Superconducting Transmission & Distribution Cable

Superconducting High Power Transmission and Distribution Cable transmit 5 to 10 times the electrical current of traditional copper or aluminum cables with significantly improved efficiency. Superconducting power cable systems consist of the cable, which is comprised of 100’s of strands of superconducting wire wrapped around a copper core, and the cryogenic cooling system to maintain proper operating conditions.

Superconducting cables offer solutions for utilities facing challenges that include:
- Substation footprint availability
- Lack of available rights of way
- Capacity load relief
- Retire/Avoid substation
- High load connections between substations
- Retire/replace transmission cable

Superconducting power cables are particularly suited to high load areas such as the dense urban business districts of large cities, where purchases of easements and construction costs for traditional low capacity cables may be cost prohibitive.

Superconducting power cables act as a bridge between electric energy transmission and distribution. Transmission voltages range from 60 kV to 765 kV and distribution voltages range from 5 kV to 46 kV. For superconducting cables this medium voltage feeds to load pockets in dense urban areas. In these high demand zones the grid is often saturated with aging infrastructure. HTS technology brings a considerable amount of power to new locations where the construction of additional transmission to distribution substations, with major transformer assets, is simply not feasible nor economical.

Another potential use of superconducting power cables is to improve grid power transmission by connecting two existing substations. In dense urban environments many substations often reach capacity limits and require redundant transformer capacity to improve reliability. Superconducting cables can tie these existing stations together, avoiding very costly transformer upgrades and construction costs.

While market interest in superconducting wire for AC Power Cable applications is extremely high, the industry is struggling to lock in a consistent supply at large volumes. The Edison Electric Institute estimates that the US transmission grid has over 200,000 miles of high-voltage transmission lines. From 2000 to 2010, US electric utilities invested more than $74.8 billion on transmission systems alone as population growth and aging infrastructure drove increased energy demand. Estimates show that $275 Billion worth of transmission cable will be needed globally between 2010 and 2019. Yet, market commercialization is also highly dependent upon cost reductions for cable components like the superconducting wire, cryostats and cooling stations.
Superconducting Transmission & Distribution Cable (cont.)

Industry wide, superconducting wire needs significant performance improvements to enable wide commercialization. Cable manufacturers are currently using wire carrying close to 90 Amps/cm widths. This low current capacity requires cable producers to buy more wire to achieve the desired current density. Higher capacity wire will increase current density and decrease the amount of wire required. Initially, cable manufacturers believe that 500 Amps/cm width is the ideal wire performance, moving to >1000 Amps/cm in 2016 and beyond.

Constructing superconducting high power transmission cable requires a great deal more superconducting wire than one might expect. Independent of the design, each cable type contains hundreds of strands of layered superconducting wire. Strands of superconducting wire are wound around a core in a one direction and then the next layer is wound in the opposite direction. This process is repeated many times. Cable manufacturers use more than 400 kilometers of superconducting wire (4mm wide @ 90 A/cm) to construct a single kilometer of superconducting power cable. The number of superconducting wire strands is determined by the wire performance. The higher the performance (increased current density) the fewer strands are required for the same power capacity. Thus, a significant increase in wire performance will greatly reduce the number of wire strands/layers needed to produce the same length power cable today, which in turn will reduce manufacturing cost, sheath diameter, transportation and handling.

High power copper based cables endure a great deal of heat at high voltages. As electrical current increases, the copper heats and causes the wire to expand. The effect of heating and cooling, expanding and contracting causes fatigue (known as “thermal cycling”), and degrades the reliability of the insulation layer. Conductus® based power cables operate at liquid nitrogen temperatures (77 Kelvin) and will not fatigue from changes in electrical current. Cables manufactured with Conductus® are all designed to operate at 77 K so that cable manufacturers can leverage the benefits of liquid nitrogen. Although prototype designs exist to use MgB2 based superconducting cables, it will be far too costly for commercial applications as the cooling with liquid hydrogen has various drawbacks and high cost. Liquid nitrogen is an abundant and cost effective cryogenic refrigerant source and a key component to cables manufactured with Conductus® wire.

Power cable manufacturers are very familiar with liquid filled cable systems. Today, some power distribution cables of 10kV or higher are insulated with high pressure oil, and are run in a rigid steel pipe, semi-rigid aluminum or lead sheath. Oil is used to maintain the integrity of the cable insulation. At higher voltages the oil is kept under pressure to prevent formation of voids that would allow partial discharges and ultimately a short circuit. Pumping systems are used to maintain oil pressure and viscosity. This experience with electrical systems using a liquid medium is helping superconducting cable adoption. Migrating to liquid nitrogen based systems versus oil seems reasonable.

There are several unique configurations utilized to construct an superconducting power cable:

- **Concentric** - This configuration winds three phases concentrically on a single inner copper core. This superconducting cable design integrates each AC phase into a single cable stacked on top each other. The Triax design is exclusive to NKT and Southwire, although other cable manufacturers, like Nexans, use concentric designs.
- **3 HTS Cables in one Cryostat** - A second cable design consists of three separate, single-phase, cables encapsulated in a single cryogenic envelope. This cable type is the most widely deployed.
- **3 HTS Cables and 3 Cryostats** - A third type of HTS cable uses three individual, single-phase cables, each encapsulated in an individual cryogenic envelope.