A cost effective design for the Toroidal Field Coils of EUROfusion DEMO

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Motivation
The generation of the DEMO fusion devices is expected to demonstrate the effective and reliable production of electricity. The cost of DEMO will be crucial to attract the interest of the utilities toward fusion. The effort of cost reduction must start from the design, where a large potential is not yet exploited.

Design approach for the DEMO Toroidal Field Coils

The requirements of the EUROfusion DEMO baseline in terms of peak field, ≈12.2 T, size and nuclear heat removal pre-define some top design choices, e.g. use of Nb₃Sn superconductor, He force flow cooling, Vacuum-Pressure-Impregnation (VPI). We maintain consolidated criteria for operation margin (ΔT ≥ 1.5 K), hot spot temperature (T_hot ≤ 150 K), dump voltage ≤ 5 kV to ground. The two pillars for cost effective design are:

- Graded, layer winding (no radial plates)
- React & Wind method for conductor

Graduated Layer Winding for DEMO TF coils

- Grading of the superconductor and steel jacket in each of the 12 layers → all materials cross sections tailored to the local field and loads.
- Convenient for quench protection (no regions with excessive temperature margins).
- The inter-layer joints are nested in the winding pack, without protrusion.
- The radial build of the TF winding pack is 20% smaller than by pancake / W&R method, with very large saving on the tokamak size/cost.
- The structural support is provided by the conductor conduit, at <15 €/kg instead of radial plates at 343 €/kg (ITER source).
- Based on an industrial cost estimate, the “graded layers, R&W” option is expected to cost 1/3 compared to the “pancake, W&R” option.

Outlook

- The R&W option for DEMO TF conductor has been developed and qualified by short length prototype tested in SULTAN and by mechanical analysis, demonstrating the effective use of Nb₃Sn (low thermal strain).
- Very low AC loss have been observed in the prototype test, suggesting that the same conductor layout can be used for the Central Solenoid, where the graded layers can span over different conductor technology, e.g. HTS, Nb₃Sn R&W and NbTi.
- A long length conductor manufacture is the next milestone, to be used for a demonstration high field hybrid winding.