Transient Study on Passing Neutral Section of Electronic Switch Considering Devices Delay Time

Lejia Han1,*, Shaobing Yang1
1Beijing Jiaotong University, Beijing, China
*Corresponding author e-mail: 16121449@bjtu.edu.cn

Abstract. The passing neutral section scheme by using electronic switches instead of vacuum circuit breakers can shorten dead time of locomotives, and can eliminate the problem of locomotive deceleration. This paper constructed the traction power supply system model and the detailed main circuit model of Chinese standard EMU, including high voltage system and traction converter based on Matlab/Simulink. Then the scheme of using electronic switch is designed, and the influence of delay time required for the detection and action of the devices is considered. By comparing the simulation and measurement data, the accuracy of the model is verified, and analysed the transient response of passing neutral section when considering the delay time.

1. Introduction
China's electrified railway adopts AC single-phase power supply with the specifications of 25 kV and 50 Hz. With the aim of avoid phase-to-phase short circuit, a phase separation device needs to be set at a certain distance from the contact network. An EMU needs to disconnect the main circuit by using its breaker before passing the neutral section. During this process, however, the disconnecting operation may cause transient faults such as overvoltage and ferromagnetic resonance. The analysis and research of passing neutral section process provides a great significance for ensuring the safety of high-speed railway operation [1,2].

China generally adopts the method of passing neutral section on the vehicle [3]. EMU needs to pass through the neutral section in the state of disconnecting main breaker and no traction current, Therefore, it become a problem that EMU has long dead time and the vehicle-mounted circuit breaker is operated frequently. Using electronic switch instead of a conventional vacuum switch can both increase the speed of the switch response and avoid transient problem, meanwhile it greatly extends the service life of switch and improves the reliability of the entire system [4]. At present, the automatic passing neutral section transient research using electronic switches has become a hot issue. Reference [5] analyzed the factors affecting overvoltage, and pointed out the ferromagnetic resonance
overvoltage caused by the saturation of the high voltage transformer, which is the main reason for the insulation breakdown of the equipment. Reference [6] proposed the scheme of using a freewheeling resistor to protect device and analyzed the phenomenon of magnetizing inrush current.

This paper constructed traction power supply system (TPSS) and introduce the parameters, and constructed the detailed Chinese standard EMU simulation model different from many existing research institutes. Based on the actual measurement data, the accuracy of the model is verified, and the transient of the EMU under the influence of the delay time of the electronic switch is discussed.

2. Model Construction and Parameter Determination

2.1 Traction power supply system

A TPSS usually includes a transformer, two traction feeders, and a neutral section, where the neutral sections between it and the neighbor substations are not considered. Its components should be separately modeled in the simulation. In this paper, the transformer is set to be the Scott type, and the feeders and the neutral section is modeled by the T-type equivalent circuit. Besides, the coupling capacitance between feeding section and neutral section is considered. The capacitor should be calculated by using the calculation method and image method of the partial capacitance in the engineering electromagnetic field theory [7].

In order to increase the system damping, absorb and suppress the overvoltage generated during the switch action, the RC branch is connected in parallel in the neutral section, and select $R=1800\Omega$, $C=500\mu F$ as the protection device parameters.

The parameters of the TPSS in this paper adopt the parameters of the power supply section of Beijing-Shenyang High-speed Railway. The main electrical parameters are shown in the Table 1.

| Parameter Name                                      | Value       |
|----------------------------------------------------|-------------|
| Reference Value of Traction Network                | 0.051394    |
| Length of Left Feeder                              | 26 [km]     |
| Length of Right Feeder                             | 28 [km]     |
| Length of Neutral Section                          | 0.5 [km]    |
| Unit Mutual Capacitance Between the Feeder and the Neutral Section | 8.915 [nF/km] |

2.2 Electronic dead section devices

Thyristor is non-contact electronic switch. Replacement of the traditional vacuum circuit breaker by thyristor can improve the response efficiency of the switching action, and can shorten the dead time in the passing neutral section process to several tens of milliseconds in theory.

The rated voltage of a single thyristor is much lower than the working requirement of TPSS. With the purpose of withstand high voltage generated during switching, multiple components are connected in series to form a thyristor blocks. The electronic switch model selected for this paper use 24 sets of anti-parallel thyristors. The structure of series electronic switch blocks is shown in Figure 1.
Figure 1. Electronic switch blocks connected in series schematic structure

2.3 Chinese standard EMU

Chinese Standard EMU traction system adopts AC-DC-AC transmission mode. Model constructed in this paper focuses on the effects of voltage transformers, roof cables, main transformers and traction converters on the passing neutral section process.

Current EMUs in China mainly use electromagnetic transformers, ferromagnetic resonance phenomenon may occur when passing neutral section. Saturable transformer module is used to simulate the working characteristics of EMU roof voltage transformer, eddy current loss and hysteresis loss of the transformer core are considered [8]. The main function of traction transformer is to provide electrical energy for train traction and the low voltage load in the auxiliary system. This paper use multi-winding transformer to simulate main transformer and consider the saturation characteristics of the core.

In the simulation, a rectified three-phase rectifier is selected, which adopts a transient current control strategy. The intermediate DC circuit can filter the ripple voltage on DC side and limit voltage fluctuation when load is abrupt, to ensure the output voltage is stable [9]. Since the inverter part has little influence on the scheme, equivalent load is used to replace the inverter and traction motor module to simplify the model.

The simulation model of Chinese Standard EMU based on Matlab/Simulink is shown in Figure 2.

Figure 2. Simulation Model of Chinese Standard EMU

2.4 The operating position of the EMU in the traction network

EMU different operating positions in the power supply system is simulated by switching. EMU is set to pull into neutral section at the maximum rated power. Switch T1 simulates the duration of EMU from left feeder before entering the neutral section, switch T2 simulates the time when the EMU runs in the neutral section, switch T3 simulates the running time of EMU leaving neutral section and
entering the right feeder. TC1 and TC2 simulate two power electronic switches respectively. The EMU position and switch action timing are shown in Figures 3.

![Figure 3. EMU operating position and switch timing](image)

### 3. Model Verification

In order to verify the accuracy of the detailed EMU model, this paper selected data obtained from the actual measurement for Chinese standard EMU on the Beijing-Tianjin intercity railway in July 2018, and compares it with the simulation. The comparison between the simulation and the measurement data when the electronic TC1 action is shown in the Figure 4.

![Figure 4. Simulation and Measurement of EMUs in Neutral Section](image)

Comparing and analyzing the simulation and measurement data of the EMU in neutral section, it can be concluded that TPSS and EMU model built by this paper are accurate and effective, which can well reflect the operation of EMU in traction power supply system.

At this stage, the electronic devices has not been put into operation in China, while the device using the vacuum circuit breaker has a longer dead time. In order to compare the simulation results of EMU with measurement data, the dead time of two electronic switch blocks is set to 0.3s in the simulation. The comparison results is shown in Figure 5.
Figure 5. Simulation and Measurement of EMUs in Neutral Section

Since the switch-closing angle selected different from the measurement to simulation process, comparison picture cannot be completely matched at the overvoltage moment. Compare the voltage waveforms can draw a conclusions that EMU model is consistent with measurement, and well react the overvoltage and ferromagnetic resonance generated when passing neutral section process. It proves that the simulation model is accurate and reliable.

4. Transient Process on Passing Neutral Section of Electronic Switch

4.1 Electronic switch delay time

Thyristor will turn off under the condition that current flowing through thyristor drops below holding current. The schematic diagram of the electronic switch switching process is shown in Figure 6.

Figure 6. Switching process of the electronic switch diagram

In the figure, A is voltage zero-crossing point and B is current zero-crossing point. Due to the power factor angle, there is a phase angle difference between point A and B. If thyristor is triggered at point A, it will be turned off at point B due to the zero-turn-off characteristic. If thyristor is turned on at point C, then actual dead time is between points B and C.
In practical applications, the switching action of thyristor is controlled by complex detection and drive circuits, both devices have a certain response delay time, which causes the thyristor not to accurately operate at the desired time. The phase difference caused by the delay action of the device will affect the transient situation. Theoretical devices delay time is shown in Table 2.

**Table 2. Delay time of the electronic switch**

| Parameter Name                  | Value [μs] |
|--------------------------------|------------|
| Transformer response time      | 90         |
| Detection circuit response time| 260        |
| Software response time         | 280        |
| Trigger circuit response time  | 20         |
| Thyristor trigger delay        | 5          |
| Thyristor dispersion           | 5          |

Considering the sum of delay times of the devices, dead time can theoretically be controlled within 0.66ms. To ensure safety, the application should be considered in accordance with the device delay time greater than 0.8ms.

4.2 Transient process considering delay time

Take the delay time of 0.8ms as an example, the passing neutral section transient process under different dead times is simulated in Matlab, and the results are shown in Figure 7.

![Figure 7. Transient process under different power outage times (Considering 0.8ms delay)](image)

The simulation results show that using electronic switches instead of vacuum circuit breakers can greatly shorten the dead time during the operation of EMUs, and can well suppress the overvoltage phenomenon generated during the switch action. However, due to the influence of the EMU high-voltage transformer and the roof cable, there is still ferromagnetic resonance when passing neutral section.

5. Conclusion

This paper constructed the TPSS model and detailed China Standard EMU main circuit model based on Matlab/Simulink, and designed the electronic switch scheme and analyzed the delay time
generated by the action of the electronic switch. By comparing simulation and measurement data, the
validity and accuracy of the model are verified. Furthermore, the transient state of passing neutral
section is analyzed in consideration of the electronic switch delay time. The research results show that
the detailed model of EMU constructed in this paper can well describe the voltage and current
changes, and considering the delay time of devices can better reflect the transient situation of the
EMU on passing neutral section. The scheme of using electronic switches can suppress overvoltage
phenomenon well, but ferromagnetic resonance still exists.

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