Design of 10 kA DC terminal connector for HTS cable

Abhay Singh Gour[1], Pankaj Sagar[1], Sudharshan H[1], R. Karunanithi[1] and V. V. Rao[2]

Centre for Cryogenic Technology, Indian Institute of Science, Bangalore[1]
Cryogenic Engineering Centre, Indian Institute of Technology, Kharagpur, India[2]
abhay.s.gour@gmail.com

Abstract

HTS cables are designed to carry bulk power with high ampacity in superconducting state. These cables require terminal connectors of same ampacity to transfer power from power converter module at room temperature to the HTS cable maintained at cryogenic temperature. This paper deals with thermal analysis of 10 kA DC terminal connector for HTS cable. The ohmic losses were computed which are used as input for steady state thermal analysis of HTS terminal connector. Based on the thermal gradient obtained from thermal analysis length of conductor for terminal connector is calculated for thermal stability of HTS cable.

Introduction

The terminal connectors have the same ampacity as that of connected HTS cable. HTS cable terminal design is complicated because of large temperature variation (77 K to 300 K), operating voltage, high ampacity and its integration and isolation with vacuum and cryogenic system. In this paper, design of HTS DC cable terminal is discussed for operating voltage of 300 V and 10 kA. This involves dimension optimization of cable terminal conductor, location of LN2 and vacuum feedthroughs to maintain the temperature gradient along the length of conductor. An FEM based thermal analysis was carried out for different heat loads and feedthough positions.

HTS DC cable description

Fig. 1 shows the detailed view of HTS cable. It comprises of HTS wire is wounded on supporting tube and surrounded by electrical insulation material enclosed inside a liquid nitrogen tube. The liquid nitrogen tube is thermal insulated by vacuum tube and non metallic jacket as shown in Fig. 1.

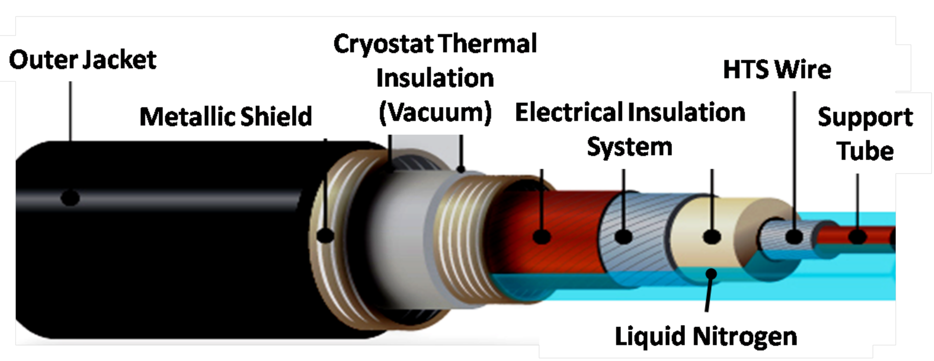

Figure 1: The detailed view of HTS cable

Design considerations for HTS cable

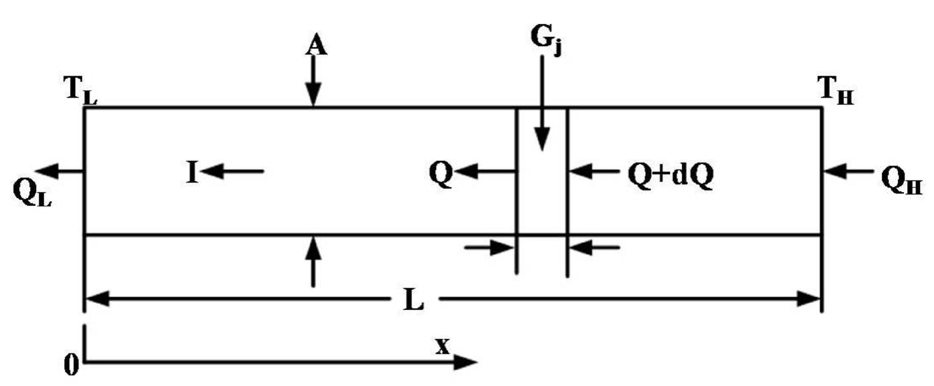

Figure 2: Schematic of conduction cooled conductor

Eq. 1 defines heat flow in a conduction cooled conductor.

$$\frac{d}{dx}[k(T)A\frac{dT}{dx}] + \frac{\rho(T)l^2}{A} = 0 \tag{1}$$

The first term of Eq. 1 corresponds to conduction heat load and second term corresponds to joule heat produced by the current flowing through the conductor. Heat conduction per unit length is given by Fouriers law of thermal conduction (Eq. 2).

$$\frac{dx}{kA} = \frac{dT}{Q} \tag{2}$$

Combining Eq. 1 and Eq. 2, the net heat load at a given temperature (T) is given by

$$Q(T) = \sqrt{Q_L^2 - 2l^2 \int_{T_l}^{T} k\rho dT} \tag{3}$$

The ratio of length to cross-section is given by Eq. 4.

$$\frac{L}{A} = \int_{T_l}^{T_n} \frac{k}{\sqrt{Q_L^2 - 2l^2 \int_{T_l}^{T} k\rho dT}} \tag{4}$$

When the conductor is conducting a current I, the minimum heat leakage QL to cryostat can be achieved by taking the minimum of Eq. 3given by Eq. 5.

$$(Q_L)_{min} = I\sqrt{2\int_{T_l}^{T} k\rho dT} \tag{5}$$

$$(\frac{IL}{A})_{opt} = \int_{T_l}^{T_n} \frac{k}{\sqrt{2\int_{T_l}^{T} k\rho dT}} \tag{6}$$

$$I_{opt} = \frac{A}{L}\int_{T_l}^{T_n} \frac{k}{\sqrt{2\int_{T_l}^{T} k\rho dT}} \tag{7}$$

When the transport current I is Iopt , the heat leakage from the conductor to the cryostat is minimal.

Design specification and Simulation

An FEM simulation for the HTS cable terminal was carried using Ansys thermal steady state simulation. The terminal is designed with an ampacity of 10 kA and operating voltage of 300 V.The boundary conditions and parameters used for the simulation are listed in the table 1.

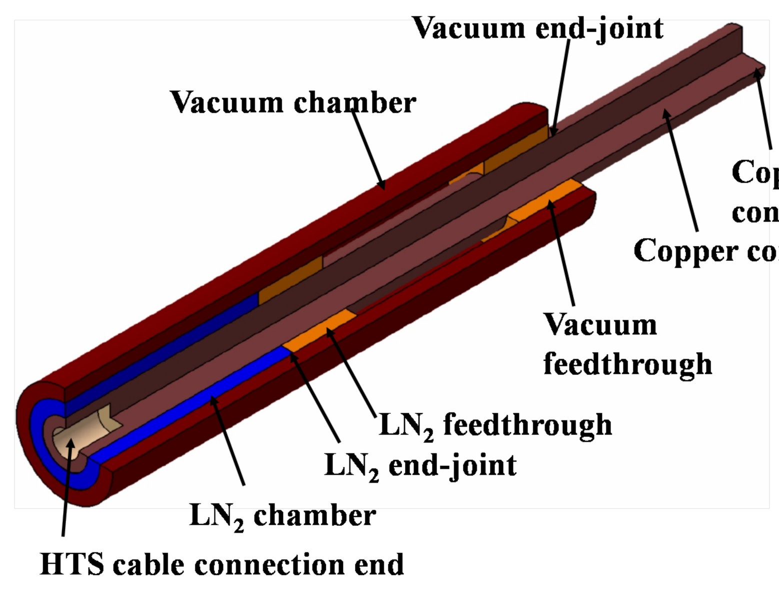

Figure 3: The sectional 3-D drawing of HTS terminal

Results and Discussions

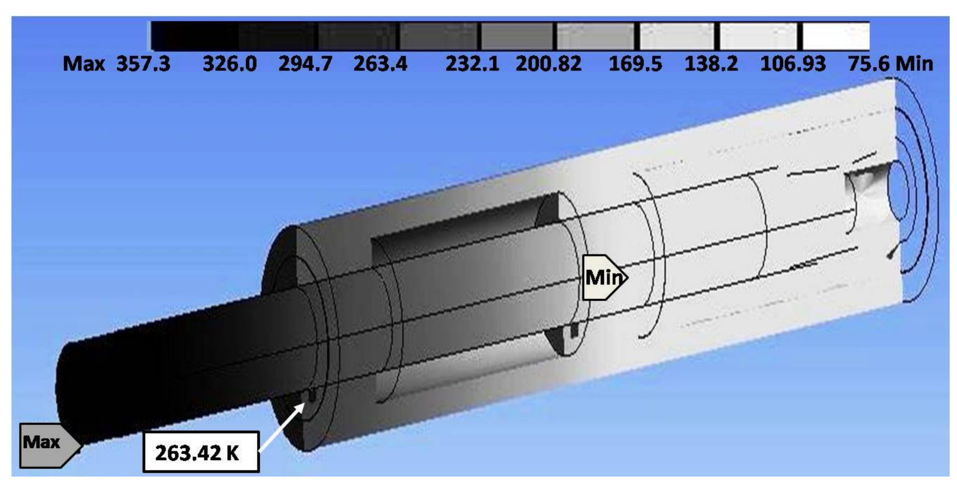

Figure 4: The FEM simulation results for heat load of 600 W, feedthorugh distance is 250 mm and conductor length in LN_2 is 300 mm

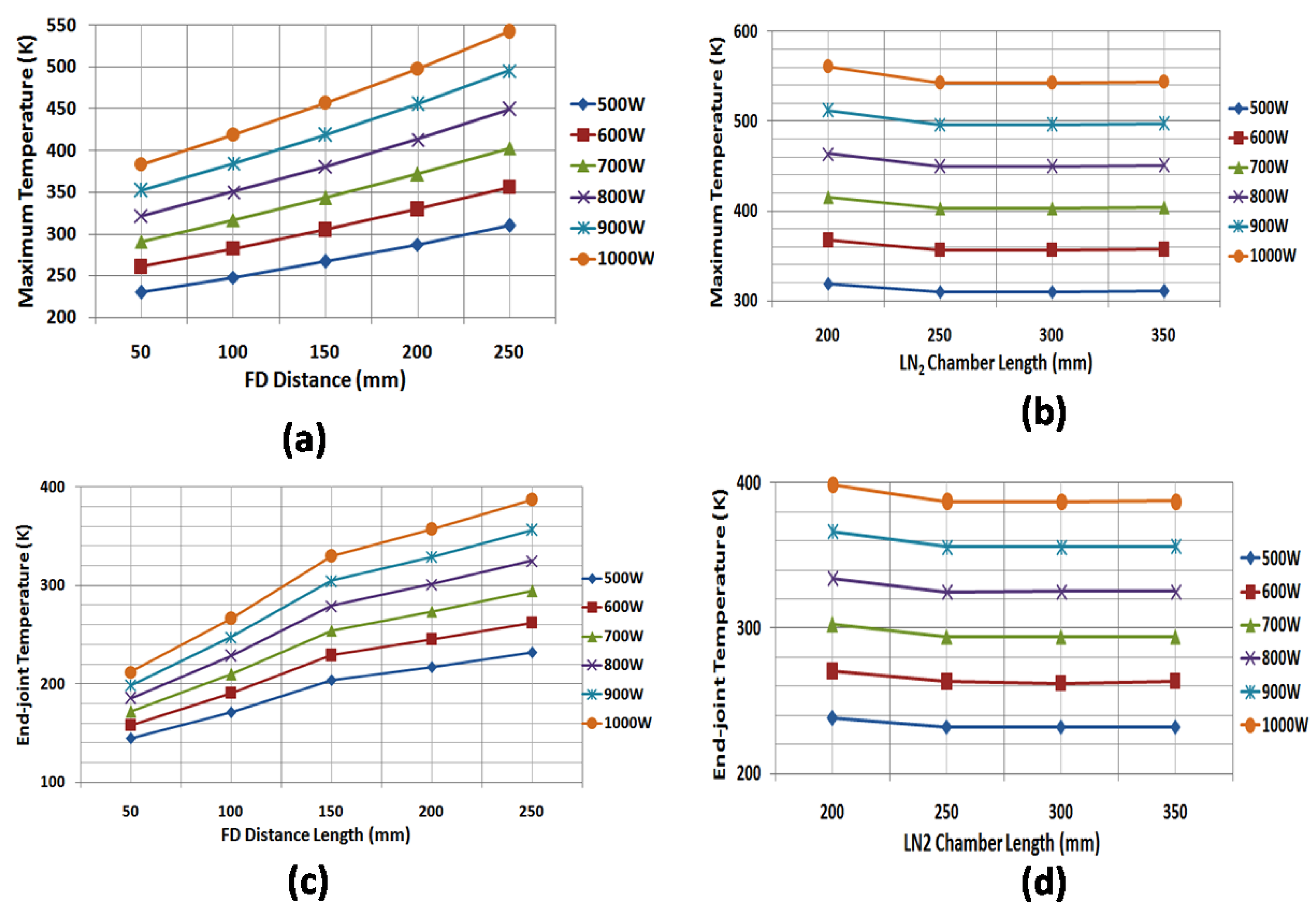

Figure 5: (a) Maximum temperature with change in FT distance for constant conductor length in LN2 300mm. (b) Maximum temperature with change conductor length in LN2 for a fixed feedthorugh distance of 250 mm. (c) End-joint temperature with change in FT distance with LN2 chamber length 300 mm (d) End-joint temperature change in LN2 chamber conductor length with FT distance 250 mm

Conclusions

The thermal analysis 10 kA DC terminal connector for HTS cable was carried out. The ohmic losses were computed and were used as heat load input for the FEM simulation. The position of the LN2 and vacuum feedthrough were optimized to have maximum temperature and end joint temperature within the limits of 360 K and 280 K respectively.

References

[1] Woo-Jin Kim, Hae-Jong Kim, Jeon-Wook Cho, Yeon Suk Choi, and Sang-Hyun Kim. Electrical and mechanical characteristics of insulating materials for hts dc cable and cable joint. *IEEE Transactions on Applied Superconductivity*, 25(3):1–4, 2015.

[2] Jian Sun, Hirofumi Watanabe, Makoto Hamabe, Toshio Kawahara, and Satarou Yamaguchi. Effects of hts tape arrangements to increase critical current for the dc power cable. *IEEE Transactions on Applied Superconductivity*, 23(3):5401104–5401104, 2013.