, the traditional approach must still be respected. That means that the minimum standard is prescribed and the designer should satisfy the minimum requirements and show them in the design project.

In our case the designer will, in the first approximation, take the longitudinal loads as 50% of the conductor tension force. This means the longitudinal loads can be so high that the post-line insulator cannot sustain the mechanical load. In the next iteration the designer will study how to reduce these loads. That can be achieved through calculating the longitudinal loads at different load ratios as the common standard predicts. Let us assume that the load ratio is 50%. Now, the mechanical forces are further reduced. Again, the designer cannot be totally satisfied. In the region without any additional load these problems will not be so exposed as in snowy areas. In the final result, some unconventional solutions are then taken when using post-line insulators in the traditional approach.

Taking an overhead line as a flexible line in a calculation, the longitudinal forces can be 6 times lower than with the traditional approach. In the compact tower we used bendable steel poles so the tower top's movement in the longitudinal direction can reach around 0.3 m for a 13 m pole. In this approach, no or only few mechanical limitations are given.

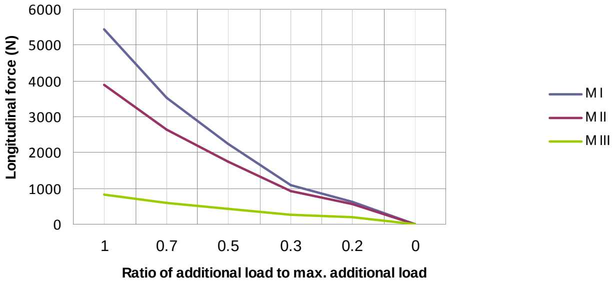

Figure 1: Longitudinal loads in systems M I,M II and M III and 120ACSR conductor.

3. CONCLUSION

The European common standard and the NNA for the design of high-voltage overhead transmission lines EN50341 should be clearer about the minimum requirements when using post-line insulation. The load factors and calculation method should be unique and well defined. For a start, we suggest checking the MDCL at unequal spans loads. One span has 50% of nominal load and other is free of load. We believe that in the future some more cases should be studied to obtain the right values. The flexible line approach can be slowly introduced and in future years included more in traditional line design.

4. REFERENCES

[1] Overhead electrical lines excceding AC 45 kV. General requirements EN 50341-1; 2001, Cenelec.

[2] Overhead electrical lines excceding AC 45 kV. NNA, EN 50341-3; 2009, Cenelec.

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Compact towers with post-line insulators designed for snowy areas

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Keywords- transmission, compact, lines, icing, overhead

I. INTRODUCTION

All over the world, getting the right of way to build new overhead transmission lines is a challenging task, often associated with an unpredictable outcome. This tends to make utilities look for alternative options that exploit the existing infrastructure. For example, the existing medium-voltage, 20-kV overhead-transmission-line routes can be upgraded to higher voltage levels. To do this, the new lines should look similar to the existing ones and the right-of-way width must be the same.

One of the technical options for narrowing the overhead line corridor is to use steel armless insulation constructions, like post-line insulators or brace-insulator assemblies. In snowy areas, rotating vee brace insulators in the case of long tension fields cannot be the right solution because of their limited stability, so post-line insulators need to be used instead. For the first time in Slovenia, compact towers with post-line insulators at the 110-kV voltage level were studied and designed. The presented overhead line route is in a country area where snow events during the winter time can occur, on average, more times per year. The post-line insulator with its base rigidly attached to the support structure should be able to withstand unbalanced loads and bending stresess inside the insulator's fiberglass core. To determine the right mechanical insulator properties, the line design should take into account the standards [1,2], the designer's experiences and, if available, the local metrological data from the line route. The main objective in the designing is to provide a safe design together with an economical solution. The design approach is presented in [3] and corresponds with the appropriate standards. In Europe, a deterministic design approach is normally used. During the design process we determine some of the undefined points regarding the use of the post-line insulators. We were forced to make analyses using different approaches to obtain more answers about the discussed topics. Variations in the major parameters, like the quantity of snow, unequal snow accretion, conductor size, insulator lengths and freedom of movement at the conductor-attaching point on the compact tower design and post-line insulator, are presented. From our design experiences some of the demands regarding standard EN 50341 are discussed.

II. BACKGROUND

The presented overhead 35-kV line is in the northwest part of Slovenia and connects the touristic resort of Kranjska Gora, known from World Cup ski competitions, with the rest of the Slovenian power network. The distribution substation will be upgraded in the future from the 35 kV to 110 kV. To achieve this goal approximately 15 km of 110 kV overhead line will need to be built. The utility has invested a lot of time, but delicate environmental conditions and the locals' objections, have prevented them from achieving their goal. An additional study in which we compared a ground cable and the possibility to upgrade the existing line with a compact overhead line to a higher voltage level, showed that from the economic point of view this would be the right solution. Long-term consumption in that area would not cover the costs for a cable. However, with an upgrade, the desired reliability level at a reasonable cost can be achieved.

The existing overhead line is a typical distribution line that consists of a combination of wooden suspension poles and angle-steel lattice-tension towers. The line is equipped with ACSR 70/12 conductors without a shield wire. The line length is 15.3 km and consists of 107 wooden poles and 25 steel towers in the present overhead-line route. The initial idea is to upgrade the existing towers and keep the route with the same width. Two options were analyzed. During the feasibility study, the first option predicted the erection of new suspension compact towers with the conductor type ACSR 95/15 and keeping all the steel-angle tension towers. Second one predicted a new line at the same tower locations with the erection of suspension and tension towers and the conductor type ACSR 240/40. A long-term power-flow study shown that the power demands in the next two to three decades will not reach the current capacity of a typical conductor at the 110 kV level ACSR 240/40 and conductors with a smaller cross-section can be used. Also, from experience we know that bigger conductors need a stronger tower, etc., and consequently larger investment costs. The conclusion was that an over-investment in stronger towers is not necessary because after that period the tower elements will be amortized. So the decision was made that for the first time in Slovenia we will use the concept of a compact tower with post-line insulators, as shown in figure 1, and move from a feasibility study to the second design stage. Some problems regarding the composite post-line insulator's mechanical properties arose during the design phase. The necessary intermediate decisions need to be accepted and we will try to present them in the following sections.

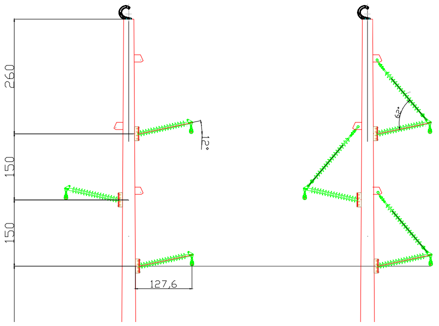

Figure 1. Compact overhead line tower head with rigid post-line insulators

III. MECHANICAL REQUIREMENTS IN THE STANDARD EN 50341

Standards for overhead power lines have existed in Slovenia for many years. In accordance with the synchronized standards in Europe, Slovenia accepted the European overhead electrical standard EN 50341-1, published in 2002. This standard consists of a main body with the general common requirements for all regional CENELEC members and gives members the option to write their individual standard body named the National Normative Aspects (NNA). With them it covers the specific country requirements. We have had SIST EN 50341-3-21 since 2009.

In the common standard EN 50341-1, in chapter 10, for the insulators it says that they should be able to withstand all the required mechanical loads, but these are not specified in detail. In chapter 4.2.10 the different load cases are presented, mainly with the idea to obtain the mechanical strength of the towers. Also, unequal loads are included to prevent mechanical tensional and longitudinal tower deformation. The given ice-load factors to be included in the deformation calculations wary from 0.3 to 0.7. These factors are given as general recommendations. But no precise information is given with respect to unequal span loads on the insulators.

The Slovenian NNA standard tries to be more precise in chapter 10 regarding the insulators. For the suspension towers' standard, three cases need to be controlled:

- the conductor load, the additional load with reduced wind load and finally the horizontal load differences,

- the conductor load, the full wind load and finally the horizontal load differences,

- the conductor load, the additional load and finally the horizontal load differences.

A problem arose because no numerical load factors for above cases are provided to make the control. Some other countries have the same definition. To overcome these problem the designers, in first design iteration, usually take the load cases given in chapter NNA 4.3.10. These are primarily intended for load checks on the towers and foundations. In the Slovenian NNA load case named 'J' the horizontal force is reduced to 50% of the nominal force on one conductor on one side of the tower. Using this case the stability of the torsional tower is checked. In load case 'K' a 20 % reduced horizontal force is applied for all conductors on one side of the tower. In this way the longitudinal stability is checked, simulating unequal additional loads on the tower. As we will discuss later, these reductions are not good in the case of post-line insulators.

We believe that previous tension force reductions are primary developed from knowledge obtained from classical suspension strings. These are able to move in the longitudinal direction. At the 110 kV level the string insulator length is 1.6 to 2m and that at case allowable longitudinal insulator movement can be assumed as free movement and only tension force is in insulator.

The post-line insulator's movement can be 0 m if the conductor is connected directly to the suspension clamp at a height in the range of 10 cm. These forces act practically directly onto the insulator's end and act to bend the post-line insulator. The mechanical strength of the post-line insulator should be able to withstand all the forces. The first calculation showed only very limited possibilities for the use of a post-line insulation solution. However, we know that in the USA this solution is often used, so we will try to get answer about where the design differences are. To get additional information about the loads different approaches to the calculation were made and compared.

IV. INSULATORS AND CALCULATION MODEL

A. *Post line insulators*

Post-line insulators are rated according to their maximum design cantilever load (MDCL). The bending moment corresponds to the combination of the loads on the overhead line. The MDCL depends on the mechanical insulator's properties – mainly the core radius and the length. The allowable forces are given in load diagrams, as presented in figure 2. The example figure presents a post-line insulator with a 63.5 mm diameter, a length of 1.25m and a 12° inclination, measured from the horizontal plane. If we assume that we have a longitudinal load, the allowable combination of vertical and transversal forces is given by the area under the longitudinal force curve. Two different transversal forces on the insulator should be taken into account, i.e., the compression and the tension.

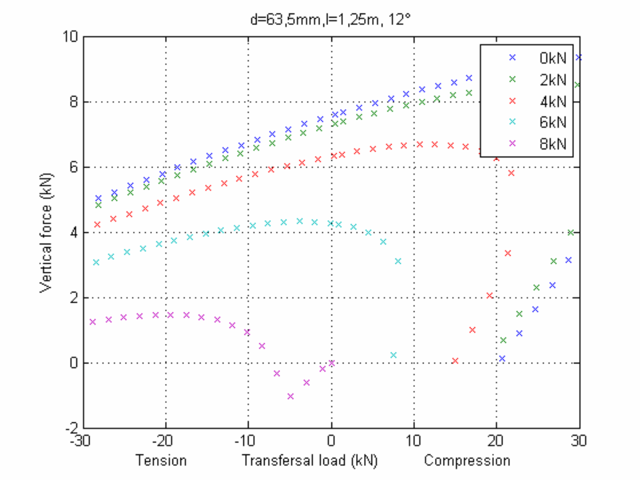

Figure 2. Sample of the post-line insulator loading diagram

In the design process, real forces on the insulator are compared with the allowable ones. Our next task is to determine the loads on the insulators and check their mechanical strength. The main influences are from the longitudinal force. We can say that the primary sources of the longitudinal forces are the unequal loads, mostly induced by snow shedding. To determine their values we made a static calculation using the following two approaches.

B. *Tension-field model*

To determine the worst snow-accretion case we introduce an overhead tension field with three equal spans, as presented in figure 3. Their span length is 170 m. Different conductor types were analyzed. By varying the additional loads in spans in four combinations, marked as Case A-D, we believe from the longitudinal loads that Case B is the most mechanically problematic.

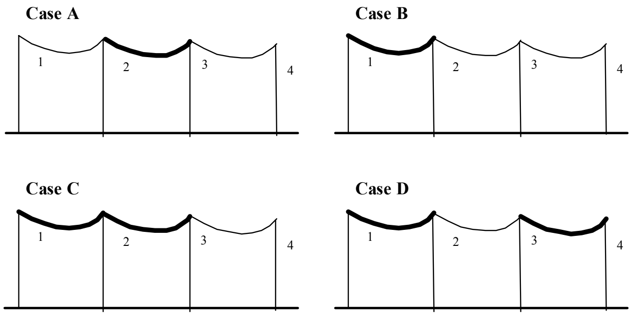

Figure 3. Load cases in three spans tension field.

Our goal is to present the difference between the longitudinal forces obtained from different traditional and flexible static calculation approaches. In the tension-field model for suspension towers, three different input data were given, i.e., M I, M II and M III, for the same presented line.

First, we calculated the forces, taking into account the conductors and the suspension clamp attached to the rigid post insulators. The suspension clamp can move in a longitudinal direction, as shown in figure 4 (left). The case M I covers the common standard EN504341 and it is a traditional approach to design. The second approach introduces to the calculation a flexible transmission line. This means we are taking into account structures bending under different loads that are acting on the structure. Two cases are important in the design. The first one is a semi-flexible line where only the insulator can bend. This is the case M II, using rigid steel-lattice towers. The case is illustrated in figure 4 (middle). The flexible line in figure 4 (right), named M III, can be imagined as steel poles, where the bending of the pole is clearly evident.

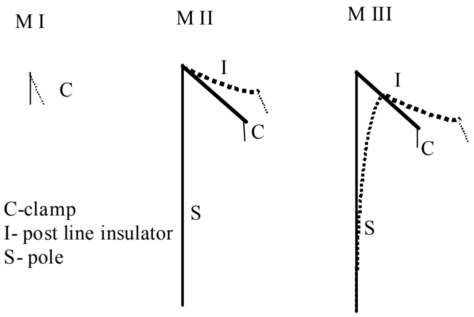

Figure 4. Overhead-line calculation approaches including structure bending

All the calculations were made with SAPS computer software for the analyses and the design of the transmission-line structures.

V. RESULTS

A. *Traditional approach*

To get information about the force values at the attachment points, the three standard-size conductors in the presented tension field in figure 2, case B, were analyzed. In Slovenia the additional load on the conductors is calculated as per equation $g = k\,1{,}8\sqrt{d}$, where d is the conductor's diameter given in mm, and k is a load parameter. This is determined by NNA and can be 1, 1.6, 2.5 or more. The task of determining the parameter k's value belongs to the line designer, who makes a decision based on the available metrological data. In table I the loads for different load parameters and conductor diameters are presented.

TABLE I. ADDITIONAL LOADS ACCORDING TO NNA

k	95/15 ACSR	120/20 ACSR	240/40 ACSR
	(N/m)	*(N/m)*	*(N/m)*
1.0	6.6	6.85	8.4
1.6	10.6	10.9	13.4
2.5	16.6	17.1	21
Conductor diameter (mm)	13.6	14.5	21.8

The conductors' mechanical horizontal sagging forces used in the calculation are 3370N, 5380N and 17630N at temperature -20°C. These are typical values that give mechanical conductor stress 90N/mm^2 at a temperature of -5°C and additional 1.6 load factor. In figure 5 the longitudinal forces are presented, based on table I. From the figure we can conclude that thinner conductors have a higher longitudinal force. The reason probably lies in the conductor's mass. The higher is the mass the more positive are the equilibrium forces acting in the longitudinal direction. Taking into account figure 2, we can conclude that using a post-line insulator can be limited by a higher additional load factor.

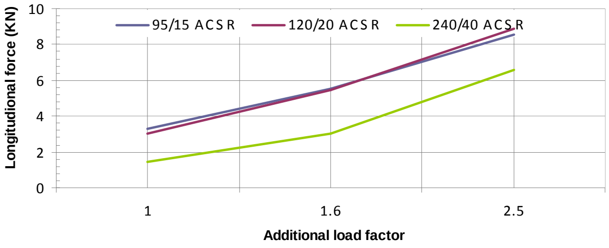

Figure 5. Longitudinal load for different conductors (M I).

To simulate more realistic terrain and determine the tower's gravity span influence on the vertical and longitudinal forces, we analyzed a line with a changing gravity span as for structure No 2 in figure 3. The used gravity spans were 170m, 250m, and 350m. The average span in the tension field stayed the same, i.e., 170m long.

At the same time we introduced the load ratio. It is given as an additional load on the conductor, derived by the maximum additional load. For example, a ratio of 0.7 means that the additional load in Case B is 70% of the value given in table I. In further calculations the maximum load parameter was taken as1.6. As we expected, the vertical load on the tower increased (figure 6 upper) while the longitudinal loads did not vary much with the gravitational load. Figure 6 (lower) shows us why the choice of load-ratio value is important. Overestimated values mean a limitation on using the insulation and increasing the investment costs because more robust overhead-line elements must be used.

In our case, at an additional load ratio of 1 the load force is near 6kN and decreases nonlinearly with a smaller ratio. Again, taking into account the loading diagram given in figure 2, we move through the load curves, which determine the mechanical post-line insulator. The lower is the longitudinal load, and the higher is the vertical and transversal force combination that ca can be applied to the insulator.

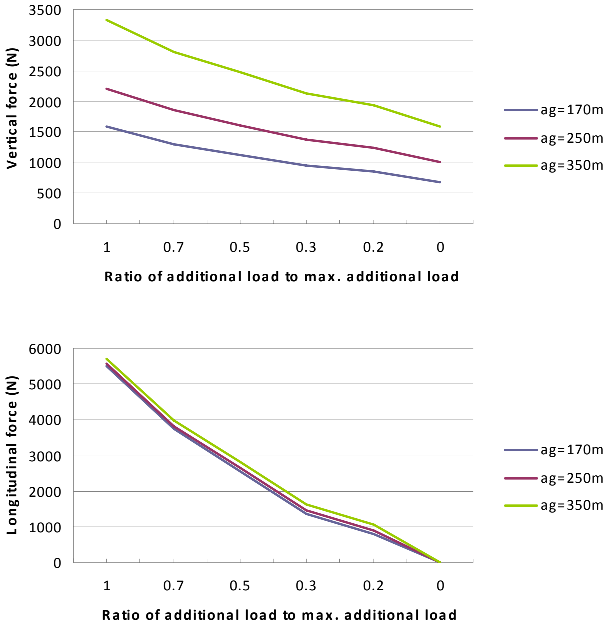

Figure 6. Vertical loads (upper) and longitudinal loads (lower) for the case of MI and different tower gravity spans

So, knowledge about the longitudinal loads is very important for compact overhead lines with post-line insulation. To decrease these forces, from theory we know that the span conductor should be increased. However, because of stability problems we do not use rotating assemblies and we are focused on rigid insulator joint to the tower body. Our next step was to get information about how the conductor type acts on the longitudinal force at different load ratios. The calculation results are given in figure 7. From the point of the longitudinal loads the conductors with a higher self-weight have an advantage over the thinner and lighter conductors. For the maximum load in case B the difference regarding the conductor types can reach 2.4kN.

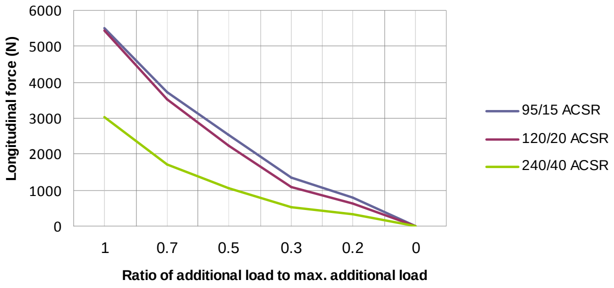

Figure 7. Longitudinal loads in the case MI and for different conductor types.

In our studied overhead line the tension towers remain untouched. Originally, these towers were predicted to be of conductors type 150/25 ACSR. So we were forced to use thinner conductors in the solution. During the first iteration to reduce the longitudinal loads, suspension clamps with different suspension lengths were simulated. By extending the clamp length a reduction in the longitudinal loads was achieved, as shown in table II. Unfortunately, with a long clamp, we lost the compactness of the tower and we believe that this can be a standard design solution.

TABLE II. CLAMP LENGTH AND LONGITUDINAL LOADS

Clamp length	**Longitudinal force**
(cm)	***(N)***
10	5.4
15	4.4
20	3.6
25	2.8
30	2.3

At this point we can say that the standard EN corresponds well to fact that most of the insulation in the European network uses suspension insulator strings. At the 110 kV level the minimum insulator string length is approximately 1.6m. This length contributes to a lowering of the longitudinal loads in conductor-shedding scenarios, given in EN to verify the tower structures. As the insulator length in the post-line isolation is a suspension clamp with an approximately length of 0.1 m the calculated longitudinal forces increase very quickly over MDCL. The traditional approach to design lines with compact post-line insulators given by designers in Europe means very limited options and it should be revised. The mechanical strength comes from the classical static sag and force approach, which demands mechanically very strong elements, i.e., insulators with a larger core diameter. In the end, this means large investment costs.

B. *Flexible-line approach*

To partially overcome this limitation we introduced and studied forces as a flexible transmission lines design approach. In general, these lines act as one connected system in the tension field. In our model, presented in figure 3, we take two bending suspension steel pole towers that are 13m high, with an inertia moment of 1.2 10-8 mm4. The post-line insulator was fixed on the top of the tower. The insulator was 1.2 m long, with a 63.5 mm core diameter and an inertia moment of 79.7 cm^4 . The tension field in the model was limited by the rigid, 13-m-high tension towers.

The two cases were studied. The first case, M II, takes into account that only the post line is able to bend and is fixed on a rigid structure, as shown in figure 3 (middle). The second case, called M III, takes into account the supports, the insulators and the conductor as a complex interconnected structure able to bend and move in all directions and present a complex static nonlinear analyses under loads. Through bending, the location of the conductors' attachments move and new equilibrium forces are given for this new state. The longitudinal forces calculated from the flexible line are much lower than with the traditional approach. If we take into account in the calculation that only the post-line insulator bends, the longitudinal force decreases by 20% at the start, as shown in figure 8. In a flexible line it can be up to 5 times lower. So the conclusion is that the standard approach gives overestimated mechanical structures with high mechanical reserves.

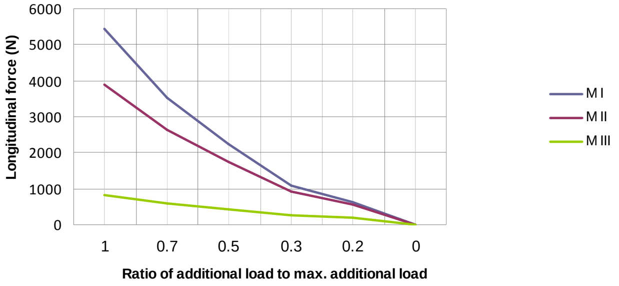

Figure 8. Longitudinal loads in systems M I,M II and M III and 120ACSR conductor.

VI. DISCUSSION

Poorly defined load factors in the NNA standards, which have to be taken into account in the design stage, can be very confusing to the line designer. Also, they can be a limiting factor when using a new material in practice. Today, the traditional approach must still be respected. That means that the minimum standard is prescribed and the designer should satisfy the minimum requirements and show them in the design project.

In our case the designer will, in the first approximation, take the longitudinal loads as 50% of the conductor tension force. This means the longitudinal loads can be from 4-13 kN, depending on the conductor type. This also means that the post-line insulator cannot sustain the mechanical load. In the next iteration the designer will study how to reduce these loads. That can be achieved through calculating the longitudinal loads at different load ratios as the common standard predicts. Let us assume that the load ratio is 50%. Now, the mechanical forces are reduced to 2kN. If we want to use a cost-effective post-line insulator with a 63.5 mm diameter the presented values mean being on the mechanical limit. Again, the designer cannot be totally satisfied. In the region without any additional load these problems will not be so exposed as in snowy areas. In the final result, some unconventional solutions are then taken when using post-line insulators in the traditional approach.

Taking an overhead line as a flexible line in a calculation, the longitudinal forces can be 6 times lower than with the traditional approach. In our case the longitudinal load is reduced to 0.6kN. In the compact tower we used bendable steel poles so the tower top's movement in the longitudinal direction can reach around 0.3 m for a 13 m pole. In this approach, no or only few mechanical limitations are given.

VII. CONCLUSION

The European common standard and the NNA for the design of high-voltage overhead transmission lines EN50341 should be clearer about the minimum requirements when using post-line insulation. The load factors and calculation method should be unique and well defined. For a start, we suggest checking the MDCL at unequal spans loads. One span has 50% of nominal load and other is free of load. We believe that in the future some more cases should be studied to obtain the right values. The flexible line approach can be slowly introduced and in future years included more in traditional line design.

REFERENCES

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