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Electrical Control Strategy for Traction System of Metro Vehicle

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Abstract: Metro vehicle is a multi-disciplinary integration system, in which traction system is the main power system of metro operation, which plays an important role in ensuring the safe operation of trains. This paper briefly analyzes the characteristics and design principles of the electric traction system of metro vehicles, and discusses the electric control strategy of the traction system and the faults that are easy to occur.

1. Introduction

With the rapid development of China's economy and the improvement of construction level, the process of urbanization is accelerating, and the scale and quantity of subway projects are increasing. In the normal operation of metro vehicles, traction system provides traction and braking force for vehicles, which directly affects the safety and efficiency of metro vehicles.

2. Characteristics Analysis of Metro Vehicle Traction System

Metro vehicle traction system is mainly composed of traction motor (MOTOR), traction inverter (VVVF), pantograph (Pan), lightning protector (LP), high voltage box (HV) and braking resistance (BR). The high-voltage box mainly includes high-speed circuit breaker, main isolating switch, charging equipment, etc. In order to enhance the reliability of the vehicle traction system, each Metro is generally equipped with two Pantographs, which work in the form of “one main and one standby”. When one pantograph fails, the traction and auxiliary inverter will not stop working, because at this time, the other pantograph can still transmit the high-voltage power supply to the power unit of the metro vehicle to maintain the normal turnover of the system. The input terminal of traction inverter is equipped with supporting capacitor, which can play the role of energy buffer and stable input voltage. At the same time, the filter reactor and the supporting capacitor in the circuit work together to stabilize the voltage and ensure the safe operation of the inverter[1]. The traction inverter device includes inverter phase controller and chopper phase controller. When traction is carried out, the metro vehicle receives DC from the contact network through the pantograph. The DC is converted into three-phase AC through the inverter. The three-phase AC acts on the traction motor to generate motor torque, and then acts on the wheel set of the vehicle through the transmission mechanism such as gearbox to form wheel traction force to drive the subway train. When regenerative braking is carried out, the traction motor works in the state of generator to generate three-phase alternating current, and the traction inverter works in the state of rectification, which will transfer the three-phase alternating current into direct current to the catenary and the electric energy to the electric vehicles in the same power supply section.

The traction system of metro vehicles includes a lot of equipment and circuit systems, which provide strong support for the safe operation of vehicles. Among them, the brake device plays an important role in the process of metro vehicle deceleration and parking. At present, there are two kinds of braking modes of urban subway trains in China: electric braking and mechanical braking. Electric braking includes regenerative braking and resistance braking. During braking, the motor operates in the fourth quadrant to generate braking force, which converts mechanical energy into electrical energy. If this part of electrical energy is fed back to the contact network, it is called regenerative braking. If it is consumed in resistance, it is called resistance braking. Mechanical braking, also known as air braking, is to control the train braking by means of compressed air and

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changing the pressure of compressed air. These three braking modes cooperate with each other to ensure the safe operation of metro vehicles.

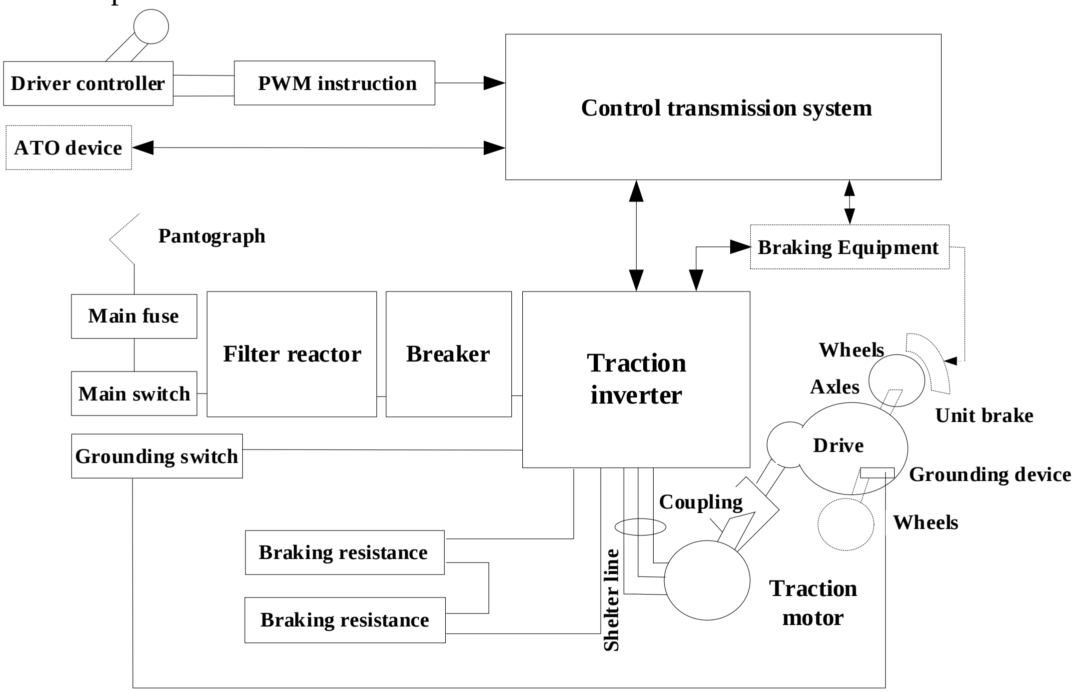

Fig.1 Electric Traction Structure of Metro Vehicles

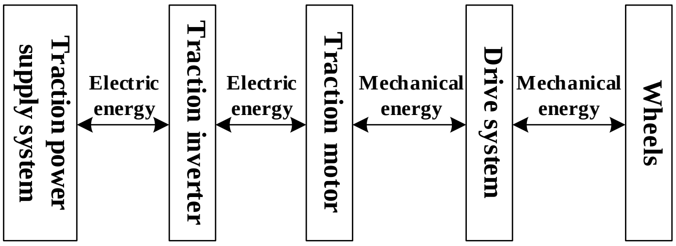

Fig.2 Working Principle of Metro Train Traction System

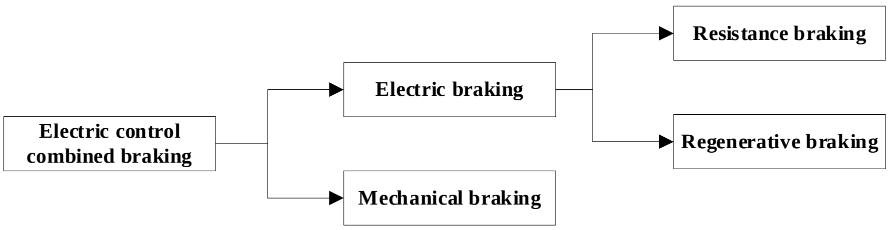

Fig.3 Braking Mode of Metro Train

3. Analysis of Metro Vehicle Traction System Design

According to the operation characteristics of metro vehicles, this paper analyzes some problems that need attention in the design of metro traction system.

3.1 Characteristics of Metro Vehicle Operation

(1)Good traction/braking performance. For general metro vehicles, under rated load (AW2), rated network pressure and wheel half wear state: average starting acceleration (0-35km/h)⩾1.0 m/s^2, average acceleration (0-80km/h)⩾0.6 m/s^2. The average braking deceleration (0-80km/h)⩾ 1.0 m/s^2, and the maximum braking deceleration is 1.3 m/s^2. The maximum operating speed is 80km/h, the impact limit is 0.75 m/s^3, and the average technical speed of typical section (excluding stop time)⩾ 55km/h

(2)Good overload capacity. During rush hours and holidays, passenger overload often occurs.

The electrical equipment of the vehicle must be able to arrive safely, stably and in time under certain overload.

(3)Good fault operation ability. For a metro vehicle with 4-motor and 2-trailer, it shall have the following performances:

a) When the vehicle loses 1/4 of its power and is overloaded, it can go back and forth for a whole journey;

b) When the vehicle loses 1/2 of its power and is overloaded, it can be started on a 35 ‰ ramp and drive into the nearest station;

c) An overloaded vehicle (traction of an unpowered no-load fault vehicle) can be started on a 35 ‰ ramp.

3.2 Principles of Vehicle Traction System Design

There are some special requirements in the actual operation of metro vehicles, so the following principles are mainly followed in the design of electric traction system[2]:

(1) Acceleration / deceleration of the vehicle.

Due to the short distance between Metro sections, the vehicle traction system shall meet the performance requirements of frequent start / braking of vehicles, and the traction and braking characteristics of vehicles shall be determined according to the basic parameters such as vehicle weight, passenger capacity, etc.

(2) Adhesion performance of vehicle

Although there are differences in the power supply mode, vehicle model and marshalling form of metro vehicles, there must be appropriate wheel rail adhesion coefficient that does not exceed the limit.

(3)Fault operation capacity of vehicle

As the metro is running in the underground tunnel, once there is a fault, it will not only cause panic to passengers, but also the difficulty of maintenance, so it is very important to reduce fault and ensure the operation safety. On the one hand, it is necessary to improve the stability and reliability of hardware and software system of the vehicle; on the other hand, the vehicle shall have certain fault operation ability. If part of the power is lost, it can drive to the designated place by itself, and if all the power is lost, it can be towed to the nearest station or depot base.

(4)Electrical performance requirements of metro vehicles for DC measuring appliances

Due to the frequent start / braking and high peak braking power of metro vehicles, the DC side current of the main circuit of the traction system takes the shape of ladder or saw-tooth wave, and the peak value varies greatly. Therefore, the DC side line reactor is designed as a hollow structure, its inductance value is almost not affected by the DC side current, so that under different operation conditions of metro vehicles, the filter circuit can provide the inverter with the desired low power source impedance and maintain a low DC side resonance frequency, as well as suppress the influence of high-order harmonics of the inverter on the power grid. In addition, the braking resistance is designed according to the braking characteristics and braking current waveform of metro vehicles, so as to optimize the parameters. The selection of DC side electrical equipment should give priority to the high-voltage electrical performance and reliability, and be able to withstand the over-voltage of the power supply network without damage.

4. Electric Control Strategy of Metro Vehicle Traction System

In the electric traction system of metro vehicles, the control strategy is a very important part, mainly divided into traction electrical control, AC drive control and brake control.

4.1 Traction Electrical Control

During the operation of metro vehicles, the driver controller or ATO will send out the corresponding traction command and send it to the traction inverter. After receiving the command, the traction inverter will realize the output torque control and train traction control combined with the braking control device. In the actual operation process, due to the influence of ramps and curves, the system sets the speed limit of train operation to ensure the safety of train operation. If the operation speed exceeds the speed limit, the system will cut off the traction until the operation speed of the subway drops to the normal operation standard, and then restore the supply of traction. In addition, when the automatic protection system (ATP) of metro vehicle is cut off, the system can provide high acceleration function for the vehicle. For example, when carrying out the ramp rescue, the system can output the traction force of 1.15 times of the usual adhesion coefficient, push the fault train parked on the largest ramp away, and dredge the operation channel.

4.2 Ac Drive Control

Many converter technologies are used in the electric traction system of metro vehicles, including traction converter technology, cooling technology, optical fiber transmission and isolation technology, as well as lamination-busbar technology. Among which traction converter technology is particularly important, which is based on high-power semiconductor devices to realize the conversion between different electric energy. These technologies play an important role in the work of metro vehicle traction system. Reasonable use of these technologies can complete the effective transformation of AC and DC energy, and ensure the safe, stable and efficient realization of traction control.

When the equipment is overheated during traction converter, the heated pipe radiator can be used to cool down the electric traction system. Through the condensation and evaporation of liquid medium, the pollution-free heat emission can be realized, the load pressure of the system can be reduced, and the efficient braking of the vehicle can be guaranteed. AC drive control technology is essentially a hybrid technology from inverter. Through the comprehensive application of asynchronous motor control technology, fault diagnosis technology, adhesion control technology and parameter identification technology, it can achieve effective control of current and provide sufficient guarantee for the safe operation of metro vehicle electrical system. In the operation stage of metro vehicles, there are often some very complex problems, which can be properly solved through the application of AC drive technology.

4.3 Brake Control

As mentioned above, metro vehicles are mainly braked by electric braking and mechanical braking, in which electric braking can be divided into regenerative braking and resistance braking. However, in the actual braking process of the train, the two braking modes have certain priority. When the train runs at a high speed, regenerative braking is preferred, which can effectively reduce the wear of brake shoes and feedback energy. The electric energy generated in the process of regenerative braking will feed back to the contact network, which will increase the contact network voltage. When the contact network voltage exceeds the limit value, the chopper controller will be opened, the resistance braking will be started, and the excess energy will be dissipated in the form of resistance heating to ensure the contact network electricity under control. When the train stops at low speed, the regenerative braking force is insufficient, and the mechanical braking is needed to supplement the braking force to make the train stop accurately. To achieve better braking effect and reduce the loss in the braking process, a variety of braking methods are often used in combination. This combined braking mode can effectively adjust the braking force of the vehicle, so that the subway vehicle can stop safely, timely and accurately.

5. Faults of Metro Vehicle Traction System

From the long-term operation of the subway, the number of traction system failures is more frequent, and the causes of failures are diverse. Next, several subway failures will be analyzed.

5.1 Abnormal Operation Failure

Abnormal operation state fault refers to a fault that causes overload and overcurrent protection of traction system when metro vehicles are in the rush hour of going to and from work, during the process of starting and stopping stations, and when they are in the three rail power free zone. The fault features are as follows:

(1)Compared with the normal state, the load of metro vehicles increases significantly.

(2)Current and voltage in the power grid fluctuate to some extent.

(3)Miss-operation of relay protection device

This kind of fault state will affect the normal operation of the electric traction system of metro vehicles, meanwhile, it will cause a certain degree of damage to the grid system of metro vehicles.

5.2 Non-Metallic Short Circuit Fault

The non-metallic short-circuit fault usually occurs in the rainy and snowy weather. Meanwhile, the rain and snow become the conductor of conducting current, causing the short-circuit fault of the power supply system. When the traction system adopts the third rail power supply mode, the third rail is to fix the whole insulation support on track bed, which has a reliable insulation relationship with the grounding flat copper. In rainy and snowy weather, rainwater flows into the insulation support and the track on the track bed. The rainwater can conduct electricity, which will reduce the insulation effect of the insulation support. In addition, long-term rain and snow may cause sundries on the surface of the insulation support and the third track, resulting in leakage phenomenon. This kind of fault phenomenon is relatively frequent. In order to prevent the occurrence of this fault, the support should be maintained regularly. Another kind of non-metallic short-circuit fault in the third rail power supply system is arc short-circuit fault, which is mainly manifested as the short-circuit fault caused by the discharge of charged body to conductor, such as the discharge of the third rail to ground.

5.3 Metal Fault

The short circuit fault caused by the metal contact between the rail and the three rail or the breakdown of the insulation support is metallic fault. For example, when the power supply system of Metro is cut off for maintenance, more metal tools need to be used. If the maintenance personnel do not clean up the tools after the completion of the maintenance, they will leave these metal tools between the three rails and the rail. When the power supply is restored, there will be a direct short circuit fault between the third rail and the rail. Therefore, the maintenance personnel shall timely clean the tools after the maintenance to prevent this unnecessary short circuit fault.

6. Troubleshooting of Metro Vehicle Traction System

(1)The faults of traction system are common in metro vehicle faults, and most of them occur at the far end of traction substation. Therefore, it is the most common method to determine the location of fault points through simulation analysis. The feeder current of short circuit point is calculated by simulation analysis, so as to observe the relationship between fault distance and current steady value. Generally speaking, the closer to the fault point, the greater the steady-state value of current, and the slower the speed of current rise will be due to the closer to the end of contact network[3], thus effectively diagnosing the sudden change of DC traction network voltage.

(2)To avoid the transient state of the sub model of traction substation in the initial stage of simulation, the simulation analysis can be carried out through the following simulation experiments: set the start-up time of a metro vehicle at 0.05s, and set the remote fault simulation experiments at 2km and 3km respectively after 0.11s to complete the simulation of the actual short-circuit fault. After analyzing the simulation results of DC feeder current, a targeted exponential function can be obtained, that is, the closer the current rising speed is to the end of the contact network, the slower it becomes, and the greater the current stability. Therefore, with the help of fault simulation analysis, the relationship among the fault point and the current value and current rise rate of the metro vehicle DC feeder can be clearly understood, so as to improve the success rate of fault detection of traction system.

7. Conclusion

In summary, the structure of metro vehicles is complex, and the electrical traction system plays an important role in the whole metro vehicle operation system. Normal operation of the traction system needs to be ensured so as to guarantee the safe and stable operation of vehicles. Presently, the traction system is still with frequent failures in the operation of metro vehicles. Therefore, it is not only necessary to improve the electrical control strategy of the traction system of metro vehicles, do a good job in the regular maintenance of equipment, reduce the frequency of failures, but also need to do a good job in the rapid troubleshooting work to ensure the safe operation of Metro and promote the healthy development of the metro industry.

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