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Analysis of the Electric Locomotives Neutral-section Passing Harmonic Resonance

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ABSTRACT

For the further analysis and suppression of the electric locomotives neutral-section passing overvoltage, on the basis of theoretical analysis of the neutral-section passing harmonic resonance conditions, this paper establishes simplified harmonic resonance simulation models of the electric locomotives neutral-section passing using MATLAB/Simulink, and makes the overvoltage simulation analysis of the existing electric locomotives neutral-section passing system in the event of a harmonic resonance. Results show that when the system harmonic resonance occurs, the operating overvoltage of the neutral-section passing is serious intensified by the overvoltage of the harmonic resonance, which will make the voltage of the pantograph collector head exceeding 100 kV. This amplitude of the overvoltage will breakdown the air gap, which will be a serious threat to the safety operation of the electric railway. However, this kind of neutral-section passing overvoltage hasn't cause the attention in the field and theoretical studies, which need more analysis and verification in the further study.

Keywords: Neutral-section passing; Harmonic Resonance; Overvoltage; Equivalent Modeling; Simulation Analysis

1. Introduction

Recently, the electric railways develop rapidly in China. With the high-speed, high-capacity and large-scale railway, the electric sectioning device based on the overlapping section with the advantages of hard-spot little and enterclose-smoothly is widely used in heterogeneous tractive power supply system. However, it exposes new problems in electric field at the same time of the application and popularization. While the locomotive passed by the electrical sectioning device, it has strong transient process such as overvoltage and overcurrent, and it brings security issues in electric railway.

At present, in view of the electric locomotives neutral-section passing overvoltage research has been comprehensive, and it conducts by two fields that the experimental research and simulation study. In the field of experimental research, locomotive Department in Lanzhou Railway Bureau organizes relevant units which sponsored Southwest Jiaotong University, China Railway First Survey and Design Institute and Zhuzhou Electric Locomotive Research Institute making field tests in the Lan-Xin Railway Wuwei to Jiayuguan Segment. The problem of over-voltage when the electric locomotive passed by the electrical sectioning device based on the overlapping section has been studied in [1]. In simulation study, the traction-locomotive system was divided into four transient processes by the physical process of the electric locomotives neutral-section passing, to establish equation of transient process, the voltage of the pantograph collector head and the renewed arc in a transient process have been calculated respectively in [2]. Simulation model of electric locomotive neutral-section passing has been built with using Pspice in [3], which made simulation analysis of the electric locomotives neutral-section passing processes when the voltage working under different degrees of saturation and the neutral-section passing processes of the system which was added the disincentives.

However, in present studies, few of them take the influence of harmonic resonance into account, except the analysis of neutral-section passing overvoltage under the condition of ferroresonance in [4]. Because of the application of the electrical sectioning device based on the overlapping section, the length of neutral section is about 150-300 m, which increases the likelihood of parameter matching with resonance. In the case of parameter matching, resonance and serious harmonic amplification may occur when the system meets the condition of harmonic resonance. Because of the voltage distortion

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which is caused by the resonance and the harmonic current increased further, interanimation of the positive feedback is formed, which results to a resonant overvoltage and the burning loss of equipment in the process of the neutral-section passing.

Based on this, according to the careful analysis of neutral-section passing transient process in the condition of harmonic resonance, the ‘traction network-locomotive’ equivalent model was built. Through the MATLAB/ Simulink, the process of the electric locomotives neutral-section passing harmonic resonance overvoltage is analyzed, and we can conclude that the harmonic resonance has a strong impact on the neutral-section passing overvoltage, which should be analyzed and considered in the future research.

2. The Analysis of the Traction Network Harmonic Transmission Characteristics

Due to the large number of actual traction network wire, the multi-conductor transmission system was simplified to an equivalent circuit of the harmonic transmission as shown in **Figure 1** to study the harmonic transmission. Among which, L_1 represents the distance of the section post and harmonic source, L_2 represents the distance of the traction substation and harmonic source, I_h represents equivalent current of the harmonic source, I_f represents the component which the harmonic source current flows to section post, I_q represents the component which the harmonic source current flows to traction substation, I_s represents the traction network current where the distance from the traction substation is s, Z_s represents the equivalent impedance of traction substation.

Through the steady-state equation and the equivalent circuit of the power transmission line, the equivalent circuit with distribution parameters on both sides of the harmonic source can be shown in **Figure 2**.

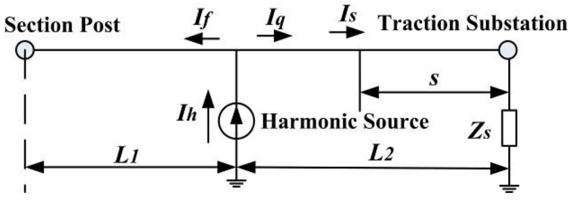


Figure 1. Equivalent circuit of the traction power supply system harmonic transmission.

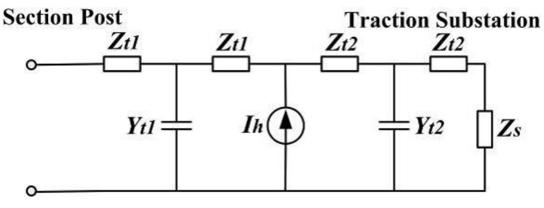


Figure 2. Equivalent circuit of traction network.

It can be concluded from derivation that:

$$\begin{cases} Z_{t1} = \dfrac{Z_t(ch\gamma L_1 - 1)}{sh\gamma L_1}, Y_{t1} = \dfrac{sh\gamma L_1}{Z_t} \\ Z_{t2} = \dfrac{Z_t(ch\gamma L_2 - 1)}{sh\gamma L_2}, Y_{t2} = \dfrac{sh\gamma L_2}{Z_t} \end{cases} \tag{1}$$

In the equation, Z_t represents the line characteristic impedance, $Z_t = \sqrt{Z/Y}$; Z , Y denote respectively the equivalent impedance and admittance per unit length of traction network; γ represents line propagation coefficient, $\gamma = \sqrt{ZY}$.

The magnification of the traction network harmonic current can be gotten as[5]:

$$A_{mpx} = \frac{I_s}{I_2} = \frac{(Z_s sh\gamma s + Z_t ch\gamma s) ch\gamma L_1}{Z_s sh\gamma(L_1 + L_2) + Z_t ch\gamma(L_1 + L_2)} \tag{2}$$

As seen in the equation (2) that A_{max} reaches its maximum when denominator is set approximately to 0, which is seen as resonance. The resonance condition can be deduced that:

$$Z_s sh\gamma(L_1 + L_2) + Z_t ch\gamma(L_1 + L_2) = 0 \tag{3}$$

As $\gamma L \ll 1$, so $th\gamma L \approx \gamma L$, and

$$Z_s = -Z_t / (\gamma L) \tag{4}$$

Consider that the equivalent impedances of traction substation mainly consist by the traction transformer inductance L_S, so

$$Z_s = \omega L_s \tag{5}$$

And the resonance frequency can be deduced:

$$\varphi = 1/(2\pi\sqrt{L_s C}) \tag{6}$$

As is seen in the equations (5) and (6) that the farther the harmonic wave source is away from the traction substation, the larger the current magnification of harmonic wave is. The transmission characteristics and resonant frequency of harmonic current in the traction network are mainly affected by the length of the traction network, the equivalent impedance of traction substation, the distribution parameters of traction network, the position of locomotive, and so on. When the harmonic frequency injected from the harmonic source to traction network is equal to or close to the resonant frequency of traction network [6], the harmonic wave is enlarged significantly, and the system resonates.

3. The Equivalent Modeling of Neutral-section Passing Harmonic Resonance Overvoltage

The process of electric locomotive’s passing section-phase is relatively complex, during which the pantograph has multiple instant contacts and separations with the contact wire of catenaries and neutral line at different positions. At these instant moments, the circuit topology changes, causing the system's electromagnetic transient processes. During these processes [7], the system parameters may meet the resonance conditions, leading to the harmonic resonance of neutral-section passing, which exacerbates overvoltage of neutral-section passing.

As for the overvoltage above, it can be analyzed by the use of the equivalent harmonic resonance overvoltage model of neutral-section passing. Equivalent model consists of four parts: catenaries, neutral section, locomotives, and the harmonic source. To establish a simplified equivalent model with coupling relationship makes a great significance to the analysis of the neutral-section passing transient process. The equivalent modeling of catenaries and the neutral section is similar to the equivalent circuit of the electric wire, which adopts π model equivalent circuit. The locomotive's equivalent model is divided into two parts of normal operation and cutting the main circuit breaker off the locomotives. When running normally, locomotive's equivalent model is replaced by impedance; otherwise, the locomotive left only interrelated circuit on the high-pressure side, and thus uses resistors, inductors and capacitors to represent that on the high-pressure side.

Based on the field measurement, more serious overvoltage in neutral-section passing occurred in the transient process after the main breaker was cut. Thus, the harmonic source considered in this paper is not provided by the locomotive itself but by other locomotives through the traction network, which here equivalent with an ideal current source. On the basis of the four parts of equivalent circuit above [8], we considered the equivalent source and equivalent impendence of the traction substation and the capacitance between catenaries and neutral section to build the equivalent model of the neutral-section passing harmonic resonance overvoltage as shown in **Figure 3**.

Among this, the left and right powered arm in the traction network are series-connected by traction substation's equivalent power (u_a, u_b) and equivalent impedance (Z_{sl}, Z_{sr}); the locomotive model is replaced by the locomotive equivalent impedance (Z_m); the harmonic source is equivalent to an ideal current source(I_h); the traction network and neutral section line equivalent circuit of left and right powered arm are formed by two parts of equivalent impedance (Z_{tl},Z_n,Z_{tr}) and capacitance (C_{tl},C_{tl1}, C_{nl},C_{nr},C_{tr},C_{tr1}) to ground, taking the capacitance (C_{cnl},C_{cnr}) between left, right arms and neutral segment of traction network into consideration at the same time, to accomplish the equivalent modeling for simulation model of harmonic resonance overvoltage of section-phase passing.

4. Simulation Analysis of the Neutral-section Passing Harmonic Resonance Overvoltage

This paper selects the automatic on-board neutral-section passing system based on the overlapping section as the research object, and the neutral-section passing transient process is divided into five transient processes, based on the different operating position of the locomotives in the electrical sectioning device.

4.1. The First Transient Process

The first transient process is the contact of the closure and the dead section transient process when the electric locomotives enter the dead section. On the basis of the previous analysis, after the appropriate circuit simplification and equivalent, the establishment of the transient process simulation model is shown in **Figure 4**.

The simulation model is built in MATLAB / Simulink as shown in **Figure 4**, by controlling the closure of the circuit breaker and setting the current value of the harmonic source analog the harmonic resonance overvoltage analysis, as the contact of the closure and the dead section transient process when the electric locomotives enter the dead section.

4.2. The Second Transient Process

The second transient process is the separate of the closure and the dead section transient process when the electric locomotives enter the dead section. On the basis of the previous analysis, after the appropriate circuit simplification and equivalent, the establishment of the transient process simulation model is shown in **Figure 5**.

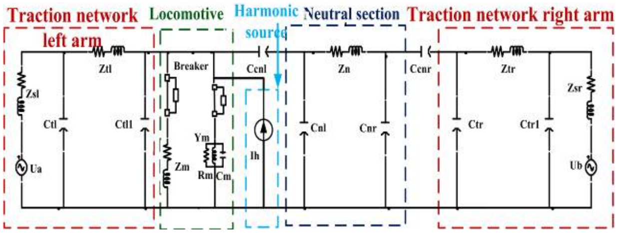


Figure 3. The equivalent schematic of the electric locomotives neutral-section passing harmonic resonance overvoltage.

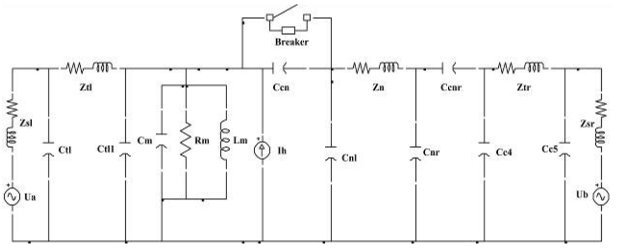


Figure 4. Simulation analysis schematic diagram of the first transient process.

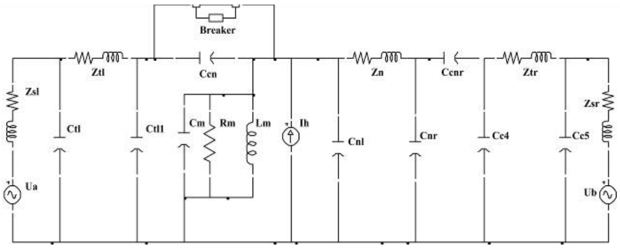


Figure 5. Simulation analysis schematic diagram of the second transient process.

The simulation model is built in MATLAB / Simulink as shown in **Figure 5**, by controlling the closure of the circuit breaker and setting the current value of the harmonic source analog the harmonic resonance overvoltage analysis, as the separate of the closure and the dead section transient process when the electric locomotives enter the dead section.

4.3. The Third Transient Process

The third transient process is the contact of the closure and the dead section transient process when the electric locomotives exit the dead section [9]. On the basis of the previous analysis, after the appropriate circuit simplification and equivalent, the establishment of the transient process simulation model is shown in **Figure 6**.

The simulation model is built in MATLAB / Simulink as shown in **Figure 6**, by controlling the closure of the circuit breaker and setting the current value of the harmonic source analog the harmonic resonance overvoltage analysis, as the contact of the closure and the dead section transient process when the electric locomotives exit the dead section.

4.4. The Fourth Transient Process

The fourth transient process is the separate of the closure and the dead section transient process when the electric locomotives exit the dead section. On the basis of the previous analysis, after the appropriate circuit simplification and equivalent, the establishment of the transient process simulation model is shown in **Figure 7**.

The simulation model is built in MATLAB / Simulink as shown in **Figure 7**, by controlling the closure of the circuit breaker and setting the current value of the harmonic source analog the harmonic resonance overvoltage analysis, as the separate of the closure and the dead section transient process when the electric locomotives exit the dead section.

4.5. The Fifth Transient Process

The fifth transient process is the closure of the main circuit breaker transient process when the electric locomotives exit the dead section [10]. On the basis of the previous analysis, after the appropriate circuit simplification and equivalent, the establishment of the transient process simulation model is shown in **Figure 8**.

The simulation model is built in MATLAB / Simulink as shown in **Figure 8**, by controlling the closure of the circuit breaker and setting the current value of the harmonic source analog the harmonic resonance overvoltage analysis [11], as the closure of the main circuit breaker transient process when the electric locomotives exit the dead section.

5. Simulation Analysis

Calculating and setting the parameters in the above models [12], the value of C_m is 1 uF, the value of L_m is 5H, the value of R_m is 100 MΩ, the value of L_n is 0.001H, the value of R_n is 0.039 Ω, the values of C_{nl} and C_{nr} are 71 nF, the values of R_{sl} and R_{sr} are 0.02 Ω, the values of L_{sl} and L_{sr} are 1.19 mH, the values of C_{tl}、C_{tl1}、C_{tr}、C_{tr1} are 40.26 nF, the values of R_{tl} and R_{tr} are 2.34 Ω, the values of L_{tl} and L_{tr} are 0.06 H ,the values of C_{cnl} and C_{cnr} are 5 uF.

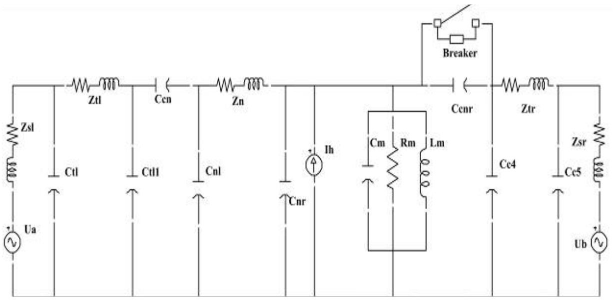


Figure 6. Simulation analysis schematic diagram of the third transient process.

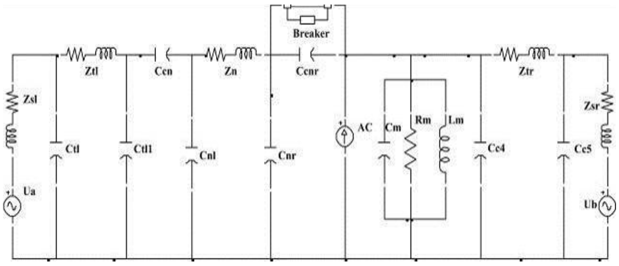


Figure 7. Simulation analysis schematic diagram of the fourth transient process.

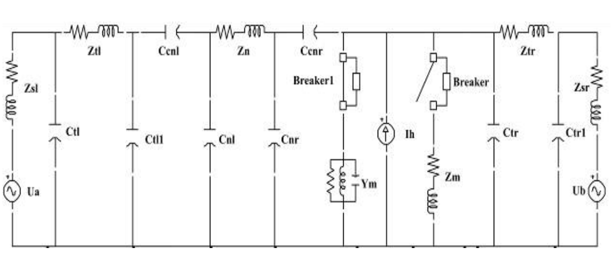
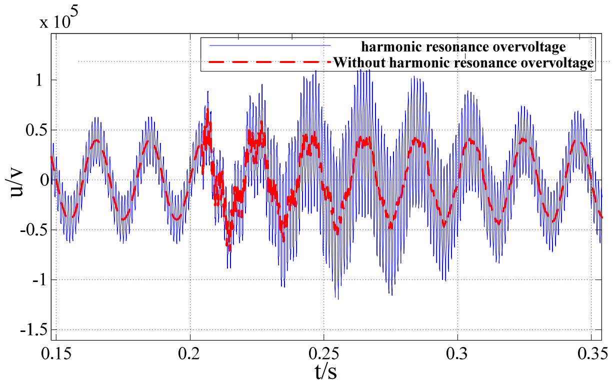
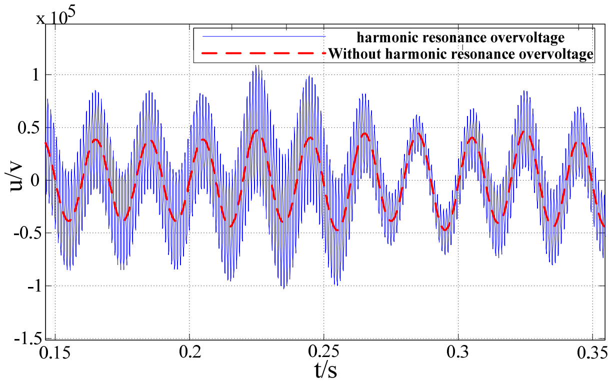


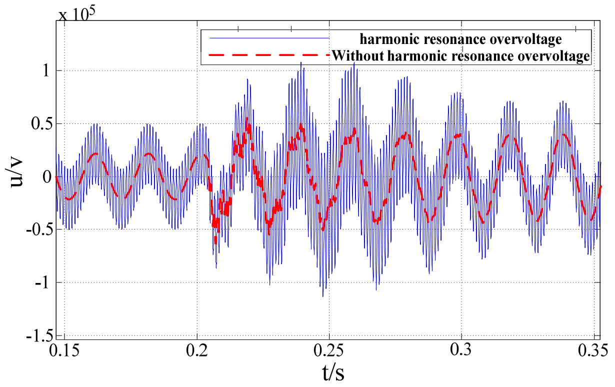
Figure 8. Simulation analysis schematic diagram of the fifth transient process.



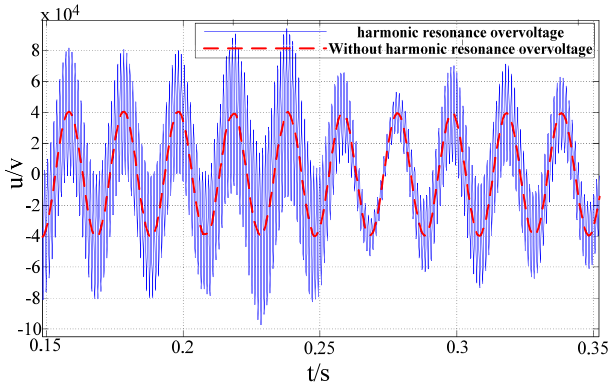
(a) The voltage oscillogram of the first transient process



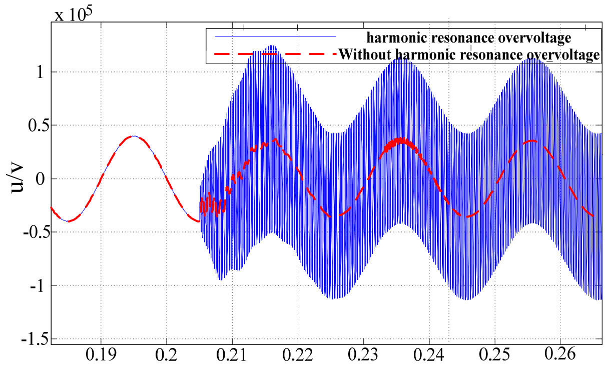
(b) The voltage oscillogram of the second transient process



(c) The voltage oscillogram of the third transient process



(d) The voltage oscillogram of the fourth transient process



(e) The voltage oscillogram of the fifth transient process

Figure 9. The voltage oscillograms of the pantograph collector head.

By setting the circuit breaker operation time is 0.20428 s, and the frequency of the ideal current source was taken to the resonant frequency of the transient process [13]. When the value of is 0 A to simulate that the system does not occur harmonic resonance overvoltage, and when the value of is 5A to simulate that the system occurs harmonic resonance overvoltage. Simulation analysis of the all five transient processes, **Figure 9** shows the waveform summary of the voltage of the pantograph collector head.

The simulation analysis shows that the operating overvoltage of the neutral-section passing is serious intensified by the overvoltage of harmonic resonance [14], when the system harmonic resonance occurs, which made the amplitude of the overvoltage exceed 100kV. Over time, the overvoltage of the neutral-section passing tends to smooth. In the first four transient processes, the harmonic resonance occurred before and after the circuit breaker operation. This is because that the system parameters don't before and after the breaker action, so the resonant frequency doesn't change significantly. However, in the fifth transient process, the system didn't occur the harmonic resonance before circuit breaker operation [15]. This is because that the system parameters change significantly after the breaker action. The frequency of the harmonic source applied to the system is the resonance frequency after the circuit breaker operation.

6. Conclusions

Through modeling the simplified traction power supply system and electric locomotive, and dividing, modeling, analyzing and simulating for the electric locomotives neutral-section passing process, one can know that overvoltage caused by the harmonic resonance when the system meet a condition that harmonic resonance could taken place can lead to the voltage during phase-separation process operating seriously intensification [16], which will make the voltage of the pantograph collector head exceeding 100 kV and penetrating the air gap and causing serious threats to the electric railway safety operation. However, this kind of neutral-section passing overvoltage hasn't cause the attention in the field and theoretical studies, which need more analysis and verification in the further study.

7. Acknowledgements

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REFERENCES

[1] Y. S. Gong, "Research of Over-voltages of Electric Locomotive Passing the Articulated Phase Insulator," *Journal of the China Railway Society*, Vol. 30, No. 4, 2008, pp. 103-107.

[2] X. Y. Zhang, "Research on Overvoltage Mechanism and Prevention in the Network-Locomotive Coupling of the High Speed and Heavy Haul Railways," ChengDu:South West JiaoTong University, 2009.

[3] Y. S. Li, "Machanism Analysis on the Overvoltage of Articulated Phase Insulator," ChengDu: South West JiaoTong University, 2008.

[4] F. L. Zhou, Q. Z. Li, J. M. He, *ect*. "Research on Simulation, Practical Measurement and Mechanism of Locomotive Over-voltage and Passing Neutral-section Based on Probability," *Electric Drive for Locomotives*, Vol. 6, 2008, pp. 13-16.

[5] Z. Y. He, H. T. Hu, L. Fang, ect. "Research on the Harmonic in High-speed Railway Traction Power Supply System and Its Transmission Characteristic," *Proceedings of the CSEE*, 2011，Vol. 31，No. 16, pp. 55-62.

[6] Y. J. Liu, G. W. Chang, H. M. Huang. "Mayr's Equation-Based Model for Pantograph Arcof High-Speed Railway Traction System," *IEEE Transactions on Power Delivery*, Vol. 25, No. 3, 2010, pp. 2025-2027. doi:10.1109/TPWRD.2009.2037521

[7] D. Ma, "Analysis of Over-voltage Transient State Process of De-energized Passage of Neutral Section Insulator," ChengDu: South West JiaoTong University, 2008.

[8] G. J. Li, X. Y. Feng, L. J. Wang, ect. "Research and Simulation on Auto-Passing Phase Separation Control Strategy of High-Speed EMU," *Transactions of China Electrotechnical Society*, 2007, Vol. 22, No. 7, pp. 181-185.

[9] J. M. Wen, B. T. Wang, Z. J. Fang, "Research and Using on Auto-Passing Phase Separation Control Strategy of High-Speed EMU," *Railway Standard Design,* 2011，Vol. 4, pp. 104-108.

[10] W. Q. Sun, S. X. Shan and G. F. Zheng, "Comparison between Home and Aboad of Automatic Passing Over of Neutral Section Device," *Electric Raileay*, 2002, Vol. 2, pp. 12-16.

[11] X. F. Ao, S. B. Liu, "Train Carried Automatic Conversion System for Passing through the OCS Phase Break," *Electric Railway*, 2006, Vol. 2, pp. 5-10.

[12] N. Li, "Research on Electromagnetic Transient Process of Electric Locomotive System," Beijing: Beijing Jiaotong univerisity, 2010.

[13] X. Yan, "A Few Questions about Auto-Passing Phase Separation on Locomotives," *Electric Drive For Locomotives,* 2004, Vol. 2, pp. 66-68.

[14] X. L. Qin, "Electric Locomotive Passing Articulated Phase Insulator Overvoltage Analysis and Protection," Beijing: Beijing Jiaotong univerisity, 2007.

[15] G. J. Li, X. Y. Feng, L. J. Wang, ect. "Research and Simulation on Auto-Passing Phase Separation Control Strategy of High-Speed EMU," *Transactions of China Electrotechnical Society,* 2007, Vol. 22, No. 7, pp. 181-185.

[16] Z. G. Fang, "Application of Transient Over-voltage Suppression Technique for EMU Auto-passing the Neutral Section with On-board Switch Closed," *Railway Technical Innovation,* 2010, Vol. 1, pp. 44-46.