Design of a Kind of Low-Cost and High-Precision Power Measuring Device

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Abstract. A kind of low-cost and high-precision power measuring device is designed, which is realized by hardware circuit and embedded software. The signal acquisition circuit, switching value input and output circuit, communication circuit of the device are analyzed. The power calculation program, storage program, timer interrupt program and communication program are described. The device has been applied in the field, and the application shows that the device meets the requirements of industrial level and has the merits of low cost, high precision and high stability.

1. Introduction
With the deepening of national power saving and emission reduction, power consumption has been paid more and more attention. By monitoring the power consumption, the power consumption management can be improved step by step and the power consumption optimization scheme can be improved continuously. As an acquisition terminal of smart power grid, high-precision power measuring device is widely used, but it also develops towards high precision, multi-function, networked, high stability, long life and other intelligent directions. [1-2]
In this paper, a kind of low-cost power measuring device is designed on the basis of meeting the requirement of high precision to monitor the power parameter to adapt to the development of intelligence.

2. Hardware Circuit Design
The composition of the power measuring device is shown in figure 1. The device mainly includes MCU control module, power module, conversion module, measuring module, storage module, display module, clock module, communication module and switch signal module.

Figure 1. Composition of power measuring device
The device is powered with a switching power, and uses STM32F103FRCT6 as the main control chip. The current and voltage of three phases are converted and sent to the measuring module, whose core is ATT7022E. The power parameters are calculated in ATT7022E automatically and read by MCU through SPI. The parameters are displayed on LCD and transmitted to RTU through the communication module. The storage module is connected to MCU through I2C bus to storage the setting parameter and power value reliably to prevent data loss during power failure. The input switching value is sent to the interrupt IO of stm32 through the opt coupler isolation circuit, and the output switching value from the standard IO of stm32 is used to control relays through the transistor drive circuit. The following will explain the main components[3].

2.1 Conversion Module
The current of the circuit under test is not more than 100A, and the input range of the ATT7022E analog to digital converter is within ±700mA. So the measured current must be converted to a low current to meet the need of ATT7022E. The ratio of the primary side to the secondary side of the chosen current transformer is 1000:1. The input current of 100A is converted to 100mA, and the voltage signal of 220mV rms is got through 2.2Ω sample resistor and sent to the current AD port of ATT7022E. [4-5]

The voltage to be measured is 220V. Considering the characteristic of ATT7022E, the voltage conversion circuit adopts the typical circuit composed of sample resistors, which can reduce the cost of the voltage transformer and the angular difference to make the sample result more precise. Through the voltage sample circuit, the input 220V voltage is converted to 220mV and sent to the voltage port of ATT7022E. [6-7] The conversion circuit is shown in figure 2.

![Conversion Module circuit](image)

**Figure 2. Conversion Module circuit**

The internal AD sample mode of ATT7022E is differential sampling, and the standard RC filtering circuit should be equipped to ensure the sampling wave precision. The filtering circuit is shown in figure 2.

2.2 Switch Signal Module
The switch signal input circuit adopts the optical coupler isolation to prevent interference to the control circuit. The input side is supplied with DC 15V and RC filtering circuit to reduce the signal peak at the moment of switch changing to prevent the misjudgment of the system. EL357N is chosen in this device, whose isolation voltage is up to 3750V. The output of the optical coupler is connected to the bias voltage of 3.3V and sent to MCU directly. The switch signal input circuit is shown in figure 3. The transistor is used to drive the relay in the switch output circuit to reduce the circuit cost.
2.3 Communication Module
In the communication module, the UART signal is transmitted through the optical coupler to realize the digital electrical isolation. Considering the actual use environment, the optical coupler of NEC2501 is chosen, and only two optical couples are used to replace the three-optical coupler design method, which can not only reduce the cost but also save the communication IO number. After the opto-isolator, the UART signal is sent to chip SN65HVD3082 to be converted to the RS485 bus. In this design, the communication port baud rate is up to 9600bit/s and the isolation voltage is up to 2500V, which can meet the need of the filed use.

3. Software Design
The standard operating system architecture is used in this program. The modular design method is adopted in the program application layer, which makes every application layer program independent from each other with excellent readability and portability. The application layer function module of the measuring device includes sample calculation module, display module, storage module, timer interrupt module and communication module. The main module is described below in detail.

3.1 Sample Calculation Module
The sample chip uses root-mean-square algorithm, which can measure the sine wave power parameter and the parameter of the distortion waveform. The chip can sample over 64 points each period to reach high accuracy and reliability. The calculation formula after discretization of the algorithm is shown below.

Current effective value

\[ I_{rms} = \frac{1}{N} \sum_{k=1}^{N} i_k^2 \]

Active power and reactive power

\[ P = \frac{1}{N} \sum_{k=1}^{N} u_k i_k \]
\[ Q = \frac{1}{N} \sum_{k=1}^{N} u_k i_k \left( \frac{T}{4} - k \right) \]

Active energy

\[ P = \sum_{n=0}^{N-1} P_n \Delta t \]

N is the sampling number; \( u(k) \), \( i(k) \) stand for the voltage instantaneous value and the current instantaneous value of the KTH sample respectively; \( I \) current effective value, \( P \) active power effective value, \( Q \) reactive power effective value and \( W \) active energy.

The sample chip used in the device has the characteristics of fast response speed and high
calculation accuracy, and it can refresh all the power parameters within 100ms. In the program, the time interrupt of 500ms is set to read all the parameter in the chip, and the high frequency data refresh can satisfy the need of the device display.

3.2 Storage Module
AT24C16 is used in this device with the storage capacity of 2kB. Though the chip is of poor performance compared with ferroelectric memory, the post is only 20% of the ferroelectric memory. Aiming at the poor performance of the chip, software optimization design of adding the redundancy check is used to store data reliably.

3.3 Communication Module
The communication module includes receiving program and transmitting program. The receiving program receives data through RS-485 port, make a check and store the data in the receiving buffer directly. The communication processing program of the main program is responsible for the data extraction, CRC check and response according to the standard communication protocol. After response, the result data is sent to the transmitting buffer, and wait to be transmitted to other device.

4 Test
The device is tested in the laboratory. Firstly, the accuracy of the effective value measurement of current, voltage, frequency is tested, and the test result is shown below as table1.

| Name          | Measured value | standard generator | Error/% |
|---------------|----------------|--------------------|---------|
| Phase Voltage | 110            | 110.003            | -0.010  |
| (V)           | 220            | 219.996            | 0.020   |
| Current       | 3              | 3.0004             | -0.01   |
| (A)           | 5.001          | 4.9998             | 0.01    |
| Phase         | 50.00          | 49.997             | 0.006   |
| (Hz)          | -45.00         | 45.003             | -0.004  |

The test result shows that the basic measurement accuracy of the device is up to 0.2 level error grade.

Secondly, the accuracy of the active energy measurement is tested under different situations. The test result is shown as table2.

| Load current/A | cosφ 1.0 | cosφ 0.5L | cosφ 0.8C |
|---------------|---------|---------|----------|
| 5             | +0.0534 | -0.0657 | +0.0536  |
| 2             | +0.0362 | +0.0674 | +0.0225  |
| 0.2           | -0.0531 | -0.1276 | -0.0557  |
| 0.1           | -0.1043 | -0.2703 | -0.1548  |
| 0.04          | -0.2462 | -0.2321 | -0.2469  |

The test result shows that the active energy measurement accuracy of the device is up to 0.5 level error grade.

5. Conclusion
The power measuring device takes STM32 as the core and reaches 0.5 level measurement accuracy with low cost after the deep reasonable hardware and software design. The remote communication of
the device is realized through the Modbus-RTU protocol to make the device intelligent. The device has been widely used in the field and well received by users.

6. Reference

[1] Liu Cencen, Wang Wei, Xia Tian. Verification of Uncertain of Verification and Measurement of the Verification Device of Electrical Meter [J]. Electrical Measurement & Instrumentation, 2018, 55(15):55-58

[2] Zhang Jianwen, Yang Yan, Shen Lei. Design of the Power Measurement Device based on MSP430 [J], Journal of Qingdao University(E&T), 2013, 28(9):15-18

[3] Fan Dayong. Design of Low-cost and high-Precision Electrical Energy Measuring Device based on STM32 [J], Transducer and Microsystem Technology, 2019, 38(10):85-88

[4] Wang Gang, Hao Dan. Design of Implement of Measurement Terminal for Multi Power Parameters Based on ATT7022 [J]. Modern Manufacturing Technology and Equipment, 2015(06):76-78

[5] Sun Lihui, Wang Hai. Design of MCU-based Multi-function Monitoring System for Electrical Utilization in Dormitory [J]. Modern Electrical Technique, 2016, 39(2):135-138

[6] Han Zhongjie, Wang Lingzhi, Lu Manjun. Smart Electricity Meter based on ATT7022 [J]. Metrology & Measurement Technique, 2019, 46(10):29-30+34

[7] Zhu Haining. Design of Multi-Function Electric Power Data Acquisition System Based on ATT7022E [J]. Research and Exploration in Laboratory, 2018, 37(5):82-86+94