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Conceptual Design Study of the Large Size and Low Magnetic Field Superconducting Spherical Tokamak Power Plant

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A new conceptual design of the 3GW-level, low-magnetic-field, superconducting spherical tokamak (ST) power plant was proposed as an attractive choice for tokamak fusion reactors. We reassessed a possibility of the ST as a power plant using the conservative reactor engineering constraints often used for the conventional tokamak reactor design for the first time. An extensive parameters scan which cover all range of feasible superconducting ST reactors was completed using the system code: TPC code by developing a new bootstrap current fraction (f_BS) scaling. The superconducting TF coils were designed by the SCONE code, where Nb_3Al is chosen as the superconducting material and the number of TF coils is set to be 12. The CS coils system is included in this design not only for position control of the steady-state ST plasma but also for flux supply for the plasma ramp-up. Five constraints: (i) advanced plasma constraint, (ii) blanket constraint, (iii) beta limit constraint, (iv) plasma confinement constraint, and (v) divertor heat load constraint, were established for the purpose of determining the optimum operation point among more than 16 million operation points obtained in the above parameters scan. Using the five constraints, we obtained 2269 operation points for the ST reactors with 3GW fusion output. Their COEs were evaluated using the classical cost model by CRIEPI, and they decisively depend on the f_BS values regardless to the aspect ratio. Compared with the estimated future energy COEs in Japan, cost-effective ST power plants can be designed if their COEs are smaller than 120 mill/kWh (2013$), corresponding to f_BS of 70 ~ 87 %. A 2D self-consistent free-boundary MHD equilibrium and PF coils configuration of the ST plant was constructed by modifying the neutral beam injection (NBI) system and plasma profiles using the ACCOME code. Off-axis NBI enables the equilibrium to have low plasma inductance, hence high elongation and reversed shear of q_min > 2. The optimized low-field/large-size ST reactor design is based on moderate and realistic plasma and fusion engineering parameters such as its acceptable wall load, but it is still attractive due to economic competitiveness against existing energy sources in Japan.

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