Short circuit tests on a HTS synchronous generator

Abstract
The integration of high temperature superconducting (HTS) windings into power machinery continues to improve. However, it is also important to assess how superconducting windings compare against conventional copper windings under true serviceable conditions.

A short circuit test can be used to assess the ability of a winding to survive a ‘sudden’ unexpected increase in current. If the machine is operating as a generator, a short circuit can arise due to an accidental low resistance connection (or fault) appearing across the stator terminals. It is important to determine how quickly the HTS winding can recover and whether it can continue normal operation.

Rotor construction
The team at the University of Southampton have performed short circuit tests upon a 2nd generation ‘air-core’ rotor built in 2010. The rotor winding is shown in Figure 1.

The BSSCO coils were stacked around a hollow stainless steel shell. An outer shell was welded to form a ‘doughnut shaped’ leak tight cryostat. The torque tubes, cooling conduit, pole pieces, current lead, stub shafts and outer vacuum vessel were bolt on components required to complete the rotor assembly, (see Figure 2).

Short circuit test
The rotor was placed inside a conventional stator. The terminals of the stator were connected to a contactor. A high current, low voltage power supply ($V_{source}$) and a dump resistor ($R$) were connected to the field circuit to power and protect the HTS winding, see Figure 3. The rotor was driven by a drive motor and inverter unit to set the frequency. The drive was decoupled and the rotor allowed to freewheel; in the same instance, the contactor was switched on to make a short across the stator terminals.

Analysis and results

Figure 4 – The rotor is driven to a frequency of 20 Hz, the input or ‘operating’ field current is set to 75 A. This current is close to the critical current ($I_{c}$) of the HTS winding, (~75 A at 77 K).

The power source tries to maintain the initial value of the field current; the voltage across the supply drops rapidly. An internal diode in power source intervenes.

- Power source fails to regain control as the voltage hits the limit of the power source.
- Power source regains control.
- After one second, an oscillatory current appears in the stator winding induced by the rotation of the rotor flux through the stator.

The voltage dropped across the resistor ($R$) and the resistance of the slip-rings and current leads drives the rotor flux down, and the field current returns to its initial value.

The oscillation occurring during the initial rise in the field current is connected to the non-steady state behaviour of the flux in the stator and is synonymous to most synchronous machines.

Figure 5 – The impact of varying the input field current at a fixed rotor frequency.

Conclusion
Large induced currents in the stator were detected. The magnitude of these currents in the stator were 3 times its nominal current (220 A), compared to 6 times reported for an (iron-core) rotor. The low air gap flux density of this (air-core) rotor and the lack of optimisation of the stator to suit the rotor were significant. In any new HTS synchronous generator; the operating limits of the power supply and the size of the dump resistor (if required) must be specified. If these points are satisfied, the HTS winding (which is the most valuable component), should be protected.