

Research on Integration Technology of Intelligent Control Systems for Power Grid Measurement Devices

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Abstract

A preliminary exploration of grid measurement equipment, intelligent control systems, and the development direction of smart meters in China. The article first reviews the origin and development of smart grids, including their definition, concepts, and construction approaches. It then explores the technical orientation of intelligent high-voltage equipment and smart distribution networks along with their key technologies. On this basis, the article deeply analyzes the structure and common technologies of intelligent control systems, demonstrating their applications in distribution power equipment, distribution network monitoring, and high-end meters through multiple case studies. Finally, the article discusses the development direction of smart meters in China, including the requirements of smart grid technology for smart meters and the development direction of electricity information collection system construction. The article points out that smart grids represent an important direction for future grid development, characterized by robustness, self-healing, compatibility, economic integration, and optimization. The technical orientation of intelligent high-voltage equipment emphasizes the importance and key technologies of high-voltage equipment intelligence. As an important component of smart grids, intelligent control systems feature a typical structure including the system under test, intelligent controllers, and communication interfaces, with common technologies including fuzzy control, neural network control, and genetic algorithms. Regarding applications of intelligent control systems, the article demonstrates their practical applications in distribution power equipment, distribution network monitoring, and high-end meters through multiple case studies. Furthermore, the article discusses the development direction of smart meters in China. Currently, although third-generation electricity meters have been developed domestically, a significant gap remains between the technology and smart grid construction requirements. Smart meters need to possess additional functions to meet the demands of smart grid construction. Meanwhile, the construction of

electricity information collection systems will also evolve toward Advanced Metering Infrastructure (AMI). In summary, this paper conducts a comprehensive preliminary exploration and analysis of grid measurement equipment, intelligent control systems, and the development direction of smart meters in China. The article aims to provide readers with an in-depth understanding of smart grid and smart meter technologies, offering references and insights for research and applications in related fields.

Full Text

Preamble

Research on the Integration Technology of Intelligent Control System for Power Grid Measurement Equipment

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Abstract: This paper presents a preliminary exploration of power grid measurement equipment, intelligent control systems, and the development trajectory of smart meters in China. It begins by reviewing the origins and evolution of the smart grid concept, including its definitions, underlying philosophy, and implementation strategies. The discussion then addresses the technical orientation of intelligent high-voltage equipment and examines smart distribution networks along with their key enabling technologies. Building upon this foundation, the paper provides an in-depth analysis of intelligent control system architectures and commonly employed technologies, illustrating their practical applications in distribution power equipment, distribution network monitoring, and high-end metering devices through multiple case studies. Finally, the paper discusses the future direction of smart meters in China, encompassing the functional requirements imposed by smart grid technology and the developmental path for electricity information acquisition systems. The analysis indicates that the smart grid represents a critical future direction for power network development, characterized by resilience, self-healing capability, compatibility, economic integration, and optimization. The technical orientation of intelligent high-voltage equipment underscores the importance of equipment intelligence and its key technological components. As a vital component of smart grids, the typical architecture of intelligent control systems comprises the monitored system, intelligent controller, and communication interface, with commonly used technologies including fuzzy control, neural network control, and genetic algorithms. The application cases demonstrate practical implementations in distribution equipment, network monitoring, and advanced metering. Furthermore, while China has developed third-generation electricity meters, significant technological gaps remain relative to smart grid construction requirements. Smart meters must incorporate enhanced functionalities to meet these demands, and electricity information acquisition systems must evolve toward Advanced Me-

tering Infrastructure (AMI). In summary, this paper offers a comprehensive preliminary investigation and analysis of power grid measurement equipment, intelligent control systems, and smart meter development trends in China, aiming to provide readers with deeper insights into smart grid and smart meter technologies while offering references and inspiration for related research and applications.

Keywords: measurement equipment; power grid; intelligent control; integrated technology

1. Inspiration from Smart Grid Theory to Practice

1.1 Origins of Smart Grid

The concept of smart grid has evolved through several key milestones. In 2001, the Electric Power Research Institute (EPRI) in the United States proposed the “IntelliGrid” concept. By 2005, the European SmartGrids Technology Platform introduced the term “Smart Grid,” while Tsinghua University concurrently proposed optimization control methodologies for power systems. In 2009, the State Grid Corporation of China officially released its research findings on “Strong and Smart Grid” development.

1.2 Definitions and Philosophy

Multiple perspectives have shaped the smart grid definition. According to the State Grid Corporation, smart grids are characterized by resilience, self-healing capability, compatibility, economic integration, and optimization. Researchers at Tsinghua University have conceptualized smart grids as multi-index self-optimizing systems, emphasizing that event-driven control represents the essence of power hybrid control theory. Academician Lu Qiang defines smart grids as intelligent power systems operating at 110 kV and below, possessing multi-index self-optimizing operational capabilities, with the primary benefit being significant reduction in network losses upon full implementation.

1.3 Smart Grid Construction Strategies

National strategies have provided clear direction for smart grid development. State Grid Corporation’s Chairman Liu Zhenya advocated for “building a strong and smart grid to drive new energy development transformations in the 21st century.” The 2011 work conference established new objectives and tasks for smart grid construction and marketing management reform, prioritizing ultra-high voltage development as paramount. For distribution systems, the approach emphasizes learning from international advanced experiences through introduction, digestion, absorption, and subsequent improvement. The National Energy Administration’s Smart Grid Symposium clarified that future grid frameworks encompass high-voltage networks including main grids (receiving-end networks),

transmission networks, and smart grids (specifically referring to distribution networks). Additionally, the State Council mandated a new round of rural power grid renovation and upgrading to establish safe, reliable, energy-efficient, environmentally friendly, technologically advanced, and standardized new rural power grids.

1.4 Technical Orientation of Intelligent High-Voltage Equipment

Research from the China Electric Power Research Institute (CEPRI) outlines that intelligent high-voltage equipment comprises high-voltage apparatus, intelligent components, sensors, and actuators. Equipment intelligence does not alter the fundamental structure of high-voltage devices but rather integrates smart components that assume all or most secondary functions, making them critical to the intelligence implementation. CEPRI's technical strategy analysis further emphasizes that intelligent high-voltage equipment must address not only its own control requirements but also the optimization needs of distribution network operation, distinguishing it significantly from conventional online monitoring approaches.

1.5 Smart Distribution Networks and Key Technologies

Smart distribution networks represent a core component of smart grid implementation, with maturity models and functional architectures guiding their development. The key technologies enabling these networks require focused research and systematic integration.

1.6 Key Insights

Several critical insights emerge from this analysis. First, power hybrid control theory provides a suitable theoretical foundation for distribution network equipment intelligent control systems. Second, dedicated research on distribution equipment intelligent control system technology represents both an urgent need to overcome technical bottlenecks in smart distribution networks and a requirement for capturing new business opportunities. Third, intelligence differs substantially from online monitoring, as intelligent high-voltage equipment must serve both equipment-level control needs and distribution network optimization objectives.

2. Intelligent Control Systems

2.1 Overview

Intelligent control systems constitute a fundamental component of smart grid architecture. The typical structure comprises three parts: the monitored system, intelligent controller, and communication interface. Commonly employed

intelligent control technologies include fuzzy control, neural network control, and genetic algorithms.

2.2 Case Study 1: Intelligent Control System for Distribution Power Equipment

Research from CEPRI has developed information flow schemes for intelligent power transformers, categorizing information processing by both procedural sequence and professional domain. Nanjing University of Science and Technology has proposed dynamic reactive power compensation methods for asymmetric loads that incorporate harmonic suppression capabilities. These approaches demonstrate how intelligent control enhances distribution equipment performance through integrated information management and advanced compensation algorithms.

2.3 Case Study 2: Distribution Network Monitoring and Intelligent Control Systems

Hunan University's research on integrated power quality control systems with harmonic suppression functions illustrates multi-objective optimization algorithms for voltage, reactive power, harmonics, and network losses, employing fuzzy PI control for composite current regulation. This case demonstrates the application of intelligent control in comprehensive power quality management and distribution network monitoring.

2.4 Case Study 3: Intelligent High-End Meters with Optimized Metering Functions

Yantai Dongfang Electronics Group has explored self-calibration technologies for electronic multifunctional electricity meters, emphasizing that meter design must be compatible with Auto-Cal requirements while addressing angle error, ratio error, and zero-power processing. Wasion Group has developed a high-precision dynamic angle difference compensation algorithm that combines the advantages of classical Newton interpolation with the linear characteristics of FIR digital filters, enabling real-time compensation for temperature drift characteristics. Additionally, Wasion Group's research on composite Newton-Cotes integration algorithms for energy metering demonstrates advanced computational approaches. These developments point toward smart high-end meters capable of automatic metering performance optimization, representing the next generation of intelligent metering devices.

3. Trend of Smart Meters in China

3.1 State Grid's "Smart Grid Technology" Perspective

State Grid's authoritative publication addresses smart meter development, noting that while China has developed third-generation electricity meters, significant technological gaps remain relative to smart grid construction requirements. Smart meters must incorporate enhanced functionalities, including automatic optimization of metering device technology for intelligent high-voltage (10-35 kV) meters and automatic optimization of metering network technology for macro-level grid measurement.

3.2 GE (China) Perspective

GE's white paper, "Building an Advanced Metering System to Drive Grid Intelligence," argues that many current smart meters are merely upgraded multifunction meters, a model ill-suited for smart grids requiring real-time performance and high information capacity. GE's smart meters feature two key characteristics: bidirectional communication capability and built-in, standards-based, open advanced intelligence programs. Specific models demonstrate these capabilities in single-phase applications.

3.3 Zhang Chunhui's Analysis of Smart Meter Development

Zhang Chunhui's research highlights that the smart meter industry is still clarifying the definition of "smart." The foundational requirement remains high-quality electronic meters, as evidenced by the varying quality among imported 0.2S-class multifunction meters despite their premium classification. Domestic collaborative research on multifunction meter quality testing has achieved preliminary results. Regarding communication capabilities, the industry must establish clear performance metrics and standards for bidirectional communication functionality.

4. Recommended Projects for 2011-2012 Grid Intelligent Measurement Products

Category 1: High-Voltage (10 kV) Electricity Meters and Computing Systems

- Intelligent, self-calibrating, high-precision high-voltage (10 kV) electricity meters
- Intelligent high-voltage (10 kV) energy metering cabinets

Category 2: Intelligent Distribution Network Equipment

- Intelligent distribution transformers

- Intelligent high-voltage (10 kV) switchgear
- Intelligent feeder terminals
- Power quality monitoring and intelligent control systems with distribution network multi-index optimization functions
- Distribution transformer derivative products

Category 3: Public/Private Transformer Area and User Intelligent Energy-Saving Products

Public Transformer Area Intelligent Energy-Saving Products: - Public transformer area energy-saving indicators - Intelligent distribution transformers - Public transformer area intelligent terminals - Power optimization compensation products

Private Transformer (High-Voltage User) Intelligent Energy-Saving Products: - Electricity, water, gas, and heat consumption information statistics standards - Energy consumption and information acquisition systems - Intelligent distribution transformers - Private transformer intelligent terminals - Power optimization compensation products - Energy efficiency evaluation testing and standards for electrical equipment - Smart home energy-saving technologies

Category 4: High-End Meters and Product Chains

Export/Import High-End Meters: - In-depth research on three-phase multifunctional meter performance evaluation methods - Technical specifications for export high-end meters

Advanced Technologies: - 0.05-class three-phase electricity meter field calibrator with impact load metering capability - Remote centralized monitoring and field calibration systems for substation (gateway and large user) three-phase electricity meters and high-voltage energy metering devices - WIMAX communication applications - Development and application of OFDM-based fast narrowband carrier communication chips - Development of short-range, low-power wireless communication chips (domestic gap) - Automatic meter reading systems with 1-hour, 100% success rate - Photoelectric converters for low-voltage fiber-to-the-home applications - Advanced network simulator technologies - Low-voltage power grid parameter testing products - Multi-purpose anti-theft monitoring systems and power equipment anti-tampering technologies - Laboratory simulation technologies for three-phase electricity meter field environment testing - Advanced training for distribution networks, energy metering, and local communication methods

Category 5: Comprehensive Reference Projects

- Projects addressing technical bottlenecks in electricity information acquisition systems

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Note: Figure translations are in progress. See original paper for figures.

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