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Experimental and Simulation Study of Partial Arc Activities on Post Insulators with Booster Sheds under Heavy Icing Conditions

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SUMMARY

The reliability of power systems is a major challenge in cold climate regions. Heavy ice or snow accumulation on high voltage insulators can lead to considerable reduction of their flashover voltage, sometimes resulting in flashover failures and power outages.

Many approaches have been proposed to improve the reliability of ice-covered insulators so far. The effectiveness of these methods depends on ice severity. Field experience demonstrates that post station insulators are more exposed to flashover failures than line insulators under the same icing conditions. This is mainly because of stronger electrical stresses, as well as smaller shed spacing causing ice bridging for a smaller quantity of ice accretion as compared to line insulators. To prevent ice bridging of insulator sheds, some methods can be applied like using booster sheds (BSs), creepage extenders, larger shed-to-shed distance profiles, or semiconducting glaze covers. The present study focuses on using BSs as a way to reduce flashover voltage of post station insulators. A booster shed (BS) is a C-shaped insulation piece with large diameter generally made of high quality insulating materials.

The complex mechanism of BS function is different in rain and icing conditions. Regarding icing conditions, an improved theory concerning the BS effects was proposed by the authors. This theory was developed using computer-aided simulations and BS experimental tests at CIGELE Laboratories. In short, it was demonstrated that the BS major effect is the formation of air gaps and that their minor effect is increasing the dry arcing distance. Moreover, a new indicator, the total ice-free leakage distance ($IFLD_{tot}$), was introduced to quantify the BS effects. $IFLD_{tot}$ can account for the increase in flashover voltage much better than the two other indicators (dry arcing distance and total length of the air gaps). However, more studies are necessary to explain the complex BS effects under icing conditions.

This paper presents a new investigation, using analysis of partial arc activities, for evaluating the flashover performance of EHV post station insulators equipped with BSs. Novel discussions on partial arc characteristics are presented by using observations recorded by cameras. Furthermore, in order to calculate BS effects on potential distributions during the flashover process of the 4-, 5-, and 6-BS configurations, new axisymmetric simulations of partial arcs are presented. The simulation results, using COMSOL Multiphysics™, show a redistribution of voltage drops along the air gaps after the formation of partial arcs along the first air gap. This voltage drop redistribution results in the development of partial arcs along the other air gaps. This phenomenon can explain the appearance of flashovers based on voltage drops in a new point of view. The experimental and simulation results of this study can be used to propose better designs for practical application of booster sheds.

KEYWORDS

Booster Shed (BS), EHV post insulator, flashover, potential field distribution, FASTCAM.

1 INTRODUCTION

A main challenge in many cold climate regions is increasing the reliability of power systems. Heavy snow or ice accumulation on insulators can lead to a significant reduction in their flashover voltage which can fall under their service voltage, causing flashovers and power outages [1]–[3].

Many publications have proposed various methods to improve the reliability of iced insulators [4]–[7]. The helpfulness of the methods differs in relation to ice severity. Ice severity can be categorized as heavy (>10-mm), moderate (6-10 mm), light (1-6 mm), and very light (<1 mm) where the numbers stand for radial ice accumulation thickness measured on a rotating cylinder [3], [8], [9]. In fact, this categorization is based on full bridging of cap-and-pin insulators at 10 mm and full bridging of standard post insulators at 6 mm.

According to field observations, EHV post station insulators are more susceptible to flashovers than line insulators under icing conditions [8], [10]. Nevertheless, as the minority of publications deal with iced post insulators, more studies are necessary in this area. The reason why ice bridging happens sooner for post insulators is mainly because of their smaller shed spacing resulting in a greater withstand voltage decrease for post insulators than for line insulators under the same icing conditions. For delaying ice-bridging of the insulator sheds, some methods are proposed; for example, using profiles with greater shed-to-shed distance, semiconducting glaze insulators creepage extenders, and booster sheds (BSs) [11]–[13]. The use of BSs on ice-covered post insulators is the main subject of this study.

A booster shed (BS) can be defined as a flexible C-shaped insulation material, generally made of ethylene vinyl acetate (EVA) or silicone rubber. The first BS was designed in the 1970s for improving the flashover performance of insulators under heavy wetting conditions [14]–[16]. After some years, it was applied under icing conditions as well [17]–[20]. However, the mechanisms of BS effects are different between these two weather conditions.

The inventors of the BS indicate that their effectiveness under heavy wetting conditions results from three factors: water shedding, discharge inhibition, and arc suppression [14], [21]. For icing conditions, an improved theory regarding the effects of BSs was proposed by the authors [22]. This theory was derived from experimental tests and computer-aided analysis at CIGELE laboratories [23]–[25]. In short, it was showed that the principal effect of BSs is the formation of air gaps and that their minor effect is increasing dry arcing distance. In addition, to quantify the BS effects, a new indicator, the total ice-free leakage distance ($IFLD_{tot}$), was proposed. However, as explaining the BS effects under icing conditions is complex, this theory can still be developed. Therefore, this article presents a new discussion on flashover performance of BS configurations based on simulations of partial arcs by COMSOL Multiphysics^{TM} and the analysis of BS experimental tests during flashover.

2 FACILITIES AND PROCEDURE OF THE TESTS

In the experimental tests, the BSs had an outer diameter of about 65.5 cm. The outer and inner diameters of these polymer slip-on C-shaped accessories are used to specify them dimensionally. The inner diameter is chosen to simply fit the insulator-core and the outer diameter to extend more than 100 mm away from the border of the insulator-shed.

The schematic diagram of the experimental tests is shown in Figure 1 and the icing parameters are presented in Table 1. The icing experiments were performed under melting regime (formation of water film). Actually, these icing parameters made it possible to produce glaze ice, known as the most dangerous type of ice for outdoor insulation.

The experiments were carried out in a large chamber (6m × 6m × 9m) principally designed for icing tests on full scale surge arresters, insulators, etc. The rating of the high voltage ac power transformer was 350 kV / 700 kVA. For regular video recording of partial arcs and flashover arcs, a security camera was used. Moreover, for recording the flashover paths, Fastcam SA1, an ultra high-speed camera which can record up to 675,000 frames per second, was used. Also, for recording the voltage and leakage current, a data acquisition system and the LABVIEW application software were used.

The icing test under melting regime includes four sequences as indicated by IEEE Standard 1783 [26]. These four periods are ice accretion, hardening, melting, and evaluation. During the ice accretion period, the temperature and applied voltage were -12 ºC and 285 kV. The value of 285 kV matches the typical voltage stress for the 735-kV Quebec substations. For hardening the accreted ice layers on the insulator, the applied voltage was set to zero for approximately 20 min, with the ventilation system working (Figure 1). Picture taking and measurements of the air gaps were done during this period (hardening). After that, the applied voltage was set at 285 kV, the ventilation system was turned off, and the temperature was increased to about 0° C for generating a thin water layer on the ice surfaces (melting period). Finally, during the evaluation period, the applied voltage was increased by steps of 5% (15 kV) and was set for a minimum of 15 min to distinguish a flashover or a withstand appearance. To determine the minimum flashover voltage, a minimum of 5-6 tests is required.

- **Maximum withstand voltage (V_{WS}):** the maximum level of applied voltage at which flashover does not occur for a minimum of 3 tests out of 4 under similar icing conditions [27].
- **Minimum flashover voltage (V_{MF}):** the voltage level higher by 5% than the V_{WS} at which 2 flashovers out of a maximum of 3 tests are produced [27].

The minimum flashover voltage of 300, 315, and 330 kV_{rms} were determined for the 4-, 5-, and 6-BS configurations, respectively [8]. A short video of the evaluation period of the present study can be seen on the Web [28].

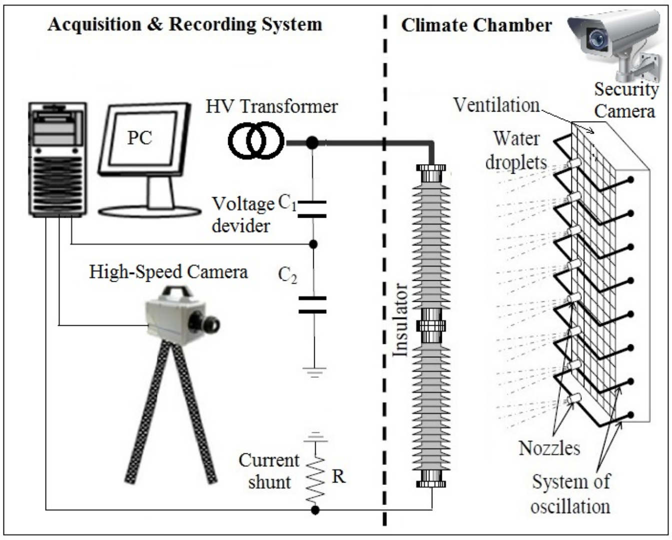

Figure 1. Schematic diagram of the test setup

Table 1. Parameters of ice accumulation

Air temperature	-12 °C
Average droplet size	80 µm
Wind speed	3.3 m/s
Freezing water conductivity at 20° C	30 µS/cm
Reference ice level on rotating cylinder	30 mm
Accretion duration	140 min
Total applied voltage	285 kV_{rms}

3 DISCUSSION ON FLASHOVER PROCESS OF BS CONFIGURATIONS

Occurrence of flashovers on ice-covered insulators with BSs depends on several factors. Electric fields have important effects on the ice formation, shape and direction of icicle growth, position and length of the air gaps along the insulator, and on the occurrence of liquid water. Other factors with significant effects on flashover occurrence are: surface pollution, rejection of ions from solid to liquid layers in the freezing and melting periods, corona space charge, ionic wind, water droplets, ice type, voltage polarity, leakage current, etc. the ice accretion period, a highly conductive layer is created on the ice surface by the rejection of impurities and ions from the applied water. In the melting and evaluation sequences, leakage current and discharge activities generate heat and more impurities which can lead to an extremely conductive water film. In presence of this highly conductive layer, a significant percentage of the applied voltage is distributed along the air gaps. If the voltage drop along an air gap is greater than the critical breakdown voltage of the air gap length, arcing activities can initiate a flashover incident. More precisely, if the voltage drop is enough to keep on the partial arcs for a while, they can expand along the air gaps and transform into a white arc. This white arc can spread along the insulator, resulting in a flashover.

Partial discharges have been a center of attention for analyzing some phenomena in power systems [29], [30]. The partial arc modeling method used in this study is mainly based on presented method in [31]. In this method, partial arc models by considering voltage drops along the partial arc during its appearance along air gaps.

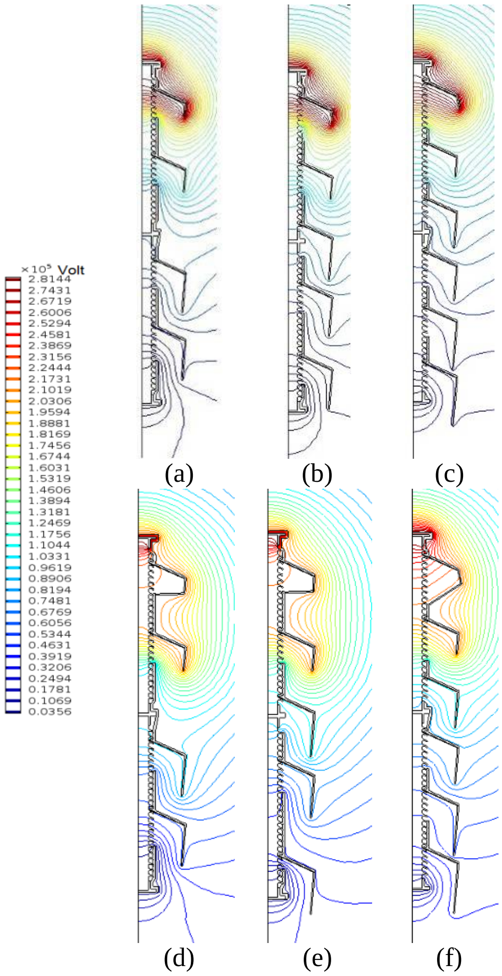

Figure 2. Equipotential line distributions for different BS configurations with and without partial arcs (PA) a) 4 BS, b) 4 BS with PA, c) 5 BS, d) 5 BS with PA, e) 6 BS, f) 6 BS with PA,

Table 2. Simulation parameters

	Porcelain	Air	Ice	Water film	BS
Relative permittivity	6	1	75	81	5
Conductivity σ_s (μS/cm) at 20ºC	0	0	0	30	0
Thickness (mm)	-	-	-	0.15	5

The voltage gradient, E_{arc}, along the partial arc is expressed as follows:

$$E_{arc} = 0.3464 I_m^{-0.3555} \qquad x < 7 \text{ cm} \qquad (1)$$

$$E_{arc} = 0.2047 I_m^{-0.6607} \qquad x > 7 \text{ cm} \qquad (2)$$

where I_m is in A and E_{arc} is in kV_{rms}/cm. The leakage current, I_m, flows on the ice surface. Then, to obtain voltage drop, we can multiply (1) or (2) by the air gap length (cm). Thus,

$$V_{arc} = E_{arc} x \qquad (3)$$

During the BS tests, a leakage current of about 18 mA was observed in transition between a breakdown streamer to a white arc on the ice surface. By substituting this value in (1) and (2), the voltage drop is obtained:

$$V_{arc} = 1.44x \qquad x < 7 \text{ cm} \qquad (4)$$

$$V_{arc} = 2.91x \qquad x > 7 \text{ cm} \qquad (5)$$

Based on these calculations, we can see that voltage drops for small air gaps (i.e. x < 7 cm) have a value less than 4%. This observation is stated in our previous paper [12] in more details. So, it shows that small air gaps do not have considerable influence on the total voltage drop. In other words, in the area of the HV electrode, a small air gap is not helpful while a sufficiently large one can be.

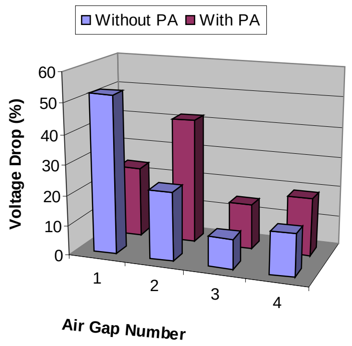

Figure 3. Comparison of voltage drops (ΔV (%)) along the air gaps of the 4-BS tests, before and after the formation of a partial arc along Air Gap1

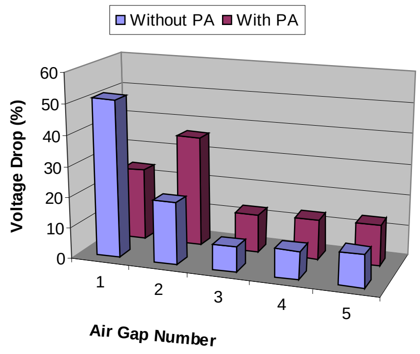

Figure 4. Comparison of voltage drops (ΔV (%)) along the air gaps of the 5-BS tests, before and after the formation of a partial arc along Air Gap1

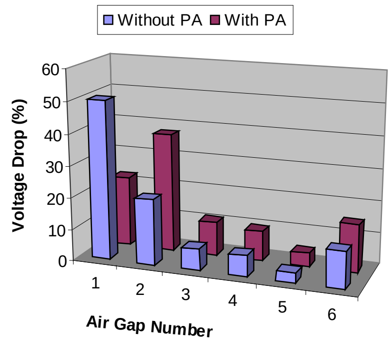

Figure 5. Comparison of voltage drops (ΔV (%)) along the air gaps of the 6-BS tests, before and after the formation of a partial arc along Air Gap1

The simulation parameters are presented in Table 2 and the simulation results of the BS configurations with and without partial arc (PA) are shown in Figure 2. Based on the BS tests [22], the lengths of the first air gap for the 4-, 5-, and 6-BS configurations were 23.2 cm, 23.2 cm, and 21.8, respectively. The voltage drops (ΔV) for the 4-, 5- and 6-BS configurations before and after the partial arc occurrence along the first air gap are compared in Figure 3, Figure 4, and Figure 5.

The simulation results show that a part of around 58.5 to 64.6% of $\Delta V_{ba\text{-}1}$ (variation of the voltage drop along Air Gap 1 before and after the formation of the partial arc) shifts to Air Gap 2. In other words, Air Gap 2 prevents the re-equilibrium of the potential distribution along Air Gap 2 and the other air gaps or acts as a potential barrier. These creative 2D axisymmetric simulation results are in good agreement with earlier validated 3D simulations in [31]. Those 3D simulations showed that for three air gap configurations on a post insulator, 77% of $\Delta V_{ba\text{-}1}$ shifts to Air Gap 2.

Based on the laboratory observations, partial arcs generally appear on the BS which is the closest to the HV electrode. If the applied voltage is raised up to flashover voltage, the voltage drop value (ΔV) of Air Gap 1 becomes greater than its breakdown voltage value (V_b), showing the possibility of initiation of a partial arc along this one. The appearance of the first partial arc leads to a redistribution of potential along the ice-covered insulator. Such redistribution can result in initiation of partial arcs along the other gaps that may finally expand into flashover arc. Thus, it may be concluded that the larger the air gap is, the greater the resistance is against the redistribution of voltage drops after the partial arc development. This can be considered as another hypothesis to explain the increase in V_{MF} as the number of BSs increase from 4 to 6.

4 DISCUSSION ON EXPERIMENTAL OBSERVATIONS

The activities of partial arcs along the air gaps of the 6-BS test during the last 3 minutes of the evaluation period are shown in Figure 6. Notice that the evaluation period activities can be directly observed on the Web [28]. The most important observations are listed in Table 3 (with a rough time step of 0.5 minute). As shown in Figure 6-a, at t_7= -3 min (i.e. 3 min before of the flashover occurrence), partial arc activity is not notable. Then, at t_6 (Figure 6-b) the first partial arc is quite distinguishable on the video [28]. The partial arcs slowly become increasingly stronger (t_5 to t_1, Figure 6-c to g) until at last at t_0 (Figure 6-h) the flashover happens. Two observations should be emphasized:

- **The sudden large movements of partial arcs along the air gaps:** As it can be seen on the video [28] and in "Figure 6-b to Figure 6-g", the movements of the partial arcs along the air gaps are fairly large and quick. For example, the length and position of the first partial arc (between BS_1 and BS_2) change rapidly and drastically among the icicles of BS_1 and on the ice surface of BS_2. A similar story can be also noticed for the activities of partial arcs along the other air gaps.
- **The movement of the ice on BS_1:** This movement (at t_2 = -1 min & 5 sec, Figure 6-f) is noticeable on the video [28] (video clock = 14:37':30"). It is also visible by comparison of the ice shape of BS_1 in "Figure 6-f and Figure 6-e".

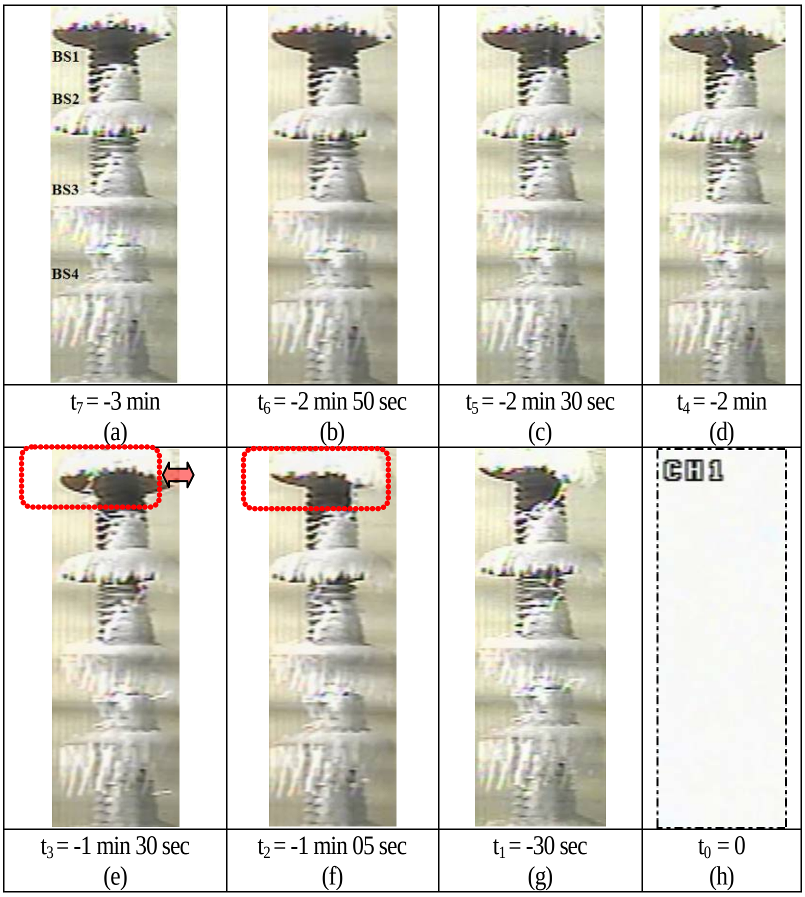

Figure 6. Appearance of partial arcs along air gaps in for the 6-BS test at CIGELE during application of 330 kV, t_7, t_6, t_5, up to t_0

Table 3. The main observations of partial arcs (PAs) during the recorded video of the evaluation period for the 6-BS experiment

Important times	Video Clock	Time to flashover	Important remarks
	14:38':40"	+5 sec	End of the video
t_0	14:38':35"	0 min	Flashover
t_1	14:38':05"	-0.5 min	PAs become stronger
t_2	14:37':30"	-1 min & 5 sec	Ice motion on BS1
t_3	14:37':05"	-1.5 min	PAs become stronger
t_4	14:36':35"	-2 min	PAs become stronger
t_5	14:36':05"	-2.5 min	The 1st PA is more visible
t_6	14:35':45"	-2min & 50 sec	The 1st visible PA
t_7	14:35':35"	-3min	No partial arc is visible
	14:35':22"	-3 min & 13 sec	Beginning of the video

These two observations show that the length of the air gaps can be changed due to partial arc activities. Moreover, the stronger partial arcs are, the more heat is generated and temperature is raised in the region of the air gaps. In short, the temperature and length of the partial arcs may change considerably. This shows that the estimation of the breakdown voltage of the air gaps with a rod-plane configuration, as it is proposed in our previous paper [25], may not be practically applicable. Furthermore, these careful observations demonstrate that the simulation results of the partial arcs should be valued more with a qualification analysis than a quantification one.

5 CONCLUSION

The flashover performance of 4-, 5-, and 6-BS configurations of an EHV station post insulator was studied focusing on partial arc activities. New 2D simulation of partial arcs of the BS configurations and experimental observations of flashover procedures were discussed. The simulation results of the partial arcs were in logical agreement with previous 3D validated simulation results of one unit post station insulator. The following conclusions and recommendation are presented:

1) The appearance of the partial arc along the first air gaps leads to a redistribution of voltage drops along the other air gaps. The role of Air Gap 2, i.e. the second closest air gap to the HV electrode, from is like a potential barrier. The more air gaps, the higher resistance against the voltage redistribution, with a resulting higher flashover voltage. Therefore, in general, a higher number of BSs should be recommended for increasing the reliability of the power system under heavy icing conditions.
2) Analysis of the experimental partial arc activities shows that the positions and lengths of the partial arcs may change rapidly and considerably. Thus, it is impossible to get sufficiently high estimation accuracy for the voltage drops using the 2D or 3D partial arc simulations. The simplified partial arc model presented is more important from a qualification than a quantification point of view.
3) It is recommended to carry out BS experiments with strong wind speed (higher than the usual 3.3 m/s). This would help to better understand the effect of different IFLDs by using the geometric model of the BS configurations presented in our previous studies.

BIBLIOGRAPHY

[1] M. Farzaneh and W. A. Chisholm, “50 years in icing performance of outdoor insulators,” *Electr. Insul. Mag.*, vol. 30, no. 1, pp. 14–24, 2014.

[2] S. Farokhi, A. Nekahi, and M. Farzaneh, “Mechanisms and processes of arc propagation over an ice-covered surface,” *IEEE Trans. Dielectr. Electr. Insul.*, vol. 21, no. 6, pp. 2634–2641, 2014.

[3] F. Yin, X. Jiang, and M. Farzaneh, “Electrical performance of composite insulators under icing conditions,” *IEEE Trans. Dielectr. Electr. Insul.*, vol. 21, no. 6, pp. 2584–2593, 2014.

[4] M. Hara and C. L. Phan, “Leakage current and flashover performance of iced insulators,” *IEEE Trans. Power Appar. Syst.*, vol. PAS-98, no. 3, pp. 849–859, 1979.

[5] M. Farzaneh and O. T. Melo, “Flashover Performance of Insulators in the Presence of Short Icicles,” *Int. J. Offshore Polar Eng.*, vol. 4, no. 2, pp. 112–118, 1994.

[6] A. Nekahi, S. Farokhi, M. Farzaneh, and B. G. Stewart, “Arc energy and temperature during its propagation over ice-covered surfaces,” *IEEE Trans. Plasma Sci.*, vol. 42, no. 1, pp. 114–119, 2014.

[7] Y. Liu and B. Du, “Pattern identification of surface flashover induced by discrete water droplets on polymer insulator,” *IEEE Trans. Dielectr. Electr. Insul.*, vol. 21, no. 4, pp. 1972–1981, 2014.

[8] M. Farzaneh and W. A. Chisholm, *Insulators for icing and polluted environments*. IEEE Press Series on Power Engineering, John Wiley, 2009.

[9] M. Farzaneh and W. A. Chisholm, “Insulator icing test methods, selection criteria and mitigation alternatives,” *IEEE Trans. Dielectr. Electr. Insul.*, vol. 14, no. 6, pp. 1462–1473, 2007.

[10] W. A. Chisholm, K. G. Ringler, C. C. Erven, M. A. Green, O. Melo, Y. Tam, O. Nigol, J. Kuffel, A. Boyer, I. K. Pavasars, F. X. Macedo, J. K. Sabiston, and R. B. Caputo, “The cold-fog test [for outdoor insulators],” *IEEE Trans. Power Deliv.*, vol. 11, no. 4, pp. 1874–1880, 1996.

[11] X. Wei, Z. Jia, Z. Sun, Z. Guan, and M. Farzaneh, “Selection of semiconductive coatings at different ambient temperatures,” *IEEE Trans. Dielectr. Electr. Insul.*, vol. 22, pp. 400–408, 2015.

[12] S. M. Ale-Emran, M. Farzaneh, and C. Volat, “Simulation analysis of the effect of booster sheds on post insulators under icing conditions,” in *IEEEE Conference on Electrical Insulation and Dielectric Phenomena (CEIDP)*, 2012, pp. 749–752.

[13] S. M. Ale-Emran and M. Farzaneh, “Numerical analysis of the combined effects of booster sheds and grading rings on an ice-covered EHV ceramic post insulator,” in *IEEE Electrical Insulation Conference (EIC)*, 2013, pp. 346–350.

[14] C. H. A. Ely, P. J. Lambeth, and J. S. T. Looms, “The booster shed: prevention of flashover of polluted substation insulators in heavy wetting,” *IEEE Trans. Power Appar. Syst.*, vol. PAS-97, no. 6, pp. 2187–2197, 1978.

[15] O. Oliveira Filho, J. A. Cardoso, D. R. de Mello, R. M. de Azevedo, and S. G. Carvalho, “The use of booster sheds to improve the performance of 800 kV multicone type insulators under heavy rain,” in *International Conference on High Voltage Engineering and Application (ICHVE)*, 2010, pp. 485–488.

[16] W. McDermid and T. Black, “External flashovers, related insulation failures and corrective measures in converter stations of Nelson River bipole 1 and bipole 2,” *IEEE Trans. Dielectr. Electr. Insul.*, vol. 21, no. January, pp. 2406–2414, 2014.

[17] V. Sklenicka and J. Vokale, “Insulators in icing conditions: selection and measures for reliability

increasing," in *7th Int. Workshop Atmospheric Icing Structures (IWAIS)*, 1996, pp. 72–76.

[18] J.-F. Drapeau, M. Farraneh, and M. J. Roy, "An exploratory study of various solutions for improving ice flashover performance of station post insulators," in *10th Int. Workshop Atmospheric Icing Structures (IWAIS)*, 2002, p. paper 4–06.

[19] C. Volat, S. M. Ale-Emran, and M. Farzaneh, "Numerical simulations of ice-covered EHV post station insulator performance equipped with booster sheds," in *IEEE International Symposium on Electrical Insulation (ISEI)*, 2012, pp. 91–94.

[20] J. Hu, K. Xu, X. Jiang, Y. Wu, Z. Zhang, L. Shun, and B. Lan, "The Influence of Booster Sheds on AC Flashover Performance of Ice-covered 750 kV Class Tension Insulator Strings," in *IEEE High Voltage Engineering and Application (ICHVE)*, 2014, pp. 1–5.

[21] P. J. Lambeth, "Laboratory tests to evaluate HVDC wall bushing performance in wet weather," *IEEE Trans. Power Deliv.*, vol. 5, no. 4, pp. 1782–1793, 1990.

[22] S. M. Ale-Emran and M. Farzaneh, "Parametric studies and improved hypothesis of booster-shed effects on post insulators under heavy icing conditions," *IEEE Trans. Dielectr. Electr. Insul.*, vol. 22, no. 1, pp. 420–427, 2015.

[23] S. M. Ale-Emran and M. Farzaneh, "Experimental design of booster shed parameters for post insulators under heavy icing conditions," *IEEE Trans. Power Deliv.*, vol. 30, no. 1, pp. 488 – 496, 2015.

[24] S. M. Ale-Emran and M. Farzaneh, "Design of booster shed parameters for post insulators under heavy icing conditions using geometric modelling and the Taguchi method," *IET Sci. Meas. Technol.*, pp. 1–8, Mar. 2015.

[25] S. M. Ale-Emran and M. Farzaneh, "Dimensioning of booster sheds for icing protection of post insulators," *IEEE Trans. Dielectr. Electr. Insul.*, vol. 21, no. 6, pp. 2576–2583, 2014.

[26] M. Farzaneh, "IEEE standard 1783–guide for test methods and procedures to evaluate the electrical performance of insulators in freezing conditions," IEEE Press, New York, 2009.

[27] M. Farzaneh and J. F. Drapeau, "AC flashover performance of insulators covered with artificial ice," *IEEE Trans. Power Deliv.*, vol. 10, no. 2, pp. 1038–1051, 1995.

[28] S. M. Ale-Emran and M. Farzaneh, "Flashover test of EHV post insulator with 6 booster sheds under icing conditions (3 min)," *(2015, 17th April)*. [Online]. Available: https://youtu.be/dXwBgfJOp8Y.

[29] M.Majidi, M.S.Fadali, M.Etezadi-Amoli, and M.Oskuoee, "Partial discharge pattern recognition via sparse representation and ANN," *IEEE Trans. Dielectr. Electr. Insul.*, vol. 22, no. 2, pp. 1061–1070, 2015.

[30] M.Majidi and M.Oskuoee, "Improving pattern recognition accuracy of partial discharges by new data preprocessing methods," *Electr. Power Syst. Res.*, vol. 119, pp. 100–110, 2015.

[31] C. Volat and M. Farzaneh, "Three-dimensional modeling of potential and electric-field distributions along an ehv ceramic post insulator covered with ice — Part II : effect of air gaps and partial arcs" *IEEE Trans. Power Deliv.*, vol. 20, no. 3, pp. 2014–2021, 2014.