The superconducting cable, a rail traffic enabler

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ABSTRACT

The proportion of urban population is expected to keep on growing in the coming decade. This will require to develop mass transit with, in particular, electrically powered trains. But providing additonal power to the railway grid is often quite complex in congested cities where space is lacking for additional rights of way or even for additional cables in existing rights of way. High Temperature Superconducting (HTS) cables, through their minimized land take, constitute a quite efficient solution to address these issues.

In a HTS cable, the core is composed of cuprate-based HTS tapes. They reach their superconducting properties, conducting current without any significant loss, when cooled at -200°C thanks to a continuous flow of liquid nitrogen. The dielectric is a paper-polypropylene composite impregnated with the flowing liquid nitrogen. A flexible vacuum-insulated cryostat provides the thermal insulation required to maintain the HTS conductor at about -200°C while minimizing the energy consumed by the refrigeration system which is typically installed at one of the two cable ends. HTS cables differ from copper or aluminium cables through their ability to carry much higher currents, which can exceed 5 kA in AC systems and several tens of kA in DC, in minimized footprints. As for resistive systems, cable unit lengths can be linked through joints whereas terminations provide the connections to the grid.

The ongoing project SuperRail for SNCF in Montparnasse, one of the largest railway stations in Paris, perfectly illustrates these benefits. Only HTS cables can provide the power required through the few empty ducts available to connect Montparnasse tracks to a downtown Paris substation. This project consists in installing two 1500 V DC cables, carrying up to 3500 A each, in 100 mm ducts. A prototype cable loop will be tested in the SNCF laboratory before the manufacturing and installation of the two cables.

KEYWORDS

SuperRail, HTS cable, railway grid.

INTRODUCTION

Railway grid architectures must be adapted to growing transportation needs in ultra-urban areas and High Temperature Superconducting (HTS) cables constitue a quite attractive solution to resolve issues specific to densely-populated areas [1,2].

The French railway company SNCF has started to investigate how HTS cables could be integrated in its power grid. Indeed, such cables constitute an unmatched solution to bring high currents, and therefore high powers, in very compact rights of way. A first project, SuperRail, started about one year ago. It aims at adding two high-capacity 1500 V DC cables between a substation and railway tracks feeding the Paris Montparnasse station.

SUPERCONDUCTING MATERIALS

Introduction to superconductivity

Superconductivity was discovered in 1911 by Heike Kamerlingh Onnes. Superconductors differ from other materials through their absence of electrical resistance when cooled at a sufficiently low temperature which depends on the material involved. Owing to the absence of resistance, no Joule losses are dissipated when a current is flowing through the superconductor and there is no voltage drop. However, cooling at a quite low temperature, typically with liquid helium at -269°C, has been needed for many decades to reach the superconductive state. The situation drastically changed in 1986 when High Temperature Superconducting (HTS) materials, only requiring cooling with liquid nitrogen at -196°C, were discovered by Georg Bednorz and Alex Müller. Only one year after they were awarded the Nobel Prize in Physics. All these HTS materials are copper oxide-based ceramics. This major step forward made economically viable new applications such as superconducting cables for power grids.

HTS tapes

Two types of HTS tapes have been used in power cables. A first generation, consisting of tens of $Bi_2Sr_2Ca_2Cr_2Ca_2Cu_3O_{10-x}$ (Bi-2223) filaments in a silver matrix, was developed [3].

Figure 1: Bi-2223 HTS tape

Today, most of HTS tape manufacturers are focusing on the second generation [4,5], i.e. coated conductors composed of a thin layer of $YBa_2Cu_3O_{7-x}$ (YBCO) on a metallic substrate in combination with some buffer layers (Figure 2). A protective layer and a shunt are typically added. Yttrium can be replaced by other rare earths such as Gadolinium and Holmium. All these HTS tapes are 3 to 4 mm wide with a thickness of 400 µm or less.

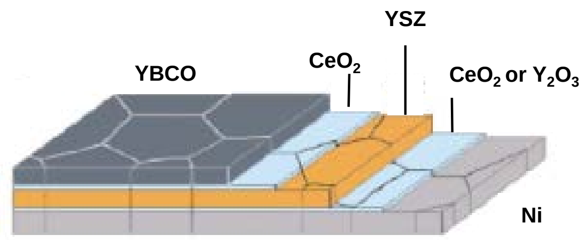

Figure 2: YBCO HTS tape