Analysis of interference and protective measures of electrified traction current on signal track circuit based on Moire signal

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Abstract. In railway transportation, electric traction can greatly improve the transportation capacity, can significantly save energy and has no environmental pollution. It is one of the main signs of railway modernization. With the development of railway transportation and the increase of train weight and train speed, the electric traction current also increases. Electric traction also brings great strong electric interference to railway signaling equipment, and the influence of traction current on signaling equipment also increases. However, the return of unbalanced traction current in the rail has the most serious conductive interference to the track circuit. If certain protective measures are not taken, it will affect the normal operation of the track circuit. The track relay malfunctions, causing an error display signal, a locked circuit error to unlock, and even burning the device. Such as rail circuit insurance, choke transformers, etc. Without the support of more advanced railway signal equipment, the advantages of electrified railways cannot be fully utilized. Therefore, it is necessary to understand the formation of the unbalanced current of the rail and take protective measures to make the signal equipment work stably and reliably.

1. Introduction
The electric locomotive in the railway system does not have any energy, but can only obtain electric energy through the traction power supply system [1]. The electric energy is converted to drive the electric motor to rotate the wheels and finally pull the train to run. Therefore, the electrified railway is composed of traction power supply system and electric locomotive [2]. Electrified railway is a modern means of transportation that uses electric energy as traction power to drive trains [3]. Because of its energy saving, environmental protection, strong power and overload capability, it can better realize fast running of Dora and improve the railway transportation capacity. It has been listed as a green mode of transportation developed by various countries in the world. The type and power of traction power are the main factors to increase the weight of the train and the key to increase the speed and density of the train [4]. The influence of electrified railway on signal system has three forms: conduction, induction and radiation. Among them, conductivity disturbance is the most serious. It is mainly manifested by the influence of unbalanced traction current on signal equipment such as track circuit and locomotive signal and the influence of ground potential rise [5]. If advanced signaling equipment cannot effectively prevent and eliminate various interferences caused by electric traction, it cannot ensure driving safety and improve transportation efficiency.

After a brief description of the effects of the electrified railway on the signal system, we introduced the traction power supply system of the electrified railway and the traction current interference sources that affect the railway signal equipment [6]. The conduction interference mechanism and the orbital flow distribution model along different power supply modes are analyzed to determine the distribution of rail reflow. In order to prevent the strong electrical interference caused by the electrified railway to the signal equipment, the signal equipment is better adapted to the electric traction mode [7]. The traction current
comprehensive analysis system is designed reasonably. Based on the analysis of the functional requirements of the system, the overall design scheme and implementation method of the system are given [8]. The system design realizes the reduction, waveform display and detailed data analysis of the traction current data acquisition and storage of the railway line, and can reflect the dynamics of the traction current in the field in real time [9]. It provides a reliable theoretical basis for the anti-interference of railway system signal equipment, and finds the interference protection measures that can effectively suppress or solve the signal system, which has certain practical value [10].

2. Development and Classification of Railway Signal Control System

2.1. Development of Railway Signals
Railway signal system is an important field of modern railway information technology. Train operation control and train dispatching command automation are key technologies for railway signal development, representing the development trend of railway train operation information and control technology. Railway signaling system involves the safe and effective operation of trains, is a key component of modern railways, and is also a comprehensive automation system to measure the level of railway modernization. Traditional signal equipment is mainly a control system based on electromechanical equipment such as transformers and relays, which has natural advantages in electromagnetic interference protection. After the 1990s, railway signals began to use a large number of applications in microelectronics, modern communications, automatic control and computer technology. The system consisted mainly of information and communication equipment. It is characterized by miniaturization, digitization and low power consumption. The composition of electronic devices is more complicated. The operating frequency and communication rate of microelectronic devices are getting higher and higher, while the power consumption, working voltage and current are gradually decreasing, that is, the signals are more sensitive.

2.2. Classification of Railway Signals
There are many classification methods for railway signal systems, which can be classified according to equipment function, safety level, electromagnetic environment, etc. Signal systems and related equipment can be roughly divided into six types according to their functions. First, the traffic dispatching command system. The centralized dispatching system and the train dispatching command system mainly adopt computer and network technologies. Second, the station interlocking. Computer interlocking technology will be gradually adopted for newly-built lines and existing lines. 3. Blocking system. The main stream is a series of non-insulated automatic block systems, in which the transmitter and receiver take digital signal processing as the core device. Four, marshalling station control system.5. China train control system. The ground equipment layer mainly includes a column control center, a track circuit, a point device, an interface unit, a wireless communication module, and the like. The train control center is the core of the ground equipment. According to the train command, the train approach, the train running condition and the equipment status, the control logic is used to generate the control command to realize the control of the running train. Others include signal microcomputer monitoring systems, intelligent railway signal power systems, and more.

3. Disturbance of Traction Current on Signal Equipment

3.1. Electrostatic Induction Interference and Capacitive Coupling
When the working power input by the contact net is applied, an alternating electric field perpendicular to the surface of the conductor is formed around the contact net conductor. Due to electrostatic induction, the overhead communication signal line in the electric field will generate electrostatic induction potential, thus causing harmful interference to the communication signal line. Because the power frequency current frequency of electrified railway traction is very low, electrostatic induction interference is very small, which is negligible relative to the signal in the signal system. Capacitive
coupling refers to the influence of induction caused by unbalanced voltage to ground in contact network. A continuously distributed alternating electromagnetic field is generated in the space around the contact net of the single power frequency AC electric traction section. Since there is a capacitance between the neighboring person or the victim device and the earth, there is a coupling capacitance between the contact net and the person or the device, so that an induced voltage is inevitably generated to form a capacitive fit. Therefore, on various signal devices installed along the railway, potentials and longitudinal electromotive forces to the earth are generated, and various signal circuits also cause induced currents to appear.

3.2. Radiation effects
Electromagnetic radiation interference is the interference that the interference source propagates to sensitive equipment through space. Once the locomotive passes through, the electromagnetic radiation interference will be generated around the catenary when there is current. This kind of interference is manifested in electrostatic induction and electromagnetic induction. There is an ”antenna effect” around the energized conductor. In this effect, when a current-carrying conductor is used as a transmitting antenna, an induced electromagnetic field will be generated around it and electromagnetic waves of a certain intensity will be radiated outward. At the same time, any other conductor in the electromagnetic field is considered to be a receiving antenna, which will generate a certain electromotive force. It is this effect that causes electronic devices to generate electromagnetic interference with each other. The causes of radio frequency interference generated by electrified railways include: spark discharge from traction contact nets, arcing between contact nets and pantograph slides, commutation of electric traction locomotives, electrified railway opening equipment, electric locomotive motors, tuning The transient process of the press and switchgear during operation.

4. Interference analysis of unbalanced rail current

4.1. Formation Circuit of Traction Current
The electric locomotive obtains electric energy from the catenary after lifting the bow, and supplies the electric energy to the locomotive motor after the main transformer depressurizes. Feeder, catenary, rail and return line form a two-wire power supply system and form a closed loop via electric locomotive. The current flowing in the traction power supply loop is traction current. Due to the conductance between the rail and the earth, part of the traction current leaks into the earth through the rail after flowing through the electric locomotive. This part of the current takes the earth as a conductor and then flows to the bus of the traction substation through the grounding network of the traction substation. The two rails of the electric traction section serve both as a channel for the track circuit to transmit information and as a return path for traction current. These two different currents are transmitted in the same rail line, and the traction current has a great influence on the normal operation of the interference track circuit. The interference voltage generated by the traction current in the orbit is proportional to the magnitude of the traction current, the imbalance factor, and the input impedance of the traction circuit current to the traction current. To reduce the interference voltage, it is necessary to reduce or suppress the imbalance factor and the input impedance of the receiver.

| Harmonic Number of Traction Current | HZ | %  | Harmonic Number of Traction Current | HZ | %  | Harmonic Number of Traction Current | HZ | %  |
|------------------------------------|----|----|------------------------------------|----|----|------------------------------------|----|----|
| 1                                  | 50 | 97.2| 9                                  | 450| 2.75| 17                                  | 850| 0.71|
| 2                                  | 100| 0.46| 10                                 | 500| 0.35| 18                                  | 900| 0.26|
| 3                                  | 150| 9.87| 11                                 | 550| 1.63| 19                                  | 950| 0.73|
| 4                                  | 200| 0.52| 12                                 | 600| 0.35| 20                                  | 1000| 0.25|
| 5                                  | 250| 9.75| 13                                 | 650| 0.98| 21                                  | 1050| 0.64|
The influence of in-band harmonics is briefly analyzed. Taking carrier frequency 1100HZ as an example, only three adjacent harmonics may cause interference. Taking 1050/1100/1150HZ harmonics as 0.64%, 0.114% and 0.57% of the total, the unbalance coefficient is 10% when the total rail current is 2000A, that is, 100A current is balanced.

4.2. Disturbance of Traction Current on Track Circuit

There are three kinds of interference of traction current to track circuit. One is stable interference. When the traction substation is cracked for some reason, the traction current interference will change with the change of train displacement and current required by the train, but with the change of time and train running state. The second is the impact current interference. When the train is running, due to gear shifting, gear shifting, pantograph off-line and switching into isolated phase insulation section, an impulse current appears in the traction circuit. Because the transient current waveform contains strong harmonic components, the signal is phase shifted after intrusion. The track circuit is unreliable, causing a “flashing red” fault and even causing the track relay to malfunction. When the contact net insulation is damaged, the traction net is in a short-circuit state, and a strong current pulse occurs for a short time, which can blow the fuse or burn the equipment. The third is the interference caused by poor traction. When the electric locomotive is running, the traction current flows through the locomotive, the rails and the earth and then returns to the substation. The traction current is not flowing smoothly, and there will be a large roundabout strong current destroying the signal equipment, causing serious equipment failure.

5. Reducing interference and strengthening anti-interference measures

5.1. Reducing unbalanced current

The imbalance coefficient of traction current cannot be equal to zero, that is, disturbance of interference current is inevitable. We can only try to reduce the intrusion of interfering current, and we must take necessary special measures to deal with the factors one by one. To reduce the unbalanced current between the two rails, it is necessary to improve the longitudinal conductance imbalance between the two rails. If a plug-and-weld connection line is used for the rail end connection line, the imbalance of longitudinal conductance of the two rails can be well improved. At the same time, good materials should
be selected for construction, and the management of operation technology should be improved, so as to improve the imbalance of longitudinal conductance of rail and improve the transmission performance of rail circuit. In addition, long rails and seamless tracks are used to reduce the influence of joint resistance on the overall longitudinal conductance of the rail network, thus reducing the influence on traction current leakage. The operating unit shall regularly carry out large and medium-sized repair on the line according to the number of years, clear the slag and improve the quality of the line. This is conducive to improving the influence of traction current backflow on floor drain, as well as stable and reliable operation of track circuit, and has obvious benefits for ensuring driving safety and improving transportation efficiency.

Improving the transmission performance of the track circuit can effectively prevent the occurrence of poor return current traction current, and reduce or eliminate the occurrence of unbalanced current. For example, reinforcement or welding of connection points such as various connecting wires, neutral connecting wires, and suction wires. Increase the cross-sectional area of various connecting lines and connecting lines. The cross-sectional area of the traction cable, the lateral cable and the ballast jumper is not less than 42 mm. Use equal-impedance rail lead wires. Each track circuit section should adopt double turbulence track circuit. It has been proved that the single turbulence section has poor anti-interference ability. When the insulation is broken, the track is broken, the turbulence transformer is broken, etc., the backflow is not smooth, resulting in poor return. The track circuit is malfunctioning. In addition, standardizing the ground lines of buildings along the railway can also reduce unbalanced currents. If the contact with the pole tower ground wire should not be directly connected to the rail, it is not ideal to connect to the center terminal of the rail and the choke transformer through the spark gap. The grounding wire of the contact pole tower should be concentrated.

5.2. Improving the Protective Performance of Equipment
Choke transformer is the main equipment for conducting traction current, transmitting information and matching the power transmitting and receiving end of track circuit in electrochemical section, so it is very important to select high capacity choke transformer matching the maximum traction current. Track circuit must adopt non-power frequency track circuit, such as 25Hz phase sensitive track circuit, frequency shift track circuit, etc. Separated from 50Hz traction current to prevent traction current interference. Anti-interference adapter is installed at the receiving and transmitting end of the track circuit to relieve the impact current and reduce the influence of unbalanced current. As the first filter, the adapter filters the large unbalanced traction current in the impact interference, and at least 95% can be filtered out. And its useful signal current consumption is very small, does not affect the normal operation of the track circuit. For powerful currents above 10A, there is a 10A security guard to protect the equipment on the receiving side of the track circuit from damage. The track-end relay coil of the track circuit is connected to the protective box to filter out the 50 Hz fundamental wave and harmonic components of the unbalanced current, and to ensure that the signal current attenuation is small.

5.3. Engineering Protection Measures for Suppressing Interference Signals in Signal System
As far as possible, or power supply mode is adopted in the selection of power supply mode, so that traction current flows back to traction substation mainly through return line, positive feeder line or external conductor. The symmetry of the power supply circuit is improved, and the influence of the induced current of the contact network is reduced. Provide the signal system maintenance staff with a complete full-line backflow layout so as to determine the specific measures to prevent backflow blockage. Parallel capacitance compensation device is installed in traction substation to reduce harmonic interference. On the one hand, it can play a filtering role, on the other hand, it can improve the power factor. Choose a reasonable type of locomotive or take measures on the locomotive to have the characteristics of absorbing the even harmonics generated by itself and to generate harmonic components as little as possible. The tower grounding wire is detached from the rail, and a dedicated line is directly connected to the tower. This dedicated line is connected to the midpoint of the current transformer through the discharge gap. In the tunnel or on the long bridge, this special line can be fixed.
with one side of the insulator, which not only ensures the grounding protection of the tower equipment, but also protects the grounding device.

6. Conclusion

Due to the gradual construction of microelectronic, computer and communication technologies as the core, and the evolution to an integrated automation system integrating dispatching command, operation control and automatic driving, the development of new signal technologies and new equipment will be seriously affected by interference. Under such development, traction power and traction current will inevitably increase, making the external electromagnetic environment of the signal system more complex. Starting from the interference source and interference effect of electrified railway on signal system, we have analyzed the conductive interference of traction current on track circuit, especially the generation and interference of unbalanced current. According to the interference mode and approach of traction current to rail circuit, the protection measures of unbalanced current of track circuit are analyzed. With the demand for railway transportation and the use of various high-tech equipment, the railway system faces more complicated and serious electromagnetic interference, and the research on electrification interference should be more in-depth and attention. The electromagnetic compatibility design of the signal system under high-speed and heavy-load conditions is especially important, and the research on the anti-interference performance of the signal equipment is intensified to ensure the safe and reliable operation of the train.

References

[1] Li Y, Tian X, Li X. Hybrid algorithm for traction transformer differential protection based on intrinsic mode function energy entropy and correlation dimension[J]. IET Generation, Transmission & Distribution, 2014, 8(7):1274-1283.
[2] Shamanov, V. I. The process of traction-current asymmetry generation in rail lines[J]. Russian Electrical Engineering, 2014, 85(8):509-512.
[3] Youssef M, Woronowicz K, Aditya K, et al. Design and Development of an Efficient Multilevel DC/AC Traction Inverter for Railway Transportation Electrification[J]. IEEE Transactions on Power Electronics, 2015:1-1.
[4] Caracciolo F, Fumi A, Cinieri E. Managing the Italian High-Speed Railway Network: Provisions for Reducing Interference Between Electric Traction Systems[J]. IEEE Electrification Magazine, 2016, 4(3):42-47.
[5] Machczynski W, Budnik K, Szymenderski J. Assessment of d.c. traction stray currents effects on nearby pipelines[J]. COMPEL International Journal of Computations and Mathematics in Electrical, 2016, 35(4):1468-1477.
[6] Li Q. On new generation traction power supply system and its key technologies for electrification railway[J]. Journal of Southwest Jiaotong University, 2014, 49(4):559-568.
[7] Lucca, G. Estimating stray current interference from DC traction lines on buried pipelines by means of a Monte Carlo algorithm[J]. Electrical Engineering, 2015, 97(4):277-286.
[8] Carpiuc S C, Lazar C. Fast Real-Time Constrained Predictive Current Control in Permanent Magnet Synchronous Machine-Based Automotive Traction Drives[J]. IEEE Transactions on Transportation Electrification, 2016, 1(4):326-335.
[9] Drew, Alan. Electric Traction: Sprague’s Efforts in Railroad Electrification [Book Review][J]. IEEE Power and Energy Magazine, 2015, 13(3):90-91.
[10] Ramarathnam S, Mohammed A, Bilgin B, et al. A Review of Structural and Thermal Analysis of Traction Motors[J]. IEEE Transactions on Transportation Electrification, 2015, 1(3):255-265.