Development of a New Superconducting Main Transformer for Trains

Hiroshi HATA
Senior Researcher, Laboratory Head, Traction Control, Vehicle Control Technology Division

In view of the recent increase in capacity of high-temperature superconducting wire rods, the Railway Technical Research Institute has developed a superconducting main transformer for trains and tested it. The purpose of the development was to reduce the size and weight of main transformers and improve their efficiency. A bismuth-based superconducting tape wire was used for each of the windings of the test-manufactured main transformer. The windings are immersed in liquid nitrogen. On the assumption that the new main transformer should be applied to Shinkansen trains, the winding voltage was decided to be 25 kV for the primary winding, 1,200 V for the secondary windings (4) and 440 V for the tertiary winding. In order to reduce the AC loss, a core-type transformer whose windings are solenoid coils was adopted. To reduce the refrigerator load, the core was set in a normal-temperature space. The refrigerator is supposed to keep the temperature of liquid nitrogen at -207 °C.

The transformer measures roughly 1.2 m in width, 0.7 m in depth and 1.9 m in height (excluding the compressor). This time, a floor-mounted type was test-manufactured as the first step of the development. It has a mass of 1.71 tons (excluding the refrigerator and compressor).

The newly-developed main transformer for railway vehicles was subjected to a type test in accordance with JIS. As a result, it was confirmed that the maximum capacity of the transformer under superconducting conditions is equivalent to 3.5 MVA. With the new transformer, it is possible to pass a current of 750 A through the secondary windings. The overall transformer capacity corresponds to 4 MVA. The superconducting transformers that have been test-manufactured in the past have a maximum capacity of 1 MVA or so. The new transformer having a far greater capacity has demonstrated that it has almost attained the level required of world-class high-speed trains, such as Shinkansen, TGV and ICE. In addition, the new transformer showed no abnormal conditions even in an AC withstand voltage test at 42 kV for 10 minutes and a 150 kV lightning impulse test, proving that it had no problems with electrical insulation. From test results, the AC loss was estimated to be 7.9 kW at 4 MVA. The reason for this is that the AC loss of the wire is 5 to 10 times greater than the theoretical value. At the present time, therefore, the new transformer, with the extra mass of the refrigerator, has no special advantages over existing transformers. However, if the AC loss could be reduced to near to theoretical value, it can be expected that the mass would decrease by some 20% and the efficiency would improve to 99% or more. In the future, we intend to focus on reducing AC loss and developing a light, large-capacity refrigerating system.

The present study was carried out with a subsidy from the Ministry of Land, Infrastructure and Transport.

Figure 1. Appearance of the test-manufactured superconducting main transformer

Table 1. Specifications of the test-manufactured superconducting main transformer

Primary voltage	25kV
Secondary voltage	1,200 V (4 windings)
Tertiary voltage	440V
Frequency	60Hz
Winding material	Bi-2223 tape wire
Reactance matrix	Comparable to existing main transformers
Installation site	Floor
Refrigerant	Liquid nitrogen