Discussion on design scheme of clock circuit in twin-core electricity meter

Dengping Tang, Li Ding *, Fan Li, Wei Wei
State Grid Hubei Electric Power company measurement center, Hubei Wuhan, China.

*Corresponding author e-mail: 35369548@qq.com

Abstract. Electricity meter based on the IR46 standard can integrate accurate measurement and online upgrade of its management function. It is the development direction of smart electricity meter in the next generation. In this paper, a topology of twin-core electricity meter is proposed, which realizes the separation of MCU of metering and MCU of management. For the problem of voltage loss of clock battery of the smart electricity meter, the clock circuit of twin-core electricity meter is designed. The scheme of clock battery with lithium battery and supercapacitor is proposed. It can effectively reduce the occurrence probability of voltage loss of clock battery in field operation. It provides theoretical guidance for the clock circuit’s design of smart electricity meter in the new generation.

1. Introduction
At present, electricity meters in China are adopting integrated design, and they are difficult to realize online upgrade. This construction is necessary to guarantee the accuracy of measurement and stability. But once the hardware and software appeared, billing way changed or fault function happened, it is only to change the whole electricity meter. Obviously, it is unable to meet the demand of flexible market future. In the future, the next generation of electricity meters will be twin-core electricity meter structure based on the IR46 standard. It will realize the separation of the measuring function and the management function, and the online upgrade of the other functions except the measuring function is possible with the premise of ensuring the measurement accuracy and stability [1]. Therefore, the twin-core electricity meter should be designed on the basis of the last generation of electricity meter, and satisfies the future demand of smart grid development [2]-[4].

The hardware and software design of intelligent electricity meters is improved according to the operating experience, and the functions are increasingly perfect. However, there are still software vulnerabilities and hardware problems, such as clock battery problems, and function extensions, etc [5][6]. Especially the intelligent electricity meter cannot work normally without external power supply when the clock battery could not operate. Eventually it will lead to clock data chaos and RAM data loss of the intelligent electricity meter, and it directly affect the vital interests of the users [7]. In 2015, National Grid proposed ten key measuring work, and the fourth work is clearly carrying out the clock battery problem of the electricity meter. The statistics indicated that the 150,000 electricity meters of the installed 460 million meters have the voltage loss problem of clock batteries. In the metrological work conference of 2015, the provincial grid companies respectively reported the battery field failures, and introduced the detecting technology of clock battery. Some province grid company has found that
there are 147,332 electricity meters have the clock battery problems, in which accounted for more than 1% of the operating meters the manufacturer number are 12, more than 5% of the operating meters the manufacturer number is 1. From 2010 to 2013, the percentage of voltage loss of installed intelligent electricity meters were 1.94%, 1.64%, 1.61% and 1.94%, respectively. In 2015 and 2016, among the unqualified samples in Hubei province intelligent meters, the failures caused by voltage loss for 31% and 48%, respectively [8][9].

Therefore, in the structure design process of twin-core intelligent electricity meters, the operating experience of previous generation intelligent electricity meters should be fully combined. It is necessary to improve the clock battery circuit topology, and optimize of its parameters. It will provide the reliable work basis for twin-core of intelligent electricity meter.

2. Twin-core Structure of Intelligent Meters

According to the IR46 standard, the measuring devices and other implementation components are separated based on their functions. The hardware and software of the measuring devices are not affected by the other function parts. It can assure the accuracy of the measuring devices. The structure of twin-core intelligent meter is shown as Fig. 1. It takes the double MCU construction. The measuring MCU realizes the measurement function, which is similar to the operating mode of the traditional intelligent meter. It has the electricity metering, time source, pulse instructions, total voltage loss, abnormal event detection, and other functions. The other functions, including electricity information collection, billing, cost control, external communication, event recording, data freeze and load control, etc. are realized by the management MCU. The data exchange between the measuring section and management section is through the data bus. The measuring section cannot be modified. The raw data for the management MC, such as pricing, communication and control functions, are obtained from the measuring MCU. The online upgrade function of management part can be controlled through the remote communication, and the process of upgrading or normal operation will not affect the measurement MCU [3] [4].

3. Clock circuit principle and fault analysis of intelligent meter

When the external power source is unavailable, or the intelligent meter is stored in the warehouse, the clock circuit of the meter is powered by the clock battery. It maintains the normal operation of the storage battery and the clock. Normally the back-up power source of the intelligent meter uses a lithium battery. Li/SOC12 battery has the high specific energy in the chemical battery, and has high working voltage, wide working temperature range and long storage life. Intelligent meters in the national grid
adopts rate measurement, and has the power to settle, timing freeze, electricity load records, LED display, and other functions. All the functions are realized on the basis of accurate timing, and accurate timing is secured by reliable clock circuit. The typical clock circuit of intelligent meter is shown in Fig. 2. The power supply is through step-down, rectifier, filter part, and the output voltage is 5.7 V after the three-terminal voltage regulator 7805 and diode D10. The voltage is divided into two roads (VDD and ZVCC node) through the diodes D11 and D12 after decompression. The two sources are provided to the data circuit, and carrier communication module, respectively. When the external power source is operated normally, there is VDD=5 V, and it is higher than the voltage of the clock battery BT1 (3.6 V). Then the diode D9 is turned off, and the clock circuit is powered by the external power source. The clock battery will not provide the power to the clock circuit. When VDD is lower than 3 V, the diode D9 is turned on, and the clock circuit is powered by the clock battery. BATC is the voltage test terminal of clock battery BT1. The working voltage of clock circuit in intelligent meter is 3 V. If chosen the battery with the rated voltage of 3.0 V, the system cannot operated normally with considering the reverse diode voltage [6].

![Clock circuit of the intelligent meter](image)

**Fig. 2** Clock circuit of the intelligent meter

Typical faults of clock circuits are analyzed, and the typical fault tree is concluded and shown in Fig. 3. It shows the clock battery failure is mainly caused by battery quality or electricity meter anomaly, etc. If the electricity meter is normal, so abnormal cells is caused by unqualified battery. Specifically, battery abnormalities include internal defects, bad matching of battery and meter, and insufficient battery capacity.

![Typical fault tree of clock battery](image)

**Fig. 3** Typical fault tree of clock battery
Although the lithium battery is widely used in back-up clock source of intelligent meter, the battery has the service life of ten years, but lithium battery has inherent passivation property. Due to different battery brand, raw materials, different environment, it leads to different life condition.

In the long time storage or small current discharge condition, lithium battery can produce passivation. Especially under high temperature and high humidity environment, passivation phenomenon is more prominent, and it is easy to cause wake of the MCU. The battery is difficult to provide required large working current quickly, and the terminal voltage is falling rapidly. It will cause abnormal MCU and real-time clock work, and the battery is consumed substantially. This greatly reduces the reliability and service life intelligent meter. In addition, the battery voltage loss, the malfunction, and security problems are always occurred.

4. Clock circuit design of twin-core intelligent meter

The twin-core intelligent meter is to ensure the reliable work of the measuring section, so the power part needs implement physical isolation. It avoids interference of the measuring section from the management section. Similar to the previous generation of intelligent meter, the power of the twin-core intelligent meter is provided by the power supply of the grid, and it realizes the separation of the measuring section and management section.

As shown in Fig. 4, the power supply is divided into 3 roads, which are provided for different sections. There are physical isolations between the three voltage regulator modules. The sources of measuring section and management section are separated, and there is not interference between them. In order to ensure the accuracy of the clock without external power source, the clock battery and super capacitor will provide power for the RTC. There is a diode between the back-up clock battery and the circuit. It prevents reverse charge to the battery due to the voltage increase of the external source. The Advantage of the scheme is not only solving the problems of battery voltage loss, but also ensuring that the measuring section will not affect the measurement section. The reliable operating of the measuring section is ensured.

The advantages and disadvantages of the current clock back-up power solutions are shown in Tab. 1. The back-up power of single-phase intelligent adopts a supercapacitor + lithium battery solution. When the external power failure, the working current of the microcomputer is provided by the supercapacitors firstly. Only when the voltage of supercapacitor is less than that of the battery, the battery provide power to the clock circuit. It can avoid the battery passivation on the microcomputer effectively. And it is also saving the clock battery capacity effectively. Even if there was no other battery
or the battery has failed, the power provided by the super capacitor can maintain intelligent meter working reliably more than 5 days. But in real condition, with the constant reliability improvement of power supply, the probability of continuous power cut-off for 3 days is very low. Therefore, the back-up power solution of supercapacitor + lithium battery can greatly improve the actual life of intelligent meter.

| Solution | Design | Advantage | Disadvantage |
|----------|--------|-----------|--------------|
| 1        | Built-in 14250 lithium-ion battery + clock chip | A、 Simple circuit  
B、 Mature solution | A、 Passivation  
B、 Low reliability  
C、 High cost |
| 2        | Built-in 14250 lithium-ion battery + supercapacitor + clock chip | A、 Low cost, and easy to replace the battery  
B、 Normal work for several days without battery  
C、 Long lifetime | A、 Passivation  
B、 Complicate construction  
C、 Poor sealed performance |

For the twin-core intelligent meter, the back-up clock source uses the supercapacitor and lithium battery, and the construction is shown in Fig. 5.

When the twin-core intelligent meter is stored, this scheme can assure that the clock circuit is powered by the battery. As the meter is installed into the power grid, the twin-core intelligent meter could be powered by the supercapacitor and lithium battery together without the external power supply. Even if lithium battery was failure, the supercapacitor can be used as the emergency power supply to maintain a certain time, and it lives some time for the battery to overtake the voltage loss caused by the passivation. Some problems, including the lifetime of battery and short maintaining time of supercapacitor, are solved effectively. Especially for the passivation of the battery, there is a buffer time to overtake, and the clock accuracy is assured without the external power supply.

As shown in Fig. 6, to meet the long work time of the clock circuit without the external power supply, the designed back-up clock source is as follows:

1. When the twin-core intelligent meter is powered by the external circuit, there are the output power VCC_MCU and VRTC. The supercapacitor and lithium battery will not output the power.
2. The external power supply will charge the supercapacitor, and it ensures that the supercapacitor does not have the reverse leakage circuit after the charging.
3. When the external power supply is unavailable, the supercapacitor will power the RTC and MCU module.
As shown in Fig. 6, the clock circuit of twin-core intelligent meter based on supercapacitor and button cell battery is designed and presented. The use of button cell battery can assure the easy replacement of the failure battery. VCC1 is the output of the power supply, and the value of the VCC1 is higher than that of the supercapacitor and the battery. The different power road is determined by the diodes of D1 and D2. When the external power supply is available, VCC1 is the power supply for the meter, and there is an output of VCC_MCU through the diode of D2. The value of VCC_MCU is higher than that of the right node after the diode D1. Then D1 is turned off. As the same operation, the bottom diode of D2 is also turned off. The meter is powered by VCC1.

Because of the diode of D1, the supercapacitor is charged by the current-limit resistor R1 and diode D1. When the external power supply is cut-off, D1 is turned off reversely.

When the external power supply is unavailable, the supercapacitor will power the clock circuit if the voltage of the supercapacitor is higher than that of the battery. There is the VCC_MCU powered by the supercapacitor. If the voltage of the supercapacitor is lower than that of the battery, there is the VCC_MCU power by the battery. The power of the supercapacitor and the battery is switched automatically through D1 and D2, according to their output voltage.

It also can assure that the supercapacitor can power the clock circuit for a certain time when the battery was failure. According to the optimal design of the RTC and the A/D sampling time, the current of the circuit is controlled below 3 μA.

After the external power supply cut-off, the supercapacitor can maintain the clock circuit for 7 days normally. If the voltage of the RTC is higher than 1 V, the clock can work normally. Considering the voltage drop of the diode, the lowest voltage of the designed super capacitor is 1.4V with the capacitance of 1.5 F. If the supercapacitor is charged enough, the output voltage of the supercapacitor can reach 4.8 V. Considering the working current of the clock circuit is 8 μA, then the supercapacitor to support the RTC operating time is

\[
T = \frac{1.5F \times (4.8-1.4) \text{V}}{8 \mu \text{A} \times 24 \text{H} \times 3600 \text{s}} = 7.4 \text{days}
\]

The battery could maintain the clock circuit worked normally for 3 year. The capacity of the battery is 220 mAH, then the operating time is

\[
T = \frac{220 \text{mAH}}{8 \mu \text{A} \times 24 \text{H} \times 365 \text{days}} = 3.1 \text{years}
\]

Due to the stability of the supercapacitor and the button cell battery, the problem caused by columnar battery could be solved.

The back-up clock circuit is tested in the single-core intelligent meters. Until July 2018, more than 11,000 intelligent meters are running normally for more than 36 months. The environment includes the
high temperature, and high humid, etc. There is not a failure of the meter caused by the clock power source. Especially for the student compartment, the meters worked normally, and withstood the test of long summer and winter vacations without external power supply. It proved that the back-up clock power source is feasible and effective. The topology will be applied in the twin-core intelligent meters.

5. Conclusion
This paper presented the twin-core intelligent meter construction based on the IR46 standard. The clock power supply problems of the previous generation of intelligent meters are presented and analyzed. The twin-core intelligent meter is operated with the physical isolation of the measuring section and management section. Based on the back-up power source of supercapacitor and button cell battery, the clock circuit can work normally for more than 7 days even if the battery was failure. There is a certain time for the battery to overtake the passivation problem. The reliability of the twin-core intelligent meter is improved, and the back-up of clock power supply could be a reference for the design of new generation of twin-core intelligent meter.

Acknowledgments
This work was financially supported by research project’’ Research on design and testing technology of dual core intelligent electric energy meter based on IR46 concept’’.

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