Research on the Development of Provincial Power Grid Electricity Consumption Information Collection Systems

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Date: 2024-01-31T00:00:00+00:00

Abstract

This article primarily introduces the construction history and related technological developments of the State Grid electricity information collection system. First, the article outlines the construction objectives and development trajectory of the State Grid electricity information collection system, with particular emphasis on the construction status and application effectiveness of the electricity information collection system in Jiangsu Power Grid. Then, the article summarizes and describes the key technologies and engineering applications of the electricity information collection system, including system architecture, terminal quantity and channel types, master station equipment, data management, and application, among other aspects. The article mentions key technologies of the electricity information collection system, including low-cost communication methods, security requirements for large consumer load control, wireless public network online technology, unified data model, and parallel data processing technology. Overall, this article provides a valuable reference for technical exploration of the State Grid electricity information collection system.

Full Text

Preamble

Research on the Development of Provincial Power Grid Electricity Information Collection Systems

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Abstract: This article introduces the construction process and technological development of the State Grid electricity information collection system. It first summarizes the construction goals and development trajectory of the State Grid system, highlighting the implementation and application outcomes in Jiangsu Province' s power grid. The paper then compiles and describes key technologies and engineering applications, covering system architecture, terminal quantities and channel types, master station equipment, data management, and application aspects. Key technologies discussed include low-cost communication methods, safety requirements for large-user load control, wireless public network online technology, unified data models, and parallel data processing technology. Overall, this paper provides a valuable reference for technical exploration in State Grid electricity information collection systems.

Keywords: electricity consumption information collection system, power grid

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In September 2008, State Grid launched the research project on "Standardized Construction of Metering, Meter Reading, and Billing." Subsequently, the construction of provincial power grid electricity information collection systems adopted "full coverage, full collection, and prepaid metering" as the overarching objectives. Since the systematic engineering began in 2010, State Grid' s service area has expanded rapidly, with the number of customers estimated to have grown from 220 million in 2010 to 390 million by 2015. The company focused on standardizing metering products and centralized procurement, and by the first batch of centralized metering product bidding in 2015, the cumulative procurement reached 364.821 million smart meters and 35.991 million communication terminals. Building on this foundation, Jiangsu Power Grid became the first to complete its provincial electricity information collection system in 2014, achieving full data collection for all 35 million users within six hours. By June 2015, Shandong Power Grid became the second provincial grid to achieve full smart meter coverage, with automated collection of electricity information for all 36.91 million users. All provincial power grids were expected to complete their information collection systems by 2016.

However, after more than five years of construction, comprehensive experience summarization covering the entire lifecycle—from system survey, design, construction, testing/acceptance, operation, assessment, and fault handling to feedback and improvement—remains lacking. Local communication technology bottlenecks have proven difficult to resolve, due to multiple factors including the accelerated construction timeline that skipped systematic planning and design phases, the adoption of low-cost local communication solutions, and emerging requirements from new electricity market reforms, smart grid initiatives, Germany' s "Industry 4.0,"and new communication concepts. In response, in January 2014, State Grid's marketing department published "Current Status and Development Trends of Electricity Information Collection System Applications," identifying problems in key communication technologies: power line carrier communication, micro-power wireless communication, wireless public networks, wireless private

networks (230MHz), and fiber optic communication. The paper called for research on a technical architecture for electricity information collection system communication networks and proposed technical solutions based on integrating telecommunications, broadcast television, and internet networks to enable data, voice, and video service convergence. State Grid Marketing Document No. [2014]82 further proposed research on "one interaction" (bidirectional interactive smart meters) and "two broadband" technologies (broadband power line carrier communication and broadband wireless remote communication). In the first batch of 2015 smart meter centralized bidding, broadband power line carrier communication chips and OFDM narrowband power line carrier communication chips were procured for the first time, with plans for large-scale pilot applications. This indicates that while most provincial grid electricity information collection systems are entering their final construction phase, system communication technology updates have already been deployed, though the baseline requirements for these updates remain unclear.

Given this prospect of comprehensive upgrades to provincial grid electricity information collection systems, this paper compiles and describes preliminary results from recent domestic collaborative research on fast, high-quality provincial grid electricity information collection system technologies, serving as a reference for technical exploration.

1. Preliminary Experience from Five Years of State Grid Electricity Information Collection System Construction

1.1 Jiangsu Power Grid: First Provincial System Completion

Jiangsu Power Grid pioneered the construction of a provincial electricity information collection system in China, completing full data collection for 40 million users within six hours.

Jiangsu Electric Power Research Institute: "Key Technologies and Engineering Applications of Electricity Information Collection Systems"

Jiangsu Power Grid in 2013 had a total electricity consumption of 475.7 billion kWh, a peak load of 81.91 million kW, over 2,800 substations of 35 kV and above, and served more than 35 million electricity customers. The system' s objectives included real-time monitoring and control of equipment operation status, power flow direction, and user energy utilization efficiency. The system architecture comprised several key components: for low-voltage users, both transformer-area centralized and unit-centralized collection modes; for large users, a coexistence model of wireless private networks and wireless public network channels; for gateway metering, direct gateway collection; for master stations, a provincial centralized deployment model; and for energy data management, an efficient data management platform.

The system deployed 335,661 Type I concentrators using GPRS public networks,

696,052 Type II concentrators using GPRS public networks, 168,214 Type I load control terminals using 230MHz private networks, 56,165 Type II load control terminals using GPRS public networks, and 145,961 radio meters using GPRS public networks. Master station equipment included two database servers, two data storage units, four application servers, two load balancers, four automatic task servers, 30 collection and communication front-end processors, eight encryption machines, two firewalls, and two core switches.

The electricity information management platform featured technologies for concurrent processing of tens of millions of collection tasks at the master station and multi-site, multi-level processing and analysis of massive data. Data applications included online monitoring of metering device status, distribution transformer operation status and power supply reliability monitoring, intelligent orderly electricity consumption, remote fee control, real-time line loss monitoring, intelligent power interaction, and comprehensive social electricity consumption analysis.

Key technologies included: first, low-cost communication methods meeting remote fee control requirements—using RS485 bus communication with multi-point concentration in transformer areas for urban customers implementing master station prepaid services, using low-voltage power line carrier communication with distribution transformer unit concentration for rural customers implementing remote power disconnection/reconnection services, and using handheld emergency terminals as auxiliary means for direct meter control. Second, adopting 230MHz wireless private networks to meet large-user load control safety requirements while improving communication capacity and rate. Third, defining a unified data model for electricity information collection that accommodates diverse historical equipment, meters, and terminals with multiple protocols. Fourth, implementing parallel data communication technology for permanent online connectivity of millions of wireless public network terminals with bidirectional service modes. Fifth, achieving six-hour rapid collection of 40 million meter data using collection front-end clustering, distributed real-time memory exchange, and parallel data processing. The system executed 128 million collection tasks daily, requiring 23,000 tasks per minute and database insertion of 3,000 rows per second. With a measured maximum task execution time of 50 seconds (calculated as 60 seconds) and nine hours of daily collection time, 30 collection servers working concurrently supported up to 9,000 tasks per second, with database insertion at 3,000 rows per second. Data processing technologies included a lightweight cache database storing simplified archive data, with collection tasks divided into 13 queues by region; memory caching in collection programs for aggregated batch data insertion; and 10% performance redundancy, with each server handling 300 concurrent collections, ensuring system performance remained unaffected even when three collection servers failed simultaneously. Sixth, rapid installation, debugging, and maintenance of massive field equipment was achieved through terminal active reporting (device asset number, IP, SIM card number, and geographic location upon power-on login), meter auto-discovery (automatic RS485 and carrier wave meter searching with master station polling for record estab-

lishment and change alarms, plus carrier wave three-layer topology mapping), automatic maintenance for meter replacement (automatic parameter changes after business archiving), installation without debugging (direct operation after record establishment and issuance, with error data automatically detected for subsequent unified troubleshooting), mobile operation terminals (enabling on-site meter replacement and terminal maintenance), intelligent collection fault diagnosis (providing specific failure reasons directly from the master station), and data verification (validating all data with invalid data sent for exception analysis).

Future research could leverage accumulated electricity data for user consumption pattern analysis, providing foundational data for power system capacity expansion, operation, and maintenance planning.

1.2 Hu Jiangyi, Zhu Enguo, Du Xingang, Du Shuwei: "Current Status and Development Trends of Electricity Information Collection System Applications"

This work briefly reviews the September 2008 launch of State Grid' s "Standardized Construction of Metering, Meter Reading, and Billing" project and the establishment of 12 technical standards for smart meters and 24 for collection terminals. By the end of October 2013, the cumulative installation reached 1.73 billion smart meters, covering 173 million users (note: State Grid' s service area exceeds 300 million users). Key technologies include communication technologies: power line carrier communication offers convenient installation without rewiring but suffers from poor reliability, real-time performance, and stability; micro-power wireless communication' s transmission distance is significantly affected by obstacles within coverage areas, with severe co-channel interference; wireless public network communication has high costs, requiring improved operation and maintenance timeliness, with weak signals in some areas making data collection difficult and 容易造成信道拥堵 during emergencies; wireless private network 230MHz communication has limited access capacity, with base station coverage of only about 30 km and data transmission vulnerable to obstruction by high-rise buildings; fiber optic communication involves large one-time investments, high costs, difficult wiring, and substantial engineering 工作量. Smart fee control technology includes three implementation methods: master station fee control, collection terminal fee control, and smart meter fee control, all requiring improved real-time performance, reliability, and stability of carrier communication. Development trends include: communication network access technology requiring rich system interfaces, flexible networking, and integrated access for data, voice, and image services to provide secure and reliable communication channels for electricity information collection and load monitoring/control, necessitating a technical architecture for collection system communication networks; information sharing and integration technology requiring improved integration levels and resource sharing between the collection system and other business systems; massive data processing and analysis applications;

mobile operation technology; three-network-convergence-based collection technology requiring technical solutions based on telecommunications, broadcast television, and internet networks to achieve service convergence, saving communication line investment and operation costs while improving comprehensive operational efficiency and system reliability, real-time performance, and economy, with advantages in energy saving and environmental protection; and smart electricity bidirectional interaction technology enabling collection and analysis of electricity information and power quality data via fiber and power line carrier channels, monitoring and managing household electrical equipment, providing real-time electricity information (outage notifications, payment information), alarm information, and pricing policies based on networking, human-computer interaction, and service integration principles, offering historical consumption records and statistical graphics to guide rational electricity use and regulate peak-valley loads, while providing a friendly, visual interaction platform with value-added services.

2. Collaborative Research Framework for Fast, High-Quality Provincial Grid Electricity Information Collection Systems

2.1 System Planning and Design

Evolving System Functions

The "Power User Electricity Information Collection System Functional Specification" Q/GDW 1373-2013 defines main functions including data collection, data management, setting control, remote control, comprehensive applications, operation and maintenance management, and system interfaces. Primary data collection items include: energy data, AC analog quantities, operating condition data, power quality limit violation statistics, event records, and other data such as fee control information. State Grid Marketing Document No. [2014]82 "Opinions on Strengthening Metering Management and Accelerating Electricity Information Collection Construction" proposed new functions: real-time electricity information collection, replacement of outdated power load control systems, construction of a unified data platform for electricity purchase, supply, and sales, support for online power quality monitoring systems, collection of outage events for dedicated and public transformers and BC-class low-voltage monitoring, monitoring of distributed power access, management requirements for electric vehicle charging/swapping services, integrated collection technology for electricity, water, gas, and heat meters, big data and cloud computing applications, low-voltage user outage event monitoring and reporting, deepened remote fee control applications, meter and terminal event recording/collection/reporting, online metering device monitoring and intelligent fault diagnosis, development of new embedded communication modules supporting bidirectional communication and open gateways, and formulation of communication protocols supporting bidirectional interaction. State Grid Marketing Document No. [2015]53 further

proposed expanding functions to support accurate fault determination and rapid processing, accelerating upgrades for remote tariff parameter issuance to local fee control meters, supporting card-free electricity purchase and recharge services, comprehensive application of outage event collection and proactive reporting to assist accurate fault diagnosis and location, comprehensive application of load monitoring data to support load calculation for business expansion, deepened management line loss analysis focusing on severely exceeding and 突变台区, and accurate verification of metering anomalies, theft suspicion, and household-transformer relationships. It also called for deepening research on intelligent bidirectional interaction and innovating smart meter interaction methods, noting that Beijing Power' s broadband power line carrier-based mobile APP and smart meter bidirectional interaction verification proved technically feasible and should be deepened.

System Overall Metrics

State Grid Marketing Document No. [2015]53 proposed system metrics: in 2015, 60.6 million smart meters were installed, achieving collection coverage for 316 million users with overall coverage exceeding 80%, with 13 provincial companies basically achieving full coverage and overall daily average collection success rate exceeding 97.5%. Specific metrics include 100% collection coverage for dedicated transformer users, public transformer areas, and grid-connected power metering points; 99% daily average collection success rate for dedicated transformer users; 98.5% for urban areas; and [text incomplete]. To evaluate whether provincial grid electricity information collection systems meet expanded functional requirements, this paper recommends supplementing the following overall system metrics: total user capacity, overall collection coverage, overall system collection time (generally not less than 10 million users/hour), automatic collection success rate by set cycle (100%/24h for monthly billing and line loss management, 100%/2h for daily line loss management and remote prepaid systems with 100%/1h optimal, and 100%/1h for AMI pilot systems with 100%/30min optimal), automatic collection success rates by user type and region, system reliability, and system availability.

Communication Bandwidth Estimation Methods

Research includes "Communication Bandwidth Prediction for Multi-Service Convergence in Smart Distribution and Consumption" by Hunan Electric Power Economic Research Institute and China Electric Power Research Institute, and "A Service Flow Calculation Method for Smart Distribution and Consumption Communication Networks Based on Service Profiles" by China Electric Power Research Institute and North China Electric Power University.

Remote/Local Communication Mode Selection and Technical Solution Formulation

2.2 Master Station and Testing

Jiangsu Electric Power Research Institute' s achievement of six-hour full collection for 40 million users involved master station equipment including 30 collection and communication front-end processors, database servers, data storage units, application servers, load balancers, automatic task servers, encryption machines, firewalls, and core switches. Other relevant work includes State Grid' s master station software standardized design (2014 revised edition), "Design and Research of Ultra-High Voltage Electric Energy Metering Master Station System Construction Scheme" by Southern Grid Extra High Voltage Power Transmission Company, and "I/O Space Analysis-Based Detection Model for Dispatching Master Station Software Systems" by China Electric Power Research Institute (Nanjing).

2.3 Remote Communication and Channels

Research includes "Technical Solution for Power Wireless Private Networks Oriented to Smart Distribution and Consumption Networks" by China Electric Power Research Institute and State Grid Electric Power Research Institute, "Zhuhai TD-LTE Wireless Broadband Pilot Project" by Southern Grid, "Carrier Aggregation Technology Based on 230MHz Power Dedicated Spectrum" by China Electric Power Research Institute and State Grid Electric Power Research Institute, and "Analysis of 4G Technology Application in Power Quality Monitoring" by Jilin Electronic Information Vocational Technical College and Tianjin Electric Power Dispatching and Communication Center.

2.4 Local Communication and Channels

Recent developments include the establishment of the Power Carrier Technology Innovation Alliance in Beijing, with the National Standardization Committee formally issuing development plans for two national standards: "Information Technology—Telecommunications and Information Exchange Between Systems —Low Voltage Power Line Communication—Part 1: Physical Layer Specification" and "Part 2: Data Link Layer Specification." Other research includes "Research and Progress on New Generation Power Line Carrier Communication Technology" by China Electric Power Research Institute, "G3-PLC and 5th Generation Carrier Communication System" by Qingdao Neusoft Company, "Application Design Scheme of Collection System Based on Dual-Channel Automatic Switching Technology"by Hubei Electric Power Company and Beijing Zhongchen Changhong Company, "Broadband Power Line Communication Chips and Applications" by Qingdao Neusoft Company, "Hi3911 Electricity Information Collection Broadband Carrier Chip" by Huawei HiSilicon, "IPv6-Based Fragment-Independent Retransmission Mechanism for Power Line Carrier Communication" by Chongqing University of Posts and Telecommunications, "PRIME Standard-Based Low Voltage Power Line Carrier Communication Networking Scheme" by State Grid Electric Power Research Institute and Haihe University, and "Statistical-Based -Persistent CSMA Algorithm and Its Application

in Electric Energy Collection Terminals" by Northeast Forestry University and Beijing University of Posts and Telecommunications, plus "Short-Range Micro-Power Wireless Communication Technology Standard Analysis and Prospect" by Shenzhen Guodian Technology Communication Company.

2.5 Bidirectional Communication and Multi-Mode Conversion Gateways

Research includes "Power Communication System Gateway Design" by Chongqing University of Posts and Telecommunications, "Lonworks-Ethernet Gateway Design Based on PIC18F66J60" by Hebei University, and "Intelligent Bridge Design for Medium-Low Voltage Power Line Interconnection" by North China Electric Power University.

2.6 Terminal Equipment

Work includes "Reliability Verification Testing for Electricity Information Collection Equipment" by China Electric Power Research Institute, Zhang Chunhui's "Highlights of Electric Meter Industry Development in 2014" noting that integrated terminals may become a new requirement, "Design and Application of Low Voltage Power Line Carrier Channel Impedance Testing Terminals" by Beijing University of Chemical Technology and Heilongjiang Electric Power Research Institute, "Field Operation Experience and Recommendations for Broadband Electricity Information Collection System Terminals" by Fuzhou Electric Power Bureau, "Implementation of Self-Description Function for New Intelligent Distribution Automation Terminals" by Dalian Power Supply Company and Guodian NARI Technology, and "Design of Integrated Electric Energy Recharge and Collection Terminal Based on Multi-Task Scheduling" by Sichuan Electric Power Research Institute and Chengdu University of Technology.

2.7 Smart Meters and Communication Modules

2.8 System Engineering Survey and Design

This includes Zhang Chunhui's "Discussion on Engineering Design and Management Methods for Local Narrowband Carrier Automatic Meter Reading Systems" and research on site selection and surveying for concentrators and gateways.

2.9 System Engineering Applications and Solutions to Local Communication Bottlenecks

As previously mentioned, after years of collaborative domestic research, low-voltage power line narrowband (low-speed) carrier communication technology bottlenecks have been broken through, though controversies have emerged regarding whether to adopt "dual-mode" communication or narrowband carrier communication supplemented by micro-power wireless bridging.

Reference documents include the "Field Work Report on Jiangjin Longmen Field Second Transformer Area in Chongqing"by Qingdao Neusoft Company and Chongqing Electric Power Research Institute, and Qingdao Neusoft' s "G3-PLC and 5th Generation Carrier Communication System," which aims for automatic meter reading success within one hour for all transformer areas, with MAC layer design supporting automatic identification and switching between carrier and micro-power wireless channels in dual-mode operation.

Comprehensive solutions for low-voltage power line narrowband (low-speed) communication system bottlenecks to achieve 100% automatic meter reading success within two hours for all distribution transformer areas require development of new products including: multi-frequency narrowband (low-speed) signal testers and noise testers; "dual-mode" communication modules combining narrowband carrier with micro-power wireless communication or gateways converting micro-power to narrowband communication; distribution transformer area identifiers; and technical measures ensuring consistency in numbering/addressing among meters, terminals, users, transformer areas, and power lines, such as Holley Metering Group' s "Design of Fixed Barcode and Electronic Tag Comparison Equipment," plus low-voltage power grid impedance testers.

3. Technical Symposium on Modern Grid Measurement Technology for Provincial Electricity Information Collection System Redevelopment

It was agreed to hold a technical symposium in late 2015 on provincial grid electricity information collection system redevelopment.

The June 13, 2015, "Research on Imported High-End Full-Performance"technical exchange meeting in Yinchuan proposed preparatory work for a 2015 new meter communication technology exchange conference. The preliminary theme was "Exploring Collaborative Research on Fast, High-Quality Provincial Electricity Information Collection System Technology," based on State Grid' s January 2014 document "Current Status and Development Trends of Electricity Information Collection System Applications."This document indicated that while State Grid' s collection systems were entering their final construction phase, fundamental communication—particularly local communication—remained a bottleneck, necessitating strengthened research on collection communication technologies and new communication system architectures with real-time performance, reliability, and stability.

Preliminary Conference Topics: 1. Collection system planning design and master station technology (speaker to be determined) 2. Interpretation of Home Plug Green PHY-2006 standard (Weisheng) 3. State Grid broadband power line carrier communication standard development process and technical disputes (Qingdao Neusoft) 4. Broadband power line carrier communication concentrator technical solution research (Chongqing Research Institute) 5. Dual-mode communication module design (Qingdao Neusoft) 6. Low-voltage power line

carrier communication channel tester design (speaker to be determined) 7. Bidirectional interactive smart meter gateway design (Chongqing Research Institute/Chongqing University of Posts and Telecommunications) 8. Preliminary experience in constructing county-level high-quality electricity information collection systems using new communication technologies (Jiangjin Power Supply Company) 9. Electric energy meter and meter reading network software architecture design (Zhengzhou Ruineng Company) 10. Backup topics: 2014 State Grid collection master station software standardized design, collection master station software testing technology research, and development prospects for "Internet+ electric meters (water, gas, heat meters, etc.)."

References

[1] Hu Jiangyi, Zhu Enguo, Du Xingang, Du Shuwei. Current Status and Development Trends of Electricity Information Collection System Applications. *Electric Power System Automation*, 2014-01-25.

[2] Dong Fengjuan. Discussion on Application Status and Development Trends of Electricity Information Collection Systems. *Electromechanical Information*, 2014-12-25.

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