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Coil optimization for HTS machines

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Abstract
- This paper presents topology optimization of a HTS racetrack coils for large synchronous machines with HTS excitation winding. The topology optimization is used to acquire optimal coil design for the excitation system for machines with 3T air-gap flux density. Several tapes are evaluated and the optimization results are discussed.

Article investigates possibility of combination of different HTS in the coils. The optimization algorithm is formulated to minimize the cost HTS of coils. The results seems to be in favor of 1G tapes.

Optimization formulation
Topoogy optimization is used in structural studies to ensure minimum material and cost and increase robustness of the structure, especially in an application where over sizing carries high cost penalty (airplane industry).

Objective function will have several contributions in order to formulate the optimization problem properly. The Eq. 3, contains the generalized objective function which is minimized.

\[
\text{min } \text{Objectiv} = \sum_{k=1}^{3} \text{obj}_k
\]

If the optimization variable, \( \text{opt} \), is 1, the current carrying HTS will be present at that coordinates and if it is 0, not. Also the sum of all variables at specific coordinate need to be either 1 or 0, corresponding to the statement that the same space could have only one tape. However, since it is not possible to constrain the optimization variable in the Consol to only binary values, term \( \text{obj}_2, \text{obj}_3 \) penalize the all values in between. \( \text{obj}_2, \text{obj}_3 \) are corresponding to 3 T air gap flux condition and price of HTS contribution.

\[
\text{obj}_j = \sum_{j=1}^{n_{exc}} \left( \int_{\Omega_{HTS}} \left( \text{opt} - \frac{1}{2} \right) \, d\Omega_{HTS} \right)
\]

\[
\text{obj}_j = \sum_{j=1}^{n_{exc}} \left( \int_{\Omega_{HTS}} \text{opt} \cdot C \cdot d\Omega_{HTS} \right)
\]

In the case of single HTS used in the coils, for the coils made from 2G 120A tape (with relative price of 3 p.u.), the price was 0.135 p.u. The coils made from 1G 180A tape (with relative price of 2 p.u.), the price was 0.0602 p.u. The coils from ultra thin 2G 140A tape would yield the price of 0.0627 p.u., offering price improvements compared to standard 2G 120A tape and almost twice more compact coils compared to 1G 180A. The cost impact of the coil space reduction is not taken into account as an overall factor in machine design, even though it could have very big impact on price of the machine in general and cause additional savings in HTS too.

Multiple excitation currents
Now, in order to estimate a potential for savings in HTS material where several excitation currents are allowed, we have examined the case were each tape has its own current supply. This is far from realistic configuration, but this extreme case should yield the lowest amount of HTS. This means that each tape runs with its maximal safe \( J \) and give us a sense on extent of savings in ideal case.

The optimization was conducted on the coils with the same tapes as in single excitation coils. The optimization has returned 0.063 psu, 0.04 pu and 0.026 psu, as the cost for 2G-120A, 1G-180A and 2G-140A coils respectively. The optimization has confirmed that the potential for HTS reduction if multiple supplies currents are allowed. The tapes with higher nonlinear \( J-B \), as 2G at 20 K, tend to have almost twofold maximal reduction in amount of HTS where in the case of 1G at 20K, the potential for savings is smaller.

\[
\text{obj}_j = \sum_{j=1}^{n_{exc}} \left( \int_{\Omega_{HTS}} \text{opt} \cdot C \cdot d\Omega_{HTS} \right)
\]

\[
\text{obj}_j = \sum_{j=1}^{n_{exc}} \left( \int_{\Omega_{HTS}} \text{opt} \cdot C \cdot d\Omega_{HTS} \right)
\]