Response to Reviewers’ Comments

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Title: Prospect of Voltage Uprating of a Conservatively Designed EHV Transmission Line  
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The authors take this opportunity to thank and express our sincere gratitude to the reviewers for sparing time to review the manuscript and give their thoughtful comments and suggestions. We have carefully considered the reviewers’ comments and made our utmost effort to incorporate the suggestions made to improve the quality of the paper. After addressing the reviewers’ comments, we believe the manuscript is now in excellent form and for this the reviewers deserve credit.

The changes made, in the manuscript, have been shown in blue colour and the manuscript has been reformatted according to the journal’s formatting guidelines for revised submissions. The following remarks highlight the changes made in response to reviewers’ comments.

**REVIEWER #1 COMMENTS:**

**COMMENT#1**

*This work deals with voltage upgrading of an existing 500 kV line to the 735 kV level. This a subject that has been treated extensively in literature; thus, the contribution of this work is not clear.*

**RESPONSE**:

The motivation and contribution of the presented work is explained in the fifth paragraph of Section 1 (Introduction). Though it is indisputable that the subject of voltage uprating in itself is not new, this work presents the first-ever reported analysis of the voltage uprating of a 500-kV double-circuit transmission line to 735-kV operation, by an electric utility. The previous maximum voltage uprating, found in literature, deals with a 230-kV double-circuit line which was upgraded to a 500-kV single circuit line [7].

A lot of effort has been put in to present an original, comprehensive and representative analysis. For instance, meticulous simulations were performed in PSCAD for statistical switching overvoltages. Field measurements for thunderstorms and tower footing resistances were made for the evaluation of lightning trip-out rates and extensive laboratory artificial pollution tests were conducted for characterization of insulation pollution performance.

It is intended that the experience and insights provided in this paper will instigate and guide similar investigations by industry practitioners and EHV grid operators around the world.

**COMMENT#2**

*Section II*

*Please provide information on how the corona inception gradient of the bundled conductors was estimated.*

**RESPONSE**

Section 2

The corona inception gradient of the *conductor bundle* was estimated by calculating the inception gradient for a *single conductor* in the bundle [R1] using the Peek empirical formula [R2]. Whereas, the bundle sub-conductor surface gradients were computed using the Maxwell Potential Coefficient Method [R3]. These comments have been introduced in the third paragraph of Section 2 (page 5) together with Table 1 summarizing the results of conductor corona inception gradient and average-maximum bundle gradient.

[R1] S. Bisnath, A. C. Britten, D. H. Cretchley, D. Muftic, T. Pillay, R. Vajeth, “The Planning, Design & Construction of Overhead Power Lines”, South Africa: Crown Publications cc, 2005.

[R2] M. P. Sarma, “Corona Performance of High-Voltage Transmission Lines”, U.K., London: Research Studies, 2000.

[R3] IEEE Radio Noise Working Group, "A Survey of Methods for Calculating Transmission Line Conductor Surface Voltage Gradients", IEEE Transactions on Power Apparatus and Systems, vol. PAS-98, no. 6, pp. 1996-2014, Nov. 1979.

**COMMENT#3**

*Section III.A*

*Provide information on the selection of the rated voltage of the surge arresters.*

**RESPONSE:**

Section 3.1

Information concerning the selection of the rated voltage of surge arresters has been incorporated in the relevant Section 3.1.5 (page 9).

**COMMENT#4**

*Section III.B*

*Please explain why the crest value of the nominal phase-to-ground uprated voltage is 600 kV.*

**RESPONSE:**

Section 3.2

The root mean square (*rms*) value of nominal *phase-to-phase* uprated voltage is 735 kV and the *crest* value of nominal *phase-to-ground* uprated voltage given by the expression is equal to 600 kV. The same expression has been included in the text of second paragraph of Section 3.2 (page 11) for clarity.

**COMMENT#5**

*Section III.C*

*Please provide the value of the critical CFO used for calculating the risk of failure of the line. Clarify if this value refers to line air clearances or insulator strings. The assumed standard deviation of 5% normally refers to air clearances and not to the case of line insulator strings; for the latter IEC 60071 series suggest a value of 7% or higher. Please provide the appropriate justifications for selecting these values (both CFO and <sigma>).*

**RESPONSE:**

Section 3.3

It is clarified that, on the original line both the minimum phase-ground tower strike distance and the dry arcing distance along the insulator string (with 23 discs) is equal to 4.1 m. However, since it is recommended in Section 5 to increase the number of discs in the insulator strings to 29 (by replacing the two 534 mm extension links with 6 additional discs), this increases the dry arcing distance of the insulator string (on the uprated line) to approximately 5.1 m. As a result, the tower strike distance of 4.1 m becomes the determinant in defining the line insulation strength. The critical flashover voltage (CFO) used in calculations for risk of line insulation failure therefore refers to the minimum tower air clearance with corresponding standard deviation (σf/CFO) of 5% as recommended in [7, 26].

In this work, the expression proposed by Gallet [25] for air-gap insulation strength under positive polarity switching impulse with critical wave front was used to calculate the applicable CFO for the tower strike distance of 4.1 m.

Information and justifications with regards to the applicable value of CFO and σf/CFO used in the evaluation of line risk of failure under switching surges has been incorporated in the second paragraph of Section 2 (page 4) and second paragraph of Section 3.3 (page 12).

**COMMENT#6**

*Section IV; Table VII*

*Title of table should be amended; this table shows thunderstorm days per year.*

**RESPONSE:**

Section 4; Table 8 (revised serial number)

Complied and amended (page 14).

**COMMENT#7**

*Section IV; NL*

*The flash collection rate of the line NL (268.48 flashes per 100 km.yr) seems relatively high to this reviewer; it must have been estimated based on Eriksson's empirical expression. Please provide information on how exactly NL was estimated.*

**RESPONSE:**

Section 4; NL

The reviewer is absolutely correct: Eriksson’s empirical expression [27] has been used to estimate the number of lightning flashes terminating on the line (NL).

The second paragraph of Section 4 (page 14) has been amended to make this clearer and to provide information on the estimation of NL.

**COMMENT#8**

*Section IV*

*Please clarify if the negative and positive CFO gradients refer to air clearances or to insulator strings. Please also consider that for fast-front surges IEC 60071 series suggest a standard deviation of 3% for air clearances.*

**RESPONSE:**

Section 4

As clarified in response to Comment#5, the specified CFO gradients correspond to the tower air-gap clearance. This has now been elaborated in the second paragraph of Section 2 (page 4) and third paragraph of Section 4 (page 15).

Furthermore, it has been indicated in the third paragraph of Section 4 (page 14) that, in the work presented by the authors, due to much smaller dispersion and for practical purposes, the lightning impulse (LI) strength has been considered as a single value (i.e. the CFO) and a probability distribution for the LI strength has not been employed. The same approach has been used by Hileman [6].

**COMMENT#9**

*Section IV.A*

*It is impossible one to check the validity of your calculations on SFFOR. This is because the values of Ic and Im as well as information on f(I) have not been provided. Please elaborate including in the text the necessary information.*

*Fig. 4; was the shielding angle varied with the height of the line in these calculations, if yes how exactly?*

*Correct numbering of ref. [28]; [please write [29]*

**RESPONSE:**

Section 4.1

Information regarding the statistical distribution of crest current (IF) of first stroke of the negative downward flash, denoted by *f(I)*, has been included in the third paragraph of Section 4 (page 14) and in Table 9.

Furthermore, values of currents Ic and Imhave been provided in the second paragraph of Section 4.1 (page 15).

In Fig. 4, the shielding angle was **not** varied with the height of line structures (this is why we observe an increase in the SFFOR, since a smaller shielding angle would be required to give the same SFFOR for a tower with more height). The text concerning this has been rephrased in the second paragraph of Section 4.1 (page 15) to avoid any ambiguity.

The text referring to [28] (now with revised number [31] on page 15) has been corrected by attributing the reference to Brown-Whitehead.

**COMMENT#10**

*Section IV.B*

*It is impossible one to check the validity of your calculations on BFR. This is because the value of I0 as well as information on f(I) have not been provided. Please elaborate including in the text the necessary information.*

*How exactly the effect of attenuation by corona was considered in (3)?*

*It is not clear to this reviewer why an upgraded line (735 kV) utilizing insulator strings with higher BIL as compared with the reference line of the same geometry (500 kV) is associated with bigger BFR (0.797 as compared with 0.445 flashovers per 100 km.yr). Please explain.*

**RESPONSE:**

Section 4.2

Information regarding the statistical distribution of crest current (IF) of first stroke of the negative downward flash, denoted by *f(I)*, has been included in the third paragraph of Section 4 (page 14) and in Table 9.

Furthermore, values for the critical current (I0) corresponding to each line section have been provided in Table 10.

When a lightning stroke terminates on the line, a high magnitude voltage appears on the overhead ground wires producing corona. The effect of corona is to decrease the surge impedance of the ground wires which in turn increases the coupling factor (Cou) between the ground wires and phase conductors. Since the critical current (I0) is inversely proportional to the factor (1 – Cou) [6], an increase in the coupling factor (Cou) results in an increase in the current I0 which according to Eq. (5) decreases (attenuates) the line BFR.

As clarified before, although the uprated line (735 kV) is provided with insulator strings of higher BIL, both the uprated and the reference line (500 kV) have the same limiting tower strike distance of 4.1 m which determines the governing insulation strength of the line (and this was used in lightning flashover calculations). The fact that both the uprated and the reference line have the same tower air-gap clearance coupled with the **effect of uprated power frequency voltage on the phase** **conductor** (which depending on the instant in time) causes an increased surge voltage across the insulation and thus results in a higher BFR for the uprated line.

Calculations for line BFR were made including the effects of corona and power frequency voltage using the computer program BFR99 which is an implementation of CIGRE’s iterative procedure [32] for estimating the back flashover performance of transmission lines.

These comments have been introduced in Section 4.2 (pages 16 and 17).

**COMMENT#11**

*Section V*

*It is not clear if Fig. 6 refers to actual test results. Please provide additional information on the experimental set-up. Please also describe the procedure for estimating the number of required disks of a string based on tests on a single disk.*

**RESPONSE:**

Section 5

The curve of Fig. 6 (now revised Fig. 7) refers to actual results of the artificial pollution tests [R4] performed on insulator samples (identical to the ones installed on the studied line) with up-and-down method [R5] in the laboratory. Text has been added in the fourth paragraph of Section 5 (page 19) to make this more evident.

Additional information on experimental procedure and set-up has also been included in the fourth paragraph of Section 5 (page 19).

Procedure for determining the number of required insulator discs in the string has now been described in the sixth and seventh paragraph of Section 5 (page 21) along with figures 8 and 9.

[R4] Artificial pollution tests on high-voltage ceramic and glass insulators to be used on a.c. systems, IEC Standard 60507, 2013.

[R5] IEEE Standard for High-Voltage Testing Techniques, IEEE Standard 4, 2013.

**REVIEWER #2 COMMENTS:**

**COMMENT#1**

*There are just a few recommendations:*

*1. In this paper, the results of the basic analysis of tower OLFs derived from examination of extreme wind, failure containment and construction & maintenance load cases with quad ACSR bunting conductors, the switching overvoltage, lightning performance, insulator pollution flashover, compliance with statutory clearance, exposure to electric and magnetic fields were shown. Could the author list the detail of each research parts as appendix?*

*2. In order to help understanding the basic design of this uprating work, it is better to list the description of the transmission line being uprated in one table, included the original and the uprating data.*

**RESPONSE**:

The authors feel that adequate details and information for each part of research has already been included in the text of relevant sections. Table (A.1) summarizing data for the original and uprated transmission line has been included in Appendix A (page 6 and 28).