

Research on Smart Meter Technology for State Grid' s Ubiquitous Power Internet of Things

Authors: Chunhui Zhang, Zhang Zhen, Zhang Zhen

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Abstract

The text primarily discusses the functional controversies surrounding State Grid smart meters and their significance in the construction of the Ubiquitous Power Internet of Things (UPIoT). At present, State Grid smart meters possess only basic interactive functions; however, achieving the “ubiquitous connection” and “holographic perception” objectives of the UPIoT necessitates that smart meters be equipped with advanced interactive capabilities. Therefore, accelerating the development of the “intelligent” features of smart meters is both timely and essential for advancing UPIoT construction. Furthermore, the article highlights that smart meters, as the sole legal metrological instruments for bilateral power flow trade settlement, offer advantages including massive deployment, extensive distribution, and close proximity to end-users and other devices, positioning them as optimal nodes for ubiquitous connection and holographic perception. Consequently, accelerating the development of smart meters’ “intelligent” functions represents the sole viable option for implementing the “ubiquitous connection” and “holographic perception” requirements in UPIoT bilateral power flow trade settlement metering.

Full Text

Research on the Ubiquitous Power Internet of Things Meter Technology of the State Grid

ZHANG Chunhui¹, **ZHANG Zhen**²

(1. State Grid Shandong Electric Power Company, Jinan, Shandong 250001, China;

2. Huaneng Jinan Huangtai Power Generation Co., Ltd., Jinan, Shandong 250100, China)

Abstract: This paper addresses the functional controversies surrounding State Grid smart meters and their critical importance in constructing the ubiquitous

power Internet of Things. Currently, State Grid smart meters possess only primary interactive functions, whereas achieving “ubiquitous connection” and “holographic perception” in the ubiquitous power Internet of Things requires advanced interactive capabilities. Therefore, accelerating the development of smart meters’ “intelligent” functions is both timely and essential for advancing this initiative. The paper further argues that smart meters, as the sole legal measuring instruments for bidirectional power flow trade settlement, offer unique advantages through their massive deployment, wide distribution, and proximity to users and other equipment, making them optimal nodes for ubiquitous connection and holographic perception. Consequently, expediting the development of smart meters’ intelligent functions represents the only viable path to implementing the ubiquitous connection and holographic perception requirements for bidirectional power flow trade settlement metering in the ubiquitous power Internet of Things.

Keywords: Power Internet of Things, Smart meters, Ubiquitous connectivity

1. Why Accelerating the Development of State Grid Smart Meter “Intelligent” Functions Is Timely

Since 2009, State Grid has faced ongoing controversy regarding the technical approach to implementing advanced interactive functions for bidirectional power flow trade settlement metering between distribution networks and users. This debate is detailed in the October 2013 paper by China Electric Power Research Institute scholars, “Discussion on the Technical Architecture of Flexible Interactive Smart Electricity Usage” (hereinafter referred to as “Document [A]”), though its resolution remains unclear.

1.1 Advanced Interactive Service Content

Document [A] categorizes smart electricity usage interactions into four types: information interaction services, marketing interaction services, electrical energy interaction services, and energy consumption interaction services. Information and marketing interaction services constitute basic services, while electrical energy interaction services represent advanced professional services, providing convenient access for customer-side distributed power sources, storage devices, and electric vehicles. These services enable bidirectional metering and billing, protection control, and intelligent dispatching to support friendly electrical energy exchange. Energy consumption interaction services, also advanced, encompass user equipment management and control, energy diagnostics and optimization strategies, and automated demand response, providing technical means to optimize user energy consumption patterns and achieve supply-demand balance.

1.2 Technical Implementation Controversy

Document [A] notes that domestic consensus has not been reached on whether smart meters should directly support various interactive services. Academic

discussions typically envision smart meters as directly bearing these functions, while practical implementations have positioned smart meters as basic user electricity information collection devices, with other terminals (such as smart electricity interaction terminals) handling advanced interactive functions from information security and cost perspectives. However, Document [A] fails to address how electrical energy interaction services and energy consumption interaction services—which involve bidirectional power flow trade settlement metering—should be implemented. This omission reveals that the approach of using smart electricity interaction terminals to carry advanced interactive services and perform bidirectional power flow trade settlement metering is unrealistic and unworkable. Thus, the issue of how to implement advanced interactive functions for bidirectional power flow trade settlement between distribution networks and users remains unresolved.

1.3 Current Imperatives

With the ubiquitous power Internet of Things now representing State Grid's most important and urgent task, this paper proposes that State Grid must first solve the practical implementation of “ubiquitous connection” and “holographic perception.” As previously argued, smart meters are best positioned as the nodes for ubiquitous connection and bidirectional power flow trade settlement metering facing users and equipment across industries. With modest investment to equip smart meters with communication modules featuring “intelligent” or advanced interactive functions, ubiquitous connection and bidirectional communication with users and industry equipment can be achieved. Therefore, accelerating the development of smart meters' intelligent functions is both timely and necessary.

2. Development Approach for State Grid Smart Meter “Intelligent” Functions

2.1 International Smart Meter Design Concepts

International smart meter designs provide valuable reference points. A 2009 report by Hangzhou Hexing Company indicated that while definitions vary across Australian, American, Nordic, Dutch (EDF), and South African (ESKOM) utilities, all converge on smart meters serving as communication and data gateways. As communication gateways, they handle upstream data communication, local data communication, water and gas meter data communication, home display unit (IHD) or customer information unit (CIU) communication, and second-circuit relay control device communication. As data gateways, they support large-capacity data storage, accommodating historical consumption data for water, electricity, and gas.

General Electric China similarly emphasized in 2009 that smart meters must feature bidirectional communication capabilities, enabling the grid to not only collect usage information but also transmit grid signals (such as real-time pricing

ing) and control commands to meters, which then respond intelligently. This includes information exchange and control commands with smart appliances and other meters. GE' s design incorporates standard-based, open built-in advanced intelligent programs that enable autonomous decision-making and response without awaiting master station instructions, with remote policy modification and software upgrade capabilities.

In 2013, Germany' s Federal Office for Information Security (BSI) developed new smart meter measurement system technical specifications, proposing the Intelligent Measurement System (IMsys) centered on smart meter gateways. This architecture connects measurement instrument networks, wide-area power markets, and demand sides through advanced bidirectional communication networks. In this system, electricity meters (and water/gas meters) function merely as data collection sensors, while the smart meter gateway serves as the intelligent core and key functional module connecting participants from different regions, representing an "Industry 4.0" intelligent exploration.

2.2 Design Requirements for State Grid Smart Meter "Intelligent" Functions

Based on the above analysis, smart meters' "intelligent" functions must satisfy the basic bidirectional communication requirements for bidirectional power flow trade settlement information and water/gas meter data, with bidirectional communication capability reflecting the degree of intelligence. This requires: (1) Communication gateway functionality, enabling intelligent responses to received information and communication with smart appliances, water/gas meters, and power control devices, necessitating protocol conversion capabilities across different communication networks; (2) Advanced "intelligent" applications, enabling autonomous real-time judgment and response to bidirectional information, requiring high-speed computational processing capabilities with advanced algorithms and software; and (3) Large-capacity data storage and exchange to support bidirectional exchange and interaction between smart distribution networks and users.

International descriptions characterize bidirectional communication capability as the soul of smart meters. This paper proposes that communication gateway functions, advanced intelligent applications, and large-capacity data storage/exchange constitute the basic functions of smart meter bidirectional communication. Their metrics and performance—including access communication methods, data/information flow types and directions, bandwidth and transmission rates, traffic, data storage capacity, peer protocols, computational processing speed, different network protocol conversion capabilities, and software characteristics such as convenience, intuitive display, stability, modifiability, reusability, and long lifecycle—require further discussion, demonstration, and refinement.

3. How to Implement “Ubiquitous Connection” and “Holographic Perception” in the State Grid Ubiquitous Power Internet of Things

Ubiquitous connection and holographic perception form the foundation of the State Grid ubiquitous power Internet of Things. This section outlines the technical route and preliminary implementation plan.

3.1 Technical Route via Smart Meter Bidirectional Communication and Gateways

The State Grid “Ubiquitous Power Internet of Things Construction Outline” requires connecting power users and their equipment, grid enterprises and their equipment, generation companies and their equipment, suppliers and their equipment, and people and objects to generate shared data. On the user side, shared data primarily includes bidirectional electrical energy (secondary energy), grid operation monitoring quantities, gas consumption (primary energy), water consumption, heat consumption (secondary energy), and distribution network power supply. Through smart meter bidirectional communication and gateways, this data is converted into bidirectional power flow trade settlement metering data between distribution networks and users, while outputting gas and water meter information to the energy industry.

As the national energy Internet advances, the scope of ubiquitous connection and holographic perception must gradually expand to include additional devices generating new shared data: user-side coal and oil consumption (primary energy), and supplier-side coal, oil, gas, and power generation water supply quantities (primary energy). The implementation of ubiquitous connection and holographic perception for these new devices requires further discussion based on the development of the ubiquitous power Internet of Things.

3.2 Key Implementation Issues

3.2.1 Metering Points for Users and Grid Enterprises According to Q/GDW378.3-2009 “Design Guidelines for Power User Electricity Information Collection Systems Part 3: Technical Solution Design Guidelines,” metering points are classified into six categories: (A) large dedicated transformer users ($\geq 100\text{kVA}$), (B) small-medium dedicated transformer users ($< 100\text{kVA}$), (C) three-phase general commercial/industrial users, (D) single-phase general commercial/industrial users, (E) residential users, and (F) public distribution transformer assessment points (F5) and grid gateway metering/assessment points (F1-F4).

In 2018, State Grid’s smart meter installations totaled 470 million units: 2.54 million for Class A, 5.87 million for Class B, 27.84 million for Class C, 21.385 million for Class D, 406.315 million for Class E, 6 million for Class F5, and 50,000 for Classes F1-F4.

3.2.2 Role and Benefits of Equipment “Ubiquitous Connection” For distribution network-user interactions, ubiquitous connection enables: bidirectional power flow trade settlement metering; effective user participation in load regulation and peak shaving; three-phase load balancing in low-voltage networks to reduce losses and prevent equipment overload; water and gas meter data collection and transmission; future real-time and diversified time-of-use pricing; demand response and demand-side management; grid-connected PV and storage monitoring and control; residential home energy management systems; and optimized electricity usage proposals from power supply departments.

For grid enterprises, benefits include: distribution network operation optimization and quality improvement; substantial loss reduction through 同期线损计算管理 (simultaneous line loss calculation management), segmented line loss calculation, and distributed reactive power compensation; and active low-voltage grid outage reporting and proactive distribution network repair.

3.2.3 Preliminary Implementation Plan Two implementation options exist for collecting voltage/current sensing information from user equipment and water/gas meter data:

Option 1: Smart meters directly collect and transmit voltage/current sensing information from user equipment and water/gas meter outputs, then calculate power and electricity consumption.

Option 2: Develop user smart electricity interaction terminals to collect voltage/current information, calculate power and energy, and gather water/gas meter data, with smart meters then interacting with these terminals for bidirectional power flow trade settlement and water/gas meter information exchange.

For large and small-medium dedicated transformer users, office buildings, and commercial complexes, a user internal maximum power load monitoring, control, and management system with smart electricity interaction terminals should be developed to ubiquitously connect all internal power supply and consumption equipment. For grid enterprise equipment, branch line terminals with simple computing functions should be installed at low-voltage line branch nodes, with software-defined intelligent distribution transformer terminals performing edge computing to ubiquitously connect all low-voltage grid equipment including smart meters, distribution boxes, user leakage protectors, and branch line terminals.

3.2.4 Equipment Quantities and Grid Load Regulation Capacity
Based on limited preliminary estimates:

Class A Large Dedicated Transformer Users (2.54 million users):
Assuming 60% participation (1.524 million users) with transformer capacities of 5,000kVA (152,000 users), 1,000kVA (457,000 users), and 100kVA (914,000 users), each connected device capacity at 5% of transformer capacity (250kVA, 50kVA, 5kVA), and 4 devices per user participating in grid regulation (20% of

transformer capacity), the ubiquitous connection involves 9.144 million devices with 262 million kVA regulation capacity, equivalent to 210 million kW active power regulation.

Class B Small-Medium Dedicated Transformer Users (5.87 million users): Assuming 80% participation (3.522 million users) with average 50kVA capacity, 5% capacity per device (2.5kVA), and 6 devices per user (30% of capacity), ubiquitous connection involves 28.176 million devices with 52.8 million kVA capacity, equivalent to 42.2 million kW active power regulation.

Class E Residential Users (406.32 million users): Assuming 80% of urban residents (162.53 million households) with 8kW design capacity per household, 6% capacity per device (0.5kVA), and 6 devices per household (40% of design capacity), ubiquitous connection involves approximately 1.3 billion devices with 487.5 million kVA capacity, equivalent to 390 million kW active power regulation.

Class C/D Three-Phase/Single-Phase General Commercial Users (27.84/21.39 million users): Assuming 80% participation (22.27/17.11 million users) with 35kVA/20kVA design capacity, 6%/5% capacity per device (2kVA/1kVA), and 6 devices per user (35%/30% of capacity), ubiquitous connection involves approximately 178/171 million devices with 267/103 million kVA capacity, equivalent to 210 million kW/82 million kW active power regulation.

In total, ubiquitous connection across Classes A, B, C, D, and E in the State Grid operating area would involve 1.686 billion devices—3.58 times the installed smart meter base—with participating user equipment capable of regulating approximately 931 million kW of active power load, representing 115% of State Grid's 2018 peak load (810 million kW).

4. Conclusion

The authors recommend that State Grid initiate projects to develop the current application technology for smart meter “intelligent” functions, then advance the construction of the State Grid smart distribution network AMI system. As previously discussed, developing smart meter intelligent functions—specifically bidirectional communication and gateway technology—enhances and expands the implementation capabilities of the ubiquitous power Internet of Things. Building upon this foundation, State Grid should further develop its smart distribution network AMI system.

Internationally, AMI (Advanced Metering Infrastructure) aims to achieve bidirectional, interactive communication between the user side and grid dispatch side. In November 2013, State Grid work conferences proposed modern distribution network construction, friendly social electricity interaction, and research on bidirectional interactive smart meters. In 2014, key State Grid metering projects required strengthening research and application of smart meter bidirectional interactive functions and new communication technologies. However,

subsequent reports on the outcomes of these advanced interactive function developments have been absent.

In 2019, with the construction of the ubiquitous power Internet of Things, advancing smart meter intelligent function development to achieve advanced interaction between distribution networks and users—encompassing bidirectional power flow trade settlement metering and water/gas meter data transmission—aligns fundamentally with early international AMI functions. International AMI technology continues evolving; on March 20, 2019, reports indicated that Landis+Gyr won the bid for Tokyo Electric Power Company’s smart meter deployment exceeding 20 million units, utilizing its Gridstream Connect platform with multiple communication technologies and Wi-SUN home energy management system standards to demonstrate future utility IoT strategies.

Thus, developing State Grid smart meter intelligent functions not only meets the needs of ubiquitous power Internet of Things construction but also positions State Grid smart distribution network AMI systems for broad domestic application and export prospects.

[1] ZHANG Chunhui, ZHANG Zhen. “Constructing a Power User IoT Network Based on State Grid ‘Ubiquitous Connection’ Smart Meters”

[2] DENG Guiping, FU Shiji, SHU Kaiqi, CHEN Jun. “Discussion on Advanced Metering Infrastructure,” *Electrical Measurement & Instrumentation*, July 15, 2010

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

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