Research on Remote Meter Reading Scheme and IoT Smart Energy Meter Based on NB-IoT Technology

Xingyuan Fan¹, Chun Zhou¹, Ying Sun¹, Jinyang Du¹ and Ying Zhao¹
¹Guangzhou Power Supply Bureau Co., Ltd, Guangzhou, 510620, China
523812935@qq.com; zhouc@guangzhou.csg.cn; 410050938@qq.com; dujy@guangzhou.csg.cn; zhaoy@guangzhou.csg.cn

Abstract. The energy meter supporting the NB-IoT standard protocol is designed to be connected to the NB-IoT network through the protocol conversion of the remote communication module itself, and directly connected to the existing centralized meter reading automation system. The acquisition terminal device is omitted, and direct communication between the main station and the energy meter is realized. The end-to-end standardized protocol reduces the complexity of the centralized meter reading platform architecture and improves the system's openness and scalability. It realizes end-to-end visual management and real-time monitoring, improving the safety, reliability and fault resistance of power collection. The overall scheme can reduce the large amount of human and material costs of system operation and maintenance.

1. Introduction
The low-voltage centralized meter reading system automatically collects, transmits and manages electricity measurement data, fundamentally changes the traditional mannered reading model, and realizes automatic meter reading and settlement [1]. However, some problems are found along with the on-site operation, such as the system function scalability is not good, meter reading time is long and the real-time performance is insufficient [2], abnormal environment interference causes terminal offline failure, which easily leads to acquisition failure [3]. Narrow Band Internet of Things technology (NB-IoT) is a revolutionary technology that has the advantages of supporting massive connections, deep coverage, and low power consumption. It is suitable for new applications of IoT such as metering and monitoring [4, 5]. The paper studies the design of a new generation of meter-based IoT meter reading scheme through NB-IoT technology. The direct communication between the energy meter and the master station system is realized, the intermediate equipment metering terminal is omitted, the complexity of the existing concentrated copy platform architecture is reduced, the centralized management and real-time monitoring capability of the energy meter is improved, and the collection coverage rate is effectively improved.

2. The Current Low-voltage Centralized Meter Reading System Architecture and Existing Problems
The low-voltage centralized meter reading system is a centralized reading and reading of electric energy data and related electricity information of a plurality of energy meters by a metrology automation system through a remote communication channel, and can remotely implement a network meter reading system for disconnecting and power transmission control. It consists of the user energy
meter, the acquisition terminal, the concentrator, the communication channel and the master station of the metrology automation system [6]. The system architecture is shown in Figure 1. The data is transmitted to the metrology automation master station through the channel and connected to the marketing system to realize automatic meter reading. At present, the communication network is mainly composed of two parts: the downlink acquisition network includes PLC, RS485 bus, wireless ad hoc network, etc., to realize smart energy meter and concentrator communication; the uplink backhaul network includes GPRS/CDMA, 4GLTE, etc., to realize concentrator and master station system communication; two parts of the network can adopt different networking technologies [7].

![Figure 1. Current low-voltage centralized meter reading system architecture.](image)

With the use of metrology automation systems in recent years, some problems have been encountered: (1) Downstream acquisition networks, most of them are private communication protocols of manufacturers, which are difficult to interconnect and achieve unified management; (2) Currently using non-standardized non-open protocols, the network link conversion of equipment such as concentrators and collectors is required, resulting in poor scalability of the system architecture and complex operation and maintenance; and the non-tunnelled carrier channel and the communication front-end machine are added in the middle, making it difficult to realize the end-to-end visual network connection from the end energy meter to the main station server; (3) The acquisition communication platform is formed by a segment of the network link, and the application layer communication is reachable, but the network layer cannot communicate end-to-end, and the communication status and operation status of each energy meter cannot be monitored in real time. When the fault occurs, the feedback cannot be made in time, and a fault occurs. It is necessary to send people to conduct on-site investigation, which is inefficient and wastes manpower.
3. Design of Remote Meter Reading Scheme Based on NB-IoT Technology

Narrow Band Internet of Things (NB-IoT) has the characteristics of low cost, low power consumption, low speed and wide coverage, and the number of concurrent connections of a single base station can be increased, and spectrum resources can be utilized efficiently [8]. Secondly, NB-IoT coverage sensitivity is 20 decibels stronger than traditional technology, with over 100 times coverage enhancement; with ultra-low power consumption, NB-IoT consumes only 1/10 of 2G. The application of NB-IoT technology in the field of smart grid will help to improve the reliable transmission and comprehensive coverage of the power collection service. The smart energy meter, which is the power terminal of the smart grid, will become an important part of the new application of the Internet of Things for the smart grid.

The meter reading architecture based on NB-IoT technology is shown in Figure 2. It mainly includes the master station layer (management system, database, system firewall, etc.), network layer (NB-IoT base station), IoT smart energy meter. In this architecture, the smart energy meter directly accesses the NB-IoT network by loading a remote communication module that supports the NB-IoT standard protocol communication, eliminating the link between the collector and the concentrator in the original system architecture, and transforming the indirect acquisition into direct acquisition. Data uploading enables end-to-end transmission, and the technical advantages are also reflected in:

![Figure 2. Remote meter reading application architecture based on NB-IoT.](image)

(1) Direct collection
The metering terminal device is omitted, and the master station directly collects the energy meter, reads the data, and issues parameters or instructions. It meets the frequency, success rate and multi-service application of power collection; at the same time, the terminal equipment is omitted, which saves a lot of equipment cost and operation and maintenance cost for power collection;

(2) High capacity
NB-IoT has 50~100 times higher uplink capacity than 2G/3G/4G, supports massive connection, and solves the problem of base station saturation in current power meter reading system;

(3) Improve collection coverage
NB-IoT boosts 20dB gain compared to LTE, which is equivalent to 100 times higher transmit power (100 times better coverage), and can overcome different levels of signal attenuation such as 144dB, 154dB and 164dB according to coverage level; the deep coverage capability solves the
problem that the current meter reading system has a partial signal difference or no signal, and improves the acquisition coverage and success rate;

(4) Low power consumption
The low power consumption solves the problem that the output power of the single-phase meter in the current power meter reading system is small, and the GPRS module cannot be directly loaded. The lower the power consumption, the longer the life and the longer the meter replacement cycle, which can save a huge amount of manpower and material resources;

(5) Concurrency and two-way interaction
The NB-IoT service rate is low, the acquisition delay can be tolerated, the concurrent services are supported, and the coverage distance is long. The high-frequency real-time power data collection can be further supported. In addition to the power enterprise collecting base station information, the NB-IoT technology is adopted. The base station can also receive the enterprise side information and synchronously send the information to each household energy meter to realize two-way interaction between the user and the power company.

4. Key Technologies of IoT Smart Energy Meter Based on NB-IoT Technology

4.1. IoT Smart Energy Meter System Design and Function
The main function of the IoT smart energy meter is measurement and data transmission. The meter design adopts the “double MCU” scheme, including the base meter part and the NB-IoT communication module part. The base meter is the management MCU, which realizes the basic functions of measurement and storage. It can be configured with different uplink communication modules, and supports NB-IoT standard protocol remote communication module. Replacing the external module in the original charge control energy meter, it can quickly connect to the NB-IoT network, and the module supports power failure detection and reporting function. The design is shown in Figure 3 below.

![IoT smart energy meter system design block diagram.](image)

4.2. NB-IoT Communication Module and Interface Design

4.2.1. Module Design
NB-IoT remote communication module can adapt to different manufacturers' energy meters, and the energy meter interface circuit adopts fixed interface definition and interface protocol, respectively +5V, +3.3V, GND, RXD, TXD, RST, after one adaptation, the subsequent use of any module does not require re-adaptation development. The energy meter remote communication module includes the main MCU, the power conversion circuit, the memory chips (DATAFLASH, EEPROM), the NB-IoT
module, the hardware watchdog circuit, the energy meter interface circuit, the debug interface circuit, etc. The system block diagram is shown in Figure 4. The main module design description is as follows:

(1) The main MCU functions as the core of the module to achieve the following functions:
1) Initialize the NB-IoT module by AT command, establish link, link maintenance and data response;
2) Reading the configuration parameters according to the communication protocol and the system, and responding to the data interaction between the energy meter and the master station;
3) Store the relevant configuration parameters into the EEPROM to avoid loss of parameter power failure, support remote upgrade, and store the contents in DATAFLASH;
4) Respond to the debugging commands of the debug interface and the printout of key information.

(2) The power conversion circuit is responsible for converting the voltage of the input power source into a voltage suitable for the system, and ensuring the stability of the output power source;

(3) The memory chips (DATAFLASH, EEPROM) respond to the storage parameters such as the configuration parameters of the main MCU and the writing and reading of the upgrade data;

(4) The module is configured with NB-IoT module, and data interaction can be performed through the NB-IoT network;

(5) The energy meter interface circuit is responsible for matching and data transmission with other interface circuits. All output interfaces adopt triode open-drain mode, and the triode output terminal is connected in series with a 100 ohm resistor to effectively prevent damage to the device caused by sharp pulses generated during frequent insertions. The input terminal uses a diode protection circuit to effectively adapt the interface circuits of different levels of different energy meters, as shown in Figure 5 below.
4.2.2. Principles of Key Tasks

Key tasks include meter reading task, uplink communication task, freezing task, active reporting task, and power failure reporting task.

(1) Principle of meter reading task

The MCU reads the base meter data according to the module reading time interval through the 645 protocol. After the data is successfully read, the data is transmitted to the protocol parsing task, and the related data is extracted according to the protocol, and then stored in the DATAFLASH, as shown in Figure 6.

(2) Principle of uplink communication task

The MCU reads the information according to the master station, performs protocol analysis, reads the relevant information from the DATAFLASH to respond, and sends the data through the remote communication module, as shown in Figure 7.

(3) Principle of freezing task

The MCU will perform daily freezing, monthly freezing and other important data freezing according to the requirements of the meter reading in the specified time. The relevant data will be stored in DATAFLASH according to a certain format, as shown in Figure 8.

(4) Principle of active reporting task

The task report can be set according to the protocol. After the active reporting task is triggered, the MCU reads the relevant data in the DATAFLASH, and then reports it to the master station according to the protocol, as shown in Figure 9.

(5) Principle of power failure reporting task

The meter provides a special power failure judging circuit for the module power supply 12V port. When the voltage drops to a certain threshold, the power failure signal is output. After receiving the power failure signal, the main MCU is judged to be a real power failure after entering the power failure interference, enters the power failure event processing task, performs data framing according to the China Southern Power Grid protocol, and uses the super capacitor backup power supply to report in real time through the NB-IoT module. The process is shown in Figure 10.
4.2.3. Interface Definition with Base Meter

The weak electric interface of the NB-IoT remote communication module adopts 2×6 double-row pins as the connecting piece, and the weak electric interface of the energy meter adopts 2×6 double-row sockets as the connecting piece, as shown in Figure 11 below, the definition of the weak electric interface pins on the meter side. The open-drain endurance of the energy meter and communication module is 5.5V, the low-level current drive capability of all output interfaces is ≥2mA, the ground voltage should be ≤0.4V when driving the load current of 2mA; in the case of VCC power supply carrying (single-phase meter 125mA), the ripple Vp-p of the VCC power supply should be less than 1‰; the communication interface is isolated from strong power.

4.3. Uplink Communication Protocol

The uplink communication protocol follows the China Southern Power Grid "Q/CSG 11109004-2013 Metrology Automation Terminal Uplink Communication Protocol", which defines the frame format, data coding and transmission rules for data transmission between the master station and the terminal of the metrology automation system. It is suitable for point-to-point, multipoint-partyline and point-to-multipoint communication. It is suitable for the master station to perform the master-slave question and answer mode for the terminal and the terminal active upload mode communication.

NB-IoT remote centralized meter reading communication module, the module completely follows the smart energy meter specification in terms of physical characteristics and energy meter data interface, which can limit the traditional energy meter RS485 communication transmission between a single meter and the module. Therefore, the inherent unreliable limitations of RS485 serial communication are effectively avoided, and the reliability of the entire network communication and the success rate of meter reading are greatly improved. Uplink through the protocol conversion of the communication module itself, after connecting to the NB-IoT network, it can directly access the existing centralized meter reading and operation network system, thereby achieving the expected direct communication between the master station and the meter. Reduce the complexity of the existing centralized meter reading platform architecture through end-to-end standardized protocols, and improve the system's openness and scalability.

5. Test and Field Application Results Analysis

Based on the above design, the IoT smart energy meter based on NB-IoT technology has the tested performance in line with power consumption, power supply voltage, overvoltage, climate impact test, electrostatic discharge immunity test, electrical fast transient disturbance test required by the China Southern Power Grid enterprise standard "Q/CSG 1209003-2015 Single Phase Electronic Charge Control Energy Meter Technical Specification" experimental requirements.

According to the remote meter reading scheme, the sample meter is installed in the field for trial operation, and the 15-minute timed reporting task is set. The real-time data such as power, voltage, current, etc. are reported through the NB-IoT network, the daily freezing data is reported at 0:30 daily, and the uploaded data is complete and accurate; when the main station has a demand, the NB-IoT
network can also actively call the relevant information of the meter, and the power failure information can be reported in time after the power failure. During the 6 months of operation, communication is normal and safe.

6. Conclusions
Based on the NB-IoT technology, the paper designs a remote meter reading scheme. This scheme eliminates the link between the collector and the concentrator in the original meter reading system architecture, and transforms the indirect acquisition into direct acquisition. The design and development of the IoT smart energy meter based on NB-IoT technology is mainly studied. The system includes the uplink module and the base meter. The base meter is compatible with different uplink modules. Based on the NB-IoT standard protocol, the remote communication module can be developed to adapt to different manufacturers’ energy meters. The hardware design, interface design and main function design of the module are analyzed. The physical characteristics and data interface of the module completely follow the energy meter specification. The function can realize meter reading, uplink communication, freezing, active reporting, power failure, etc.; the uplink communication protocol is in accordance with the existing uplink communication protocol of the metrology automation terminal, and is transmitted through the protocol conversion of the communication module itself, and directly connected to the centralized meter reading system after accessing the NB-IoT network. After being certified by a third-party testing organization, the meter is accurate in measurement, normal in communication, and the performance meets the standard requirements. After half a year of on-site trial operation, the operation is stable, the function is reliable, and the coverage signal is good. The research and pilots laid the foundation for the comprehensive application and promotion of NB-IoT smart energy meters, and opened a new era of intelligent meter reading for Internet of Things applications.

Acknowledgements
This research was financially supported by China Southern Power Grid Corporation Science and Technology Project (Grant No. 080006KK52160001).

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