Tailoring Wettability Through Coating Deposition on High-Voltage Overhead Conductors to Decrease Corona Discharge Power Losses

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Motivation

- Overhead high-voltage transmission lines are vital for power transport but face challenges: durability, corona discharge, and leakage currents, leading to economic and environmental impacts.
- Corona discharge is air ionization around the conductor when the electric field strength exceeds the air's breakdown limit. It is significantly affected by environmental conditions, especially rain.
- Developing new functional materials using laser nanotechnology, such as superhydrophobic, superhydrophilic, and slippery liquid-infused porous surfaces coatings, can be an effective way to drastically improve efficiency and safety of energy transportation

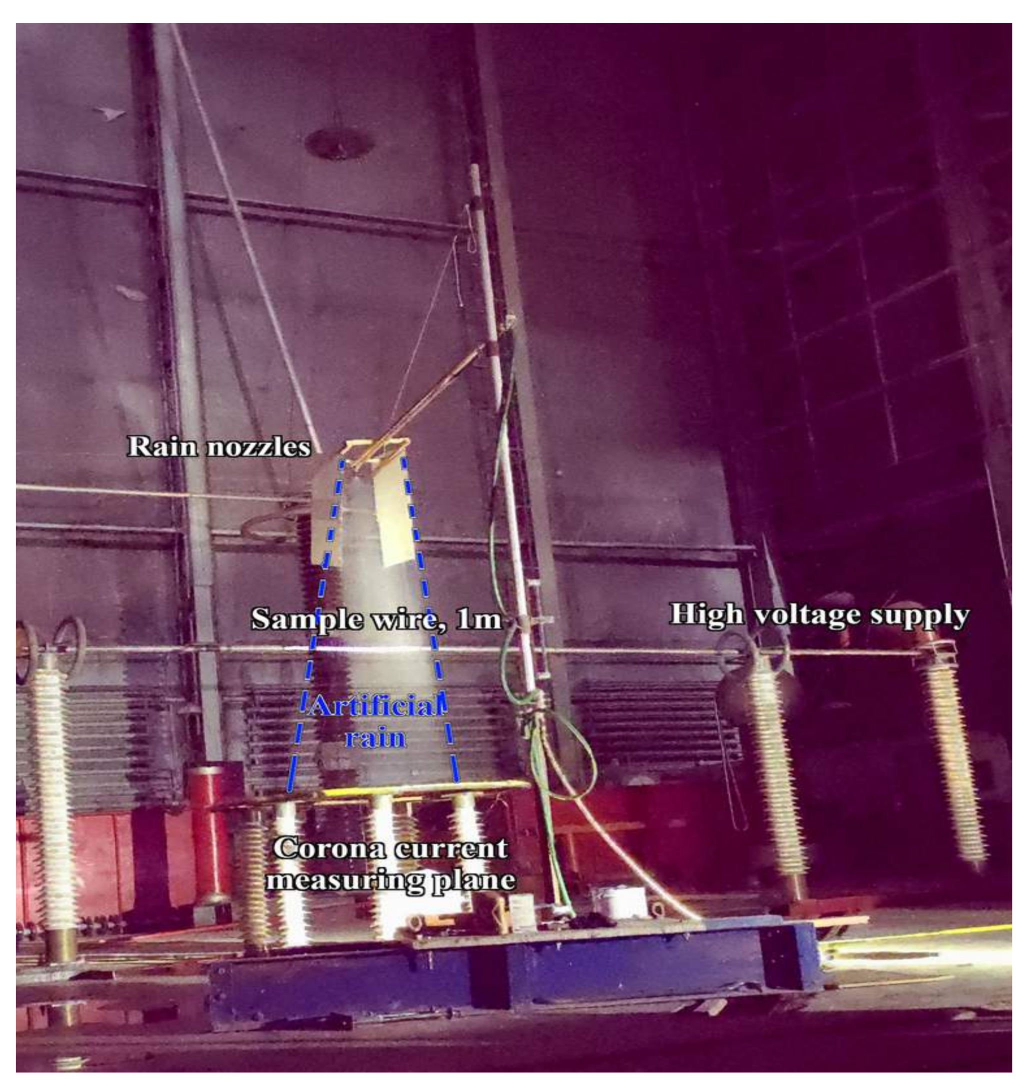
Goals

- To evaluate the performance of coatings with altered wettability, in particular hydrophilic and superhydrophilic organosilane coatings, and compare them with superhydrophobic (SHC) and SLIPS coatings, for high-voltage overhead conductors.
- Investigate their efficiency in reducing corona discharge currents under both dry and simulated rainy conditions.
- Assess critical properties for practical application, including ice adhesion characteristics and corrosion resistance.
- Identify coatings offering the optimal trade-off for improving the performance and longevity of transmission lines

Materials and Methods

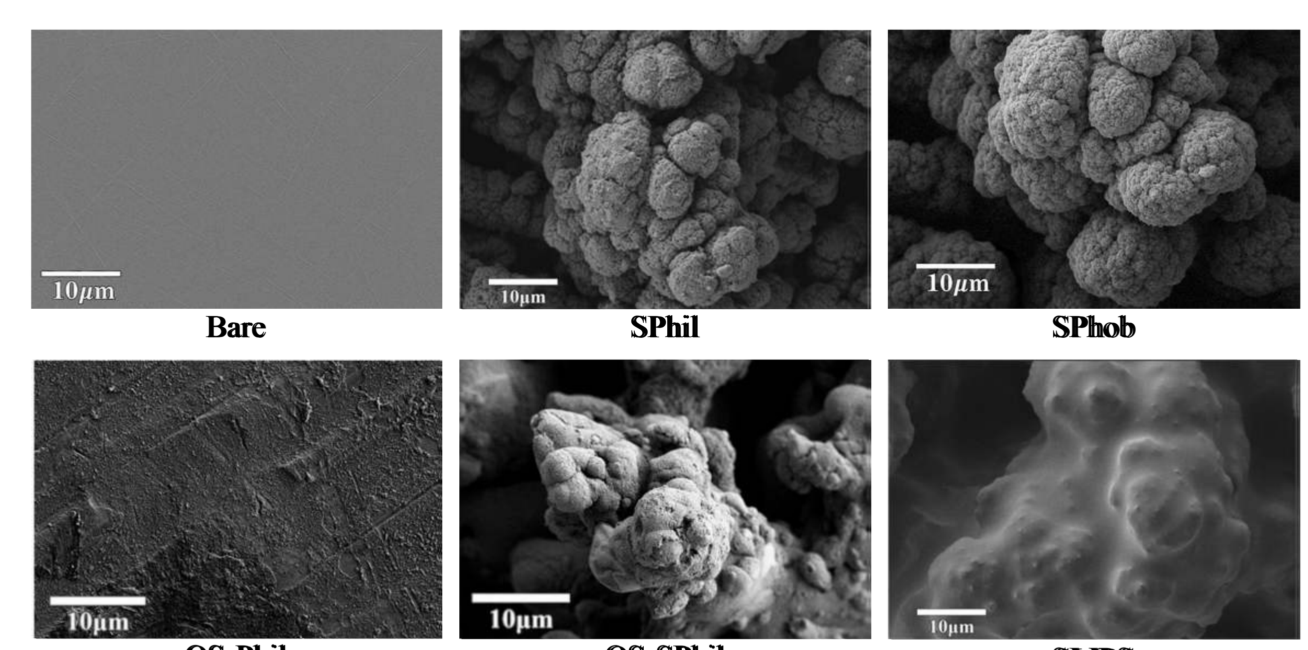
Evaluation

- Corona Discharge Tests: Conducted using a high-voltage setup at the Siberian Research Institute of Electric Power Industry in a wire-plane configuration. Input voltage 105 kV simulated conditions for 220 kV lines. Tests performed under dry and simulated rain conditions (0.25-0.37 mm/min intensity) using 50 Hz alternating voltage.
- Measured corona discharge power loss vs. applied voltage. Studied evolution of properties over prolonged exposure (3h cycles). Observed discharge characteristics using electron-optical flaw detector.
- Ice Adhesion: Shear ice adhesion strength measured at -3°C using a centrifugal technique.
- Corrosion Resistance: Corrosion current determined via the Tafel method on potentiodynamic polarization curves in 0.5 M NaCl solution.



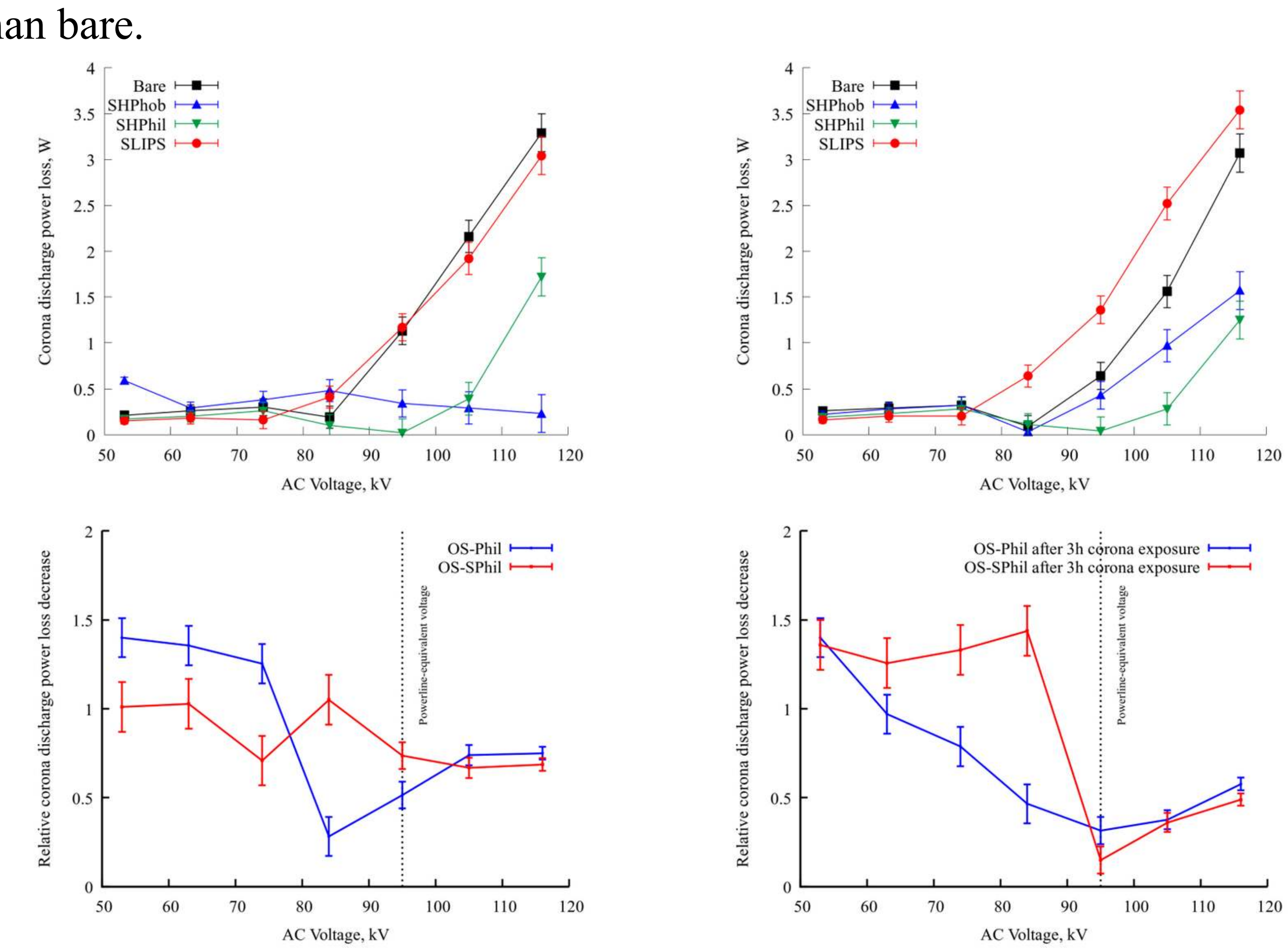
Coatings

- All wire with coating samples were made on the basis of 110cm long AC240/32 high-voltage wires commonly used for 220 kV powerlines. They consist of a steel core and aluminum wires (8030 or 6101 alloy)
- The following samples were fabricated and investigated:
- Bare: Untreated wire samples after washing.
- Superhydrophilic (SPhil): Laser texturing via nanosecond IR laser creating hierarchical micro- and nano- morphology, resulting in highly developed surface roughness and superhydrophilicity (contact angle ~11 ± 3°).
- Superhydrophobic (SPhob): was fabricated as SHPhil samples modified with adsorbed molecularly thin fluorooxysilane layer. Superhydrophobicity achieved with contact angle 171.5°±1.0 and roll-off angles < 2°.
- SLIPS: SPhob samples infused with 100 cSt silicone oil. Smoother surface, contact angle ~108°, sliding angle ~4°, low water adhesion. Water slides slowly.
- Organosylane Hydrophilic (OS-Phil): Bare wires coated by dip coating in an organosilane solution. Solution includes water, PEG-400, isopropyl alcohol, and 3-aminopropyltriethoxysilane. Forms a protective film after solvent evaporation and thermal curing. Smooth surface with organosilane film. Initial contact angle ~50.9 ± 0.8°
- Organosylane Superhydrophilic (OS-SPhil): SHPhil samples with adsorbed organosilane coating



Corona Discharge Performance

- Under rain conditions both SPhob and SPhil coatings significantly reduce corona discharge currents
- However, SPhob and SPhil have different behavior upon long exposure (3h) to corona discharge: SPhob become slightly worse, while SPhil become slightly better.
- SLIPS coatings doesn't demonstrate anti-corona properties, because increase corona currents in rain due to too slow water removal and sliding droplets.
- OS-Phil and OS-SPhil organosilane coatings reduce power losses by 25–60% compared to bare wires. After 3 hours of exposure, losses remain ~2.5 times lower than bare.



Conclusions and Outlook

- Superhydrophobic (SPhob) and superhydrophilic (SPhil) coatings are effective in reducing corona discharge currents in rainy conditions.
- SLIPS coatings unexpectedly increase corona currents in rain.
- Despite reducing corona, the increased ice adhesion and higher corrosion rates of SPhil coatings limit their overall applicability.
- OS-SPhil shows better corrosion resistance and ice adhesion properties, however applicability is still handicapped.
- The organosilane hydrophilic (OS-Phil) coating offers a promising balance by providing significant corona discharge reduction, maintaining moderate ice adhesion (similar to bare wires), and enhancing corrosion resistance. OS-Phil coating emerges as a highly suitable candidate for improving the durability and efficiency of high-voltage transmission lines under diverse environmental conditions.

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