DESIGN, DEVELOPMENT & TESTING OF TOROIDAL FIELD POWER SUPPLY (TFPS) FOR SMALL-SCALE SPHERICAL TOKAMAK (SS-ST)

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1. INTRODUCTION

A Small Scale Spherical Tokamak (SS-ST) is currently being commissioned at Institute for Plasma Research (IPR). It will help fusion scientist and engineers to understand the challenges and issues in development of spherical tokamak. In its first phase of operation, the machine aims to achieve a plasma current of 28 kA with a pulse duration of approximately 15-20 ms and a magnetic field strength of 0.1 T. This paper describes the design, developmental aspects, and testing of the Toroidal Field Power Supply (TFPS), which is an essential subsystem of the SS-ST. [1, 2]. The TFPS is a critical system and requires to supply very high current for TF coil for long duration compared to other power supplies. TFPS has been designed to supply a maximum current of ~12.7 kA (which gives maximum field as 0.15 T) to the toroidal field (TF) coils, with a current drop (droop) of ~5% during a ~250 ms flat-top period. Coil insulation voltage level of 1.5 kV has also considered during design. This implies, the di/dt during ramp up and ramp down should be carried out in a way so as to limit the emf produced in the coil within the rated coil insulation level. This TFPS design incorporates a Super-Capacitor bank as a energy storage element and utilizes inverter-grade thyristors as switching components. Super-Capacitors are compact in size and stores huge energy. A D-type commutation circuit is employed to achieve the desired pulse length. It will facilitate the various pulse lengths for different operations having requirements of distinct pulse length. This paper presents the analytical calculations and circuit simulations performed to determine the appropriate sizing and selection of the power supply components. It provides details of the fabrication and assembly of a 600 F, 120 V super-capacitor bank, a 13 kA thyristor stack, and its commutation circuit. These all are designed to meet the TF coil requirements and deliver the necessary TFPS current. The paper also highlights the successful achievement of the 12.7 kA current profile for the TFPS, along with circuit simulation results, system design, control strategy, measurement and protection system and experimental test results. These studies show that the proposed design is simple, reliable and provide useful insights for developing power supplies for compact tokamaks.

2. DESIGN, SIMULATION & ANALYSIS

The SS-ST has Toroidal Field Power Supply (TFPS), Equilibrium Field Coil Power Supply (EFPS) and Ohmic Transformer Power Supply (OTPS). There are total six TF coils which are connected in series. The technical requirements of TFPS are given in Table-1. The duration of current droop mentioned in the Table-1 can be defined as the current drop in percentage during the given time period.

Table-1: TFPS Parameters & Requirements

Sr.No.	Parameters/Requirements	Values
1.	Total Coil Resistance	5.6 mΩ
2.	Total Coil Inductance	230 µH
3.	Required Coil Current for achieving magnetic field of 0.15T at the major radius 0.28 m	12.7 kA
4.	Maximum Coil Insulation break- down voltage	1.5 kV
5.	Current Droop for 250 ms	~ 5%
6.	Current Variation	Flexibility in Coil Current Value
7.	Total Flat Top Duration	250 ms

The TFPS is consist of mainly four sections viz. (a) Capacitor Charging Power Supply (CCPS) (b) Super-Capacitor Bank Assembly (C) Switching circuit and (d) Commutation circuit. Considering the requirement mentioned in the table-1, 600 F, 150 V has been super capacitor bank has been chosen. This complete circuit is source free RLC series circuit. Considering Source Free RLC series Circuit, 2nd-order linear differential equation with current, 'I', as the independent variable, it can be analysed.

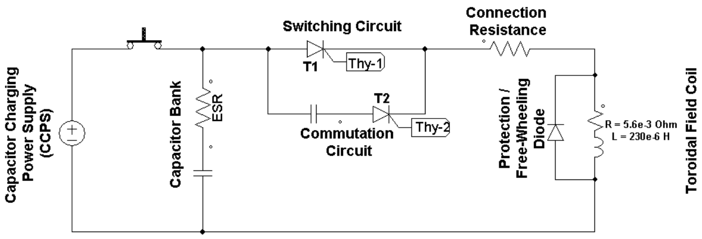

Fig-1: TFPS Schematic

$$i(t) = 13.98 \text{ x } 10^3 \ (e^{-33.618t} - e^{-0.2798t}) \ ....\textbf{Eq-1.}$$

3. CCPS AND SUPER CAPACITOR BANK ASSEMBLY

Either thyristor converter based system or capacitor bank based system used in charging of TF coil in conventional as well as spherical tokamak. In this machine Super Capacitors are used for charging the TF coil.Fig-2 shows the super capacitor bank (SC-bank) assembly which is the compact high power density component of the system. This SC bank shall be charged through CCPS up to the desired voltage and shall be discharged to the coil using the switching circuit as shown in fig.1. And the desired pulse length shall be achieved through the commutation circuit. It's D-type commutation circuit and operated from the isolated power source.


Fig-2: Super Capacitor bank Assembly

4. EXPERIMENTAL RESULTS, FINDINGS AND KEY NOVELTY POINTS

The experimental result shown in fig.3 shows the successful demonstrations of 13.4 kA coil current on the dummy TF coil. The dummy TF coil has same parameters as actual TF coil of SS-ST. The flat top of pulse duration is ~390 ms and total pulse length is ~600 ms which also includes current ramp up and ramp down time. The coil current profile satisfies the droop requirements ~ 5% for 250 ms and also other objectives. The key novelty points of this research and development works are as follow:

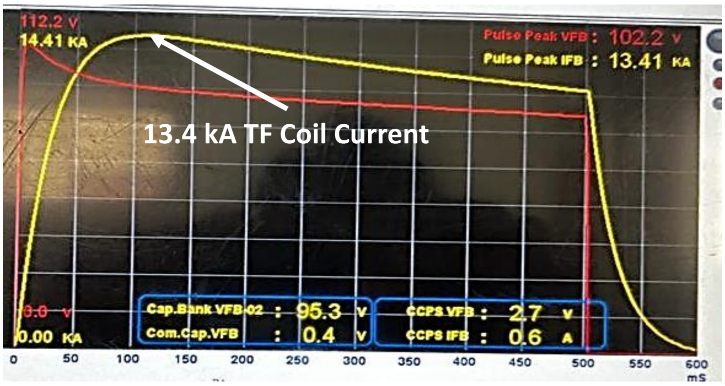

Fig-3: Experimental Results: TF Coil current

- Compact and modular super-capacitor bank based design of TFPS for ~ 13 kA current requirement.
- Isolated separate power supply of D-type forced commutation circuit to avoid early passing of current through TF coil
- Over voltage and over current protection during the pulse operation.

REFERENCES

[1] Urmil Thaker, Vaibhav Ranjan, Supriya A. Nair, Development of prototype power supply for ohmic transformer system of SSST, Fusion Engineering and Design,Volume 196,2023, 114016, ISSN 0920-3796, https://doi.org/10.1016/j.fusengdes.2023.114016.

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