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High Voltage Heads UNDERGROUND

Underground cables have provided a necessary substitute to the transmission of power through overhead lines for over 140 years, especially in urban areas and underwater. Throughout this time, electrical engineers have introduced improved insulating materials and cable designs, and developed solutions to unforeseen modes of breakdown and failure.

Screening the core

By the mid-1920s it had become clear that 22,000V provided a natural limit for belted three-core cables buried underground—ten times less than the maximum overhead line voltage at the time. Out-of-phase currents gave rise to complex electrical stresses that exposed the weak tangential dielectric strength of paper insulation, causing it to degrade and ultimately fail. The Hochstadter screen resolved this problem by enveloping each core within an earthed screen. This consisted of a thin metal sheath interwoven with the outer layer of paper insulation. Patented by Martin Hochstadter in 1914, this type of screened cable was first put into operation in 1920. Hochstadter cables rated up to 60kV became standard by the end of the 1920s.

"The Hochstadter screen… was the most important single contribution to the art of cable making during the first quarter of the twentieth century."
Robert M. Black, *The History of Electric Wires and Cables* (1983)

Three-core oil-filled cables, like this Okonite medium voltage cable, incorporated three separate open steel ducts located between the cores. Single-core cables featured a central duct.

Filling the void

At voltages higher than 60kV, thermal expansion due to the heating effects of electrical current introduced voids in between the helical cores. To deal with this problem, the Chief Engineer of the Pirelli Company of Milan, Italy, Luigi Emanueli, proposed to allow a thin mineral oil to flow in and out of pressurized reservoirs as the cable cores expanded and contracted with temperature. Following successful field trials in the mid-1920s, the Edison Company installed 132kV oil-filled Pirelli cables underneath Chicago and New York. Oil-filled cables rapidly became the norm for high-voltage transmission and were manufactured under license worldwide.

Unwrapping the paper

The mid-1920s also marked the beginning of the development of synthetic insulating materials. Around 1935 polyvinylformal resins (Formvar) offered a more economical alternative to cotton in motors and transformers. But it was not until the invention of cross-linked polyethylene (XLPE) in 1963 by Al Gilbert and Frank Precopio, working in GE's New York research laboratory, that impregnated paper insulation in underground high voltage power cables began to be displaced. XLPE matched the temperature rating of impregnated paper insulation but with a dielectric loss factor an order of magnitude less. These advantages led to the rapid uptake of XLPE cables. During the 1970s, however, engineers soon encountered similar challenges to those that afflicted underground cables over one hundred years ago: "water treeing" (below center and right) caused by moisture ingress in medium voltage cables (<69kV) and, at higher voltages, "electrical treeing" (below left) due to high-permittivity contaminants. The relationship between electrical tree formation and partial discharge in cables rated up to 500kV and beyond remains a critical area of research.

This recent 132kV XLPE submarine power cable could carry 180MW of power from an offshore wind farm to the UK national grid. Optical fibers provide a means of monitoring the cable's temperature.