Hybrid energy transfer lines with liquid hydrogen and superconducting cable - first experimental proof of future power lines

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ABSTRACT

The transfer of high power flow over long distances will be the one of the major task for energetics in this century. Liquid hydrogen attraction is clear -- it has the highest energy content of any known fuel and when it's burned, the "waste" is water. It could be transferred via cryogenic tubes like other cryogen liquid. Moreover, with the use of "gratis" cold to cool a superconducting cable an extra electrical power can be delivered with the same line. One of solutions is to use DC power cables made of cheap MgB_2 superconductor with single phase liquid hydrogen as a cooler and energy carrier. The team of Russian researchers developed and tested the two first in the world prototypes of the future hydrogen and superconducting energy transport systems. Two systems with 10 m length (in 2011) and 30 m length (in 2013) has been developed and tested. The first system with 2.5 kA cable and outer diameter ~80 mm could deliver ~30 MW of chemical energy by liquid hydrogen and ~ 50 MW of electrical power at 20kV and 2.5 kA, i.e. ~80 MW in total. The second system with diameter ~120 mm underwent high voltage test at 50kV DC and could deliver ~55 MW of chemical energy by liquid hydrogen and ~ 75 MW of electrical power at 25kV and 3 kA or ~130 MW of power in total. Details of hybrid energy transport lines and their test results are presented.

KEYWORDS

Liquid hydrogen, superconducting cables, MgB_2, energy transmission.

INTRODUCTION

Energy transfer problem is as much important as its production. The future power transmission demands could be more than tenths of GW with thousands kilometers for delivery. Some successes in high power liquid helium cooled superconducting cables in the end of 70-ties had not further developments due to high cost of helium cooling [1], [2]. The discussions about high power superconducting grids renewed again with HTS discovery [3]. One of ideas that were in the air for a long time is to use the liquid hydrogen both as a cryogen for superconducting cable and as an extra fuel to provide a very high flow of the energy. That means hybrid energy transfer line or super-grid idea [4]. This idea became more attractive as the necessity to use of hydrogen in the power energetics and for other purposes becomes a rather popular point of view. Hydrogen has highest fuel efficiency among others – 120 MJ/kg. Hydrogen is the best cryogen as well having the cooling capacity 446 kJ/kg against 199 kJ/kg for LN_2. Therefore, the idea to place into a transfer line with liquid hydrogen a superconducting cable to transmit the electricity in parallel is quite natural. The idea of hybrid energy transfer has been discussed in [5], [6], [7] as well.

This theoretical idea had needed the experimental realization. It became even more interesting after discovery of MgB_2 superconductor that can work at liquid hydrogen and it is much cheaper than HTS conductors as it was mentioned in [8], [9]. The first practical experimental realization of the hybrid energy transfer method is presented in this paper.

RUSSIAN PROGRAM FOR HYBRID ENERGY TRANSFER LINES

The Russian project in hybrid energy transfer lines so far has been performed in two stages described below.

First stage and first tests

The Russian program in study of hybrid energy transfer has been initiated by Russian Academy of science in the framework of the program "Basic Principles of Development of Power Systems and Technologies, Including High Temperature Superconductors" supported by the Presidium of the Russian Academy of Sciences. The first stage of the project started in 2011. The details of the first stage of the project are described in [12], [13], [14].

The choice if superconductor was obvious: reacted MgB_2 produced by Columbus Superconductor (CS) SpA in Genoa, Italy [15]. It was cheap enough and easily purchasable. We selected rectangular tape with 3.65 mm × 0.65 mm size, because with the tape we could implement our standard technology developed for HTS power cables [16]. The expected critical current of this tape at 20 K was ~520 - 540 A.

The design of a prototype of a superconducting MgB_2 cable consists of three elements: a former, current carrying layers and insulation (Fig. 1) [12]. The former is a central element that performed the supporting function as well as a protection function in case of fault.

The superconducting current carrying path consists of two serially connected layers; each of them consists of five MgB_2 tapes helically wound on the former. The number of tapes has been selected to ensure the maximum current not more than 3 kA inasmuch as DC power supplies limited us by this current.