Technology to Prevent Regenerative Braking Failure on AC-AC Sectioning Post

Abstract
JR Kyushu has developed an innovative technology to prevent regenerative braking failure when a car mounted on an AC regenerative braking system runs through an AC-AC sectioning post.

1. Introduction
Advancements in power electronics technology in recent years have led to an increased popularity of cars that use PWM converters in AC-electrified railway sections to enable regenerative braking operation. The AC regenerative control enables stable electric braking without requiring cars which consume electric power in the sectioning post. If a car runs through an AC-AC sectioning post or the car’s pantograph detaches from the trolley, the regenerative braking operation fails because the energy generated by braking cannot be turned back to the trolley. This results in extreme impact on a car during operation. JR Kyushu’s 815-type train with an air supplement control method, which is composed of motor car and single trailer, has been the first to adopt the PWM converter, as shown in photo 1. A cost effective method, which applies a compact brake resister and brake chopper in combination, has been incorporated into the train cars for preventing regenerative braking failure. Table 1 shows the major specifications of the 815-type train; and figure 1 shows its traction system.

815-type AC electric car
2. Background of Technological Development

Regenerative power flow is cut off when a car operating the AC regenerative braking system runs through an AC-AC sectioning point. This results in a steep voltage increase of the filter capacitor at the direct current (DC) stage. To protect the power device, the controller stops the electric braking system. This phenomenon is called a failure of regenerative braking operation. When such a failure arises, the electric braking system is promptly released, thus activating the air braking system. At that time, an impact occurs, affecting passengers and possibly damaging driving units and bogies.

With this kind of AC electric train, which is composed of a motor car and a single trailer or several
trailers, the motor car is operated under the condition that the electric braking system activates before the air braking system does. The trailer operates only on air braking. Air braking, which is easily influenced by external materials, temperature, car speed and dryness or moisture, causes mechanical abrasion. In this situation, the air supplement control is applied to the car mechanism, contributing to a higher regeneration braking ratio and less abrasion on the braking shoe by applying the braking force of the motor car to the trailer. However, this results in greater impact on car equipment and passengers because of the increased braking force.

The 815-type train was created as a commuter train for the future generation, and features an aluminum car body and AC regenerative braking system. Technological development of this kind of AC electric train emphasized the prevention of negative impact caused by regenerative braking failure. Also, additional focus was placed on a good solution to reduce impact from the air supplement control method which JR Kyushu plans to use. With these concerns in mind, two major methods described in the next section were discussed.

3. Discussions about Techniques to Prevent Regenerative Braking Failure
Two major techniques to prevent regenerative braking failure were discussed by comparing individual advantages and disadvantages.

**Brake chopper control**
The theory of the brake chopper control is that braking energy can be absorbed by the resister only during a very short time of no-voltage generation when the car runs through an AC-AC sectioning post, or when the car’s pantograph detaches from the trolley. The braking chopper, which is used in combination with the resister, controls the amount of electric power flowing to the resister. Thus, failure of regenerative braking can be prevented. The advantages of this mechanism are that neither special car operation, nor positioning data of AC-AC sectioning posts, is required. Furthermore, back and forth vibration of the car is not generated. However, a high-speed response capability is required to detect a no-voltage status when the car runs through the AC-AC sectioning post; it is also necessary for the chopper’s control function.

**Air brake switching at the forward AC-AC sectioning post**
This technique features a switch from electric braking to the air braking system at the point before the car runs through the AC-AC sectioning post, based on positioning data of the sectioning posts pre-registered in the data control unit mounted on the car. The switching operation helps prevent regenerative braking failure. No special hardware is needed, and it has the advantage that no arc is generated from energy flowing from the pantograph to the trolley. Conversely, disadvantages include the need to manage positioning data of the sectioning posts, which could result in more human error.

From the results of examinations into the above techniques, JR Kyushu determined a technological development to prevent regenerative braking failure by applying the brake chopper control with a compact brake resister, achieving better performance and reliability at a lower cost. However, in order to make this technique feasible, JR Kyushu tackled the development of an appropriate control method to achieve a high-speed response capability for detecting a no-voltage status.
4. Key Technical Elements of the Resister and Chopper in Use Brake resister

In consideration of an AC-AC sectioning post 8 meters in length, and a maximum braking force of 62kN (in the case of the 813-type train), the maximum energy to be absorbed by the brake resister when the car runs through the AC-AC sectioning post is sought by the following formula, regardless of car speed and energy efficiency:

\[ \text{Braking force} \times \text{Sectioning post length} = 62\,[\text{kN}] \times 8\,[\text{m}] = 0.5\,[\text{MJ}] \]

Next, assuming that the resister is operated two times for five minutes each, the capacity of the brake resister to absorb energy is sought by the following formula:

\[ \frac{(\text{Absorbed energy} \times \text{Number of operation})}{\text{Interval time}} = \frac{(0.52\,[\text{MJ}] \times 2\,[\text{times}])}{(5\,[\text{min}] \times 60)} = 3.3\,[\text{kW}] \]

As shown above, the capacity required is very small. Consequently, we were able to adopt a compact, air-cooled braking resister with superior cost performance and maintenance.

Brake chopper

Sustainable operation time of the brake chopper at the speed which the generating energy reaches its maximum (75km/h) is sought by the following formula:

\[ \frac{\text{Sectioning post length}}{\text{Car speed}} = \frac{8\,[\text{m}]}{(75\,[\text{km/h}]/3.6)} = 0.38\,[\text{sec}] \]

As the operation time is extremely short, the heat discharge system of the brake chopper can be simplified.

The brake resister and brake chopper, both of which are easy to handle, are placed on the converter/inverter device at the DC stage, instead of the conventional over-voltage discharge circuit, resulting in cost reductions.

5. Control of Brake Chopper

In the proposed method, the electric braking system is operated continuously while the car runs through the AC-AC sectioning post. Arc generation may occur if detection of electric power interruption, or a no-voltage status, is delayed when running through the post. To solve this problem, prompt detection of electric power interruption is crucial even when the pantograph is attached to the trolley via the arc. Focus was placed on the extreme change of the converter modulation ratio at the time of the pantograph’s detaching from the trolley. Thus, in the case of an extreme change in the modulation ratio, the converter is promptly stopped. This results in a steep voltage increase in the DC stage, where the energy generated by the motor is converted to DC by the motor’s driving unit when running through the post. Then, the brake chopper controls the amount of energy absorbed by the brake resister to regulate voltage within a tolerable range. Figure 2 shows the basic operation of the proposed brake chopper.
6. Effects Obtained by the Proposed Method
A running test for the car was carried out using the proposed method. The running test results when the proposed method was incorporated, as shown in figure 3, revealed the continuous operation of the inverter even when the car was run through the AC-AC sectioning post.
Back and forth vibration acceleration was regulated within 0.04 to 0.06G from peak to peak, bringing about a satisfactory test result. We also tested performance without operating the brake chopper, as shown in figure 4, in the case of a motor car without the proposed method incorporated.

Running test result 2 (without operating brake chopper)

In this case, a critical level with a vibration acceleration of 0.23G from peak to peak in a back and forth direction occurred because the converter/inverter device was stopped simultaneously when the car was run through the sectioning post. Our forecast, based on the theoretical value, was 0.1G in operating the air supplement control. However, its actual value increased to the critical value because the coupled buffer made from rubber springs had a large impact on the car body through the air supplement control. The tests showed that the use of the brake resister and brake chopper helped to prevent regenerative braking failure, and contributed to reducing the negative impact on passengers and the car body in the air supplement controlling condition. Thus, the tests clarified the validity of the proposed method.

7. Conclusions
JR Kyushu has applied a unique, advanced and low-cost technological development onto new commuter train models, which can prevent regenerative braking failure on AC-AC sectioning posts. Use of the brake resister and brake chopper in combination eliminates the need for special and strenuous operational procedures to control car braking systems, and has good cost performance. In addition, the proposed method improves passenger comfort inside a moving car. The 815-type commuter trains (52 cars in service) and the 885-type express trains (62 cars in service), into which the new technology has been incorporated, are now in service. No trouble has been reported. Photo 2
shows the 885-type express train. The proposed method will be integrated as a standard mechanism in all future trains at JR Kyushu.

885-type AC electric car