Development Process and Key Technologies of High-Voltage Energy Meters

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Abstract

This paper primarily provides an overview of the development history, key technologies, industry prospects, and related project research of high-voltage electricity meters. Characterized by simplified structure, safety and reliability, and whole-machine testing, high-voltage electricity meters garnered attention from power departments and the electricity meter industry since their inception. However, due to limitations in traceability and certification of high-voltage measurement standards, high-voltage electricity meters have remained in trial and continuous improvement phases. With the State Grid's low-price centralized bidding for smart electricity meters, high-end meter enterprises were prompted to transform their development models, and high-voltage electricity meters emerged as a focal point for new technology measurement product development. After 2011, high-voltage electricity meters have achieved complete integration from product design and manufacturing through measurement traceability to grid application solutions, marking a significant milestone in the development history of high-voltage electricity meters. At the appraisal meeting for the project "Research on Sensor-type High-voltage Electricity Meters and Their Verification Technology" in the Chongqing power grid, high-voltage electricity meters which passed provincial-level scientific and technological achievement evaluation became measurement products, entering the provincial power grid market for the first time for metering in power grid economic and technical performance evaluation. The measurement traceability technology of high-voltage electricity meters is also a research focus, including the overall error verification platform for high-voltage electricity measurement devices from Huazhong University of Science and Technology, the overall verification device for high-voltage electricity from Zibo Jibao Instrument Transformer Research Institute, and high-voltage (10kV) electricity measurement standard devices and on-site calibration devices established by five institutions including the National Institute of Metrology, China. Regarding the key technologies and industry prospects of high-voltage electricity meters, future work must address issues including the

definition of product specification limits, standardization of diverse structural designs, performance evaluation methods for high-voltage electricity measurement and data transmission solutions, product standards and verification regulations for high-quality high-voltage electricity meters, and electromagnetic compatibility testing for high-voltage electricity meters. Concurrently, in-depth development is also required in accuracy, functionality, and intelligence to satisfy the practical demands of smart grid development.

Full Text

The Development Process and Key Technologies of High-Voltage Energy Meters

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Abstract

This paper systematically reviews the development history, key technologies, industry prospects, and related research projects concerning high-voltage energy meters. Characterized by simplified structure, safety, reliability, and whole-machine assessment, high-voltage energy meters have attracted significant attention from power utilities and the metering industry since their inception. However, due to limitations in metrological traceability and certification for high-voltage metering standards, these devices remained in trial and improvement phases for an extended period. The centralized low-price bidding strategy for smart meters by State Grid Corporation prompted high-end meter manufacturers to transform their development approaches, making high-voltage energy meters a focal point for new metering product development. Since 2011, comprehensive integration has been achieved across product design, manufacturing, metrological traceability, and power grid application schemes—representing a major milestone in the evolution of high-voltage energy meter technology. At the appraisal meeting for the "Sensor-Type High-Voltage Energy Meter and Its Calibration Technology Research" project in Chongqing Power Grid, high-voltage energy meters passed provincial-level scientific and technological achievement evaluation, marking their first entry into provincial grid markets for economic and technical performance assessment metering. Metrological traceability technology constitutes another research priority, encompassing the overall error verification platform for high-voltage metering devices developed by Huazhong University of Science and Technology, the integrated verification apparatus from Zibo Institute of Metering and Protection, and the high-voltage (10 kV) energy metering standard and field calibration devices established by five organizations including the China National Institute of Metrology. Future development must address critical issues including product specification standardization, reg-

ulation of diverse structural designs, performance evaluation methodologies for high-voltage metering and data transmission schemes, quality standards and verification procedures for premium products, and electromagnetic compatibility testing. Concurrently, in-depth development of accuracy, functionality, and intelligence capabilities is essential to meet the practical demands of smart grid construction.

Keywords: High-voltage energy meter; metrological traceability; smart grid; sensor technology

1. History of High-Voltage Energy Meter Development in China

The development trajectory of high-voltage energy meters in China spans nearly a decade of continuous innovation. In 2003, Tsinghua University introduced the "Multifunctional Electronic High-Voltage Energy Meter," followed by research on novel high-voltage meter designs in 2004. That same year, Xi'an Gaoyan Electric Company developed electronic current and voltage sensors. Wuhan Guoce Company launched its high-voltage energy meter development program in 2006, with subsequent progress reports published in 2008 . The Zibo Institute of Metering and Protection pioneered sensor-type high-voltage energy meters in 2007. Tsinghua University advanced the field further in 2009 with a fully digital high-voltage energy metering system. In 2010, Zhejiang Huacai Company introduced a 10 kV direct-connection high-voltage energy meter , while Xi'an Gaoyan Electric Company continued developing new electronic sensors. The same year saw the issuance of Shandong Provincial Local Metrology Verification Regulation "High-Voltage Energy Meter JJG (Lu) 89-2010," alongside Chongqing Electric Energy Metering Center's research on error influence factors in three-phase high-voltage metering boxes. In 2011, the Chongqing Electric Power Research Institute and Zibo Institute of Metering and Protection completed the technical report for their joint project on sensor-type high-voltage energy meters and calibration technology. That year also witnessed the collaborative development of high-voltage (10 kV) energy metering standard and field calibration devices by five organizations including the China National Institute of Metrology, while Wuhan Guoce Hengtong Company released anti-theft application solutions for 10 kV high-voltage energy meters. The company further expanded its portfolio in 2012 with distribution network line loss application solutions.

2. Chongqing Power Grid: Appraisal of the Sensor-Type High-Voltage Energy Meter Project

The appraisal meeting for the "Sensor-Type High-Voltage Energy Meter and Its Calibration Technology Research" project, organized by the Chongqing Science and Technology Commission in March 2011, successfully passed provincial-level scientific and technological achievement evaluation. This milestone marked the

first time high-voltage energy meters entered provincial grid markets as certified metering products for economic and technical performance assessment. Key supporting documents included the Shandong Provincial Local Metrology Verification Regulation "High-Voltage Energy Meter JJG (Lu) 89-2010" and the comprehensive technical report from the project collaboration between Chongqing Electric Power Research Institute and Zibo Institute of Metering and Protection.

3. Metrological Traceability Technology for High-Voltage Energy Meters

Research in metrological traceability has been pursued through multiple avenues. Qu Qingchang conducted fundamental research on key technologies and traceability methods for high-voltage energy metering. Huazhong University of Science and Technology developed an overall error verification platform for high-voltage energy metering devices. The Zibo Institute of Metering and Protection created integrated verification apparatus specifically for high-voltage energy applications. Critically, five organizations including the China National Institute of Metrology collaborated to establish high-voltage (10 kV) energy metering standard devices and field calibration systems, forming the core of China's national energy metering infrastructure and filling an international gap in this domain.

4. Key Technologies and Industry Outlook

4.1 Critical Technology Discussions

The advancement of high-voltage energy meter technology requires resolution of several fundamental issues. These include establishing definitive product specifications, standardizing diverse structural designs, developing performance evaluation methods for high-voltage metering and data transmission schemes, formulating quality standards and verification procedures for premium products, and implementing comprehensive electromagnetic compatibility testing protocols. Additionally, the application prospects for high-voltage energy meters in power grids over recent years demand careful analysis.

4.2 Proposed Development Projects

Project Background: Since the publication of the first high-voltage energy meter research in 2002, the technology has undergone extensive pilot testing and improvement, though its commercial prospects remained uncertain until recently. The 2011 State Grid work conference emphasized strengthening electricity market analysis, constructing comprehensive marketing monitoring systems, and intensifying anti-theft and energy conservation efforts. The March 2011 appraisal meeting in Chongqing enabled sensor-type high-voltage energy meters to enter provincial markets. However, the 0.5S-class meters approved at that meeting exhibit limited accuracy and functionality, necessitating further development to meet smart grid requirements.

Development Objectives and Content:

Project (1): Intelligent, Self-Calibrating, High-Precision High-Voltage (10 kV) Energy Meter
Given current limitations in high-voltage metering standard certification, these meters primarily serve anti-theft monitoring, line loss analysis, and instrument transformer error verification, functioning as auxiliary meters for dedicated transformer billing or as public transformer high-voltage meters, while also supporting intelligent energy measurement in distribution networks.

- **High Precision:** 0.2S class, comprising 0.05-class 10 kV electronic voltage and current sensors and a 0.1S-class three-phase multifunctional meter
- **Anti-Theft Design:** Integrated secondary and high-voltage circuits
- **Traditional Multifunctionality**
- **Novel Metering Technologies:**
  - Low power factor calculation due to harmonics
  - Ih, Uh anti-theft metering
  - Non-sinusoidal, full-power measurement
  - I^2h, U^2h energy loss metering
  - Power quality monitoring
- **Computational Functions:**
  - Billing instrument transformer composite error calculation
  - Billing energy meter error comparison
  - User electricity consumption response characteristic mapping
- **Performance Optimization:** Integrated digital closed-loop control unit
- **Self-Calibration Technology**
- **IED and Intelligent Component Configuration**

Project (2): Intelligent High-Voltage (10 kV) Energy Metering Cabinet
Comprising intelligent, self-calibrating, high-precision high-voltage energy meters; reactive power/harmonic/voltage asymmetry/load imbalance monitoring and optimization control modules (IED); corresponding compensation products; 10 kV intelligent circuit breakers with IED modules; and related intelligent components.

Market Capacity Estimate: State Grid and China Southern Grid currently operate approximately 2.3 million dedicated transformers (high-voltage customers) and 1.8 million public transformers. By 2015, driven by deepening energy conservation requirements and assuming adoption by 1% of the combined transformer base with each high-voltage energy meter priced at 20,000 RMB, annual sales could reach approximately 820 million RMB.

Five-Year Goal: Establishing national high-voltage energy metering standards will position intelligent, self-calibrating, high-precision high-voltage (10 kV) energy meters as a novel metering method for power billing applications, ensuring promising market prospects.

4.3 Industry Outlook: Deepening Development Projects

Future development should focus on constructing a comprehensive high-voltage energy metering standard system, pursuing national working measurement standard accreditation for high-voltage (10 kV) energy metering devices, developing a complete product series, establishing quality standards and verification procedures, creating products supporting the IEEE 1459-2000 standard, and exploring long-term applications in grid energy efficiency, power quality, trade settlement, and macro-level metering. Furthermore, research into the transformative impact of high-voltage energy meter applications on grid energy metering technology and legal metrology management systems is warranted.

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