

Development of Power User IoT Network Based on State Grid’s “Ubiquitous Connection” Smart Meters

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Abstract

This text primarily introduces the design and development of the power user electricity IoT network based on State Grid’s “Ubiquitous Connection” smart meters. This network serves as a bidirectional power flow trading settlement metering network enabling advanced interactive functions between new-type smart distribution grids and users. The author notes that current State Grid smart meters merely carry the “smart” designation and require functional upgrades to become true State Grid “Ubiquitous Connection” smart meters—devices equipped with bidirectional communication and gateway capabilities for bidirectional power flow trading settlement metering between distribution grids and users, as well as for transmitting water and gas meter data to enable advanced interactive functions. These advanced interactive functions are consistent with the international smart meter development trajectory, and it is recommended that State Grid undertake preliminary design and development efforts. To meet the requirements of State Grid’s “Ubiquitous Power Internet of Things” initiative, the author suggests that subsequent development of the power user electricity IoT network based on State Grid’s “Ubiquitous Connection” smart meters remains necessary. Given that residential users constitute approximately 86% of the total user base in State Grid’s operating region (470 million households), preliminary research is currently required on the residential user electricity IoT network based on State Grid’s “Ubiquitous Connection” smart meters. This network comprises State Grid “Ubiquitous Connection” smart meters, indoor IoT systems, collection terminals, network command centers, and databases—forming a bidirectional power flow trading settlement metering network. Furthermore, the text addresses the framework design of the residential user electricity IoT network, logical design within the IoT network, and connections with external related systems. Specifically, the network command center can interface with provincial grid IoT management center data platforms, power marketing systems, distribution management systems, among

others. In summary, this text provides important reference and guidance for the design and development of the power user electricity IoT network based on State Grid's "Ubiquitous Connection" smart meters.

Full Text

Building a Power User IoT Network Based on State Grid's "Ubiquitous Connection" Smart Meters

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Abstract

This paper presents the design and development of a power user Internet of Things (IoT) network based on State Grid's "ubiquitous connection" smart meters. This network serves as a bidirectional power flow trading settlement metering network with advanced interactive functions between the new smart distribution grid and end users. The authors argue that current State Grid smart meters are merely labeled "smart" and require functional upgrades to become true "ubiquitous connection" smart meters equipped with bidirectional communication and gateway capabilities. These upgraded meters would enable bidirectional power flow trading settlement metering between distribution networks and users, as well as advanced interactive functions for transmitting water and gas meter data—capabilities that align with international smart meter development trends and warrant priority design and development by State Grid.

To meet the construction requirements of State Grid's "ubiquitous power IoT," the authors recommend developing a power user IoT network based on these enhanced smart meters. Given that residential users account for approximately 86% of State Grid's total customer base (470 million households), priority should be given to researching residential user power IoT networks. Such networks would comprise State Grid "ubiquitous connection" smart meters, indoor IoT systems, collection terminals, network command centers, and databases to form a bidirectional power flow trading settlement metering network. This paper addresses framework design, logical architecture within the IoT network, and connections with external systems, including interfaces between the network command center and provincial grid IoT management data platforms, power marketing systems, and distribution management systems. Overall, this work provides important reference and guidance for the design and development of State Grid's power user IoT network based on "ubiquitous connection" smart meters.

Keywords: Ubiquitous connectivity, Smart meters

The power user IoT network based on State Grid’s “ubiquitous connection” smart meters represents a branch of State Grid’s “ubiquitous power IoT”—a bidirectional power flow trading settlement metering network enabling advanced interactive functions between the new smart distribution grid and users. In a previous publication dated March 28, 2019, titled “Advancing the Development of State Grid Smart Meter ‘Smart’ Functions to Enhance and Expand the Implementation Capabilities of State Grid’s Ubiquitous Power IoT,” the authors explained that current State Grid smart meters are only nominally “smart.” They require functional upgrades to become true State Grid “ubiquitous connection” smart meters featuring bidirectional communication and gateway functions for bidirectional power flow trading settlement metering between distribution networks and users, plus advanced interactive capabilities for transmitting water and gas meter data. These advanced functions align with international smart meter development roadmaps, and the authors recommend that State Grid initiate their design and development.

To support the rapid implementation and tangible results of State Grid’s “ubiquitous power IoT” construction, the authors suggest that State Grid should subsequently develop a power user IoT network based on these “ubiquitous connection” smart meters. Since residential users constitute about 86% of State Grid’s total customer base (470 million households), research must prioritize the residential user power IoT network based on State Grid’s “ubiquitous connection” smart meters. This network consists of State Grid “ubiquitous connection” smart meters, indoor IoT systems, collection terminals, network command centers, and databases to form a bidirectional power flow trading settlement metering network. This paper discusses the architecture design, functional specifications, interface communication categories and protocol selection, and network command center considerations for this residential user power IoT network.

1. Framework Design of Residential User Power IoT Network

This section references the European OPEN meter system and Landis+Gyr’s AMI (Advanced Metering Infrastructure) framework, combined with State Grid’s “Ubiquitous Power IoT Construction Outline” requirements for “ubiquitous connection” and “holographic perception,” as well as operational architectures for State Grid’s distribution IoT and electricity information collection systems, to propose a preliminary framework design.

(1) Preliminary Framework Design

1) Building Indoor IoT Systems

Conditions for Connected Devices: - Power equipment participating in grid load regulation must be equipped with voltage and current sensors and output in-

terfaces. - Water and gas meters must be replaced with smart/digital meters featuring metering data output interfaces. - Indoor distributed power sources, distributed energy storage devices, and electric vehicle charging equipment generally have electricity consumption output interfaces.

Two Optional Connection Schemes:

Scheme 1: The State Grid smart meter directly collects and transmits perception information from these indoor power equipment and water/gas meter output data through its gateway function. The meter then calculates the power and electricity consumption of these indoor devices.

In this scheme, devices connect directly to the meter (gateway): - Meter (gateway) connects to: power equipment (participating in grid load regulation), water/gas meters, distributed power sources, distributed energy storage devices, electric vehicle charging equipment, IHD (In-Home Display), and handheld operation terminals. - Water/gas meters connect to handheld operation terminals.

Scheme 2: If the State Grid smart meter's metering function remains unchanged, an indoor interaction unit must be developed. This unit collects voltage and current output information from indoor power equipment, calculates power, measures electricity consumption, and collects water/gas meter output data. The State Grid smart meter then performs bidirectional power flow trading settlement metering and transmits water/gas meter data through its gateway function for advanced interaction.

In this scheme, devices connect via the indoor interaction unit: meter (gateway) → indoor interaction unit → power equipment (details omitted).

2) Logical Design Within IoT Network

Logical Design for Metering Box Applications: Network Command Center (Database) (1-z) Concentrators (1-n) Collectors (2-m) Meters (gateway) or [(2-m) Meters (gateway) Indoor Interaction Unit] Indoor IoT System. As needed, a supplementary design can be implemented: Network Command Center (Database) Collectors.

Logical Design for Individual Residential Users: Network Command Center (Database) (1-z) Concentrators Meter (gateway) or [Meter (gateway) Indoor Interaction Unit] Indoor IoT System. As needed, a supplementary design can be implemented: Network Command Center (Database) Meter (gateway).

3) Connection with External Systems

Network Command Center Provincial Grid IoT Management Center Data Platform Power Marketing System Distribution Management System.

(2) IoT Network Connection Methods

For simplicity, this section only describes the IoT network connection method for metering box applications.

1) Communication Interface Numbering Convention: - Meter (gateway) interface: K - Indoor water/gas meter interface: L - Indoor power equipment interface: S - Concentrator interface: M - Collector interface: C - Network Command Center interface: N - Provincial Grid IoT Management Center Data Platform interface: H

2) Internal Network Connection Methods

Indoor Connections (Scheme 1): - Meter (gateway) K1 S1: Power equipment (participating in grid load regulation) - Meter (gateway) K2 L1: Water/gas meter - Meter (gateway) K3 S2: Distributed power source - Meter (gateway) K4 S3: Distributed energy storage device - Meter (gateway) K5 S4: Electric vehicle charging equipment - Meter (gateway) K6 S5: IHD (In-Home Display) - Meter (gateway) K7: Handheld operation terminal - Water/gas meter L2: Handheld operation terminal

Outdoor Connections: - Meter (gateway) K8 C1: Collector - Collector C2 M1: Concentrator - Concentrator M2: Handheld operation terminal - Collector C3: Handheld operation terminal - Concentrator M3 N1: Network Command Center - Network Command Center N5 C4: Collector

3) External Network Interface Numbering: - Network Command Center N2 Power Marketing System (electricity billing, telecom billing, EV charging billing) - Network Command Center N3 Distribution Management System (low-voltage grid outage management, dispatch management for distributed power source and storage device grid connection) - Network Command Center N4 H1: Provincial Grid IoT Management Center Data Platform

2. Functional Specifications of Residential User Power IoT Network

According to State Grid’s “ubiquitous power IoT” construction requirements—focusing internally on performance improvement and externally on integrated development—the primary task of building a residential user power IoT network based on State Grid’s “ubiquitous connection” smart meters is to effectively advance advanced interactive functions between the smart distribution grid and residential users. Functional design requirements include:

Large-capacity household appliances should participate in grid load regulation to shave peaks and fill valleys, balancing load surplus and deficiency, enabling bidirectional power flow trading settlement metering between the smart distribution grid and residential users. Calculations show that if 80% of urban residential users in State Grid’s operating area (162.53 million households) participate in grid load regulation, with six appliances per household of 0.5 kVA or above capacity, State Grid would have approximately 1.3 billion “ubiquitously connected” household appliances available for regulating 390 million kW of active power load—representing 48% of State Grid’s 2018 peak load (810 million kW). Energy conservation and consumption reduction should be promoted through

the development and application of urban residential user energy management systems. The meter (gateway) should collect and transmit water and gas meter data to create a new scheme for large-scale promotion of State Grid's "multi-meter integration" information collection. Intelligent phase-switching technology for residential users should be employed to balance three-phase power loads in low-voltage grids, reducing line losses and preventing low-voltage power equipment from overheating due to overload. Indoor grid-connected monitoring and control management for photovoltaic and energy storage devices should be implemented. Indoor electric vehicle charging equipment requires metering and interactive management. Future real-time pricing, diversified time-of-use pricing, and demand response interactive management capabilities should be incorporated. Finally, the second circuit (e.g., refrigerator) power preservation function for residential users should be advanced.

3. Interface Communication Categories and Protocol Selection

1) Interface Communication Technical Elements

Interface numbering includes: (a) communication category technology; (b) communication category subclass technology; (c) lower layer (IoT layer, link layer) protocol; (d) upper layer (application layer) protocol. Note that both lower and upper layer protocols are data exchange protocols. The full protocol names are listed below:

- Q/GDW 1376.2-2013: Communication Protocol for Power User Electricity Information Collection System - Part 2: Concentrator Local Communication Module Interface Protocol
- DL/T645-2007: Multi-function Electric Energy Meter Communication Protocol
- DL/T698.45-2017: Electric Energy Information Collection and Management System - Part 4-5: Object-oriented Interoperable Data
- Q/GDW 11612-2016: Technical Specification for Interoperability of Low-Voltage Power Line Broadband Carrier Communication - Part 1: General, Part 2: Technical Requirements, Part 3: Test Methods, Part 4: Physical Layer and Communication Protocol, Part 5: Link Layer and Communication Protocol, Part 6: Application Layer Technical Requirements
- CJ/T 188-2018: Technical Conditions for Data Transmission of Household Metering Instruments
- Q/GDW 1376.1-2013: Communication Protocol for Power User Electricity Information Collection System - Part 1: Master Station and Collection Terminal
- Q/GDW 1376.4-2013: Communication Protocol for Power User Electricity Information Collection System - Part 4: Data Transmission Protocol Based on Micropower Wireless

2) Collector C2 to Concentrator M1 Interface Communication

Scheme

Option 1: Fast, Protocol-Sharing Communication Scheme - a) Communication category: Micropower wireless - b) Communication subclass: PLC subclass (OFDM narrowband PLC), Micropower wireless subclass (Zigbee) - c) Lower layer protocol // d) Upper layer protocol: Q/GDW1376.2-2013 // d1 DL/T645-2007, DL/T698.45-2017 // d2 DL/T698.45-2017

Option 2: High-Speed, Protocol-Dedicated Communication Scheme - a) Communication category: PLC - b) Communication category (PLC) subclass: State Grid broadband PLC - c) Lower layer protocol: Q/GDW11612.4-2016, Q/GDW11612.5-2016 // d) Upper layer protocol: Q/GDW11612.6-2016, DL/T645-2007

The above Collector C2 to Concentrator M1 interface communication schemes can serve as references for selecting communication schemes for the following connected power equipment interfaces: - Meter (gateway) K1 S1: Power equipment (participating in grid load regulation) - Meter (gateway) K3 S2: Distributed power source - Meter (gateway) K4 S3: Distributed energy storage device - Meter (gateway) K5 S4: Electric vehicle charging equipment - Meter (gateway) K6 S3: IHD

3) Meter (gateway) K8 to Collector C1 Interface Communication Scheme - a) Communication category: Bus - b) Communication category (bus) subclass: RS-485 - c) Lower layer protocol: Schneider Electric's "Industrial Fieldbus Mod Bus Protocol" // Upper layer protocol: DL/T645-2007

4) Meter (gateway) K2 to Water/Gas Meter L1 Interface Communication Scheme - a) Communication category: a1 Bus, a2 Micropower wireless - b) Communication category subclass: b1 Bus subclass (M-Bus), b2 Micropower wireless subclass (Zigbee) - Lower layer protocol: CJ/T188-2018 // Upper layer protocol: (none specified)

5) Concentrator M3 to Network Command Center N1 Interface Communication Scheme - a) Communication category: Wireless - b) Communication category (wireless) subclass: GPRS/4G/5G - c) Lower layer protocol: Q/GDW1376.1-2013 // d) Upper layer protocol: DL/T645-2007 or DL/T698.45-2017

The above Concentrator M3 to Network Command Center N1 interface communication scheme can serve as a reference for the Network Command Center N5 to Collector C4 interface communication scheme selection.

6) Meter Gateway K7 to Handheld Operation Terminal Interface Communication Scheme - a) Communication category: Wireless - b) Communication category (wireless) subclass: Micropower wireless - c) Lower layer protocol: Q/GDW 1376.4-2013 // d) Upper layer protocol: (none specified)

The above Meter (gateway) K7 to handheld operation terminal interface communication scheme can serve as a reference for selecting communication schemes

for the following connected device interfaces: - Concentrator M2 Handheld operation terminal - Collector C3 Handheld operation terminal - Water/gas meter L2 Handheld operation terminal

Note: The selection of lower layer and upper layer protocols for data transmission listed above is provided for reference.

4. Network Command Center

The Network Command Center serves as the unified operation and management platform for the residential user power IoT network based on State Grid's "ubiquitous connection" smart meters and must achieve full coverage of the network.

(1) Network Command Center Design Outline

This section is written with reference to the main station portion of "Electricity Information Collection System Technology and Application" by Zhang Jing et al. (hereinafter referred to as Reference [C]).

1) Functional Design

The Network Command Center's business management scope can be divided into five parts: basic functions, advanced functions, statistical query functions, operation management functions, and system management functions.

Basic Functions: - Collection point setup - Data collection management - Interface management - Electric vehicle charging equipment metering and interactive function management - Future real-time pricing, diversified time-of-use pricing, and demand response interactive management

Advanced Functions: - Management of large-capacity household appliances participating in grid load regulation - Online monitoring and management of distributed power source and distributed energy storage device grid connection - Assistance with intelligent phase-switching operations for residential users in distribution systems - Management of residential user second circuit (e.g., refrigerator) power preservation operations - Setup and management of home energy management systems - The following advanced functions require branch terminals with simple computing functions to be installed at line branch points: transformer area and line segment loss calculations; transformer area distributed reactive power compensation calculations and reactive power compensation equipment switching operation management; transformer area transformer-line-customer relationship calculations - Decision analysis operations - Data application functions for queries, statistics, and analysis provided by value-added services

Statistical Query Functions: Provide queries for collection point comprehensive information, collection data, system work orders, SIM card operations, and reports.

Operation Management Functions: Include file management, communication monitoring, event management, time synchronization management, and equipment maintenance.

System Management: Management of residential users, passwords, permissions, templates, and codes within the network.

2) Planning and Design

Planning and Design Decision Factors: - Number of residential users, meters (gateways), collectors, concentrators, and indoor connection devices, along with access data volume - Requirements for data collection and transmission speed and reliability - Requirements for Network Command Center data processing capability

Planning and Design Content: - Network Command Center logical design - Network Command Center structure - Hardware configuration - Software configuration

The above planning and design content can be referenced in Reference [C].

Planning and Design Reference Documents: - Q/GDW 378.3-2009: Design Guidelines for Power User Electricity Information Collection System - Part 3: Technical Solution Design Guidelines - Q/GDW 378.1-2009: Design Guidelines for Power User Electricity Information Collection System - Part 1: Master Station Software Design Guidelines - Q/GDW 1379.1-2013: Inspection Technical Specification for Power User Electricity Information Collection System - Part 1: System Inspection Technology

(2) Network Command Center and Data Upload System

It should be noted that the residential user power IoT network based on State Grid's "ubiquitous connection" smart meters is not an independent technical implementation process, but rather a fully configurable infrastructure that must be integrated into current and future power networks and operational processes. Given that data and basic/advanced functions aggregated by the Network Command Center primarily serve or are used by the smart grid's power marketing system and distribution management system, and considering that power trading settlement data security is more critical and frequently used, this paper recommends that the Network Command Center be directly embedded in the smart grid's power marketing system, with networked applications to the distribution management system. Simultaneously, the Network Command Center must upload aggregated data to the provincial grid IoT management center data platform.

(3) Reference: Landis+Gyr AMI Grid Stream Technology

- 1) In February 2016, Landis+Gyr launched the Grid Stream communication platform capable of connecting multiple grid-deployed AMI solutions

(Note: Grid Stream is Landis+Gyr's AMI command center). "The grid router greatly assists the Grid Stream communication platform's grid connection adaptability and processing capabilities for distributed intelligence and customer intelligence solutions. As a grid edge server, the device provides real-time guidance and processing of data transmitted from front-end systems and smart community networks." "The new grid router expands Grid Stream grid management by establishing connections with other relevant networks and devices to help utilities and the communities they serve achieve broader energy management goals."

- 2) On March 20, 2019, Landis+Gyr announced that the deployment of smart meters and related equipment for Tokyo Electric Power Company (Japan) had exceeded 20 million units installed, with the project scheduled for completion in 2020. Upon completion, the deployment will connect nearly 30 million devices between Tokyo Electric Power Company and its users through multiple communication technologies and the Wi-SUN Home Energy Management communication standard. Currently, Landis+Gyr's Grid Stream big data management system processes up to 1 billion data packets daily for this project and supports Tokyo Electric Power Company's requirement for meter data reading every 30 minutes. Landis+Gyr's Grid Stream head-end system has the capability to manage over 30 million meters. Meanwhile, Landis+Gyr has accumulated rich experience in ultra-large-scale project deployment and meeting flexible and diverse communication methods, which will further advance the development strategy of Landis+Gyr's Grid Stream Connect platform and future utility IoT solutions.

The authors will address the topic of building a large-scale dedicated transformer user power IoT network based on State Grid's "ubiquitous connection" smart meters in a separate discussion.

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