Foreword

Critical Technology Series of Traction Power Supply System of Dedicated Passenger Line is the first work of China that studies the traction power supply systems of high-speed railways from the aspect of a macrosystem. It marks the transition of our study on traction power supply systems from an elementary level of a simple study on independent subsystems to a high level of integrated study on the entire system. Beyond all doubts, the release of this series is just at the right time for the development of traction power supply systems of high-speed railways of China at a special stage.

Electrified railways began in China in 1958. China completed the process, which advanced countries took 100 years to complete, by using only over 50 years through constant endeavor, from nothing, from common speed to high speed, and from low load to heavy load. The 11th Five-Year Plan is the stage when we realize new leaps in railway technology innovation and enter the era of high-speed railways. The reasons for success in high-speed rail innovation are based on original innovation, integrated innovation, and innovation after introduction, digestion, and absorption. In such a situation, *Critical Technology Series of Traction Power Supply System of Dedicated Passenger Line* is included into the 11th Five-Year Plan of the National Important Books.

A traction power supply system is the power source of an electric traction car, including both stationary equipment (traction substation) similar to the power supply and a pantograph and contact line system as the connection link between stationary equipment and mobile energy consumption equipment (vehicle). Traction power supply systems need to be highly reliable and also need to provide high-quality electric energy.

Considering AT feeding mode used by traction power supply systems of high-speed railways, AC–DC–AC drive technology applied to EMU and mass and decentralized objectives for dispatch by power supply line relay protection principle and failure distance measurement principle of new traction power supply systems, which need to be updated constantly. Functionality of automation systems, integrated dispatching systems, and management information systems of traction substations need to be optimized constantly.

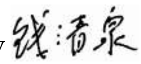
Pantograph and contact line systems, as electric energy transmission media of traction substations and power traction units, should provide safe and reliable power transmission for stationary power consumption by the auxiliary facility of vehicle, living facility, and for mobile power consumption by the traction vehicle. Besides, in the case of a regenerative brake of vehicle, pantograph and contact line systems should fulfill the backward feeding. Interaction between a pantograph and a contact line is dependent on many factors. The study method separating pantographs and contact lines into two independent subsystems is no longer applicable to the operational requirement of high-speed railways. Pantograph and contact line systems are also closely linked to design, construction, operation, and maintenance.

Quality of electric energy of electrified railways is a long-standing problem. It shows up as negative sequence, reactive power, and harmonics on lines of AC–DC electric locomotives. On lines of AC–DC–AC electric locomotive/EMU, the development of technology significantly improves reactive power and harmonic-related problems. However, negative sequence becomes worse due to growth of power of a single electric locomotive/EMU. It is expected that negative sequence will become the major factor influencing power quality of electrified railways. Difficulty of treatment and capacity input will also increase. It is urgent to apply some innovative technical schemes.

I'm very pleased to share that the teachers of College of Electrical Engineering, Southwest Jiaotong University have systematically summarized their achievements in research and practice and provided this series of books, *Traction Power Supply Automation for Dedicated Passenger Line*, *Pantograph and Contact Line System*, and *Electric Energy Quality Analysis and Control for Electrified Railway*, covering the critical technical field of traction power supply systems of high-speed railways. The series of books takes the opportunity to face the challenge of the development of traction power supply systems and forms the concepts and achievements in compliance with the development requirements of traction power supply systems of our high-speed railways. It not only provides technical support for construction and operation of our high-speed railways, but also theoretical support for cultivating high-speed railway construction and management talents.

I firmly believe that *Critical Technology Series of Traction Power Supply System of Dedicated Passenger Line* will be widely used and has unlimited development potential, both in disciplinary development or engineering application.

Qingquan Qian

Academician of the China Engineering Academy 

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Preface

Baoji–Fengzhou section of Baoji–Chengdu railway was approx. 91-km long and was built between 1958 and 1961. It began operation on August 15, 1961 and was the first AC-electrified railway of China. The completion of the Baoji–Fengzhou section marks the first step of traction power innovation in the history of Chinese railways.

The selection of the current mode of power supply systems and pantograph and contact line systems is a priority for the construction of electrified railways. Through overall comparisons and intensive studies, single-phase industrial frequency AC 25 kV was finally chosen. Compared with the current system, confirmation of the pantograph and contact line system mode is much easier. The first batch of 6Y1 mainline electric locomotives trial produced by China use a ДЖ-5 four-wrist diamond-shaped dual-arm pantograph, so the contact line of the Baoji–Fengzhou section should be compliant and designed depending on characteristics of such a pantograph.

In the process of evolution over 50 years, pantographs and contact lines of the Chinese electrified railways have experienced some changes. Considering interconnection and interworking requirements of the Chinese railways, the basics of content of interaction between pantographs and contact lines can no longer be changed fundamentally.

In the current circuit of traction power supply systems of railways, pantographs are mobile devices while overhead contact lines are stationary. The exact match between them is the precondition for completing electric energy transmission needed by electric trains. To enable hundreds of amperes of current to flow through the contact point of a pantograph and contact line smoothly, the system of pantographs and contact lines should meet very tight requirements of electrical performance, mechanical performance, and material.

Limited by economic and technical conditions, an affluent design for a pantograph and contact line system is impossible. Thus, professional design for pantographs and contact lines, conscious planning for each facility, and careful use and installation of those advanced and tested components are very important. Together with scientific operation and maintenance measures, the system can reach the expected life cycle.

Reliable transmission of electric energy is the final target of the pantograph and contact line system. The theoretical basis for realizing this target is closely related to electrical engineering, mechanical engineering, and material. With an increase in operation speed, impact of factors, such as aerodynamics on pantograph and contact line systems, cannot be ignored. Problems derived from extreme weather events have attracted more attention.

These topics promoted the author to write a textbook closely relate to pantograph and contact line systems and have transdisciplinary characteristics to help students of colleges and universities of traction power supply, field technicians, and other personnel interested in this field to acquire professional knowledge of the design, construction, operation, and maintenance of pantograph and contact line systems. This will also promote the improvement of technical expertise of pantograph and contact line systems of the Chinese railways.

Pantograph and contact line systems are two subsystems belonging to one current collection system and coupled together by a contact point. On the basis of the contact points of pantograph and contact line systems, this book introduces in detail: pantographs, the geometrical characteristics of pantographs and contact lines, dynamic interactions, and material interfaces and electrical contacts, and describes the method of applying basic knowledge to system design, construction, operation, and maintenance.

This book consists of nine chapters in total. Sections 3.5.2, 3.5.6, and 7.7.2 are written by Fang Yan; Sections 9.6 and 9.7 are written by Zeng Ming; Section 8.6 is written by Han Feng; and the rest are written by Jiqin Wu. The compiling editor of the entire book is Jiqin Wu.

Gao Shibin and Chen Weirong reviewed the content of this book.

This book is written with assistance of the Transportation Bureau, Ministry of Railways, CSR Zhuzhou Electric Locomotive Co., Beijing CED Railway Electric Tech Co., Ltd., and relevant people.

Wang Baoguo, Wang Zufeng, Jin Baiquan, Hou Rigen, Ren Xingtang, Pan Ying, Li Zongzhi, Xu Jianguo, Zhang Weihua, Li Lan, and Dong Zhaode provided numerous precious opinions and advice during the compilation of this book.

With the full support of Southwest Jiaotong University Press, this book is included into the 11th Five-Year Plan of the National Important Books. The graduate school of Southwest Jiaotong University has included this book into the textbook construction project of postgraduate students and provided assistance in compilation and publication. The author thanks these organizations and individuals for their support!

Due to my limited knowledge, shortcomings and omissions may be unavoidable. Your comment is appreciated.

Jiqin Wu

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CHAPTER 1
Introduction

1.1 OVERVIEW

Energy for electric trains [including electric locomotive and electric multiple units (EMU)] running on electrified railways comes from a stationary power source, power plant. Electric energy is transmitted via substations and different voltage class transmission lines, and finally to electric trains, as shown in Fig. 1.1.

Traction substations are distributed along the railway. They convert electric energy into the voltage class required by electric trains and feed electric trains through two conductor groups: contact lines above electric trains and tracks under electric trains. During regenerative brakes, these two conductor groups transmit electric energy from electric train to substation.

Contact lines are the main part of contact line system. They can be divided into trolley-type contact lines, where there are only contact lines and no continuous messenger wires (Fig. 1.2A), or overhead contact lines with catenary suspension, where contact lines hang onto messenger wires through droppers. Overhead contact lines with catenary suspension can be divided into contact lines with stitch suspension (Fig. 1.2B) or contact lines without stitch suspension (Fig. 1.2C). Contact wire is the most important part of contact lines.

Electric energy required or fed out by electric trains is transmitted through direct contact between one or several current collectors called pantographs, which are mounted on the roof of the train and the contact lines above it, as shown in Fig. 1.3.

The part of pantographs that touches contact wires directly is called the contact strip. Certain contact forces between the contact strip and the contact wire are maintained to keep constant electric contact between them.

Forms of contact lines are decided depending on the operating requirement of the electric train and the characteristics of pantograph used. Contact lines cannot exist independently. The supports, poles, and foundations along the line are called overhead contact line systems.

Pantograph and Contact Line System. http://dx.doi.org/10.1016/B978-0-12-812886-2.00001-X

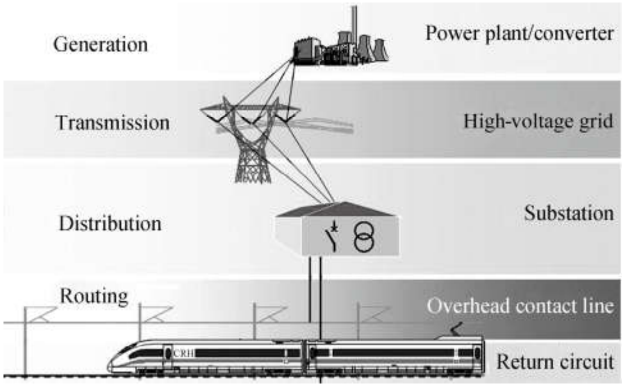

FIGURE 1.1
Transmission of electric energy required by electric trains.

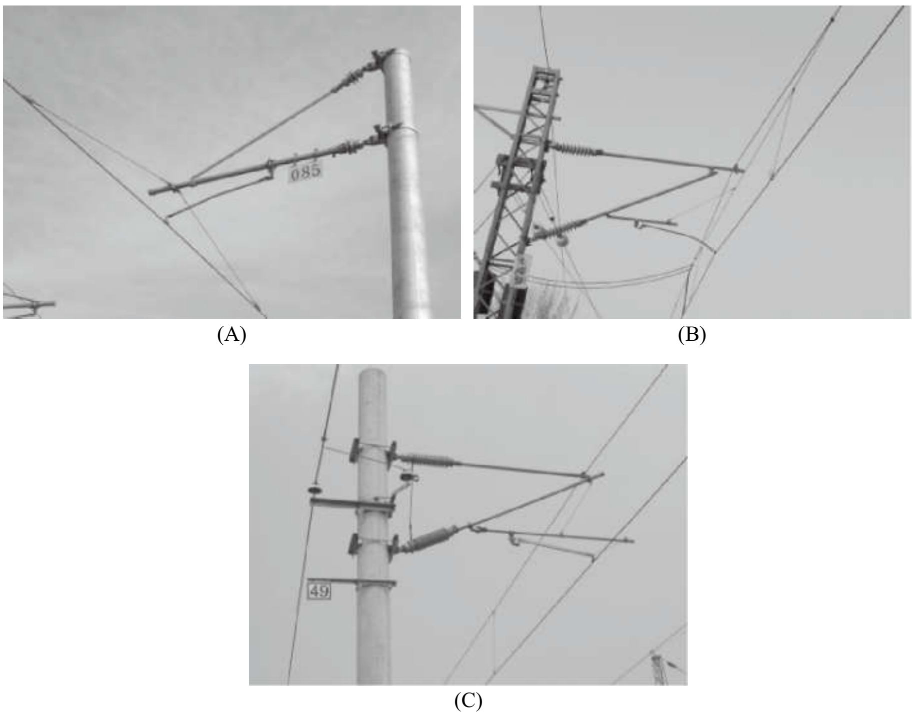

FIGURE 1.2
Contact lines. (A) Trolley-type contact lines, (B) contact lines with stitch suspension, and (C) contact lines without stitch suspension.

In sections, the single-cantilever suspension shown in Fig. 1.4 is used in priority.

In multitrack sections, the head span shown in Fig. 1.5 is often used to replace cantilever support.

FIGURE 1.3
Electric train collects electric energy from contact lines through pantograph.

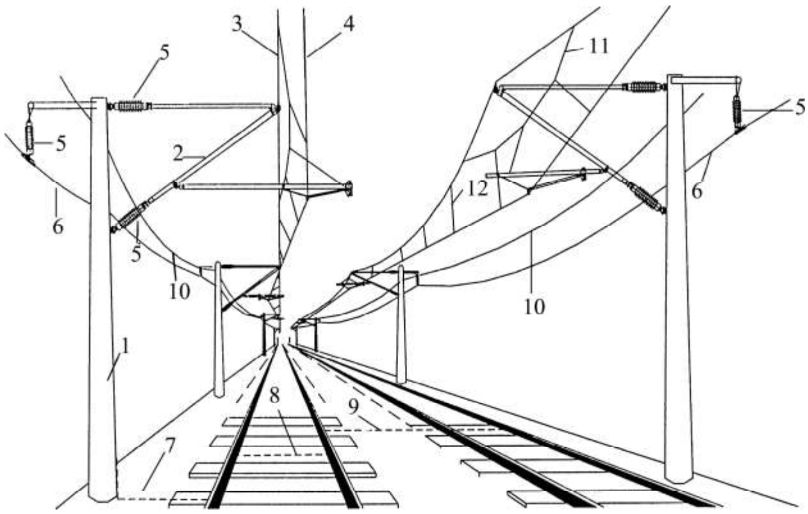

FIGURE 1.4
Single-cantilever catenary suspension overhead contact line. 1, Pole; 2, cantilever; 3, messenger wire; 4, contact wire; 5, insulator; 6, feeder; 7, pole foundation; 8, rail connection; 9, up-down track connection; 10, return wire; 11, stitch wire; 12, dropper.

For high-speed contact lines, the combination of portal structure and the inverted pole shown in Fig. 1.6 is often used to replace the pole to realize mechanical isolation between overhead contact lines of different tracks.

Wires and their insulators are suspended above the line by supports at certain intervals. Spatial orientation of contact wires in horizontal directions vertical to the line is realized by a steady arm. The connecting point between the steady arm and contact wire is called the steady point. The distance between the two adjacent supporting points or suspension points of a contact line is called a span.

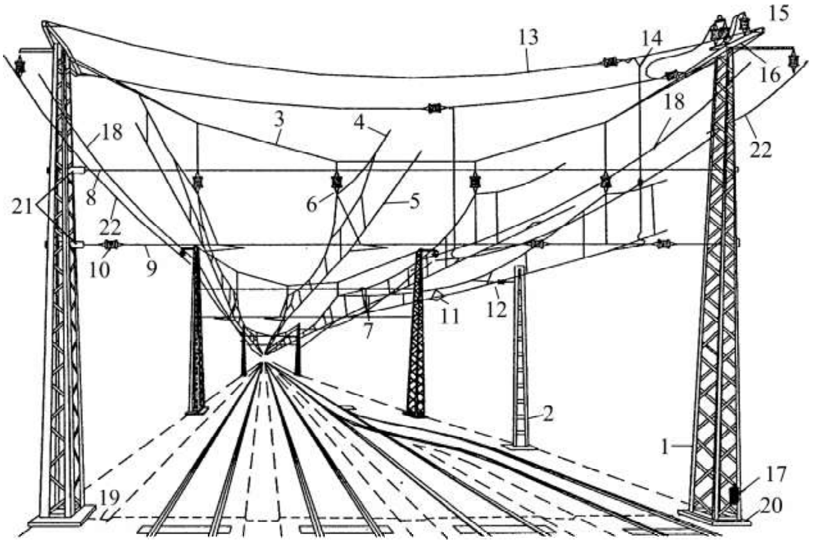

FIGURE 1.5
Head span of contact line. 1, Diagonal steel pole; 2, cross bar pole; 3, lateral messenger wire; 4, messenger wire; 5, contact wire; 6, suspension point; 7, electric connection; 8, upper safety rope; 9, lower safety rope; 10, insulator; 11, section insulator; 12, curve steady arm; 13 and 14, switch jumper; 15, isolating switch; 16, cross arm; 17, electric operating mechanism; 18, return wire; 19, pole grounding; 20, pole foundation; 21, safety rope compensation; 22, feeder.

FIGURE 1.6
Portal structure contact line.

In tunnels, on some low-speed electrified railways or urban rail transit lines, current collection systems consisting of pantographs and overhead contact rails (or overhead rigid contact lines) can be used to feed electric trains. Overhead contacts or rails hung over tracks in tunnels are shown in Fig. 1.7.

FIGURE 1.7
(A) Rigid contact line and (B) bus bar with embedded contact wire.

The contact wire of the conductor rail is embedded directly into a bus bar (Fig. 1.7B); it is not subject to the tension along the line. To distinguish from rigid contact lines, we often call contact lines with tensile devices "flexible contact lines."

In urban rail transit, contact rails insulated against the ground can also be used to feed electric trains. Contact rails can be horizontally close to the track as a third rail and parallel to the running rail. The collector shoe is used as a current collector, as shown in Fig. 1.8.

Due to the diversity and long history of contact lines, one objective, or its meaning, gradually evolved into different terms. IEC60050-811 has defined some major terms. They are:

1. Contact line system:

   Support networks for supplying electrical energy from substations to electrically powered traction units, which cover overhead contact line systems

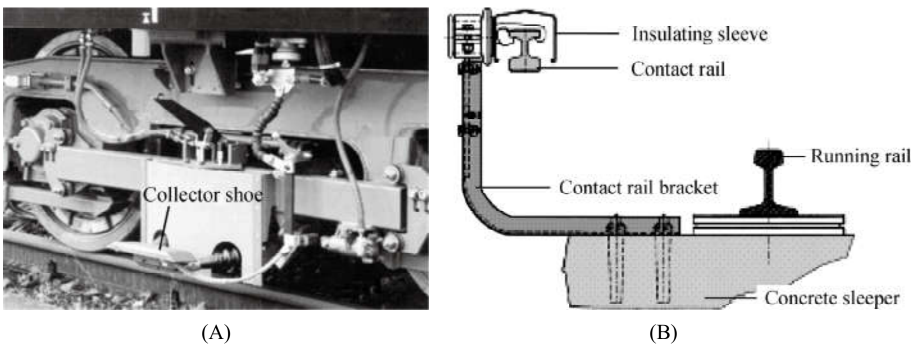

FIGURE 1.8
Collector shoe and contact rail. (A) Collector shoe and (B) contact rail.

and conductor rail systems; the electrical limits of the system are the feeding point and the contact point to the current collector. The system comprises:
   a. the contact line;
   b. structures and foundations;
   c. supports and any components supporting or registering the conductors;
   d. head and cross spans;
   e. tensioning devices;
   f. along-track feeders, reinforcing feeders, and other lines, such as earth wires and return conductors, as far as they are supported from contact line system structures;
   g. any other equipment necessary for operating the contact line; and
   h. conductors connected permanently to the contact line for supply of other electrical equipment, such as lights, signal operation, point control, and point heating.
2. Contact line:
   Conductor systems for supplying traction unit electric energy via a current collector, mainly consisting of:
   a. reinforcing feeders,
   b. cross-track feeders,
   c. disconnectors,
   d. section insulators,
   e. overvoltage protection devices,
   f. supports that are not insulated from the conductors, and
   g. insulators connected to live parts.
   But excluding other conductors, such as:
   a. along-track feeder sand,
   b. earth wires and return conductors.
3. Contact lines:
   A device of which one or more double-groove contact wires are hung on one or more longitudinal catenaries.
4. Overhead contact line system:
   Contact line systems using an overhead contact line to supply current for use by traction units.
5. Overhead contact lines:
   Contact lines placed above or beside the upper limit of the vehicle gauge, supplying traction units with electrical energy via roof-mounted current collection equipment.
6. Contact rail systems:
   Contact line systems using conductor rails for current collection.
7. Overhead contact rails:
   Rigid overhead contact lines, of simple or composite section, mounted above or beside the upper limit of the vehicle gauge, supplying traction units with electrical energy via roof-mounted current collection equipment.