Introduction

In the rapidly evolving landscape of electricity usage, sustainability is now a top priority. The generation of electricity from renewable energy sources is growing at an unprecedented rate, driven in part by the global goal to achieve net-zero emissions by 2050, which is essential to limit global warming to 1.5°C. Concurrently, the electrification of society—through technologies like heat pumps for space heating and cooling, the adoption of electric vehicles (EVs), and the production of hydrogen—is significantly increasing the demand for electricity. This dual trend of rising electricity demand and the push toward renewables is putting immense pressure on power grids, leading to grid congestion and volatility in both electricity utilization and prices. Grid congestion occurs when capacity limits are reached, preventing the physical transport of sufficient electricity from one area to another.

An often-overlooked component in this grid infrastructure is the cable joint—a crucial element in medium- and high-voltage power systems. Cable joints are responsible for connecting segments of electrical cables, particularly in underground and underwater power transmission networks. The performance of these joints is vital for the reliability and longevity of the entire electrical system, as they are frequently exposed to high electrical, mechanical, and thermal stresses. If not properly insulated, cable joints can become weak points that are prone to failure, especially as power systems are subjected to heavier loads and fluctuating conditions brought about by renewable energy sources.

Traditionally, XLPE (cross-linked polyethylene) cables have been widely used due to their strong dielectric properties and durability. However, cable joints using solid insulation, such as cold shrink bodies, face significant challenges when exposed to the higher thermal and electrical loads associated with renewable energy integration. One of the primary concerns is harmonic distortion, which arises from the non-linear loads introduced by renewable energy sources such as wind and solar. Harmonics increase the electrical and thermal stresses within the power grid, leading to excessive heat generation within the cable joints. This can result in overheating, partial discharge, and even failure of the solid insulation.

In response to these challenges, liquid insulation has emerged as a potential solution that offers superior thermal performance. Liquid-insulated joints, like the M-Series joints from Lovink, demonstrate better heat dissipation under high-load conditions, significantly reducing the temperature within the connector compared to solid insulation.

Furthermore, liquid insulation offers additional benefits such as resistance to partial discharge and the ability to compensate for imperfections during installation. This is especially important as the workforce skilled in cable jointing diminishes, making the system more tolerant to human error. Given the increasing complexity of modern power grids, particularly with the rise of renewable energy sources, there is a pressing need to explore the potential advantages of liquid insulation in cable joints.

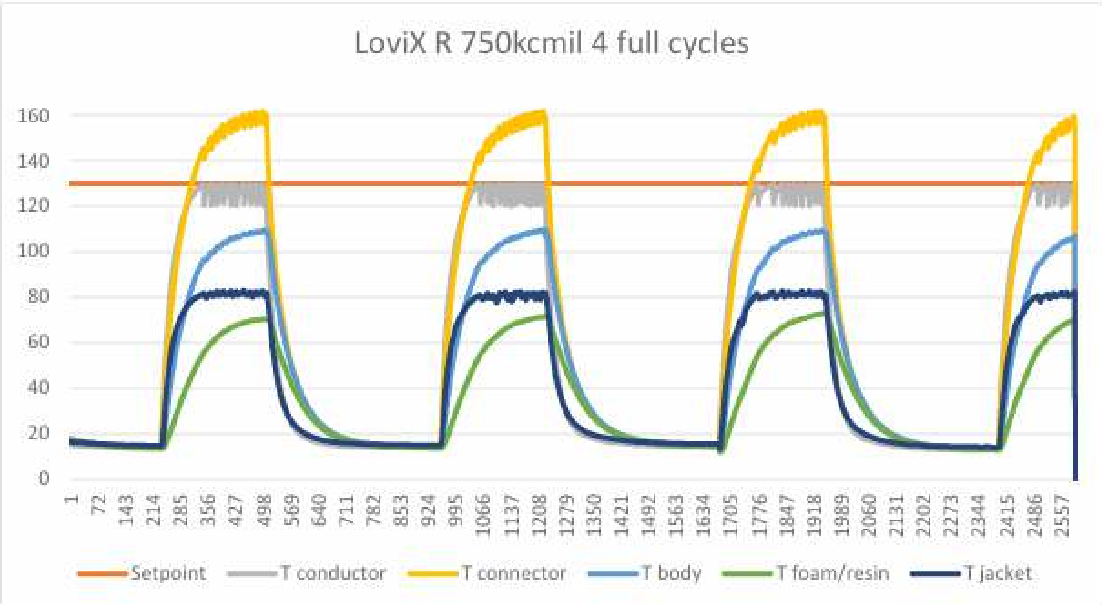
Research Questions
- How can the adoption of liquid insulation in cable joints address the challenges posed by the integration of renewable energy and grid congestion?
- What thermal, electrical, and mechanical benefits does liquid insulation offer in reducing failure rates and improving longevity?
- How does liquid insulation perform under harmonically distorted conditions compared to solid insulation in cable joints?

Results

In this study, two types of cable joints were analyzed: one using solid insulation (cold shrink body) and the other using liquid insulation (Lovink's M-Series joint). The primary focus was on the thermal performance of the joints under standard operating conditions, particularly at a core temperature of 130°C, which aligns with the IEEE standards for maximum operating temperature.

Thermal Performance of Cold Shrink Joints

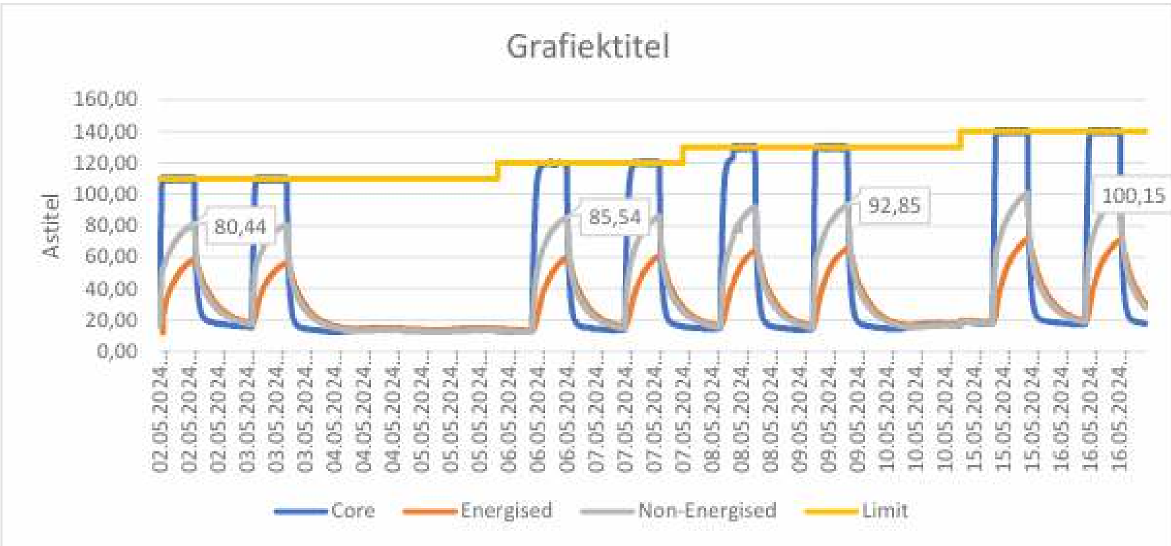
For the cold shrink joint, the core temperature was measured at 130°C, but the temperature of the connector within the joint was found to rise significantly, reaching approximately 160°C. This indicates a delta of 30°C between the core and the connector, demonstrating that solid insulation traps heat within the joint, leading to overheating. This overheating could



potentially cause accelerated aging of the joint and increase the risk of failure, particularly in grids where harmonics and heavy loads are prevalent.

Thermal Performance of M-Series Liquid Insulation Joints

T foam/resin T jacket in contrast, the liquid insulation joint performed significantly better in terms of heat dissipation. At the same core temperature of 130°C, the connector temperature in the M-Series joint was measured at 92.85°C, which is approximately 37°C cooler than the core temperature. Even when the core temperature increased to 140°C, the connector temperature only reached 100.15°C, showcasing the liquid insulation's superior ability to manage thermal loads.



The delta T (temperature difference) between the cold shrink joint and the M-Series joint was substantial. In cold shrink systems, the connector temperature was 160°C at a core temperature of 130°C, whereas in the M-Series joint, the connector temperature was only 92.85°C under the same conditions. This represents a temperature difference of 67.15°C, clearly illustrating the effectiveness of liquid insulation in maintaining a lower operating temperature within the joint.

Discussion

The results of this study highlight the significant thermal advantages of liquid insulation over solid insulation in cable joints, particularly in the context of modern power grids that are subject to higher loads and harmonic distortion due to renewable energy integration. The thermal performance of the liquid-insulated M-Series joint was notably superior, with connector temperatures remaining far below those observed in the solid-insulated cold shrink body. This is a critical finding, as overheating is one of the primary causes of cable joint failure, and mitigating this risk is essential for ensuring the reliability of power grids.

The lower connector temperatures observed in the liquid insulation joint can be attributed to the liquid's ability to dissipate heat more efficiently. Liquid insulation provides a more uniform distribution of heat and can absorb thermal stresses, reducing the likelihood of hotspots within the joint. In contrast, solid insulation tends to trap heat, leading to a build-up of thermal energy, which can cause insulation degradation and increase the risk of failure.

Furthermore, the ability of liquid insulation to handle imperfections in cable preparation during installation offers another practical advantage. Human error, such as uneven cable peeling, can create weak points in solid-insulated joints that are more susceptible to failure. Liquid insulation, however, is more forgiving in such cases, as it can fill in gaps and compensate for minor installation flaws, improving the overall reliability of the joint.

In conclusion, liquid insulation provides a clear performance advantage over solid insulation in cable joints, particularly in medium-voltage systems. By reducing the risk of overheating and offering greater tolerance to installation errors, liquid insulation could play a key role in improving the reliability and durability of cable joints in future power grids.

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