cryogenic space. This prediction is summarized in Table III. This indicates that the contribution from AC loss is about equal to that from cryostat and electrical bushing losses combined. It is important to realize that the transformer design presented here is particularly challenging to achieve efficiency approaching that of conventional transformer technology of the same rating. The electrical efficiency (considering only AC loss) is very good at 99.95%, but for a valid comparison we must apply a realistic cooling penalty of say 30:1 (30 W of energy to remove 1 W of heat from the cold space). Thus the overall efficiency of our 1 MVA transformer is expected to be closer to 97%. Current efficiency standards for a transformer of this rating stipulate a minimum efficiency of 99.27% - when measured at 50% of rated load [14]. Estimating AC loss at 50% of rated load produces a comparative efficiency value of about 98.5% for the HTS transformer – still somewhat short of the efficiency already attained with conventional technology.

TABLE III
PREDICTED HEAT LOAD ON CRYOGENIC SPACE AT RATED CURRENT

Source	**Heat load** (W)
Cryostat	113
Electrical bushings [13]	343
AC loss in LV [12]	390
AC loss in HV	90
Total	936

To achieve an HTS transformer with considerably higher efficiency, we consider that a commercially viable transformer will have a much higher rating and operate at higher voltages. For example a 10 MVA 66kV – 11kV transformer will have lower current electrical bushings (so reduced heat leak via this path), and marginally higher cryostat heat leak. AC loss can be expected to scale with conductor length.

IV. SUMMARY

We have presented results from experiments to determine the heat leak into the cryostat, and to accurately predict the AC loss we can expect in the Roebel cable winding of a demonstration 1 MVA three phase transformer. The predicted electrical efficiency is very good but the combined heat loads, factored by the cooling penalty associated with extracting heat from a cryogenic environment, mean that the overall efficiency of the transformer is somewhat less than existing transformer standards specify.

The future potential for a practical HTS transformer lies in higher rated and higher voltage machines, but our current project is a valuable demonstration of a particularly challenging application for HTS conductors – proving the advantages offered by Roebel cable technology in high current AC windings. Utilising 2G-HTS Roebel cable, AC loss is not a fundamental obstacle to HTS transformer commercialisation.

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