## Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foreword</td>
<td>xiii</td>
</tr>
<tr>
<td>Preface</td>
<td>xvii</td>
</tr>
<tr>
<td>Introduction</td>
<td>xix</td>
</tr>
<tr>
<td><strong>1 Overview</strong></td>
<td>1</td>
</tr>
<tr>
<td>1.1 Active Power Loss and Electric Energy Loss</td>
<td>1</td>
</tr>
<tr>
<td>1.1.1 Main Types of Active Power Loss</td>
<td>1</td>
</tr>
<tr>
<td>1.1.2 Calculation of Electric Energy Loss</td>
<td>2</td>
</tr>
<tr>
<td>1.1.3 Electricity Line Loss and Line Loss Rate</td>
<td>3</td>
</tr>
<tr>
<td>1.1.4 Calculation and Analysis of Line Loss</td>
<td>5</td>
</tr>
<tr>
<td>1.2 Calculation of AC Resistance</td>
<td>7</td>
</tr>
<tr>
<td>1.3 Influence of Temperature and Voltage Changes on Line Loss in the Measuring Period</td>
<td>7</td>
</tr>
<tr>
<td>1.3.1 Influence of Temperature Change on Line Loss in the Measuring Period</td>
<td>7</td>
</tr>
<tr>
<td>1.3.2 Influence of Voltage Change on Line Loss in the Measuring Period</td>
<td>9</td>
</tr>
<tr>
<td>1.4 Influence of Load Curve Shape on Line Loss</td>
<td>10</td>
</tr>
<tr>
<td>1.4.1 Load Curve and Load Duration Curve</td>
<td>10</td>
</tr>
<tr>
<td>1.4.2 Parameters of Characterization Load Curve</td>
<td>12</td>
</tr>
<tr>
<td>1.4.3 Relationship Between Loss Factor and Load Factor</td>
<td>15</td>
</tr>
<tr>
<td>1.5 Influence of Load Power Factor and Load Distribution on Line Loss</td>
<td>16</td>
</tr>
<tr>
<td>1.5.1 Influence of Load Power Factor</td>
<td>16</td>
</tr>
<tr>
<td>1.5.2 Influence of Load Distribution of Multi-Branch Line</td>
<td>17</td>
</tr>
<tr>
<td>1.6 Influence of Measuring Instrument Error on Line Loss</td>
<td>18</td>
</tr>
<tr>
<td>1.6.1 Composition of Electric Energy Metering System and Constitution of Metering Error</td>
<td>18</td>
</tr>
<tr>
<td>1.6.2 Composition of Electronic Watt-Hour Meter Error</td>
<td>18</td>
</tr>
<tr>
<td>1.6.3 Influence of Metering System Error on the Calculation of Line Loss Rate</td>
<td>19</td>
</tr>
<tr>
<td><strong>2 Calculation of Line Loss by Current Load Curve</strong></td>
<td>21</td>
</tr>
<tr>
<td>2.1 RMS Current Method and Loss Factor Method</td>
<td>21</td>
</tr>
<tr>
<td>2.1.1 RMS Current Method</td>
<td>21</td>
</tr>
<tr>
<td>2.1.2 Loss Factor Method</td>
<td>22</td>
</tr>
<tr>
<td>2.1.3 Other Calculation Methods</td>
<td>22</td>
</tr>
</tbody>
</table>
2.2 Derivation of Functional Relationship $F(f)$ by Ideal Load Curve
  2.2.1 Derivation of $F(f)$ Formula by Ideal Load Curve with Two Variables
  2.2.2 Derivation of $F(f)$ Curve by Ideal Load Curve with Four Variables
2.3 Derivation of Approximate Formula of $F(f)$ by Statistical Mathematical Method
  2.3.1 Binomial Approximate Formula of $F(f)$
  2.3.2 Trinomial Approximate Formula of $F(f)$
  2.3.3 Approximate Formula of Family of $F(f)$ Curves with Four Variables
2.4 Derivation of $F(f)$ Formula by Mathematical Analysis Method
  2.4.1 Direct Integration Method
  2.4.2 Subsection Integration Method

3 Probability Theory Analysis of Current Load Curve
  3.1 Probability Meanings of Load Curve and Its Parameters
  3.1.1 Probability Meaning of Load Duration Curve
  3.1.2 Probability Meanings of Minimum Load Rate and Load Rate
  3.1.3 Barth Formula of Loss Factor
  3.2 Analysis of Rossander Formula as Distribution Function
    3.2.1 Rossander Formula of Load Duration Curve
    3.2.2 Exponential Distribution Function
    3.2.3 Derivation of Loss Factor Formula
    3.2.4 Comparison of Direct Integration Method and Distribution Function Analysis Method
  3.3 Comparison of Various Loss Factor Formulas
    3.3.1 Loss Factor Formula Comparison Procedures Prepared by Monte Carlo Method
    3.3.2 Comparison Results of Various Loss Factor Formulas
  3.4 Three-Mode Division of Active Load Duration Curve
    3.4.1 Three Modes of Load Management in the Electric Power System
    3.4.2 Differences and Relations of the Three Operation Modes
    3.4.3 Probability Division of Three Operation Modes

4 Calculation of Line Loss by Power Load Curve
  4.1 Line Loss Calculation Considering Power Factor
    4.1.1 The Maximum Apparent Power is Caused by the Maximum Active Power
    4.1.2 The Maximum Apparent Power is Caused by the Maximum Reactive Power
  4.2 Maximum Load Power Factor Method of Tröger
  4.3 Annual Average Power Factor Method of Glazynov
  4.4 Equivalent Load Curve Method
    4.4.1 Equivalent Load Curve Method of Cweink
    4.4.2 Improvement and Extension of the Cweink Method
    4.4.3 Equal Time Equivalent Load Curve Method
    4.4.4 Unequal Time Equivalent Load Curve Method
  4.5 Analysis of Errors of Various Line Loss Calculation Methods
    4.5.1 Analysis of Relative Error in Line Loss Calculated by rms Current Method
    4.5.2 Analysis of Relative Error in Line Loss Calculated by Loss Factor Method

5 Line Loss Calculation after Reactive Compensation
  5.1 Calculation of Load Curve Parameters after Reactive Compensation
    5.1.1 Calculation of Reactive Load Curve Parameters at Under-Compensation
    5.1.2 Calculation of Reactive Load Curve Parameters at Weak Over-Compensation
    5.1.3 Calculation of Reactive Load Curve Parameters at Strong Over-Compensation
5.2 Calculation of Loss Reduction Effect of Reactive Compensation
5.2.1 Calculation of Compensation Effect at High Natural Power Factor
5.2.2 Calculation of Reactive Compensation Effect at Low Natural Power Factor
5.3 Calculation Curves of Annual Electric Energy Losses for Power Grid Planning and Design
5.3.1 Calculation Curves of Annual Electric Energy Losses of 35–110 kV Transmission Lines
5.3.2 Calculation Curves of Annual Electric Energy Losses of 220 kV Transmission Lines
5.3.3 Calculation Curves of Annual Electric Energy Losses of Agricultural Electric Lines Consuming Electricity on a Quarterly Basis

6 Change Law for the Electric Energy Losses of Power Grids
6.1 Basis of Analysis of Line Loss Changes
6.1.1 Line Loss Binomial
6.1.2 Condition of Minimum Line Loss Rate
6.2 Calculation and Analysis of No-load Loss
6.2.1 Higher-Order Expression
6.2.2 Square Expression
6.2.3 Quasi Square Expression
6.3 Calculation and Analysis of Load Loss Coefficient C
6.3.1 Calculation of Load Loss Coefficient
6.3.2 Inclusion of Load Loss Coefficient
6.4 Determination of Voltage Level by Loss Reduction Requirement
6.4.1 Voltage Characteristics of Various Loads and Comprehensive Loads of Distribution Lines
6.4.2 Control of Voltage Level and Reduction of Electric Energy Loss

7 Analysis and Control of Line Loss Rate Indicators of Power Grids
7.1 Analysis of Line Loss Rate Composition
7.1.1 Line Loss Rates and Total Line Loss Rate of Different Voltage Grids
7.1.2 No-load Line Loss Rate and Load Line Loss Rate
7.2 Analysis of Influence of Grid Electric Supply Structure on Line Loss Rate
7.2.1 Repeated Electric Supply Rate
7.2.2 Calculation of Loss Reduction Effect of Reducing Repeated Electric Supply Rate
7.3 Analysis of Power Sales Quantity Composition
7.3.1 Influence of Power Sales Quantity without Loss or Power Sales Quantity with Loss on Line Loss Rate
7.3.2 Calculation of Influence of Transit Electric Supply on Line Loss Rate
7.4 Multiple-factor Analysis of Changes in Electricity Line Losses
7.4.1 Loss Structure Coefficient and Electricity Line Loss Increase Rate Function
7.4.2 Loss Structure Function and Calculation of Increase in Electricity Line Losses
7.5 Marginal Line Loss Rate and Optimal Distribution of Increase in Electric Supply
7.5.1 Marginal Line Loss Rate
7.5.2 Optimal Distribution of Increase in Electric Supply

8 Theoretical Calculation of Electric Energy Losses of Power Grid Units
8.1 Classification of Electric Energy Losses
8.1.1 Classification of Electric Energy Losses by Whether Theoretical Calculation is Feasible
8.1.2 Classification of Calculable Technical Losses by Change Law
8.1.3 Classification of Electric Energy Losses by Different Power Grid Units
8.2 Calculation of Electric Energy Losses of Overhead Lines
  8.2.1 Calculation of Corona Losses of Power Transmission Lines
  8.2.2 Calculation of Resistance Heat Losses of Overhead Lines
  8.2.3 Calculation of Electric Energy Losses of Low-voltage Lines
8.3 Calculation of Electric Energy Losses of Cable Lines
  8.3.1 Calculation of No-load Losses (Dielectric Losses in Insulating Layers) of Cable Lines
  8.3.2 Calculation of Load Losses of Cable Lines
8.4 Calculation of Electric Energy Losses of Main Transformers
  8.4.1 Active Power Losses of Main Transformers
  8.4.2 Calculation of Electric Energy Losses of Main Transformers
  8.4.3 Calculation of Electric Energy Losses of Main Transformers in Parallel Operation
8.5 Calculation of Electric Energy Losses of Other Electrical Equipment
  8.5.1 Shunt Capacitors
  8.5.2 Shunt Reactors and Series Current-limiting Reactors
  8.5.3 Synchronous Compensator
  8.5.4 Watt-hour Meter and Other Instruments
9 Calculation of Electric Energy Losses of Multi-branch Lines
  9.1 Basic Method for Calculating Electric Energy Losses of Multi-branch Lines
    9.1.1 Weighted Average Method
    9.1.2 Point by Point Section Simplification Method
  9.2 Equivalent Resistance Method and Calculation of Electric Energy Losses of Distribution Transformers
    9.2.1 Equivalent Resistance of a Line
    9.2.2 Calculation of Electric Energy Losses of Distribution Transformers
    9.2.3 Equivalent Resistance and Equal Resistance of Common Distribution Transformers
    9.2.4 Calculation of Electric Energy Losses by Equivalent Resistance Method
  9.3 Double Component Balance Method
  9.4 Dispersion Coefficient Method
    9.4.1 Calculation of Power Losses of Typically Distributed Loads
    9.4.2 Dispersion Coefficient
    9.4.3 Conversion of Length Under Different Sectional Areas of Conductors
    9.4.4 Calculation of Power Losses of Complexly Distributed Loads
    9.4.5 Calculation of Electric Energy Losses by Dispersion Coefficient Method
  9.5 Calculation of Electric Energy Losses of Multi-branch Lines by Voltage Drop Method
    9.5.1 Calculation of Line Loss Rate by Proportionality Coefficient Method
    9.5.2 Calculation of Line Losses by Voltage Drop Measurements
  9.6 Comparison and Selection of Calculation Methods of Electric Energy Losses of Multi-branch Lines
  9.7 Calculation of Loss Reduction Benefits after Connection of Distributed Resources to System
    9.7.1 Calculation of Loss Reduction Benefits During Generation Period of Distributed Resources
    9.7.2 Calculation of Line Loss Change During Consumption Period of Distributed Resources
9.7.3 Calculation of Loss Reduction Benefits During the Full Period of Distributed Resources 181
9.7.4 Benefit Evaluation of Distributed Energy System 181

10 Calculation of High-voltage Power Grid Losses 183
10.1 Characteristics and Requirements of Loss Calculation 183
10.1.1 Classification of High-voltage Power Grids 183
10.1.2 Characteristics of Regional Power Grids and Requirements of Loss Calculation 184
10.1.3 Characteristics of Prefectural Power Grids and Requirements of Loss Calculation 184
10.2 Real-time Loss Measuring Method for High-voltage Power Grids 184
10.2.1 Function and Method of State Estimation 185
10.2.2 Real-time Calculation of Losses by State Estimation Combined with Excel 186
10.2.3 Typical Day Method Based on Actual Load Measurement and State Estimation 187
10.2.4 Comprehensive Analysis Method of Losses Based on Real-time System Data 189
10.3 Equivalent Node Power Method for Calculation of High-voltage Power Grid Losses 190
10.3.1 Equivalent Node Power and its Distribution 190
10.3.2 Relationship between Power Losses and Electric Energy Losses Under Distribution of Equivalent Node Power 191
10.3.3 Analysis of Equivalent Node Power Method 195
10.4 Calculation of Losses of High-voltage Power Grids Based on Power Losses under Three Modes 196
10.5 Calculation and Analysis of Samples 197
10.5.1 Verification of Loss Calculation of Standard Power Grid with 39 Nodes 197
10.5.2 Three-mode Calculation Based on Total Loads and Measured Loss Power over 24 h in one Province During 2004 204

11 Analysis and Calculation of Loss Allocation 209
11.1 Occurrence of Loss Allocation Problem and Possible Solutions 209
11.1.1 Analysis of Double Load Power Supply Model 210
11.1.2 Analysis of Triple Load Power Supply Model 211
11.1.3 Possible Solutions to Loss Allocation 214
11.2 Theoretical Preparation for Loss Allocation 214
11.2.1 Three-mode Section Division of Active Load Duration Curve 214
11.2.2 Calculation of Influence of Transit Electric Supply on Electricity Line Losses 214
11.2.3 Calculation of Marginal Line Loss Rate 215
11.2.4 Calculation of Optimal Distribution of Increased Electric Supply 215
11.3 Analysis and Calculation of Allocation of Increased Losses in Regional Power Grids 216
11.3.1 Allocation of Losses in the Main Part of Regional Power Grids to Provincial Power Grids 216
11.3.2 Allocation of Increased Losses Caused by Power Transmission and Reception in Inter-Provincial Power Grids 216
11.4 Calculation of Loss Allocation Under Complex Trading Setup 223
11.4.1 Loss Allocation for Pilot Project of Direct Electricity Purchase by Large Customers Under “One to Many” Model 223
11.4.2 Shapley Method of “Many to Many” Loss Allocation 224
11.4.3 Marginal Loss Coefficient-Based GMM Method 228
12 Technical Measures for the Reduction of Line Losses

12.1 Selection of Reasonable Connection Mode and Operation Mode

12.1.1 Introduction of High-voltage Grids to Large Cities or Load Centers

12.1.2 Stepping up of Power Grid Voltage, Simplification of Voltage Class, and Reduction of Repeated Substation Capacity

12.1.3 Reasonable Determination of Closed Loop Operation or Open Loop Operation of Loop Net, or Change of Break Points of Loop Net

12.1.4 Realization of Economic Power Distribution by Longitudinal and Transverse Voltage Regulating Transformer or Series Capacitor

12.1.5 Prevention of Remote Supply by Nearby Power or Round about Power Supply

12.1.6 Reasonable Arrangement of Equipment Overhaul and Practice of Live-Line Overhaul

12.1.7 Replacement of Conductors, Installation of Composite Conductors, or Construction of Secondary Loop Lines

12.2 Reasonable Determination of Voltage Level of Power Grids

12.3 Utilization of Reactive Power Compensation Equipment and Increase in Power Factor

12.3.1 Calculation of Loss Reduction Effect of Reactive Compensation

12.3.2 Optimal Configuration of Reactive Compensation Equipment in Power Grids

12.3.3 Exploitation of Reactive Potential and Reduction of Reactive Consumption

12.4 Economical Operation of Transformers

12.4.1 Economical Operation of Two-Winding Transformers of the Same Model

12.4.2 Economical Operation of Two-Winding Transformers of Different Models

12.4.3 Economical Operation of Three-Winding Transformers of Different Models

12.5 Adjustment and Balancing of Loads

12.5.1 Adjustment of Load Curves

12.5.2 Balancing the Loads of Lines or Transformers, and Adjusting the Power Sources of Dual Power Customers

12.5.3 Balancing Three-Phase Loads

12.6 Strengthen Power Grid Maintenance

12.7 Strengthen Power Consumption Management and Measuring Management

12.8 Application of New Designs, New Materials, and New Technologies

12.8.1 New Design for Loss Reduction in Ground Wires of High-voltage Transmission Line

12.8.2 Application of Energy-saving Hardware and Energy-saving Conductors

12.8.3 Application of Harmonic Control Technology and High-Temperature Superconducting Technology

13 Line Loss Prediction and Loss Reduction Plan for Power Grids

13.1 Univariate Prediction of Electricity Line Losses and Line Loss Rate

13.1.1 Basis for Predicting the Indicator of Line Loss Rate

13.1.2 Univariate Prediction of Electricity Line Losses

13.1.3 Univariate Prediction of Line Loss Rate

13.2 Multivariable Prediction of Electricity Line Losses and Line Loss Rate

13.2.1 Multivariable Prediction of Electricity Line Losses

13.2.2 Multivariable Prediction of Line Loss Rate

13.2.3 Rolling Prediction Method

13.3 Main Content and Preparation Process of Loss Reduction Plan

13.3.1 Content and Preparation Basis of the Loss Reduction Plan

13.3.2 Preparation of the Loss Reduction Plan

13.3.3 Implementation and Monitoring of the Loss Reduction Plan

13.3.4 Introduction of an Example of the Loss Reduction Plan
### 14 Analysis of the Influence of Power Grid Line Losses on Power Grid Enterprises

14.1 Influence of Line Losses on the Profits of Power Grid Enterprises  
14.1.1 Calculating the Profits of Power Grid Enterprises  
14.1.2 Break-Even Point Power Sales Quantity  
14.1.3 Profit and Tax Amount per Unit Power Sales Quantity  
14.1.4 Analysis of Factors Affecting Profits  
14.2 Link Cost and Link Electricity Price  
14.2.1 Significance of Division of Internal Links of Power Grid Enterprises  
14.2.2 Calculation Model of Link Electricity Price Under a Simple Electric Supply Structure  
14.2.3 Calculation Model of Link Electricity Price Under a Complicated Electric Supply Structure  
14.2.4 Equivalent Merging of Parallel Electric Supply Structure  
14.3 Influence of Line Losses on the Composition of Multi-section Electricity Prices  
14.3.1 Type of Electricity Price and Comparison of Calculation Methods  
14.3.2 Analysis of Composition of Two-Section Electricity Prices Under the Single Electricity Purchaser Model  
14.3.3 Recursive Calculation of Multi-Section Electricity Prices  
14.3.4 Controlling the Aggregate Level of Electricity Price  
14.3.5 Analysis and Discussion  
14.4 Analysis of Coal–Electricity Price Linkage  
14.4.1 Interpretation of the Existing Policy of Coal–Electricity Price Linkage  
14.4.2 Analysis of the Linkage between On-Grid Price and Coal Price  
14.4.3 Linkage between Sales Price and On-Grid Price  
14.5 Analysis of Electricity Price Factor in Post Project Evaluation  
14.5.1 Reverse Calculation of Mark-Up in Link Output End  
14.5.2 Calculation of Mark-Up Allocation Coefficient of Simplified Electric Supply Network  
14.5.3 Mark-Up Calculation of Complicated Electric Supply Structure  
14.5.4 Calculation of Annual Power Sales Mark-Up Revenue of a Single Transmission and Transformation Project  

### 15 Management and Utilization of Line Loss Mass Information for an Electric Power System

15.1 Evaluation and Functions of Two Management Information Systems Under the Guidelines  
15.1.1 Functional Design Requirements for Two Types of Software  
15.1.2 Functions of Line Loss Calculation and Management Information Systems Developed by Provincial Power Grid Enterprises  
15.1.3 Integrated Management System for Theoretical Calculation of Line Losses Developed by Regional Power Grid Enterprise  
15.1.4 New Management Requirements  
15.2 Value Creation and Support Processes for Power Grid Enterprises  
15.2.1 Information-Oriented Development of Large Enterprises and Application of Enterprise Resource Planning  
15.2.2 Value Creation and Support Processes of Power Grid Enterprises  
15.3 Composition of Model Driven Decision Support System  
15.3.1 Structure and Functions of Decision Support System  
15.3.2 Intelligent Decision Support System and Group Decision Support System  
15.3.3 Conceptual Model of Power Grid Enterprise  
15.3.4 Business Conceptual Model of Power Grid Enterprise
15.4 Utilization of Line Loss Mass Information 322
15.4.1 Basic Concept of Data Warehouse 322
15.4.2 Basic Concepts of Data Mining and Online Analysis 323
15.4.3 Application of Data Warehouse Technology in Electric Power Dispatching and Marketing Systems 324
15.4.4 In-Depth Utilization of Line Loss Mass Information – Integration of Data in Dispatching and Marketing Systems 328

Appendix A Calculation Curve of Corona Loss Power $\Delta P_{\text{cor}}$ 335

Appendix B Calculation of Electrical Parameters of Power Grid Units 341
B.1 Parameters of Overhead Lines 341
  B.1.1 Parameters of Overhead Transmission Lines 341
  B.1.2 Parameters of Steel Conductor Overhead Lines 343
  B.1.3 Parameters of Two-Wire One-Ground Overhead Lines 343
B.2 Parameters of Transformer 343
  B.2.1 Parameters of Two-Winding Transformer 343
  B.2.2 Parameters of Three-Winding Transformer 344

Appendix C Derivation of Loss Factor Formula by Subsection Integration Method 347

Appendix D Actual Measurement Analysis of No-load Power Losses and Relationship between No-load Current and Voltage of Distribution Transformers 351
D.1 Actual Measurement Analysis of $\Delta P_0(U)$ of General Transformers 351
D.2 Actual Measurement Analysis of $\Delta P_0(U)$ of Low Loss Transformers 351
D.3 Actual Measurement Analysis of $I_0(U)$ of General Transformers 352

References 353

Index 357