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In-Situ Application of Capacity Enhancing Photonic Coatings to Overhead Conductors: Static Re-rating without Reconductoring

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SUMMARY

A capacity enhancing spectrally selective coating (SSC) was applied to overhead Transmission and Distribution (T+D) conductors in-situ with a purpose-built overhead power line coating robot (PLCR). The capacity enhancing coating functions by spectral selectivity; minimising solar absorptivity (α , solar absorptivity of 0.16 at 100 μ m film thickness) and maximising thermal emissivity (emissivity, ϵ , - 0.93 out of 1). The SSC passively lowers the temperature of the conductor for a given current level, increasing the maximum allowable conductor current before exceeding thermal rating. In-situ SSC application permits a continuous enhanced static rating of the line, increasing ampacity by as much as 30%, without reconductoring. The demonstration and verification of such technology is deemed important in the current context, where rapid and cost-effective maximisation of existing overhead conductors is essential to meet the growing capacity related challenges facing transmission and distribution network operators (TNO's/DNO's). Firstly, this paper outlines the technology required to deliver this service and the key design challenges. Secondly, the experimental verification of the technology is reported through an 80 m demonstration in Maribor, Slovenia. Dedicated temperature data is reported to verify the temperature reduction of the conductor, post coating application, relative to an uncoated control. Finally, future opportunities and challenges are reported in the context of in-situ power line coating becoming a scalable and mainstream service. Most notably, the in-situ application of alternative functional coatings to address other T+D issues, such as corona noise reduction via superhydrophilic coatings and icephobic coatings to proactively mitigate ice accretion.

KEYWORDS

Overhead Lines, Coatings, Thermal Ratings, Grid Enhancing Technology, Robotics, Photonic Coatings, Icephobic.

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Introduction

Context: Energy Transition and Grid Operators

Grid operators are facing a simultaneity of phenomena which are rapidly increasing electricity demand. Electrification is driving the load growth as transport, heating and energy systems are integrated. Climate change is driving further cooling requirements during summer, with global space cooling energy demand growth forecast to increase between 66% and 182% from 2020 to 2050 [1], making space cooling the largest consumer of energy in buildings. Artificial Intelligence, cryptocurrency and data centres are forecast to increase power consumption by up to 100% by 2026 [2]. Collectively, this is driving an increase in global electricity demand of 75% - 150% by 2050 [3]. However, the rate of growth in electricity demand is higher than the forecast rate of Transmission and Distribution (T+D) capacity build out. It is reported that global grid capacity needs to grow to 2.5x its current size by 2050 [4] but 10 out of 26 TSO's in Europe have grid expansion plans lower than the national wind and solar expansion targets [5]. The US grid has expanded historically at a rate of 1%/year and this would need to double between 2024 to 2035 to achieve the projected transmission needs in 2035 [6].

Objectively, there is an urgent requirement to increase T+D capacity. A significant limitation on load growth is the thermal rating of overhead conductors. Currently, to statically re-rate conductors, reconductoring is typically required, however, the pace of reconductoring is not consistent with the rate of capacity increase; “with siting, permitting, and construction of new transmission infrastructure taking up to 10 years to build out in some past cases, pressures are compounding on the existing transmission system” [6]. It is important to explore technologies that can statically re-rate existing overhead conductors in a manner that utilises the existing overhead conductors, in addition to the existing right of way. This has the potential to drastically reduce the uprating cost (£/MW) and the time to additional capacity, as the service could be conducted in line with a maintenance cycle.

Capacity Enhancement of Conductors via Surface Modification

The vast majority of existing conductors installed today are ACSR conductors. The thermal limitations these conductors are well understood [7]. Elevated conductor temperatures lead to increased resistive losses and restrict the current-carrying capacity of conductors with a specific cross-sectional area. Surpassing a conductor's thermal limit results in excessive sag, exceeding approved clearances. Additionally, operating aluminium wires outside of specified limits poses a risk of strength degradation. Lowering the temperature of an overhead conductor at a given current level can increase the current carrying capacity for a fixed cross-sectional area or lower the resistive losses at the specified current level. The former is salient to increasing the ampacity of conventional conductors, the latter relevant in the context of HTLS conductors, which operate with elevated current carrying capacity and I^2R losses, which can be made more efficient with up to a 10% reduction in power losses. This is evidenced in Table 1 via IEEE-738(2023) calculations. An ACSR Hawk operating in the same conditions will see a 25% increase in its ampacity (626A Coated vs 501A Uncoated) at its MACT of 90°C.

Table 1: Ampacity increase, temperature and loss reduction of ACSS Hawk (uncoated) and ACSS/SSC (coated) and ACSR variants. Model parameters: 35 °C Ambient, 1000 W/m² Solar Intensity, 0.5 m/s wind speed. Uncoated Solar Absorptivity (α) = 0.5, Emissivity (ϵ) = 0.5. SSC α = 0.12, ϵ = 0.93.

	Uncoated ACSS Hawk	ACSS/ SSC Hawk	% Δ	ACSR Hawk	ACSR/ SSC Hawk	% Δ
Ampacity (A)	1085	1298	19.6%	501	626	25%
Operating Current (A)	1085	1085	-	501	501	-
Temperature (°C)	250	189	24.4%	90	70.7	21.4%
Resistance (Ω) per km	0.233	0.201	13.5%	0.151	0.142	6.0%
Power Loss (W) per km	273672	236612	13.5%	37778	35498	6.0%
Annual Losses (MWh) per km	2397	2073	13.5%	331	311	6.0%

Previously, it has been empirically demonstrated that the application of spectrally selective coatings to overhead conductors results in ampacity increases aligned with or exceeding models of CIGRE 601, and that this performance is consistent over multiple years [8–10]. Previous research of multi-year field trials in South Africa and Saudi Arabia demonstrates a peak cooling of 33.6%, with no discernible performance drop throughout the field trial period. Further, in a comparison of empirical cooling compared to that simulated by CIGRE 601, in a method similar to [11] it was shown that empirical cooling exceeded CIGRE 601 forecasts by 1.53x on average and hence ratings uplifts calculated by these models are a safe assumption [10].

In-situ Application of Spectrally Selective Coatings: Power Line Coating Robotics

Robotics are increasingly being utilised in power lines. Utilising robots for power line maintenance offers several benefits, including enhanced safety by reducing the need for human workers to operate in hazardous environments, increased efficiency in identifying and repairing defects, and the ability to perform tasks without shutting down power lines. A primary use to date includes inspection [12–15]. Alternative uses include cleaning insulators [16], circuit breaker racking [17,18] and safety inspections [19]. This paper reports the demonstration of a new use case for robotics in overhead power lines: the application of functional coatings.

The rest of this paper is organised as follows. Firstly, we provide a description of the SSC, PLCR, pilot trials and experimental design. Secondly, we analyse the results of the pilot trials, including analysis of the thermal performance of an SSC coated conductor compared to an uncoated control. Finally, we conclude by assessing the challenges and opportunities that relate to the large-scale deployment of in-situ power line coating as a service.

Materials and Methods

Spectrally Selective Coating Test Protocol

SSC's have been demonstrated in performance and durability in previous research [8–10]. The SSC reported was modified and designed for in-situ application to overhead conductors and is reported to use inorganic binder and pigmentation systems which result in long term durability, resistance to weathering, environmental and mechanical resistance. The test protocol for laboratory verification of this is reported in Table 2.

Table 2: Lab Verification Test Protocol of SSC Deployed in the Field.

<i>Test</i>	<i>Description of Test and Standard</i>
Solar Reflectivity	ASTM E903 Standard Test Method for Solar Absorptance, Reflectance, and Transmittance of Materials Using Integrating Spheres
Emissivity	Wavelength dependent measurement of emissivity 1.5-20 μm : Spectral Normal Hemispherical Reflectivity at Room Temperature (SNHRRT) [20]
Adhesion	ASTM D3359-17 Standard Test Methods for Rating Adhesion by Tape Test
Pencil Hardness	ASTM D3363-20 Standard Test Method for Film Hardness by Pencil Test
Acidic Stability	Internal Test: 72 hours submersion in pH 4 $\text{HCl}_{(\text{aq})}$ under ambient conditions, subsequent visual inspection, adhesion and hardness tests
Moisture Stability	Internal Test: 72 hours submersion water under ambient conditions, subsequent visual inspection, adhesion and hardness tests
Temperature Stability	Internal Test: 72 hours at 150 $^{\circ}\text{C}$ in a circulating oven, subsequent visual inspection, adhesion and hardness tests
Flexibility	ASTM D522, Mandrel bend test
UV Stability	ASTM G155, UV accelerated aging, 4000 hours
Corrosion Stability	ASTM B117-19, salt spray corrosion resistance, 2000 hours
Thermogravimetric Analysis (TGA)	Mass loss as a function of temperature, 30 $^{\circ}\text{C}$ to 900 $^{\circ}\text{C}$ at 10.00 $^{\circ}\text{C}/\text{min}$ in air
Differential Scanning Calorimetry (DSC)	Heat flow as a function of temperature, 30 $^{\circ}\text{C}$ to 350 $^{\circ}\text{C}$ at 10.00 $^{\circ}\text{C}/\text{min}$.

The power line coating robot (PLCR) is an advanced system designed to automate the process of applying functional coatings to overhead power lines. The PLCR's subsystems are integrated and

coordinated through the onboard computing system. The central controller synchronizes the activities of the base platform, PTM, and CAM, ensuring seamless operation and efficient completion of the coating process. The robot's architecture allows for modular upgrades and adjustments, enabling it to adapt to different power lines and coating materials. The power line coating robot is demonstrated in Figure 1.



Figure 1: (Left) CAD Isometric view of the PLCR mounted on a conductor. (Right) PLCR coating conductors in the field.

Experimental Field Trial

In collaboration with ELES, d.o.o and Infrastrukturni Center za Energetske Meritve - Tehnološki Center (ICEM-TC), a pilot trial was conducted to verify the performance of conductors retrofitted with SSC. This experiment was carried out at the Polygon DLR test station located in Maribor, Slovenia. The DLR Polygon Maribor test station comprises a 70-metre span featuring two lengths of Optical Phase Conductor (OPPC) conductors installed in series, with a fibre optic Distributed Temperature Sensing system (DTS) providing a measurable temperature of the core. A low-voltage, high-current AC transformer injects current into the lines, ensuring that both conductors experience identical electrical and environmental conditions. This setup enables a direct comparison of performance between the coated and uncoated conductors. Figure 2 illustrates a schematic representation of the test station layout. The PLCR was utilized to treat a conductor with the SSC coating, while high-resolution conductor core temperature data was collected for both standard and coated conductors. The objective was to assess the performance improvements facilitated by the coating application.

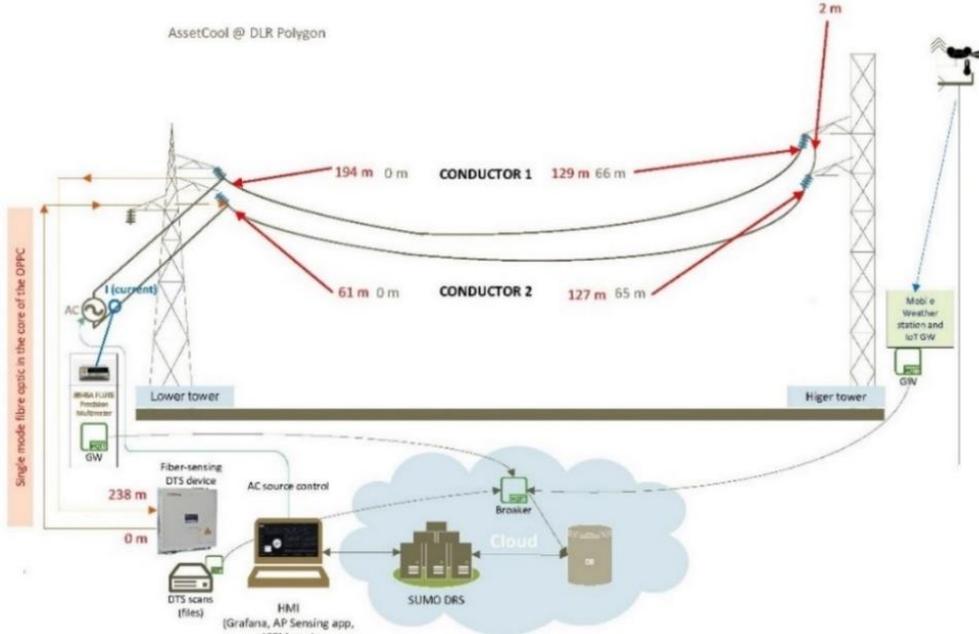


Figure 2: DLR Polygon Test Station Schematic

Experimental Design

The field trial consisted of several steps. First, the PLCR robot was employed to pre-treat and coat one span of the OPPC conductor, while the second span was left untreated to serve as a control sample. After the coating had cured, the temperature reduction of the coated conductor relative to the untreated conductor was analysed under varying meteorological conditions and power loads. The testing schedule, detailing the environmental conditions and times of day for each trial, is provided in Table 3. Various power loadings were applied during each test to ascertain the value of the coated conductor. These were 250A, 645A, 710A, 775A, intended to induce conductor temperatures from nominal conditions of 45 °C to 120 °C.

For data acquisition, core temperature readings were taken every minute and sampled every 0.5 meters along the conductors using an AP Fibre-sensing Distributed Temperature Sensing (DTS) device. This device operates by sending a series of laser pulses through an optical fibre, detecting changes in backscattered light to measure temperature along the fibre's length with high spatial resolution. AC current data were collected using an 8846A Fluke multimeter, while weather data were obtained from a local dedicated weather station.

Table 3: Test Periods and weather conditions of thermal loading.

Test Number	Start Time	End Time	Time Period Covered
Test 1	8:30 AM	12:00 PM	Morning
Test 2	12:00 PM	3:00 PM	Afternoon
Test 3	6:00 AM	2:00 PM	Early Morning to Late Morning
Test 4	6:00 PM	10:30 PM	Evening
Test 5	11:30 AM	4:00 PM	Late Morning to Late Afternoon
Test 6	9:00 PM	1:30 AM	Night to Early Morning
Test 7	9:30 AM	1:30 PM	Late Morning to Early Afternoon
Test 8	9:00 AM	1:00 PM	Late Morning to Early Afternoon

Results

SSC Laboratory Verification

A summary of lab verification testing can be seen in Table 4. The coating had an average approximate dry film thickness (DFT) of 70 µm across the tests. The optical properties of the SSC are verified to demonstrate high solar reflectivity (0.84 at 100µm) and 0.93 emissivity as per ASTM E903 and SNHRRT [20] respectively. The graphical representation of these is included in Figure 3. The calculations in Table 1 highlight the potential for SSC's with solar reflectance above 0.8 and emissivity of 0.9. Analysis by CIGRE 601 and IEEE-738 show the potential capacity increase from such optical properties on the surface of the conductor can be as high as 30% increase in ampacity [8,9].

The coating showed excellent adhesion and stability, showing resistance to moisture, acid and temperature. The coating demonstrated a high hardness, indicating good durability and abrasion resistance, and also retained a high degree of flexibility, with a successful mandrel bend test of 1.7 cm, well beyond that required for the curvature or vibration of any *in situ* stresses. The SSC showed broad stability to corrosive atmospheres; after testing for 2000 hours the film remained intact with only very slight observable changes (4/5 by ISO 105-A02:1993) as per Figure 4 (left), indicating that the coating functions as effect barrier protection to the underlying conductor¹.

¹ The coating is currently undergoing long term UV stability testing (4000 hours), with reporting due in October 2024. This will be entered into the final paper submission.

Table 4: Summary of the lab testing of SSC.

Test	Result
Total Solar Reflectivity	83.9% at 100 μm DFT
Emissivity	0.93
Adhesion (Ad)	5B
Pencil Hardness (Hard)	HB
Acidic Stability	No cracking, peeling, discolouration or other film failure. Ad: 4B, Hard: B
Moisture Stability	No cracking, peeling, discolouration or other film failure. Ad: 4B, Hard: HB
Temperature Stability	No cracking, peeling, discolouration or other film failure. Ad: 5B, Hard: 2H
Flexibility	No coating failure with bend diameter of 1.7 cm

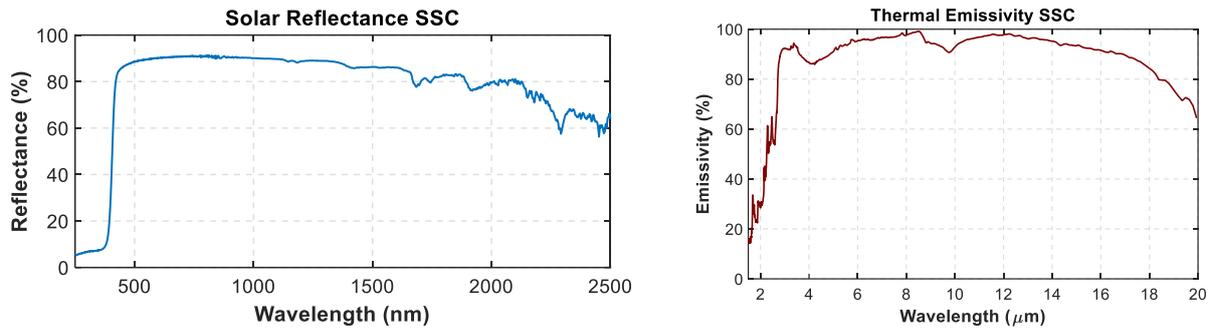


Figure 3: (Left) Solar Reflectance of 83.9% at 100 μm WFT as per ASTM E903 and (Right) wavelength dependent emissivity, with an average emissivity of 0.93 as per SNHRRT [20].

TGA analysis of the coating (Figure 4, right) showed three discrete stages of mass loss. Firstly between 100 and 300 $^{\circ}\text{C}$, due to loss of trapped moderate-to-high boiling organic solvents and other volatiles. Secondly between 300 and 570 $^{\circ}\text{C}$, due to the decomposition of organic groups and additives within the coating and the oxidation of $-\text{CH}_3$ groups to CO_2 . Thirdly between 570 $^{\circ}\text{C}$ and 730 $^{\circ}\text{C}$, due to degradation of the $\text{Si}-\text{CH}_3$ groups within the resin. It is possible to conclude the coating is completely stable up to 300 $^{\circ}\text{C}$, well within the operating range of all globally utilised T+D conductors. Confirmatory analysis of the DSC shows a broad endothermic transition with an onset temperature of 340 $^{\circ}\text{C}$, attributed to the decomposition of organic additives within the coating. Once again, significantly beyond the operating temperature of all conductors.

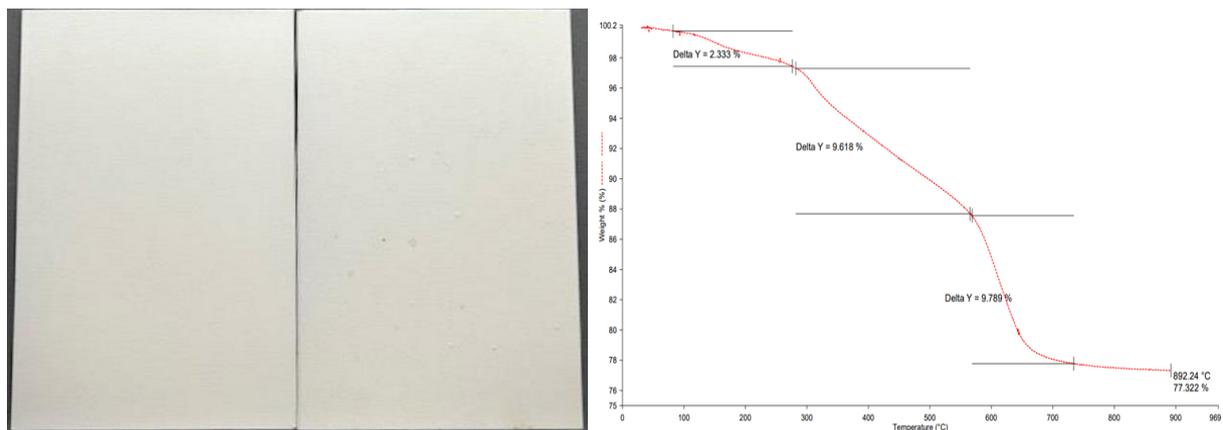


Figure 4: Left: SSC standard (left) and SSC after 2000 hours of ASTM B117-19 salt spray corrosion testing (right); Right: TGA trace of SSC between 30 and 900 $^{\circ}\text{C}$ showing three discrete sections of mass loss.

Experimental Verification of PLCR and In-Situ SSC Application

The SSC was successfully applied to the overhead conductor. Figure 5 illustrates the conductor before and after the coating application.



Figure 5: (Left) Conductor before the coating application, (Right) after the coating application.

The experiments were initiated one day after coating completion. Figures 6- 8 present the temperature comparison between the uncoated and coated conductors under various loading conditions, highlighting a consistently lower temperature for the coated conductor.

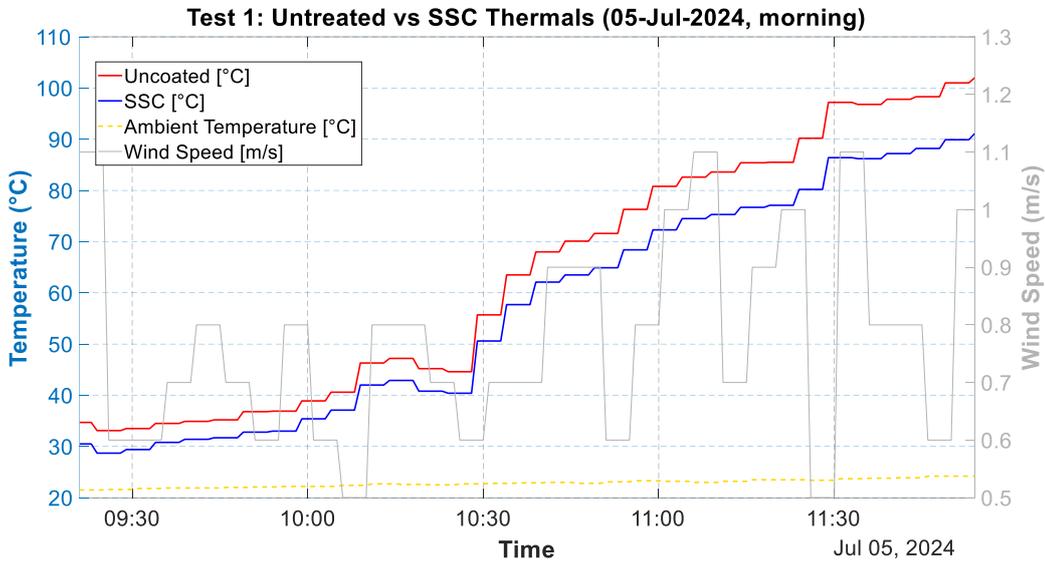


Figure 6: First thermal test of a retrofitted spectrally selective coating under varying load conditions.

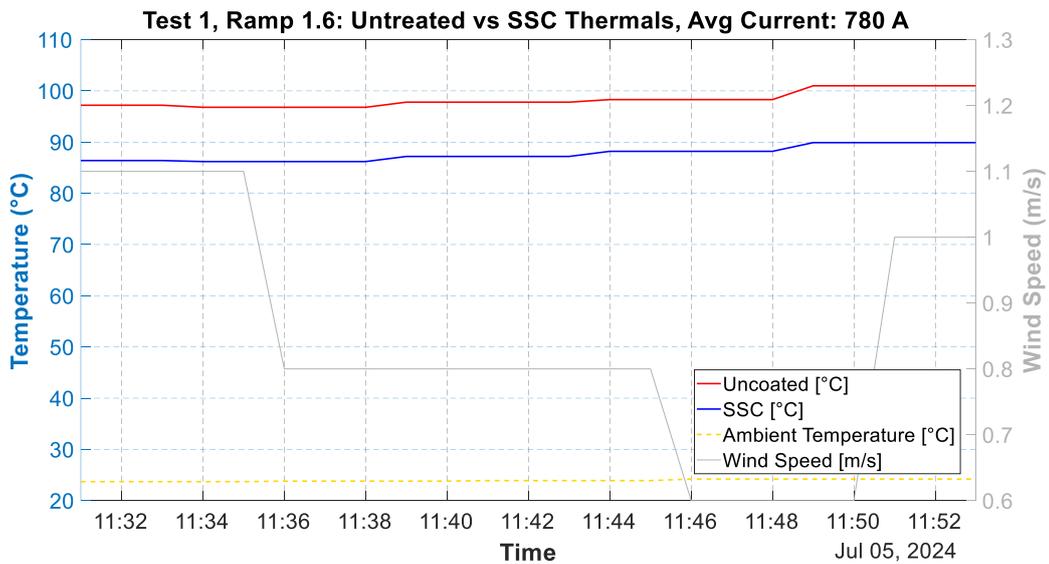


Figure 7: Daytime temperatures of conductors at a 780A load.

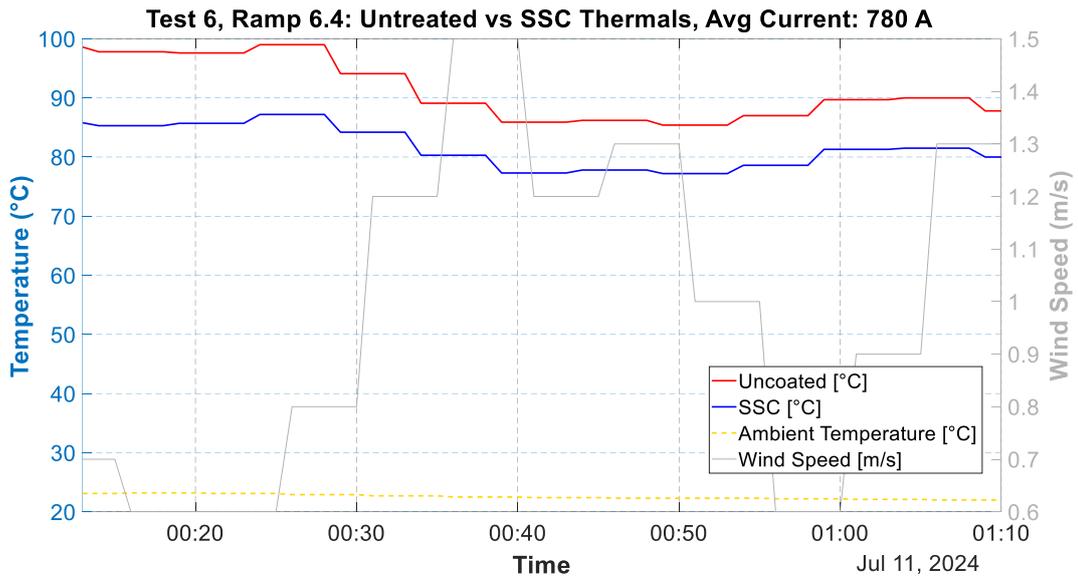


Figure 8: Nighttime temperatures of conductors at a 780A load.

Table 5 provides the data for Test ramp 1. The coated conductor consistently exhibited lower temperatures across all loading conditions, achieving cooling levels between 8.6% and 12.6%. Table 6 provides analysis of temperature differences under nominal loading conditions across various meteorological scenarios and revealed sustained cooling effects, even at night (Tests 3 and 6). Cooling was strongly correlated with wind velocity, with the highest wind speeds in Test 6 reducing cooling to 5.2%, while the lowest wind velocities yielded a cooling effect of 10.6%.

Table 5: Test 1 Loading and Maximum Temperature Data.

Current (A)	Maximum Uncoated Temperature (°C)	Maximum SSC Temperature (°C)	Cooling (%)
254	34.8	30.4	12.6
254	36.8	32.8	10.9
453	40.6	37.1	8.6
636	71.6	64.9	9.4
707	85.5	77.1	9.8
777	101.0	89.9	11.0

Table 6: Overview of Core Data from Distinct Tests.

Test	Current (A)	Max Uncoated (°C)	Max SSC (°C)	Cooling (%)	Wind Speed (m/s)	Wind Direction (°)	Solar (W/m ²)
1.1	250	34.8	30.4	12.6	NA	NA	NA
1.2	250	36.8	32.8	10.9	0.72	71.4	574
2.1	250	42.8	39	8.9	0.93	108.7	958
3.1	250	34.1	31.2	8.5	0.48	175.4	47
4.1	250	47.2	42.2	10.6	0.47	107.7	322
5.1	250	48.6	44.2	9.1	0.77	54.4	847
6.1	260	32.5	30.8	5.2	1.05	198.5	0
7.1	250	46.0	41.3	10.2	0.63	74.6	620
8.1	250	45.1	40.5	10.2	0.72	153.9	550

Table 7 shows the resultant temperature from loading at 645A. Here we see consistent cooling from 8.9 to 10.7%, with the lowest cooling seen at nighttime where there is no solar heat gain to reflect, with the cooling difference coming from purely the increase emissivity of the coating.

Table 7: Conductor temperatures and ambient conditions at a 645A loading.

Test	Current (A)	Max Uncoated (°C)	Max SSC (°C)	Cooling (%)	Wind Speed (m/s)	Wind Direction (°)	Solar (W/m ²)
1.4	640	71.6	64.9	9.4	0.75	56.7	725
2.3	650	77.5	70.6	8.9	0.86	129.1	899
5.2	650	90.1	81.9	9.1	0.86	70.1	870
6.2	650	78.4	71.4	8.9	0.75	196.8	0
7.2	650	84.6	76	10.2	0.78	60.4	739
8.2	640	87.1	77.8	10.7	0.95	71.9	698

At 710A and 780A (Table 8 and Table 9 respectively), consistent cooling in all conditions is further demonstrated. Cooling ranged from 9.8% to 12.9%, with a strong correlation with wind velocity.

Table 8: Conductor temperatures and ambient conditions at a 710A loading.

Test	Current (A)	Max Uncoated (°C)	Max SSC (°C)	Cooling (%)	Wind Speed (m/s)	Wind Direction (°)	Solar (W/m ²)
1.5	710	85.5	77.1	9.8	0.85	68.7	814
2.4	710	94.9	84.8	10.6	0.94	120.7	882
3.6	710	106	92.3	12.9	0.8	88.2	759
3.8	720	98.9	87.7	11.3	0.78	84.7	869
4.3	710	111	95.2	14.2	0.49	181.9	10
5.3	720	105	93.9	10.6	0.86	121.7	837
6.3	710	99	86.5	12.6	0.63	198	0
7.3	710	104	92.2	11.3	0.71	64.7	818
8.3	710	104	91.6	11.9	0.79	78.1	804

Table 9: Conductor temperatures and ambient conditions at a 780A loading.

Test	Current (A)	Max Uncoated (°C)	Max SSC (°C)	Cooling (%)	Wind Speed (m/s)	Wind Direction (°)	Solar (W/m ²)
1.6	780	101	89.9	11	0.85	53.2	856
2.5	770	116	101	12.9	0.74	83	797
3.9	780	108	96.7	10.5	1.15	127.3	719
5.4	780	118	104	11.9	1.09	112.4	799
6.4	780	99	87.2	11.9	0.98	234.4	0
7.4	770	116	102	12.1	0.78	95.4	870
8.4	780	111	99.9	10	0.82	64.5	853

Discussion

The application of spectrally selective coatings to overhead conductors presents a potentially significant advancement in power transmission technology. This study successfully demonstrates that such coatings can be applied in-situ to existing conductors, effectively enhancing their thermal rating. The findings indicate that the PLCR facilitates the application of coatings to conductors already installed on a network but also verifies the functionality of the coatings themselves.

To contextualise the cooling data, simulations with IEEE-738 were performed to estimate the cooling range for the conductors, current levels and environmental conditions during the test period [21]. It is considered that if the performance is in line with IEEE-738 simulations, utilising the empirical environmental conditions from the field, this is confirmatory evidence for the functioning of the SSC and its ability to provide additional ampacity, as determined by IEEE-738 [8–10]. The results of the simulations are in Figure 9.

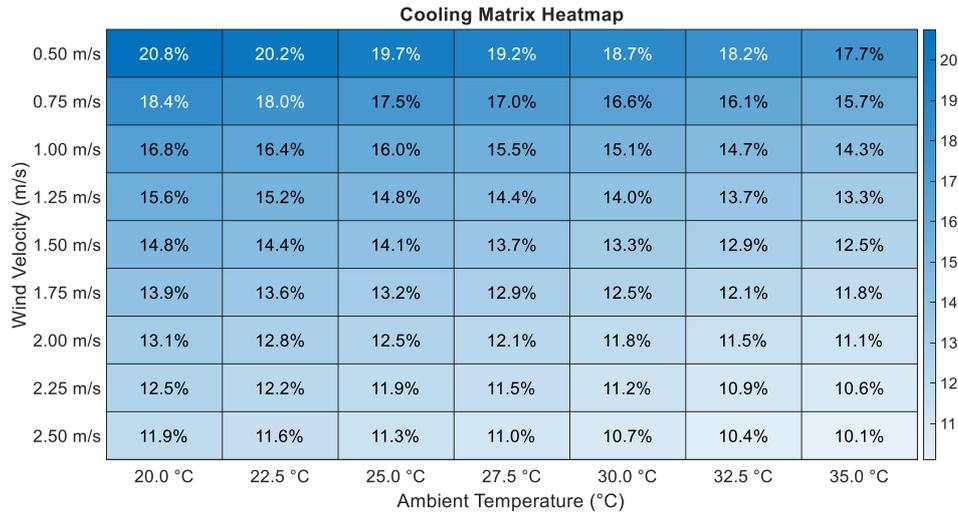


Figure 9: Cooling Matrix Heatmap utilising empirical weather conditions from the trial. Matrix values refer to theoretical cooling percentage after application of the SSC to an OPPC conductor for the environmental conditions in the field. 1000 W/m² Solar Intensity, 45° Wind Angle, 0 m Elevation, Modelled with IEE738. Note the current changes with each iteration to keep the Uncoated OPPC Hawk at MACT (90°C).

As can be seen by Figure 9, the range of temperature reductions (expressed as a %), in the environmental conditions experience range from 10.1% to 20.8%. In the short test period reported, the temperature reduction demonstrated was well aligned with this, suggesting it is performing in line with theoretical expectations, consistent with previous research [8–10]. Environmental factors, such as wind speed and solar irradiation, do play a role in influencing the cooling efficiency of the coating, however, critically the coating offers greatest cooling in low wind conditions which are adopted for static thermal rating. This also offers the potential for integration with Dynamic Line Rating (DLR) technology, as a mitigation of the scenarios with low wind. Further, the study demonstrates that the coatings maintain their effectiveness across various meteorological conditions, thereby confirming their efficacy in real-world scenarios.

In terms of broader SSC verification, optical data has been provided to verify the spectral selectivity of the material, with 83.9% solar reflectivity at 100µm DFT and emissivity of 0.93. These properties substantially optimise the performance of conventional conductors, both in full sunshine and at nighttime. High solar reflectance is particularly critical at lower conductor temperatures, which is typically associated with installed conductors operating in N-1 conditions. Table 10 demonstrates that applying a high emissivity coating in these conditions can in fact have a detrimental effect on conductor ampacity, where lower conductor temperatures are concerned. With a 60 °C MACT, the SSC can have a 33-46% increase in ampacity relative to uncoated or black coated conductors.

Table 10: Comparison of different surface finishes. An Uncoated ($\alpha - 0.5$, $\varepsilon - 0.5$), Black ($\alpha - 0.9$, $\varepsilon - 0.9$) and SSC ($\alpha - 0.16$, $\varepsilon - 0.93$) HAWK ACSR. Conditions: Ambient Temperature: 35°C, Solar Intensity 1000 W/m², Wind Speed 0.5 m/s, Elevation 0 m, Modelled with IEE738.

	SSC	Black	Conventional
Ampacity at 60°C MACT	412	221	274
% Reduction Relative to SSC	-	46%	33%

Laboratory data is provided to indicate broad environmental stability, including 2,000 hours of ASTM B117 salt spray. Long term accelerated aging is ongoing, including 4,000 hours of ASTM G155 UV data. TGA and oven-based exposure testing highlights thermal stability in the range required for operation on conductors. Extended accelerated aging and durability data collection will continue, however, consistent with previous research [8–10], the performance consistency and general durability of inorganic based composites have been demonstrated.

The ability to retrofit existing conductors with spectrally selective coatings has substantial potential to address the growing demand for electricity transmission capacity in a novel, cost efficient manner. This retrofit approach offers a practical solution to increase the ampacity of existing transmission lines without the need for extensive and costly infrastructure modifications, such as reconductoring or constructing new lines. By passively reducing the operating temperatures of conductors, the coatings can significantly enhance current-carrying capacity, reduce resistive losses, and mitigate issues such as excessive sag and strength degradation of aluminium wires. This is a novel way to statically re-rate existing conductors, utilising both the existing conductors and right of way.

Beyond application of SSC materials, this in-situ coating technology offers the potential to apply a variety of coatings to existing lines as a means to address various issues experienced by utilities in a novel and cost-effective way. For example, coatings have been extensively tested to mitigate corona noise [22–25], mitigate ice [26] and could play a role in addressing heavily corroded lines in the field [27,28]. This technology offers the ability to move from a paradigm of heavy engineering to modifying specific issues with functional coatings and smart robotics, offering potential life extension of conductors and mitigation of capital spend.

Future Work

Long-term durability remains an area for continued and extensive research, particularly concerning prolonged exposure to UV radiation and corrosive environments. However, initial tests indicate promising resistance to these factors. Collecting further performance/cooling data from PLCR applied coatings will reinforce performance further, beyond the multi day test period outlined in this research. Integration with DLR technology is of interest, as utilities will be able to statically re-rate their conductors with 20-30% additional ampacity, with confidence in the low wind periods or areas (e.g. wind protected spans), the temperature rise will be mitigated. Further trials applying different functional coatings, such as corona noise mitigation coatings, ice accretion coatings and corrosion mitigation coatings will also be pursued. Finally, rapidly increasing the productivity and automation of the robotic platforms, so this service can be conducted at scale is also required.

Conclusions

The successful demonstration of spectrally selective coatings applied to conductors via robotic systems marks a notable advancement in the field of power transmission. This study validates the dual benefit of the retrofit technology: the coatings can be efficiently applied to conductors that are already part of an operational network, and the coatings provide tangible improvements in thermal performance, to increase ampacity and reduce resistive losses. The implications of this technology are vast, offering transmission and distribution network operators a cost-effective and scalable solution to enhance grid capacity. Retrofitting existing conductors with these coatings provides a strategic approach to address the growing energy demand without the prolonged timelines and financial burdens associated with new infrastructure projects. This innovation aligns with global objectives to optimize current grid assets, ensuring reliability and efficiency in electricity delivery. As a result, spectrally selective coatings and the associated robotic application technology present a transformative opportunity for the power industry, enabling substantial advancements in grid management and energy efficiency.

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