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Design of a novel inductive type fault current limiting HTS power cable

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1 Introduction

In a power system, fault currents are on the rise and are becoming a common problem. There are several methods to restrict fault currents. However, the methods can involve instability of the power system. In Republic of Korea, Korea Electrotechnology Research Institute is carrying out the development of a 154 kV class high temperature superconductor (HTS) cable with fault current limiting function since May 2017. In this project, a novel inductive type fault current limiting (NIFCL) HTS power cable is proposed. This paper presents design of a NIFCL-HTS cable for trans-mission system, which takes the form of wound cable with iron core based on configuration of single phase in one cryostat. The results of design are discussed in detail.

2 Concept of NIFCL-HTS power cable

A. Principle of the cable

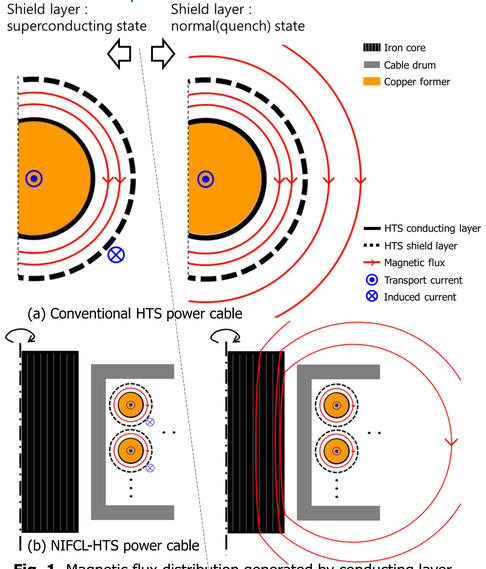
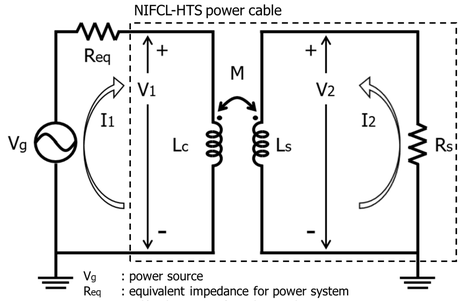


Fig. 1. Magnetic flux distribution generated by conducting layer depending on quench of shield layer.

B. Characteristics of the NIFCL-HTS power cable



Vg : power source
Req : equivalent impedance for power system
Lc : self inductance of conducting layer
Ls : self inductance of shield layer
M : mutual inductance between conducting and shield layer
Rs : resistance of shield layer
V1, V2 : voltage drops on conducting and shield layer
I1, I2 : currents on conducting and shield layer

Fig. 2. Equivalent circuit diagram for the NIFCL-HTS power cable applied to a power system.

Circuit equation for the NIFCL-HTS power cable in a power system

$$V_g = (R_{eq} + XL_c)\, I_1 + X_m I_2$$

$$0 = X_m I_1 + (XL_s + R_s)\, I_2 \quad \text{.....Circuit equation}$$

$$I_1 = \frac{(XL_s + R_s)\, V_g}{(R_{eq} + XL_c)(XL_s + R_s) - X_m^2} \quad \text{.....Current in conducting layer}$$

$$I_2 = \frac{X_m V_g}{-(R_{eq} + XL_c)(XL_s + R_s) + X_m^2} \quad \text{.....Current in shield layer}$$

$$Z_{power\ system} = \frac{V_g}{I_1} = R_{eq} + XL_c - \frac{X_m^2}{(XL_s + R_s)} \quad \text{.....Total impedance}$$

$$Z_{NIFCL-HTS\ power\ cable} = \frac{V_1}{I_1} = XL_c - \frac{X_m^2}{(XL_s + R_s)} \quad \text{.....Impedance of NIFCL-HTS cable}$$

Table I Parameters for the performance characteristics prediction of the NIFCL-HTS power cable

Parameters	Value	Parameters	Value
Vg	88.912 kV(L-to-G)	Lc	2.5/5/10/20 mH
Req	1.411 Ω	Ls/M	2.45/4.9/9.8/19.6 mH
Maximum fault current	63 kA	Rs	0.01~30 Ω
		f/ω	60 Hz / 376.99

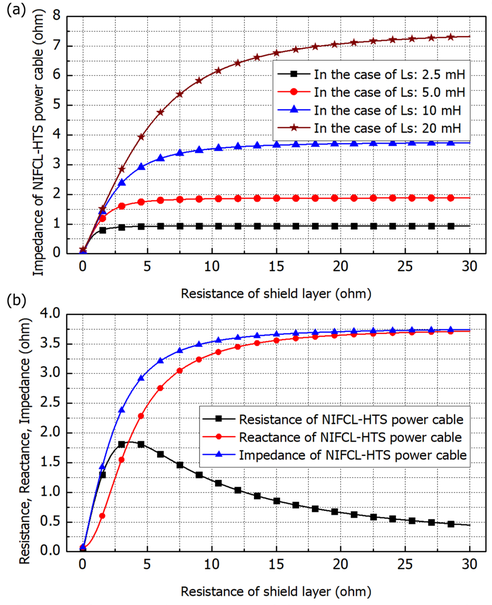


Fig. 3. Performance characteristics of the NIFCL-HTS power cable depending on resistance of shield layer (a) effect of self-inductance for conducting layer (b) impedance, reactance and resistance components in the case of 10 mH Ls.

3 Design of a 154 kV class NIFCL-HTS power cable

A. Performance prediction model of the cable

Table II Specifications of designed 154 kV class NIFCL-HTS power cable

Parameters	Value	Parameters	Value
Outer radius of conducting layer	22.0 mm	Outer radius of cryostat	75.0 mm
Outer radius of insulation layer	36.3 mm	Number of turns	36 turns
Outer radius of shield layer	37.1 mm	Length of wound cable	492 m

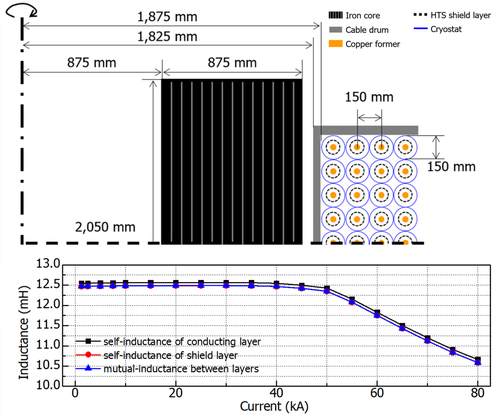


Fig. 4. Structure of the 154 kV class NIFCL-HTS power cable; axisymmetric structure and upper half, and inductance components of the cable

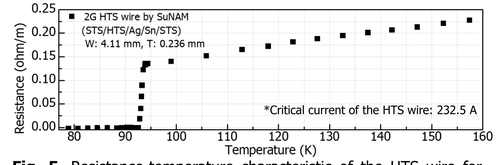
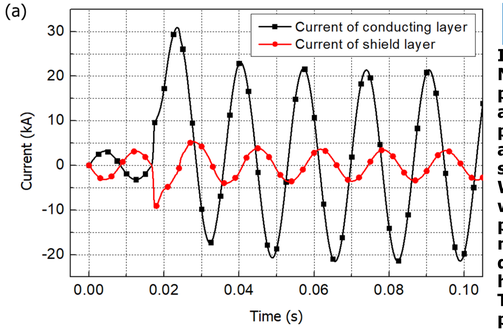


Fig. 5. Resistance-temperature characteristic of the HTS wire for shield layer of the 154 kV class NIFCL-HTS power cable.

B. The results



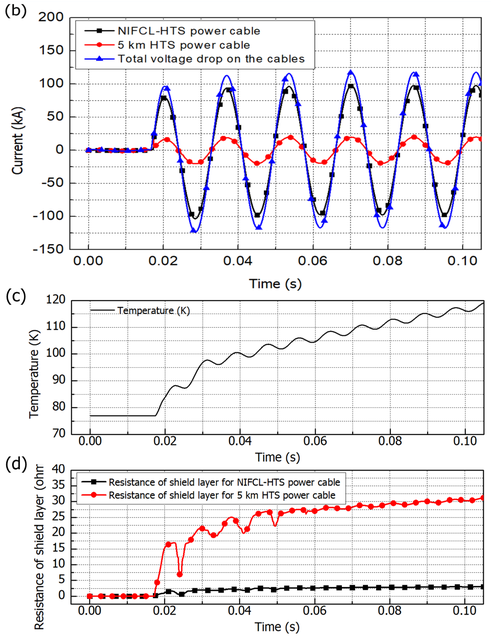


Fig. 6. Performances of the NIFCL-HTS power cable connected with 5 km long HTS power cable during a fault period (a) current limiting effect based on 63 kArms (b) voltage drop on the cables (c) temperature of the HTS shield layer (d) resistance of the HTS shield layer.

4 Conclusions

In this paper, the authors were proposed and designed a NIFCL-HTS power cable to review its possibility. The principle of the cable was explained and when it is applied to a power system, the characteristics was predicted based on circuit theory. And also, the electrical and thermal behaviors were analyzed through FEM simulation.

When the cable is applied on a transmission system, which has HTS power cable, it is expected to show good performances for current limiting. In order to have noticeable performances, it is needed to research and develop proper HTS wire having high resistance and heat capacity.

To confirm its possibility and to evaluate the effect, the prototype NIFCL-HTS cable will be tested early next year.