Chapter 64
Measurement and Analysis on Low-Frequency Oscillation in Xuzhou Electrical Railway Hub

Jing Li and Mingli Wu

Abstract The low-frequency oscillation in the traction network is a new phenomenon as with AC-DC-AC locomotives utilized in electric railways. However there are few researches focused on it. It has been noted that the low-frequency oscillation in Xuzhou North Railway Hub is particularly extraordinary because it caused abnormal voltage fluctuation. Therefore, it is necessary to investigate this low-frequency oscillation phenomena in detail. By designing test plan, we do some measurements in Xuzhou North Traction Substation and Sub-feeder Switching Post (SFSP). Besides, the voltage and current of primary winding of traction transformer in HXD_2B locomotive are also measured to fully analyze whether low-frequency oscillation is caused by traction network or locomotive. And then through the analysis on data and waveform, the cause of low-frequency oscillation of electric railway is concluded. Finally, some measures to suppress low-frequency oscillation are put forward.

Keywords Traction power supply system · Locomotive · Low-frequency oscillation · Suppression solutions

64.1 Introduction

The low-frequency oscillation phenomena have occurred in a variety of AC locomotives and the electric multiple units train (EMU) at different times, different locations, and different traction power supply conditions [1]. However, the low-frequency oscillation, which occurred in north Xuzhou, is particularly extraordinary in that it caused abnormal voltage fluctuations. As a result, it affects the

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stability of traction power supply system, as well as the safe operation of electric locomotives to some extent.

Not only are tractive force and running speed of electric locomotives influenced by voltage level of traction power feeding system, but also are carrying capacity and traffic volume of section [2]. In addition, Xuzhou North Railway Hub is an intersection between Beijing–Shanghai railway and Lanzhou–Lianyungang railway. So the voltage level of traction power supply system is particularly important.

In this paper, the cause of this phenomenon is fully analyzed, based on the measurement of electric quantities in Xuzhou North Traction Substation, Sub-feeder Switching Post (SFSP), and HXD_2B locomotive. After that, solutions to this problem are proposed.

64.2 Field Measurement

To do further research, some electrical quantities are measured in Xuzhou North Traction Substation, SFSP, and HXD_2B locomotive. A waveform-recorder, the EMAP system, is adopted in this test. The sampling frequency is 10 kHz.

The power supply schematic diagram of Xuzhou North Traction Substation and SFSP is shown in Fig. 64.1. Here are the measured electrical quantities: (1) Xuzhou North Traction Substation: voltage of phase a, current of phase a, voltage of phase b, current of phase b (all of 27.5 kV side), and current of feeder 211 (for Xuzhou North Sub-feeder Switching Post); (2) Xuzhou North Sub-feeder Switching Post:

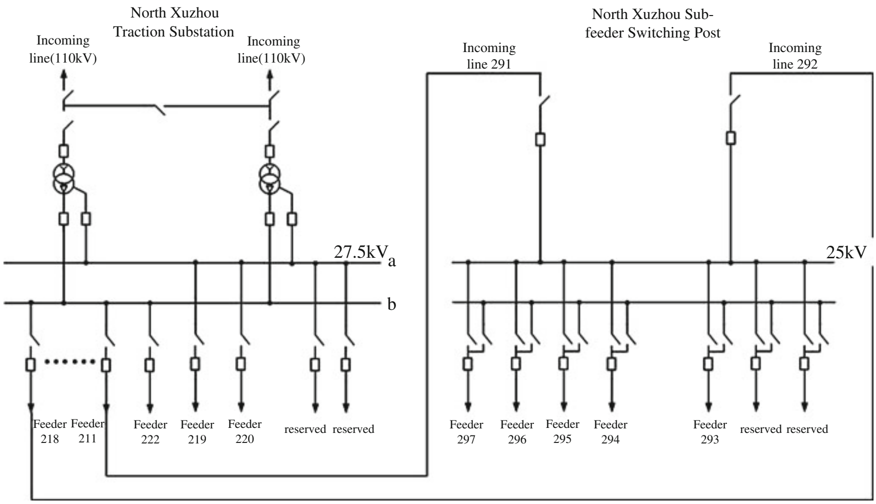

Fig. 64.1 The schematic diagram of the power supply

27.5 kV bus voltage, current of incoming line 291, current of feeder 293 (for uplink arrival field), current of feeder 294 (for downlink freight yard), current of feeder 295 (for downlink starting filed), current of feeder 296 (for locomotive depot), and current of feeder 297 (for uplink freight yard).

Apart from the ground test, an HXD_2B electrical locomotive is also measured. The electrical quantities of HXD_2B are the current and voltage of primary winding of traction transformer.

64.3 Measured Results

From January 7 to 10 in 2014, some measurements on low-frequency oscillation phenomenon were taken in Xuzhou North Railway Hub. The current signals were measured by current clamps, and the voltage signals were measured by voltage transducers. They were all obtained from the control panels in substations or onboard.

64.3.1 Substation Measurement Results

After analyzing the testing data, it is found that when the low-frequency oscillation occurred, the traction power supply voltage may reach to an excessively large or

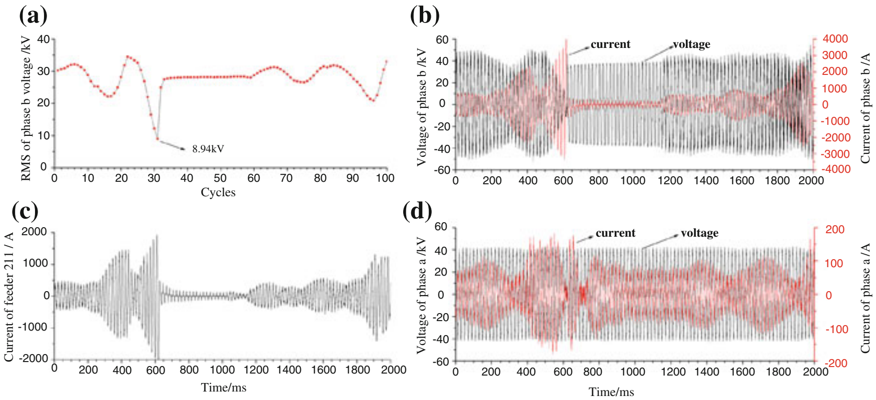

Fig. 64.2 The waveforms of electrical quantities in substation: **a** RMS of phase b voltage, **b** voltage waveform and current waveform of phase b, **c** current waveform of feeder 211, **d** voltage waveform and current waveform of phase a

small value which is not allowed by AC voltage of electric traction standard for the railway main lines [3]. We have captured many moments when the low-frequency oscillation phenomena occurred. Some typical waveforms of related electrical quantities are shown in Figs. 64.2 and 64.3.

As shown in Fig. 64.2, the root mean square (RMS) value of voltage of phase b in substation reaches to the smallest value 8.94 kV during the whole measurement. In addition, the current signals begin to oscillate at the same time when the voltage signals begin to oscillate. Furthermore, current signals of a few feeders come into synchronous fluctuation once the fluctuation occurs in one feeder, which shows that a certain type of locomotive even in different areas of the same power supply section also can come into a synchronous state of unstable oscillations through the network voltage coupling. The range of total current fluctuation is from 0 to 2500 A. The current signals fluctuate like a calabash during the period of 0.6–1.0 s and then reach to a small value. However, after about 1.3–1.4 s, they begin to fluctuate again. The oscillation frequency ranges from 0.6 to 2 Hz. Therefore, the case in north Xuzhou is the low-frequency oscillation of voltage and current. It must be pointed out that we also captured the stable low-frequency oscillation phenomenon, which is similar to the cases occurring in other places.

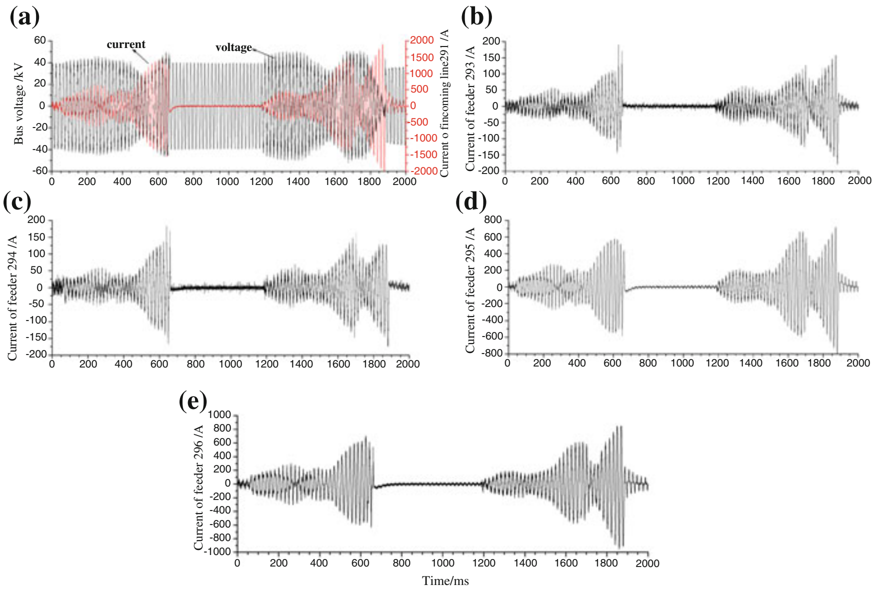

Fig. 64.3 The waveforms of electrical quantities in SFSP: **a** bus voltage waveform and current waveform of incoming line 291, **b** current waveform of feeder 293, **c** current waveform of feeder 294, **d** current waveform of feeder 295, **e** current waveform of feeder 296

64.3.2 HXD_2B Electrical Locomotive Measurement Results

During the test, most locomotives running in the related sections were HXD_2B. Therefore, HXD_2B electrical locomotive may contribute to this phenomenon. We tested the current and voltage of primary winding of traction transformer onboard HXD_2B. The measurement results are displayed in Fig. 64.4. It is clear that when the current oscillated, the voltage is abnormal.

The oscillation of HXD_2B is intermittent. In the end of the oscillation, the current value is very small, near to the magnetizing current of traction transformer.

64.3.3 Measurement Analysis

In a word, the low-frequency oscillation causes the abnormal fluctuation of catenary voltage in this case. The voltage fluctuation in SFSP is more intense than that in substation. The minimum value of bus voltage in substation is 8.94 kV, and the maximum value is 36.1 kV. The minimum value of bus voltage in SFSP is 5.29 kV, and the maximum value is 37.8 kV.

Voltage fluctuation is synchronous with current fluctuation. That is to say, the traction power supply voltage is steady when the current is normal. During the low-frequency oscillation, the phase difference between the current and voltage is always changing, as shown in Fig. 64.5. In Fig. 64.5, when the phase of current leads, the voltage value increases and vice versa. The phase difference between voltage and current reflects the exchange of reactive power. In fact, the low-frequency oscillation of electric railway is not caused by power supply but the phase difference, namely the reactive power exchange. Furthermore, it is just to mean that the current collection of load causes low-frequency oscillation.

By analyzing the measurement results of ground test and locomotive test and investigating relevant locomotive circumstances in the power supply area during the test, we may draw a conclusion that it is the low-frequency oscillation of current of HXD_2B electric locomotives that causes the abnormal fluctuation in Xuzhou North

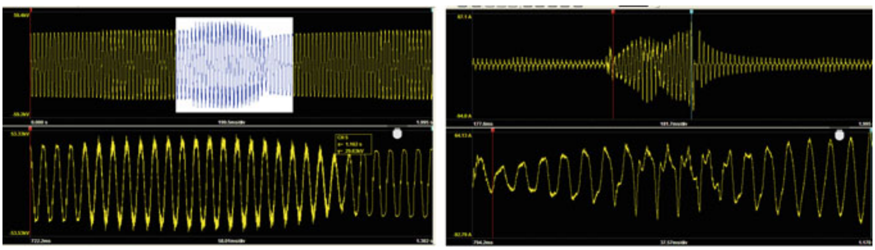

Fig. 64.4 The waveforms of current and voltage of HXD_2B: (*left*) voltage waveform, (*right*) current waveform

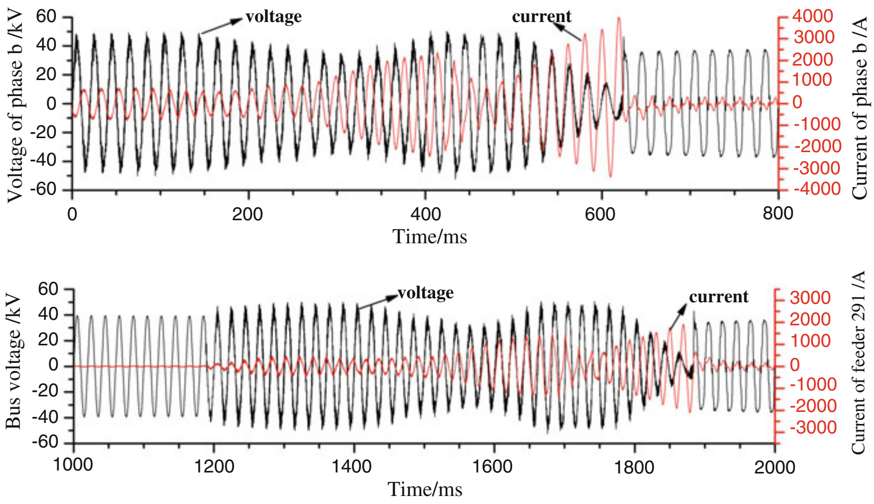

Fig. 64.5 Enlarged drawing of some electrical quantities in Fig. 64.2: (*top*) voltage waveform and current waveform of phase b, (*bottom*) bus voltage waveform and current waveform of feeder 291

Railway Hub. The locomotive current is determined by the control strategy of its line-side converters [4–6].

In order to guarantee the locomotive power balance, the current of locomotive tracks the voltage change of network. But when the current cannot follow the voltage changes, the running state of a locomotive transforms between traction and brake frequently. Due to unsuccessful control, the power factor of locomotive is not 1 or −1. As a result, the traction current contains reactive component, and the inductive and capacitive current come into oscillation state, eventually lead to oscillation [7].

64.4 Solutions to Suppress the Low-Frequency Oscillation

When the low-frequency oscillation occurs in electrical railway, the voltage value of power supply system may reach to an excessively large or a small value which is not permitted by the electrical railway. What is worse, the operation system of locomotive may be blocked so that the normal transportation has to stop. Moreover, some equipment in locomotive may be destroyed. For traction power supply system, the catenary voltage level is affected, which is not safe for railway system.

For Xuzhou North Railway Hub, load balance between phase a and phase b of transformer is not good. The average load of phase b is about three times as large as that of phase a, which is disadvantageous for controlling the number of locomotives in the same supply arm and restraining voltage fluctuation. Therefore, some isolated feeders can be supplied by phase a to modify load balance so that voltage fluctuation can be suppressed. This method is only a short-term control measure. In the long run, some solutions can be put forward in respect of both locomotive and power supply system.

In terms of power supply system, we can improve the transformer capacity in substation to enhance the source. Assuming that the power supply capacity is infinite, regardless of current change in the circuit, the voltage of power supply will be unchangeable. Therefore, to some extent, improving transformer capacity is effective to suppress the abnormal voltage fluctuation caused by low-frequency oscillation.

In terms of locomotive, we can obtain the critical number of locomotives which may cause the low-frequency oscillation so that we can avoid that number of running locomotives. What is most effective is to modify the control strategy of the line-side converter. The failing control when the load is very light seems to make contribution to the current fluctuation, eventually leads to the low-frequency oscillation. We can change the PI parameters of the controller of line-side converters [8, 9]. Also, we can add a power oscillation damping (POD) controller into line-side converter control to change the reference value of current loop as the voltage amplitude changes [10].

64.5 Conclusion

In this paper, the low-frequency oscillation phenomenon occurred in Xuzhou North Railway Hub is displayed by substation and SFSP measurement results and locomotive measurement results. It is concluded that the low-frequency oscillation is caused by the current collection of HXD_2B electrical locomotive. Some solutions to suppress the low-frequency oscillation are put forward in respect of both locomotive and power supply system.

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