Design optimization of flat HTS three-phase cables based on coated conductors

SuperOx

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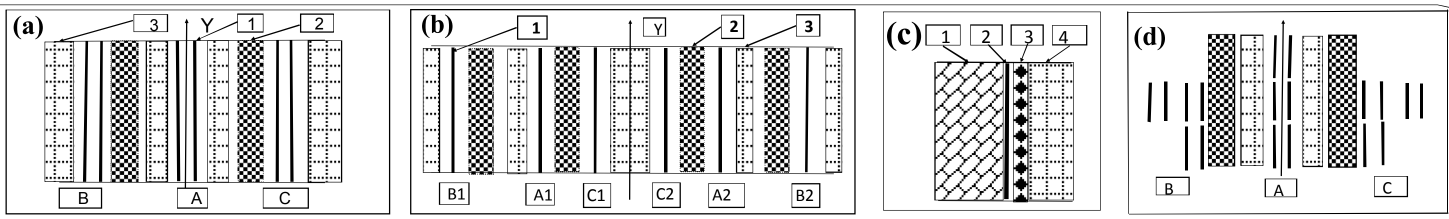
INTRODUCTION

In the applied superconductivity laboratory of JIHT RAS are steadily in progress works on the design optimization of high temperature superconducting (HTS) cables with coated conductors (CC's) as current-carrying elements [1, 2]. It is aimed to the minimization of the total AC losses $\boldsymbol{P}_S$ represented as a sum of hysteresis $\boldsymbol{P}_h$ and eddy current ones $\boldsymbol{P}_e$ calculated as described in [5, 6]. Flat three-phase cables (with the extended rectangle cross-section shape), due to the interaction of magnetic fields of phases, are similar to coaxial designs, have the same currents penetration pattern and, hence, the same AC losses values. In many aspects flat cables have a lot of advantages, e.g, better flexibility, cooling conditions etc. That's why, in many instances they can compete with coaxial designs. Here we analyze two methods of optimization: using of CC's modified configuration and butt ends shielding of the cable cross-section. The former allows diminishing of AC losses due to the decreasing of the distance between the layers of tapes, measured between CC's coatings, from 84 to 4 μm, and the latter – due to the suppression of the perpendicular magnetic field component on the butt ends. Both the methods allow diminishing of AC losses in 2 – 3.5 times at the most important for practice current amplitudes values.

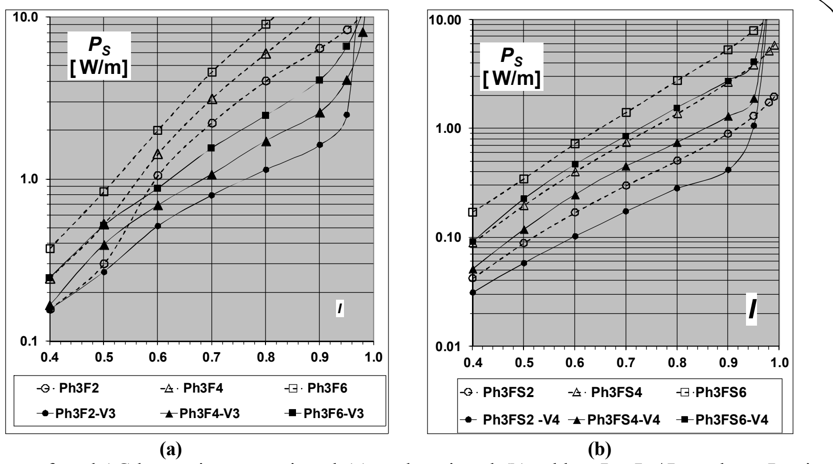


(a), (b) – Non-sectioned (Ph3F) and sectioned (Ph3FS) cables: 1 – HTS layers (30 tapes per layer), 2 – electric insulation, 3 – extra copper layers, A,B,C – cable phases (in a sectioned cable the sections of phases are connected in parallel); **(c)** – standard «SuperOx» CC's [3,4] (δ – is the layer thickness). Layers LTR: substrate δ = 50 μm, HTS δ = 1 μm, silver δ = 2 μm, copper δ = 40 μm. The tape width is 4 mm. In CC's with the modified configuration the copper is transferred to the substrate side. Positioning of these CC's in the layers of cable phases with the silver coatings faced to each other allows a reduction of the distance between HTS layers to 4 μm. **(d) –** schematic diagram of CC's positioning in cable butt ends with the shielding of the latter (variants V3, V4).

Structures of flat cables.

The critical current of a single tape is taken 85 A, respectively, for all the cables, the critical current of a phase is J_{CF} = 5,1 кА , the cable height is H=123 mm. The total cable thickness d is given without the thickness of external insulation layers. The cable structure is described as follows (LTR): A_i, B_i, C_i – are the phases of layer i, Cu "xx" – is the extra copper layer thickness [mm], in "xx" – is the insulation layer thickness [mm]. Modifications of cables according to variants V3 and V4 do not change the characteristics given in the table below.

Type	d [mm]	Srtucture
Ph3F2	7,58	Cu1,0-B_1-B_2-in2-Cu0,5-A_1-A_2-Cu0,5-in2-C_1-C_2–Cu1,0
Ph3F4	11,58	Cu1,0-B_1-B_2-in4-Cu0,5-A_1-A_2-Cu0,5-in4-C_1-C_2–Cu1,0
Ph3F6	15,58	Cu1,0-B_1-B_2-in6-Cu0,5-A_1-A_2-Cu0,5-in6-C_1-C_2–Cu1,0
Ph3FS2	11,6	Cu0,5-B_1-in2-Cu0,5-A_1-in2-C_1-Cu1,0-C_2-in2-A_2-Cu0,5-in2-B_2-Cu0,5
Ph3FS4	19,6	Cu0,5-B_1-in4-Cu0,5-A_1-in4-C_1-Cu1,0-C_2-in4-A_2-Cu0,5-in4-B_2-Cu0,5
Ph3FS6	27,6	Cu0,5-B_1-in6-Cu0,5-A_1-in6-C_1-Cu1,0-C_2-in6-A_2-Cu0,5-in6-B_2-Cu0,5



Power of total AC losses in non-sectioned **(a)** and sectioned **(b)** cables. $\boldsymbol{I} = \boldsymbol{J}_0/\boldsymbol{J}_{CF}$, where $\boldsymbol{J}_0$ – is the phase current amplitude. In variant V3 are used modified configuration tapes, in V4 – standard ones. Butt ends shielding is used in both variants.

CONCLUSIONS

AC losses in HTS cables hardly affect the economic characteristics of power systems (including the choice between AC and DC cables), if they are much lower than natural cryostat heat losses (ca. 3 Wt/m). Within the practically important range of current amplitudes ($I \leq 0,8$) the most of cables modified as V3, V4 satisfy this criterion. As a result of these modifications, the value of $\boldsymbol{P}_h$ in non-sectioned cables decreased more significantly than $\boldsymbol{P}_e$. That's why, the contribution of the latter in $\boldsymbol{P}_S$ became essential (>50%), and their reduction can be considered as an important reserve for the further $\boldsymbol{P}_S$ decreasing. The value of $\boldsymbol{P}_e$ can be significantly decreased by a reduction of the extra copper amount in a cable or by replacement of it by another material with the lower electric conductivity. But the opportunity to do this should be subject of further investigations

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