A Review of the Evolution of Energy-Saving Train Equipment

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It is widely known that energy for train operation can be saved effectively by reducing vehicle weight, as well as electricity used (partly through the use of regenerated power). This essay chronologically reviews the evolution of energy saving technology applied to the circuitry for train speed control.

Until about 1975, the speed of electric train was controlled mostly via the resistance control method, which involves controlling the starting current of a dc motor using a resistor. In this method, the resistor consumes some electricity at the start-up or rheostatic braking of the car, resulting in energy loss in the form of heat generation. Also, when applied to a subway, the method gave rise to a problematic increase of temperature in the tunnel.

Since the oil crisis in 1976, there has been a growing interest on energy saving. Also, the progress in semiconductor technology has resulted in the development of a high-dielectric strength and high-capacity thyristor, leading to the use of the chopper control method (also called the armature chopper control, the field chopper control, or the superimposed field excitation control).

Chopper control eliminates heat loss caused by the resistor when controlling the dc motor speed. Also, it permits the introduction of an electricity regenerating brake that permits the use, in a car, of part of the electricity generated at rheostatic braking, as well as the transmission of the electricity to overhead wiring to power other cars. Chopper control therefore resulted in drastic energy saving, as well as the elimination of useless heat generation.

The use of semiconductors also made it possible to eliminate contacts, enhancing reliability and saving labor and energy for maintenance.

The GTO (gate turn off) thyristor was developed in the late 1970s, and the practical VVVF inverter control method was introduced in the 1980s.

This method, using a small but high-output three-phase induction motor, permitted the reduction of the proportion of M cars by enhancing adhesion performance. Energy saving was promoted further through the use of the T car delayed brake, which improved the ratio of electricity regeneration. However, a problem with the method was an unpleasant buzzing sound emitted by the VVVF inverter at start-up or braking.

This problem was resolved by the introduction of the IGBT (insulated gate bipolar transistor) element, which subdued the sound by improving the switching frequency. The element also reduced high-frequency noises and heat loss. In addition, the introduction of induction motors made significant contributions to enhancing reliability and saving labor for maintenance, as compared to dc motors.

It is difficult to determine changes in the ratio of energy saved as a result of the progress of control technology, for the ratio depends on various conditions including vehicle weight, track and operation conditions, and railway line characteristics. According to data provided by the Osaka Municipal Transportation Bureau, the power dissipation per kilometer of an armature chopper-controlled car (Type 10) is approx. 66% of that of a conventional resistance-controlled car (Type 30). On the same basis of comparison, the power used by a GTO thyristor VVVF inverter car (Type 66) is 53% of the figure for a resistance-controlled car (Type 60). Other data show that the power dissipation of a GTO tyristor VVVF inverter car (Type 20) is about 80% of that of an armature chopper-controlled car (Type 10). Accordingly, a Type 20 car consumes approx. 52.8% of the power necessary for a Type 30 car (this figure is calculated as the product of the two percentages: 80% and 66%). This means that the energy required to power a GTO thyristor VVVF inverter car is only about half that for a resistance-controlled car.

Motor size and weight will be reduced even further in the future, through the introduction of VVVF inverters of ever lower costs and smaller losses.

For instance, train cars (Series 21 and afterward) newly designed for Kintetsu Corporation use IGBT elements for the main circuit of a VVVF inverter. Compared to a conventional inverter using GTO thyristor elements, the new inverter has a greater output, while its weight and volume are reduced by one-third.

Another innovative feature is a frameless structure introduced to a three-phase induction motor, which expands capacity while reducing weight by about 20%.

Also, there is a growing trend toward improving equipment in efficiency and energy saving by using HID for front lights, and LED for tail lights, as well as various indicators and auxiliary lights.