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A comparison of two practical approaches to preventing inter-span phase contacts during snow shedding on the same 110-kV overhead line

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ABSTRACT

Field experiences in a few particular areas of Slovenia have shown that during periods of snowfall some overhead lines are randomly exposed to short-circuit events between conductors that lie in a vertical disposition. This paper presents two practical approaches to reducing the probability of these inter-span contacts that result from the snow shedding. Both approaches refer to the same overhead line, so that a direct comparison can be made. The first overhead-line circuit is equipped with phase spacers; the second one is equipped with V strings. Up to now, both approaches have served well in practice. In this paper a transmission line is presented, and the differences between the two approaches with regard to the design parameters are given. The advantages and disadvantages of both approaches are summarized.

1. Introduction

This paper presents and compares two practical approaches to reducing the probability of inter-span contacts caused by snow shedding on the same double-circuit overhead transmission line. The project was realized in Slovenia. On the same double-circuit overhead line, the first conductor circuit was equipped with phase-to-phase spacers. The second conductor circuit was rearranged and equipped with ‘vi’ (V) insulator strings. This was the basis for our study of the advantages and disadvantages of both approaches to preventing inter-span phase contacts caused by snowfall events.

The majority of the Slovenian 110-kV grid consists of double-circuit lines with a vertical configuration of cross-arms. Most of the upper and lower cross-arms of the towers are of the same length, while the central one is longer. Field experiences in a few particular areas of Slovenia have shown that during periods of snowfall these overhead-line types are randomly exposed to short-circuit events between the upper and lower conductors. The implementation of higher standards for the supply of reliable electrical energy to local users has made the utility decide to take steps to prevent the occurrence of such events. So, in 2001 the utility assembled one 20-kV line circuit composed of ACSR150/25 circuit conductors with phase spacers. The presented overhead line was originally built in 1985 using double 110-kV overhead steel lattice towers, but since then it has been operating a circuit at the 35-kV and 20-kV levels.

In 2006, the utility decided to prepare a second 35-kV circuit to operate at the 110-kV level. The predicted scope of the work encompassed the replacement of all the insulator strings with new ones and the replacement of the existing ACSR150/25 conductors with stronger ACSR240/40 versions. However, a question arose, as to whether the phase spacers were required or not. Based on the positive experiences of a neighboring utility, with regard to tower-head modifications, the advantage of easier line maintenance in the future helped the utility to come to a decision to change the classical insulator string on the upper cross-arm for a ‘V’ string made from composite insulators, rather than use phase spacers. In the same year the project was realized and, until now, the overhead line has operated well in practice. In this way we were given the opportunity to compare both approaches on the same line and note the relevant advantages and disadvantages.

In the first part of the paper we present the basic overhead-line technical data, give a description of the line route and describe the climatic conditions in that part of Slovenia. In the next section we present the problem arising from the tower's configuration and the principle of avoiding unwanted events on the line. Two approaches are presented. First, we discuss the phase spacers, and then we look at the V strings. The results of our comparative study of the differences are outlined in order to manage the designer's point of view on the relevant approaches. We then briefly present the influence of the different conductor type on the foreseen sags during the accretions and shedding of the snow. Finally, some of the advantages and disadvantages are noted, and a cost estimation for both approaches is presented.

When the project started, one of the utility's demands was that the overhead line should operate continuously with two different conductor types and two different insulator-equipment types. As part of the paper we describe how to reduce the possibility of short-circuit events using both approaches.

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2. Presentation of the overhead line

2.1. Basic technical data for the overhead line

The overhead line, with a length of 18 km, was originally built with steel lattice towers. The total number of towers is 75, out of which there are 48 suspension towers and 27 tension towers. The route follows a narrow valley, so that the line is broken up into short tension fields. The original insulation includes porcelain cap tape insulators, while the conductors are of the aluminum-conductors steel-reinforced (ACSR) 150/25 type. At the time when the line was built, such a conductor energy capacity was sufficient to cover the consumption in that part of the supply area. According to the national legislation, the overhead transmission line is statically and electrically designed for a uniform normal load on the conductors. As with most cases in European countries, the tower-head geometry is determined by the required mid-span distance *C* using the equation$C = q\sqrt{f + li} + D$, where *f* is the conductor sag, the length *li* is the insulator string and *D* is the minimum electrical clearance to the grounded objects. The parameter *q* depends on the conductor's mutual layout in space; this must be calculated separately. For the conductors that lie in a horizontal, inclined or vertical plane, the parameters are 6.1, 7.3, and 14.6, respectively, for the ACSR 240/40 conductor. It is clear that the required mid-span distance in the vertical disposition is 2.4 times higher than the required horizontal distance. Also, the mid-span distance depends on the conductor sag. This sag is determined through the nominal load on the conductors in order to achieve the required design static force in the conductor's attachments. The load is calculated as per equation$g = k1,8\sqrt{d}$, where *d* is the conductor's diameter given in mm, and *k* is a load parameter that is determined by national legislation and can be 1, 1.6, 2.5 or more. The task to determine the parameter *k*'s value rests with the line designer, who makes a decision based on the available metrological data. The observed line is divided into more sections, with *k* equal to 1.6 and 2.5, which gives longitudinal additional loads on the conductors of 1.34 N/m and 2.10 N/m, respectively. The conductor's final stress in the conductor attachments is 80 N/mm^2 in both cases. According to a national standard, such a stress is achieved at the maximum nominal load on the conductors at a temperature of −5 °C. In order to obtain the allowed sags that determine the minimum distances between the conductors, towers with heads of the ‘barrel’ type are observed to have an average line span of 249 m. Their dimensions are presented in Fig. 1.

It should be noted that the suspension towers have upper and lower cross-arms of the same length. As reported in previous papers (Zemljaric, 2004), problems can occur with this type of suspension tower. However, it is interesting that short circuits were, in most cases, reported mainly for these tower types with dimensions of 2.5 m, 3.3 m and 2.5 m. On similar tower types, with some shorter cross-arms (2.1 m, 2.9 m, and 2.1 m), short-circuit events are rarely reported. The reason probably lies in the lower average wind speed and the different average span between the towers.

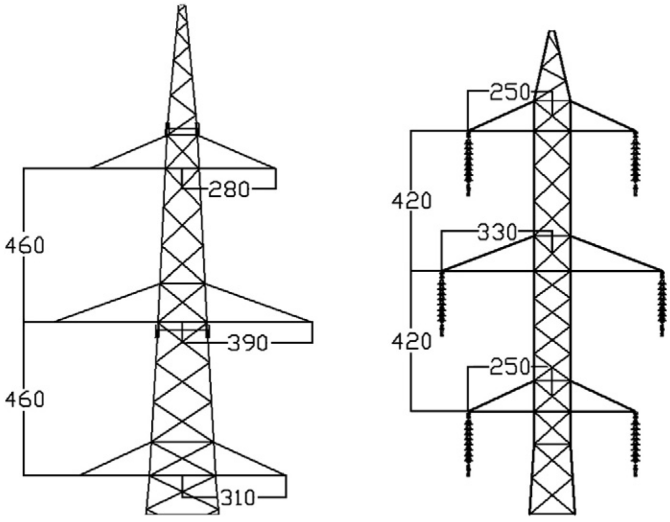

Fig. 1. Typical tension (left) and suspension towers (right).

2.2. Climatological conditions

Slovenia is a European country located to the south of Austria and to the east of Italy. The presented line route runs through the Sava Bohinjka valley, between two popular tourist resorts, Bled and Bohinj, which lie around 50 km north-west of the Slovenian capital, Ljubljana, Fig. 2.

The altitude of the line is from 490 m to 500 m, but the surrounding hills, with very steep slopes, reach an altitude of up to 1000 m. Most of the valley is narrow, so that all the major infrastructure objects like roads, railway lines and the overhead line, share their right of way and sometimes cross each other.

In summer, the average temperature in the region is 12 °C. In winter, in January, the average temperatures are −2 °C to 0 °C, see Fig. 3 (lower). These winter temperatures are close to the typical temperatures, i.e., 0 °C to +2 °C, when wet snow can be expected. There are approximately 6 to 8 snowy days per year, when the height of the new snow exceeds 10 cm, see Fig. 3 (upper).

The days when the snow falls in a particular area are given in Table 1. The climatological data were obtained from ARSO (2009c). Data were collected in weather stations laying near line route, about 5 km north-east in Lesce and 4 km west in Bohinska Cesnjica. The number of days when a short-circuit event can occur varies from year to year, and such days are possible during the period from October to March.

3. Problem description

3.1. Line history

In the winter of 1999, the distribution utility for the line being considered registered several short-circuit events. Unfortunately, the event locations on the line were unknown. Analyses of the line distances between the protective relays and the phase disposition on the line could not be made because the line operated at medium voltage without a protective relay. This was the first time in Slovenia that the problem of a short circuit due to snow was recorded. We believe that the reason lies in a higher standard of electrical energy supply to consumers and the very large number of events in 1999. Previously, no such large number of events was recorded. In November 1999, the utility recorded 95 events within 2 days, as shown in Table 2. It is interesting to note that the number of events is different from circuit to circuit on the same line.

In order to prevent similar problems in the future and increase the reliability of the power supply, the utility decided to take the necessary measures to achieve this goal. After a study of such events (McClure et al., 2001; Zemljaric, 2004) it became clear that short-circuit events were possible, taking into consideration a dynamic conductor behavior. In order to prevent such events the utility decided to use phase spacers. In 2001, only the 20-kV line, i.e., the more important distribution system for line conductors, was fitted with phase spacers. Since the short-circuit locations were unknown, phase spacers were used on the whole line. Before installation, all the ground clearances were checked. As expected, they were a little lower than the original, but within a regular technical normative. Since then, the line has been operating without problems.

In 2003, a second utility registered short-circuit events on a similar overhead-line type, but for a totally different location in Slovenia. At