Direct drive high temperature superconducting (HTS) wind turbine generators have been proposed to tackle challenges for ever increasing wind turbine ratings. Due to smaller reactances in HTS generators, higher fault currents and larger transient torques could occur if sudden short circuits happen at generator terminals. In this paper, a finite element model that couples magnetic fields and the generator’s equivalent circuits is developed to simulate short circuit faults. Afterwards, the model is used to study the transient performance of a 10 MW HTS wind turbine generator under four different short circuits, i.e., three-phase, phase-phase clear of earth, phase-phase-earth, and phase-earth. The stator current, fault torque, and field current under each short circuit scenario are examined. Also included are the forces experienced by the field winding under short circuits. The results show that the short circuits pose great challenges to the generator, and careful consideration should be given to protect the generator. The results presented in this paper would be beneficial to the design, operation and protection of an HTS wind turbine generator.