Overview of urban rail transit energy feedback traction power supply system

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Abstract. The power feedback traction power supply device is composed of rectifier unit and four-quadrant converter device. The four-quadrant converter device can work either in the rectifier state which can provide energy to the dc catenary or in the inverter state which can feed excess regenerative braking energy back to the ac power grid. At the same time, it can make reactive power compensation for ac medium voltage network and improve the power factor of the system. This paper mainly introduces the research technology of urban rail transit energy-fed traction power supply system.

1. Introduction
At present, urban rail transit traction power supply generally uses diode rectifier unit power supply (750VDC and 1500VDC) \cite{1, 2}. This power supply mode has the disadvantage that the DC output voltage fluctuates widely and the energy can only flow in one direction. When the urban rail train regeneratively brakes, the excess energy generated (the part that cannot be absorbed by the nearby train) will cause the traction network voltage to soar, resulting in reduced train regenerative braking capability or even regenerative braking failure. The traditional solution is to consume this part of the energy with the on-board braking resistor.

Because the urban rail train has the characteristics of short distance between running stations, frequent starting and braking \cite{3}, etc., the on-board braking resistor not only increases the weight of the train, but also consumes a large amount of regenerative braking energy \cite{4, 5}. At the same time, it also brings the tunnel temperature to rise, and the weight control is added. The burden of the ventilation system causes problems such as secondary consumption of electrical energy. As shown in Figure. 1.

The medium-voltage energy-feeding type regenerative braking electric energy utilization device (abbreviation: medium-pressure energy feeding device) can not only feedback excess energy back to the AC grid during regenerative braking of the train, but also avoid the white consumption of the regenerative braking energy of the train.
To save energy, it can also provide traction energy for the train and reduce the DC network pressure drop. In addition, since its power factor is arbitrarily adjustable, it can also be used to achieve reactive power compensation for the AC medium voltage grid. The energy-feeding mode consisting of a diode rectifying unit and a power feeding device is as follows:

![Figure 1. Schematic diagram of energy flow in traction power supply system](image)

2. Working principle
The core of the regenerative braking power utilization device is a high power inverter. The inverter is a power conversion device developed on the basis of pulse width modulation technology. The main circuit can be regarded as a three-phase inverter (PWM inverter) plus an AC inductor L, as shown in Figure 3.

![Figure 2. Application scheme of energy feedback system](image)
Figure 3. Inverter circuit topology diagram

The PWM inverter uses pulse width modulation technology to output three-phase AC with amplitude and phase control on its AC side, as shown in Figure. 3, \(U_a, U_b,\) and \(U_c\). The AC inductor \(L\) acts as a buffer between the inverter and the grid. The power supply voltages \(e_a, e_b,\) and \(e_c\) fall on the inductor \(L\) and determine the magnitude of the AC current. In the case where the grid voltage \(e_a\) and the AC inductance \(L\) are constant, the magnitude and phase of the current \(i_a\) can be controlled by the magnitude and phase of the control, thereby controlling the inverter transmission power. The control of the alternating current is the core of the inverter control. In order to achieve control of the alternating currents \(i_a, i_b,\) and \(i_c\), it is necessary to control the amplitude and phase of the inverter output voltages \(U_a, U_b,\) and \(U_c\). It is worth noting that the amplitude and phase of \(U_a, U_b,\) and \(U_c\) are relative to the grid voltages \(e_a, e_b,\) and \(e_c\). To this end, the amplitude and phase of the grid voltages \(e_a, e_b,\) and \(e_c\) must be accurately detected, and used as \(U_a, U_b,\) and \(U_c\) control references to synchronize the inverter output with the grid voltage.

3. Energy feedback system application technology

The energy feeding system mainly has the following two functions in the traction substation:

3.1. Recycle regenerative braking energy to reduce network voltage fluctuations

The energy feedback system has the advantages of recycling regenerative braking energy and reducing network voltage fluctuation. The energy-feeding system feeds back the regenerative braking energy of the train to the medium-voltage network for reuse. At the same time, avoid tunnel temperature rise and reduce the secondary energy consumption of the environmental control system. And the energy feeding system can also provide traction energy for the train, reduce the DC voltage fluctuation, and improve the traction power supply quality.

Figure 4. Schematic diagram of energy feedback
Figure 5. Schematic diagram of traction power supply

The energy feedback system has high reliability, high power density and perfect protection function. The groundbreaking application of the world's most advanced IGBT intelligent power module to the product has achieved great success, which has significantly improved the reliability and power density of the medium voltage energy feeding device. At the same time, Ethernet-based real-time monitoring and intelligent fault diagnosis technology enable the product to have hierarchical protection and intelligent diagnosis.

Figure 6 shows the functional characteristics of the IGBT intelligent power module. The module integrates functions such as heat sink, IGBT, driver, voltage sensor, current sensor, temperature sensor, etc., combined with proprietary substrateless technology (directly integrates the IGBT chip onto the heat sink, reduces thermal resistance, and improves heat Recycling capacity) and crimping technology (instead of welding technology to improve reliability and longevity) make it unique and outstanding even in extremely harsh environments.

Figure 6. Schematic diagram of IGBT intelligent power module

In order to make the train regenerative braking ability as much as possible, reduce the train braking energy capacity demand and power impact of the single station absorption device, based on the traditional "constant pressure absorption" scheme, creatively based on "pressure swing absorption" technology A distributed cooperative absorption scheme for train regenerative braking energy. The scheme is that when the train brakes, as the braking power increases, the absorption voltage of the energy-feeding device of each substation is allowed to rise linearly within a certain range, thereby triggering the adjacent station energy-feeding device to also be put into operation, so that the train
enters. The regenerative braking peak power at the station can be absorbed by the energy feeding devices of multiple adjacent stations, thereby reducing the power impact on the single station, which is beneficial to the regenerative braking energy being better utilized in the subway system and reducing the electric energy. The probability of sending back to the urban grid.

Figure 7 shows the typical curve of the external characteristic between the regenerative braking power utilization device and the existing diode rectifier unit in the project. Curve 1 is the DC output characteristic curve of the regenerative braking power utilization device; curve 2 is the DC output characteristic curve of the diode rectifier unit; \( U_{dd} \) is the ideal no-load DC voltage of the diode rectifier unit; \( U_{1k} \) is the no-load voltage of the energy feeding device (reverse Change the turn-on voltage), this value is obtained by multiplying the 10kV bus voltage by a coefficient, which can be automatically adjusted with the fluctuation of the voltage of 10kV. By default, the \( U_{1k} \) value is higher than the ideal no-load voltage \( U_{dd} \) of the diode rectifier unit \( \Delta V=30V \); \( U_{LIM} \) is the energy-feeding Device inverter voltage limit value, the default setting value is \( U_{LIM}=1750V \); point A is the limit power point, AX is the power limit curve, the voltage rises along the curve AX direction, and the power remains unchanged, the default limit power value is 2MW; \( U_{OV} \) is DC overvoltage protection value, and the default setting value \( U_{OV}=2100V \).

**Figure 7.** External characteristic fit curve

3.2. Reactive power compensation, improve system power factor

For urban rail transit traction power supply systems, reactive power compensation can be divided into centralized compensation and zone compensation. Since the AC side of the energy-feeding traction power supply device is connected to the medium voltage network through a transformer, when a traction-type traction power supply device is arranged in each traction substation, the partition compensation of the medium voltage network can be realized by using the entire power supply system achieves a higher power factor.

The ideal reactive power compensation strategy should be to make the current power factor in any cable in the medium voltage network that supplies power to the traction meet the given requirements. In order to meet this requirement as much as possible, the compensation partition should be divided according to the medium voltage network structure, and Reasonably allocate the compensation capacity of each energy-feeding traction power supply device so that the current power factor of the cable in each zone meets the given requirements.

The reactive power generated in each zone consists of two parts: one part is the reactive power generated by the electrical equipment in the substation (including traction power and substation power equipment), and the reactive power \( Q_{Le} \); the other part is the reactive power \( Q_{Dn} \) generated by the cable distribution parameters in the partition. The reactive power of this part is difficult to measure, and the whole medium voltage can only be measured by the main substation. The total reactive power of the network is calculated indirectly after Q. Since the reactive power of the cable is distributed with the line, the
compensation law of the cable reactive power in each partition must be obtained first when compensating the reactive power of the part.

The cable of length \( L \) is equivalent to a \( \Pi \)-type circuit, and the medium-voltage network can be considered to be connected by \( K \) \( \Pi \)-type equivalent circuits. If the capacitive reactive power is defined as negative, the reactive power generated by the medium-voltage network is the expression is:

\[
Q_n = -2\omega L_0 C_0 V^2 + j\omega K I_0 I^2
\]  

(1)

Among them, \( L_0, C_0 \) represent the inductance of the cable and the distributed capacitance to the ground. The first term in equation (1) represents the capacitive reactive power generated by the cable, and the second term represents the inductive reactive power generated by the cable. During off-peak hours or during nighttime parking periods, the load current is greatly reduced, and the cable generates inductive reactive power with little negligence. Since the network voltage is kept constant, the capacitive reactive power generated by the cable is basically unchanged, and it is only related to the size of the distributed capacitor. If the cable capacitance per unit length is \( C_r \), the equivalent capacitance \( C_n \) of each partition and the emitted capacitance are not. The power \( Q_{bn} \) is proportional to the line length and its expression is:

\[
Q_{bn} = -j\omega C_r l_n V^2
\]

(2)

Where \( l_n \) is the cable length of each partition.

4. Conclusion
This paper introduces the development background and advanced technology of the energy-feeding traction power supply device. It can not only realize the traction power supply, but also can feedback the braking energy to the power grid, realize the reactive power compensation to the medium voltage ring network, and improve the power factor. Good energy saving effect and broad application prospects.

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