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A New Parallel IGBT Current Sharing Control for Tokamak Vertical Stabilization Current Supply System

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Tokamak reactors used in fusion plants usually require a high current supply. Different sets of coils are installed in order to confine the plasma current within the vessel, one of which is the vertical stabilization (VS) coil. The
current going through the coil will produce a magnetic field, which can control the position of plasma. For example, the VS coil in ITER requires a periodic pulse current peaking at 80 kA within 0.2 seconds followed by smaller pulses of 20 kA at 10 or 6 Hz for a few seconds [1]. However, the current available power electronic devices cannot reach such a high current level without paralleling the device itself or paralleling power converters. A conceptual vertical stabilization power supply design consisting of 40 full-bridge converters in parallel was proposed in [2]. However, parallel operations of IGBTs, power devices or converters need to be controlled to eliminate/reduce the current mismatches caused by differences in device/circuit parameters such as gate resistance, stray inductance, input and output capacitances or turn-on/off signal delay. Otherwise, these parameter mismatch could lead to unbalanced
current sharing and further derate or even damage the device. In this paper, current sharing issue and considerations are investigated with the vertical stabilization coil power supply topology proposed in [2] as a case study.

Firstly, the parameter mismatches will be modeled into both a detailed circuit simulation model and a system analytical model using differential equations to observe and analyze the effects of the parameter mismatch on current sharing. Current mismatches in both transient and steady states are investigated. Mismatches in transient state may cause a certain device or converter to withstand a much higher current than rated by being turned on earlier than other
paralleled units. The current spikes during transient state could cause device damage immediately. For mismatches during steady state, the current level is lower than that from transient mismatch, however, a prolonged higher current
than designed could cause excessive heat and faster component degradation. To suppress the current mismatch, a novel control method for the paralleled full-bridge converters was proposed where the amount of current unbalance
is indicated by voltage across an inserted inductor. The voltage measurement will be used to adjust the gate emitter voltage of the power device. Due to the intrinsic dependence of emitter current to the gate voltage of IGBTs, the
current rising rate during transient state and current level during steady state can then be effectively controlled. This self balancing control does not require additional current reference generation, high end measurement devices, or
complicated computation procedure, compared to most of the existing technologies. A MATLAB/Simulink simulation model was established to demonstrate that the proposed current balancing control algorithm could effectively suppress
the current unbalance caused by parameter mismatches among paralleled modules. To further verify the design, real-time simulation was done with OP4510 platform.

[1] L. Yue, I. Lee, and X. Yao, “Tokamak vertical stability coil power supply based on modular multilevel converter,”in 2016 IEEE Power Modulator and High Voltage Conference (IPMHVC), 2016, pp. 1–5, in press.

[2] I. Song, H. Liu, J. Li, G. Gao, E. Daly, and J. Tao, “Conceptual design of iter in-vessel vertical stabilization coil power supply system,”
IEEE Transaction on Applied Superconductivity, vol. 24, no. 3, 2013.

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Yes

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