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Research on Internet of Things Electricity Meters based on NB-IoT Technology

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ABSTRACT

With the development of smart power grid and the rise of NB-IoT technology, this paper designs an Internet of Things electricity meter with NB-IoT communication technology, which mainly includes control unit, power metering unit, load control unit and NB-IoT communication unit.STM32F103C8T6 is used as the controller to realize the control and data storage of electricity meters. Voltage sampling circuit, zero line current detection circuit and fire line current detection circuit are used to realize electric energy measurement and electric larceny detection. The uplink adaptation algorithm and NB-IoT wireless communication module data are adopted to realize stable data transmission. Experiments have verified the accuracy of energy metering and the stability of data reporting of the proposed electricity meter of the Internet of Things. The experimental results show that the electricity meter of the Internet of Things has reliable and stable operation and high measurement accuracy, and has a good reference value in the design of electricity meters and the application of NB-IoT technology.

1. Introduction

Smart grid is a fully automated power transmission network that can monitor and control each grid node to ensure the two-way flow of information and electric energy between all nodes in the whole transmission and distribution process from the power plant to the end user [1]. As the key terminal to realize multi-information interaction in smart power grid, electric energy meter undertakes the task of collecting, measuring and displaying electric energy data. With the development of intelligent electricity meters, the communication mode of traditional electricity meters is mainly through GenRAL Packet Radio Service (GPRS) and micropower wireless ad-hoc network technology. Literature [2-4] discusses and studies the application of GPRS technology in electricity meters. Literature [5-7] introduces the application of micro-power wireless ad-hoc network technology in intelligent electricity meters. The analysis shows that the factors of high cost, complex data structure and high power consumption of GPRS are gradually abandoned by the market. The sensitivity of the micro-power wireless ad-hoc network technology is limited, the coverage is small, the communication distance is short, and it is seriously affected by obstacles. These two communication technologies are no longer suitable for the current smart electricity meters, and cannot meet the demand of smart electricity meters for smart power grids.

In order to solve the communication problems of current smart electricity meters, reduce the power consumption of data transmission and increase the distance of wireless communication, it is a top priority to study an electricity meter applying new Internet of things technology and make it more in line with the operation and management of smart grid. This paper focuses on the application of NB-IoT technology in Internet of Things electricity meters, designs a kind of Internet of Things electricity meters combining uplink adaptation algorithm and NB-IoT communication technology, and discusses the hardware circuit and software algorithm of Internet of Things electricity meters in detail. Finally, the accuracy of power metering and stability of data reporting of electricity meters in the Internet of Things are experimentally verified.

2. Numerical approach

Narrow Band-Internet of Things (NB-IoT) is an emerging technology in the field of IoT, characterized by low frequency, low power consumption and long transmission distance. Its core technology is oriented towards low-end Internet of Things terminals (low consumption current) and suitable for remote meter reading of electricity, water and gas meters [8-10].

The birth of remote meter reading technology first solved a series of problems of manual meter reading. It is more advanced than manual meter reading technology with higher efficiency and safety. Due to the gradual expansion of the market, the coverage area is

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more and more extensive, resulting in the communication base station users' small capacity, high power consumption, poor signal and other problems. Compared with traditional remote meter reading, NB-IoT remote meter reading has the following advantages.

Broad coverage, NB-IoT indoor coverage capability is strong, which improves 20dB gain compared with GPRS and is equivalent to 100 times of coverage area capability. It can not only meet the needs of wide coverage in rural areas, but also apply to areas with deep coverage such as factory areas, underground garages and underground Wells.

Have the ability to support mass connection, NB-IoT technology has the characteristics of wide coverage and access ability, a sector can be up to 50000 connections, support sensitivity low latency, low equipment cost, low power consumption and optimize the network architecture.

Low power consumption, NB-IoT power consumption is only 1/10 of 2G. NB-IoT electricity meters can increase battery life by at least 10 years.

Low cost. Traditional wireless electricity meters require Ethernet to transmit data to the collector and then network to realize the remote meter reading function. However, now NB-IoT electricity meters communicate directly with the operator base station without the need to build a relay network like traditional wireless electricity meters. And the radio frequency and antenna of the operator's base stations are basically reusable, eliminating the need for complex hardware upgrades, reducing a large investment.

NB-IoT networking consists of terminal devices, NB-IoT base stations, core networks, IoT support platforms and application servers [11].Terminal equipment through a IoT service SIM card access NB-IoT network, realizes the terminal equipment and NB-IoT base station information transmission, information through the core network is sent to the IoT support platform, the Internet of things supported platform sends the data to business operation and processing the application server, then the result feedback to the terminal equipment, Figure 1 for NB-IoT network structure.

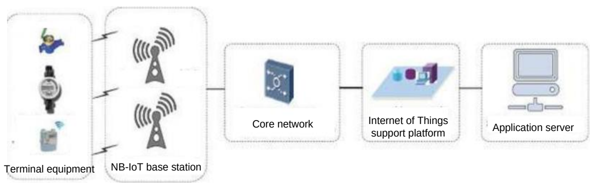

Fig.1. NB-IoT networking structure diagram.

3. NB-IoT electric meter hardware design

NB-IoT electricity meter is mainly composed of five parts: power metering circuit, NB-IoT wireless communication circuit, power supply circuit, load control circuit and control unit. The power metering circuit USES ATM90E26 as the core metering chip, the control Unit USES STM32F103C8T6 as the Microcontroller Unit (MCU) of the Internet of Things electricity meter, and AT24C4096 as the external storage. NB-IoT wireless communication module circuit adopts Quectell company BC95 as the communication chip, energy metering chip and MCU through the SPI communication, MCU through GPIO to control load switch, MCU and NB-IoT data transmission through the UART module, MCU and memory chip through the I2C read and write data, power supply circuit is mainly to provide power for the circuit, it doesn't do in detail in this paper. The NB-IoT meter hardware structure is shown in Figure 2.

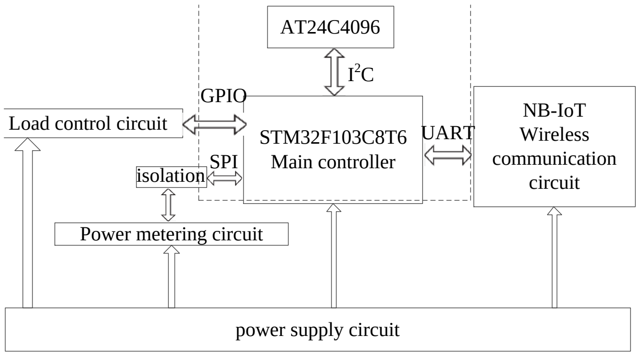

Fig.2. NB-IoT electricity meter hardware structure diagram.

3.1. Control unit design

The control unit of the Internet of Things meter described in this paper is based on STM32F103C8T6 microcontroller, which adopts the kernel with 32-bit reduced instruction set (ARM) architecture, and the operating frequency can reach 72MHz. The working voltage of the chip is between 2.0V and 3.6V, and it has three low-power modes of sleep, stop and standby, which can realize power supply voltage monitoring and temporary power limitation. It also has RTC function timer, which can realize real-time storage of power data. In terms of communication interface, the chip supports I2C, UART, SPI and other communication interfaces. AT24C4096 chip is used for data storage, and data communication between it and MCU is carried out through I2C. The schematic diagram of the control unit circuit is shown in Figure 3.

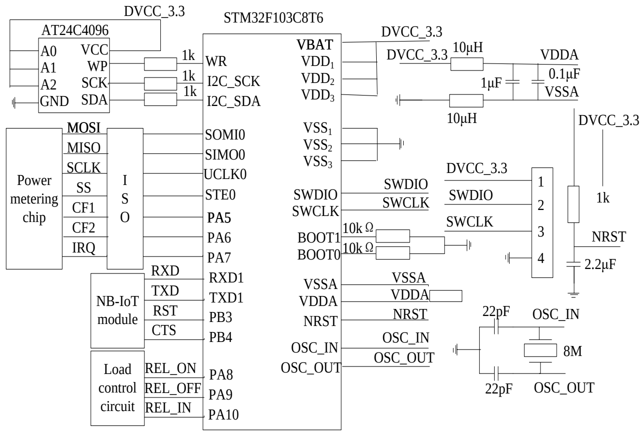

Fig.3. Schematic diagram of control unit circuit.

3.2. Power metering circuit design

The power metering circuit is mainly composed of power metering chip ATM90E26, voltage sampling circuit, fire current sampling circuit and zero current sampling circuit. Of electric energy metering chip ATM90E26 internal integration of the three Analog to Digital Converter (ADC), ADC converts the sampling circuit of the Analog Signal is converted to a Digital Signal to the modulator to the inside of the chip of Digital Signal Processing chip (DSP), the DSP to calculate the electrical energy, power, voltage, frequency and other information through the SPI interface is sent to the main control unit, Figure 4 shows the circuit diagram of ATM90E26 and its peripheral circuits.

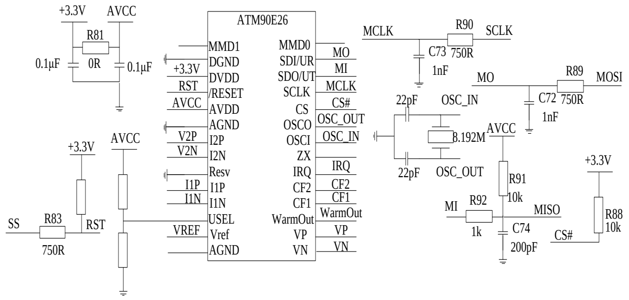

Fig.4. Power metering chip ATM90E26 and its peripheral circuit diagram.

In the voltage sampling circuit, voltage sampling is carried out by means of resistance partial voltage, and resistance and capacitance are added in the input circuit to remove the high-frequency interference in the collected signals. Finally, the partial voltage signal is input into the pins of VP and VN of the power metering chip. The schematic diagram of the voltage sampling circuit is shown in Figure 5.

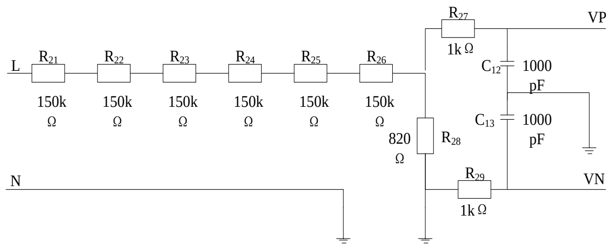

Fig.5. Voltage sampling circuit schematic.

In Figure 5, R21~R26 is used as the partial voltage resistance, and the resistance value depends on the sampling range of the power metering chip. The sampling resistor R28 is divided in series with it, and then filtered through R27,C12, R29 and C13, and the voltage signal is transmitted into the power metering chip ATM90E26. Since the allowable input voltage range of VP and VN pins is 120μVrms~600mVrms, the ratio of the partial voltage resistance to the sampling resistance should satisfy the following formula:

$$K < \frac{0.6V}{220V * 1.2} = 1:440 \tag{1}$$

According to the above formula, the partial pressure resistance using 150kΩ Surface Mounted Devices resistor, sampling resistor option 1kΩ Surface Mounted Devices resistor, eventually input voltage calculation formula for metering chip:

$$V_n = \frac{R_{28}}{R + R_{28}} \times V \tag{2}$$

where R is the sum of the voltage dividers, V is the firewire voltage, and Vn is the sampling voltage.

The current sampling circuit of the fire line adopts the manganese-copper resistance sampling method to collect the current of the fire line to measure electric energy. The current sampling circuit of the fire line is shown in Figure 6.

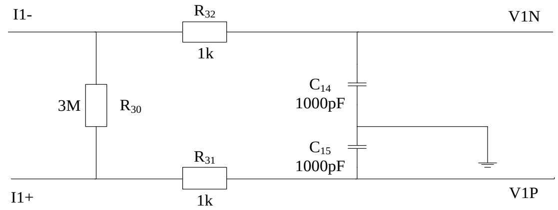

Fig.6. Schematic diagram of firewire current sampling circuit.

In figure 6: R30 manganin resistor, due to its resistance only 3mΩ, almost all current flows through the on line manganese copper, the metering chip collecting manganese copper on both ends of the voltage, can be calculated through the voltage signal wire current value.

The zero line current sampling circuit adopts the current transformer with the specification of 5(60)A/2.5mA variable ratio of 2000 to collect the zero line current. By comparing its sampling value with the sample value of the fire line current sampling circuit, it can judge whether the user is stealing electricity. The zero line current sampling circuit is shown in Figure 7.

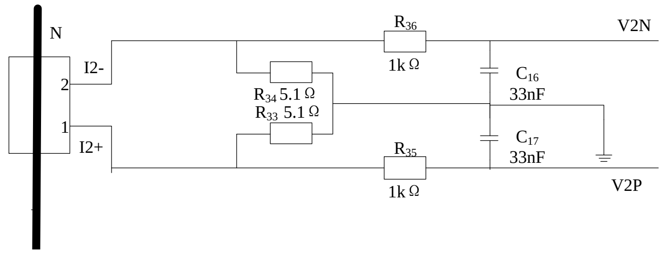

Fig.7. Zero line current sampling circuit schematic.

In Figure 7, R33 and R34 are connected in series to form the sampling resistance. The voltage of the sampling resistance will change with the change of the input current of the zero line, and then the voltage will be filtered through R35, C17, R36 and C16 and input into the sampling pins V2P and V2N of the power metering chip. The voltage formula of the sampling resistance is as follows:

$$V(I_n) = \frac{I_N \times R}{N} \tag{3}$$

where, N is the variable ratio of the terminal coil of the current transformer, R is the sampling resistance, and IN is the current value of the zero line. When the maximum effective current of the meter is 60A, calculated by the above formula, The effective value of voltage at both ends of sampling resistance 10.2Ω is 306mV, in electric energy metering chip ATM90E26 allowed within 120μVrms~600mVrms input range.

3.3. Load control circuit design

Load control circuit is composed of load switch circuit and load detection circuit. The load switch circuit can control the load of the MCU by controlling the on and off of the relay. The dual input and dual output differential amplifier is used to suppress the common mode signal so as to control the on and off of the relay. The schematic diagram of the load switch circuit is shown in Figure 8.

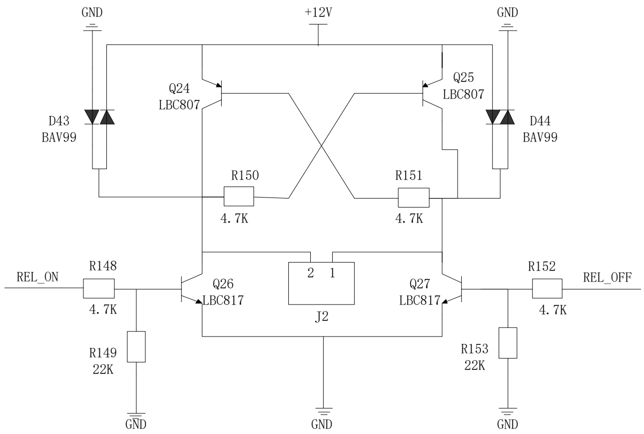

Fig.8. Load switch circuit schematic.

In Figure 8: MCU controls the conduction of triode through the output levels of REL_ON and REL_OFF, making the voltage at both ends of relay J2 change constantly so as to control the conduction and turn-off of relay.

Load detection circuit for the built-in load switch of watt-hour meter have the effect of real-time detection on load status, if the real working state of the load switch in watt-hour meter and the load switch does not agree to send instructions state lasts more than 5s, is regarded as a load switch misoperation, and to record the event on the meter, figure 9 for load detection circuit principle diagram.

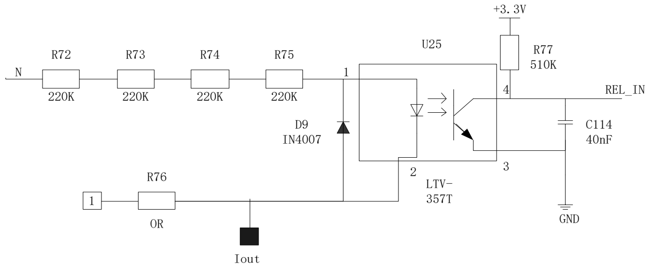

Fig.9. Load detection circuit schematic diagram.

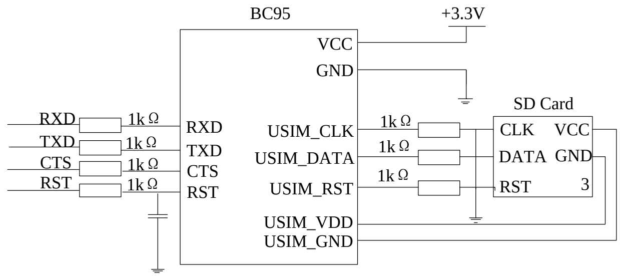

Fig.10. NB-IoT wireless communication circuit schematic

In Figure 9: The zero line voltage reaches the input end of the optocoupler after passing through the current limit of R72~R75. When the input end voltage of the optocoupler reaches the conducting voltage of the LED, the audion at the output end of the optocoupler also conducts, and the REL_IN pin of the MCU is also set to the low level to judge the real-time working state of the relay.

3.4. NB-IoT Wireless communication circuit design

The wireless communication part adopts BC95 module to realize the communication of electricity meters in the Internet of Things. BC95 chip is compact in size, which can effectively reduce the cost in large-scale deployment. It supports ultra-low power consumption and ultra-high sensitivity, and the current power consumption in PSM state is only 5uA. It is embedded with rich service protocol stack and supports COAP protocol and UDP protocol. The NB-IoT wireless communication circuit diagram is shown in Figure 10.

4. Algorithm design

Algorithm design mainly includes uplink adaptation algorithm design and main program design of Internet of Things electricity meters.

Uplink adaptive algorithm is designed, by detecting the uplink block error rate, choosing the appropriate modulation coding scheme, modulation and coding scheme (MCS) level and the data transmission of repetitions, ultimately determine the optimal level of MCS and the repetitions of data transmission, improve the reliability of NB-IoT watt-hour meter data transmission and NB-IoT uplink station data throughput. Uplink adaptation consists of inner link adaptation and outer link adaptation in the process of a data transmission, block error rate determined mainly by sending a confirmation acknowledgement / negative acknowledgement (ACK/NACK) reply to calculate, the inner link adaptation through the current block error rate adjustment repetitions, in order to meet the needs of data channel in LTE block error rate under 10% of the requirements, two threshold is set at 8% and 12%, if the current block error rate is less than 8%, reduce the repetitions of data transmission, If the current block error rate is greater than 12%, the number of data transmission repeats will be increased[12].

Outer ring link configuration, the adjustments to the equipment level of MCS, it is set to trigger events: the MCS Upgrade events (UGE) and MCS downgrade events (DGE), in order to accurately quantify UGE and DGE, introduction about time t compensation factor $\Delta C(t)$, UGE trigger condition for $\Delta C(t)$ than ceiling ΔC_{max}, DGE trigger condition for $\Delta C(t)$ below the lower limit value, as shown in figure 11.

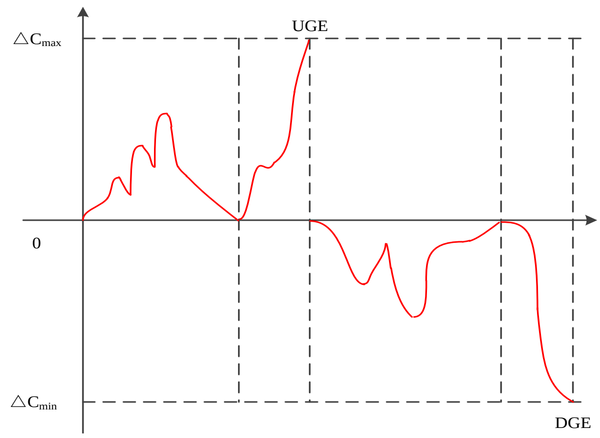

Fig.11. UGE and DGE events.

When $\Delta C(t)$ reaches ΔC_{max}, the MCS level triggered by DGE increases by 1. When $\Delta C(t)$ reaches ΔC_{max}, the MCS level triggered by DGE decreases by 1. Once an event is detected, the misblock rate will be reset.

During each uplink transmission, According to the uplink transmission hybrid automatic repeat request (HART) feedback, $\Delta C(t)$ is calculated as follows.

$$\Delta C(t)\begin{cases} min\{\Delta C(t-1)+C_{stu},\Delta C_{max}\}, \text{HARQ is ACK}; \\ max\{\Delta C(t-1)-C_{std},\Delta C_{min}\}, \text{HARQ is NACK}; \\ \Delta C(t-1), \text{HARQ is N/A}; \end{cases} \quad (4)$$

Where N/A represents the discontinuous output, that is, NB-IoT base station does not detect the signal of upstream channel, C_{stu} and C_{std} are the increment of compensation step size, the initial value of C_{stu} is 0.1, and the relationship between C_{stu} and C_{std} is:

$$C_{std} = C_{stu} \times \frac{1-B_{tar}}{B_{tar}} \quad (5)$$

where B_{tar} is the target value of block error rate.

According to that, according to ΔC constantly updated MCS level, determine the repetitions of data transmission to ensure the reliability of data transmission (BLER is less than 10%), repeat the number affected by channel state and previous MCS level, if the current channel conditions is poor and adjustment of the MCS level also cannot achieve block error rate of the standard value, need to increase the repeat number, to ensure the reliability of data transmission, A good choice if the current channel conditions of MCS generate less than 10% of the block error rate, the need to reduce the repetitions, increase the uplink NB-IoT base station data throughput.

The main program of the electricity meter of the Internet of Things is mainly to complete the initialization of the electricity meter, measure the electric energy data, store the electric energy data and send and receive the data through NB-IoT module. The main program flow chart of the electricity meter of the Internet of Things is shown in Figure 12.

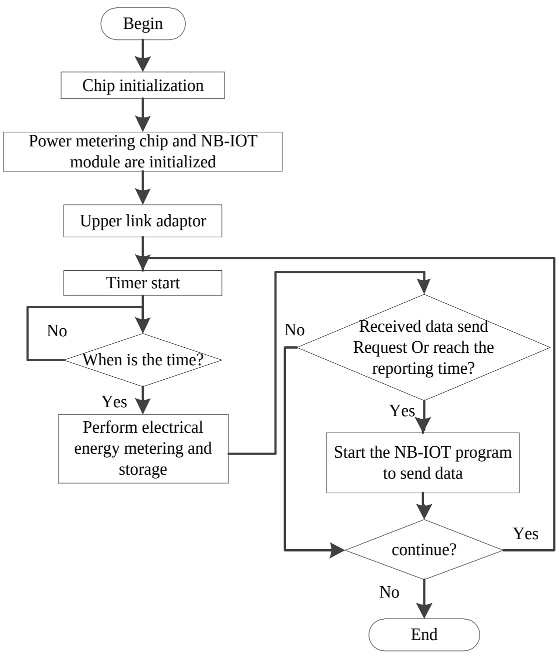

Fig.12. Main program flow chart of Internet of Things electricity meters.

On the Internet of electric meter for electricity or after reset, the variables and memory space, clock, serial port is initialized, subsequent ATM90E26 and NB-IoT a piece of outer equipment such as initialization module, and then call the upper link adaptation process adjustment meter data repetition frequency and the MCS grade, start the timer after initialization is complete, according to the set time interval power data, and for computing, storage of electricity data obtained. When a data request is received or the data escalation time is reached, the NB-IoT data escalation program is called to send the stored energy data to the NB-IoT module through a serial port, thus realizing the remote meter reading function.

5. Experimental measurement

A test platform was built to test the performance of NB-IoT electricity meters, including measurement accuracy test and communication stability test. Through a voltmeter, ammeter, and power factor meter measured the actual load voltage, current and power factor, according to the record once per minute the instantaneous value of voltage, current and power factor and calculate the instantaneous power, then every 5 minutes are normalized calculation measuring load power consumption, with six power consumption of the load value, as the consumption of the total electricity load for half an hour, table 1 the comparison table for measuring accuracy test result.

Table.1. Comparison table of measurement accuracy test results.

order number	Time/min	Meter reading quantity/kwh	test bench detects the power/kwh	error/%
1	30	5.13	5.16	0.59
2	60	10.27	10.34	0.68
3	90	14.59	14.70	0.75
4	120	18.68	18.82	0.74
5	150	22.53	22.64	0.49
6	180	26.77	26.83	0.23
7	210	30.13	30.24	0.37

In the communication stability test, the platform developed based on Ali Cloud Internet of Things platform was used as an application server to communicate with NB-IoT electricity meter. The test results showed that the average data delay of NB-IoT electricity meter was between 3 and 6 seconds when the NB-IoT electricity meter did not join the upper link adapter program. The average data delay when adding a layer link adaptor is between 3 and 4 seconds. Figure 13 shows the communication test interface.

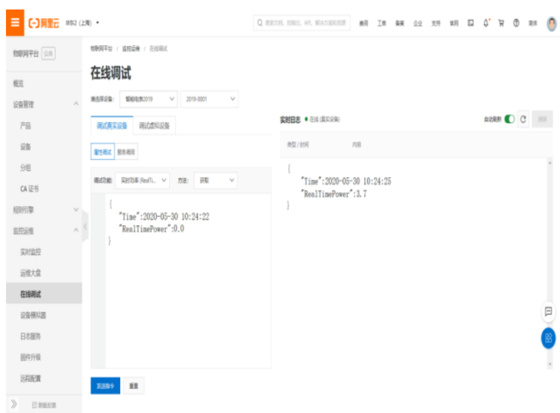

Fig.13. Communication test interface.

6. Conclusion

This paper studies a kind of electricity meter of the Internet of things based on NB-IoT technology, and discusses in detail the software and hardware design scheme of the electricity meter of the Internet of things. The meter uses the power metering chip ATM90E26 to measure the power, and the built-in live line current detection circuit and zero line current detection circuit to judge the power stealing behavior of users; the new NB-IoT technology and the uplink adaptation algorithm are used to adjust the MCS level and the number of repetition of data transmission, so as to enhance the stability of data transmission and the throughput of the base station. The meter designed in this paper has the advantages of low power consumption, long wireless communication distance, anti stealing, stable data transmission and so on. The actual test results show that the NB-IoT technology involved in this paper is accurate in electric energy measurement and stable in communication, which can provide reference for the design of electric energy meter and the application of NB-IoT technology.

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