Research on Analytical Monitoring System for Single-Phase Electrical Appliances

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Abstract. In view of the limitations of the current domestic power monitoring system, in this paper an intelligent single-phase electrical appliances analysis and monitoring system have been designed. The system takes STM32 as the control core, and the electric energy metering circuit is used to collect signals. The learning and recognition functions of electrical appliances are designed. The whole single-phase electrical appliances analysis and monitoring system can be used to monitor the operation of one or more electrical appliances in the circuit and display specific electrical parameters. The system uses a special measurement chip RN8208G, and the current precision can reach 1 mA. It is reliable, suitable for long-term operation and not easy to make mistakes. In this paper, the design of a specific electrical monitoring system is novel and has broad prospects for development.

1. Introduction
So far, the smart meters used in China are mainly electromechanical and electronic. The Mechatronics design, which adds some electronic components to the original Mechatronics meter to realize the corresponding functions, compromises the huge use base of the mechatronics meter, and is only an electronic transformation of the old one. All-electronic circuit is highly integrated from the acquisition sensor to the controller. The design simplifies the complicated mechanical structure and improves the measurement accuracy. At the same time, there is no problem of wear and tear of the structure and parts like mechanical meters, and simplifies the production and saves the cost.

With the development of society, the shortcomings of mechanical meters have gradually emerged, such as poor accuracy of electric energy measurement, single function, weak anti-interference ability and so on. In the past, the level of standardization of electric meter system was low, and the technical scheme and function realization were quite different. Users can not know the actual energy consumption of a certain electric appliance in the circuit. Under the current energy-saving background, the functions of traditional meters are far from being satisfied.

In 2018, the development of smart meters is very rapid. At present, the total number of smart meters in China has approached 1.8 billion, but less than half of them are smart meters. It is estimated that the penetration rate of smart meters will reach 59% by 2020. This is a booming industry. Two years ago, the market share of smart meters exceeded 12 billion dollars. With the rapid development of industrial 4.0, the market of smart meters will become larger and larger under the wave of automation.
The single-phase electrical appliances analysis and monitoring system designed in this paper is also a special kind of smart meter. Intelligence lies in the tracking and monitoring of a single specific electrical appliance. Unlike ordinary smart meters, it still inherits the main functions of the original meters and can only measure all power consumption in a general way. For the special needs of users, such as the need to know the real power consumption of an electrical appliance, it can be easily realized. Compared with other smart meters, the interactivity of users has also been greatly improved. The rich system functions can be realized by simple operation of users. LCD screen shows a variety of electrical parameters, which is simple and easy to understand.

2. Analysis and Monitoring System for Single-Phase Electrical Appliances

After analysis, considering the actual needs of the system design, the STM series MCU with large memory, rich functions and high frequency is selected to complete the design of the monitoring system. In this design, STM32F103ZET6 is used as the main control chip. 32 MCU connects peripherals through AHB system bus and is divided into two bridges, APB1 and APB2, which have abundant peripherals, IO interfaces and a large number of interrupt priorities.

![Figure 1. System block diagram](image1)

2.1. Selection of Electric Energy Monitoring Sensor

According to the working mode of Hall sensor, it can be divided into magnetic balance current sensor and direct current sensor. Magnetic Balanced Current Sensor (Closed Loop): A compensation link is added on the basis of the open loop, and a secondary coil is wound around the magnetic concentrator. When the measured current passes through the wire to generate a magnetic field, the secondary coil will also generate a current in the magnetic field, and the secondary current will compensate the original side. But this closed-loop Hall sensor has complex structure and high price.

![Figure 2. Principle Diagram of Closed-loop Hall Current Sensor](image2)
Direct current transducer (open-loop): When current passes through the wire, electromagnetic field will form around the wire due to electromagnetic induction. The intensity of magnetic field is proportional to the current passing through the wire. Hall element induces magnetic field through magnetic core, transforms magnetic field signal into micro-current signal output, and amplifies it directly through operational amplifier circuit.

2.2. Design of Electric Energy Monitoring Circuit.
RN8208G is an electric energy measurement chip, which is used to measure voltage, current, electric energy, power, voltage line frequency, etc. It can support phase and gain correction in software. Support SPI/UART interface, through IS pin selection. Power supply monitoring is used to monitor the AVDD voltage in the normal working range to ensure the normal working voltage of the chip. Two ADC differential input, small error, high accuracy, active power dynamic error in one thousandth.

Above is the power monitoring circuit. AVDD is an analog power port. A power monitoring circuit for continuous monitoring of analog power supply (AVDD) is designed in RN8208G chip. The power supply voltage should be above 4V and the fluctuation should not exceed 0.1V. Otherwise, the chip will be reset and the power supply voltage must be above 4.3V.

RST_N is an effective low-level reset. V1P, V1N are current input pins, V3P, V3N are voltage input pins. The current channel pin collects current. The current sampling circuit is designed in the diagram. In practice, the current transformer is used to replace the current sampling circuit. In the same diagram, the voltage transformer is used to replace the current sampling circuit in the actual operation. Both inputs are fully differential. Considering that the maximum input voltage of the input pin can not exceed the absolute value of 1000mV in normal operation, the selected current or voltage sensors are all 1:1000, which ensures that the sampling signal range is within the allowable range.
REFV is a 2.5V reference voltage input and output pin. The external reference voltage source is directly decoupled by a parallel capacitor and connected to the pin. AGND is simulated. IS is the pin used to determine the communication mode of the chip. Serial communication mode is used when IS = 0; SPI communication mode is selected when IS = 1. PF and QF are not used for the time being. OSCI and OSCO are used to connect external crystal oscillators, and C8 and C9 capacitors act as filters. DVDD is a digital power supply and DGND is a digital power supply. When the IS pin equals zero, B0 and B1 are used to set the serial port baud rate. This design uses 4800 baud rate, so B1 is grounded and B0 is connected to high level. RX and TX pins are the receiving and sending pins of serial communication. They are connected with the sending and receiving of single chip computer serial port respectively. The communication connection between power metering chip and main control chip is realized.

2.3. Design of Voltage and Current Acquisition Circuit.

![220V electric signal acquisition circuit diagram](image)

Figure 5. 220V electric signal acquisition circuit diagram

Figure 5 shows that in order to collect electrical energy signals directly from 220 V circuit to the electric energy metering chip, according to the voltage of the electric energy metering chip and the working voltage of the current input port, the working voltage of the chip can not exceed the limit of ±1000mv. In this paper designed a sampling ratio of 1:1000 to meet the input requirements. The sampling circuits in the figure are equivalent circuits, because the voltage transformer and current transformer are used to realize the signal minimization through the turn ratio of the transformer. The use of transformers can achieve high-voltage isolation, ensure the safety of the chip circuit, do not destroy the chip because of the short circuit, overcurrent and other problems of the high-voltage circuit, but also have a high accuracy.

3. Software Design of Single-Phase Electrical Appliance Analysis and Monitoring System

3.1. Programming of Metrological Correction.
Firstly, the ADC differential input port gain multiplier is selected. Voltage signal can be amplified 4 times, current signal can be amplified 16 times. The desired multiplier can be obtained by configuring system registers. The multiplier range selection is shown in Table 1.
Table 1. ADC Channel Gain Multiplier Table

| Voltage gain multiple | Current gain multiple |
|-----------------------|-----------------------|
| 1                     | 1                     |
| 2                     | 2                     |
| 4                     | 8                     |
| \                     | 16                    |

Then set the pulse frequency register. This paper sets HFConst (16 bits). PFCNT is the value of the fast pulse counter. If \( 2 \mid PFCNT \mid \geq HFConst \), PF will output the pulse. Formulas for calculating parameters of HFConst:

\[
HFConst = \text{INT}[14.8528 \times V_u \times V_i \times 10^{11}(V_u \times V_i)]
\]

\( V_u \) is the voltage signal after the gain of the voltage input channel, \( V_i \) is the voltage signal after the gain of the current input channel, \( U_n \) is the rated voltage, \( I_b \) is the rated current, \( EC \) is the meter constant.

Start-up current setting is to configure latent and start-up threshold registers. Start-up threshold can be configurated by PStart registers. It is 16-bit unsigned number. When compared, it is compared with the absolute value of 24-bit high of PowerP for start-up judgment. The energy accumulation mode is set up with the metering control register EnergyCLR (bit 15), which is 0, and the energy register is cumulative; this bit is 1, and the energy register is zero-clearing after reading.

Power gain correction can be achieved by configuring GP registers. The corresponding formula is:

\[
P_{\text{gain}} = \frac{-\text{Err}}{1 + \text{Err}}
\]

\( \text{Err} \) is the standard meter at rated current, the error value read out in the case of PF = 1.

After entering RMS correction, the following operations are needed. First, current offset correction is carried out. The steps of correction are as follows: In the case of rated voltage, the input current channel is 0, and the value of IRMSOS register is read repeatedly at least ten times, then the average value is taken, assuming that the average value is A, the square of A is obtained, which is converted into binary number, and its binary inverse code is assigned to IRMSOS register, thus offset correction is completed. Current correction and voltage correction are correction current and voltage conversion coefficients. Current conversion coefficients are corrected at rated current input and voltage conversion coefficients are corrected at rated voltage input.

![Flow chart of correction program](image-url)
3.2. Learning Programming of Electrical Appliances.
Figure 7 is the flow chart of electrical learning program. KEY0 button is the learning mode button. Press KEY0 button to enter the learning mode. When the learning appliance is stable, the real-time electrical parameters are constantly refreshed and recorded. When KEY0 button is pressed again, the instantaneous electrical parameters such as voltage, current and power are finally recorded. The first recorded electrical device is named No. 1 electrical device. By analogy, the electrical appliances of the second study are named No. 2 electrical appliances, and the electrical appliances of the third study are named No. 3 electrical appliances. Exit learning mode is still to press KEY0 button, the difference is that the LED lights will go out and play an indicative role. The learning mode of electrical appliances is to learn one by one, and record one kind of electrical appliances every time in and out of the learning mode. At present, three storage locations are set, and no record is made after three storage locations.

![Flow Chart](image)

Figure 7. Learning Program Flow Chart

3.3. Programming of Electrical Apparatus Recognition.
Electrical identification is based on learning. First of all, electrical learning is necessary. Only when electrical learning is completed, can electrical identification be realized. The purpose of electrical identification is to identify individual electrical appliances under complex electrical conditions, so as to record and track the power consumption of individual electrical appliances. In order to ensure the accuracy of electrical identification, it is necessary to continuously read the measured electrical data and update the comparative data in real time. Then compare the real-time reading electrical data with the electrical data of the learning electrical appliances. It is easy to identify single electrical appliances by means of current comparison, voltage comparison and power comparison. But it is difficult to distinguish all electrical appliances when multiple electrical appliances are used at the same time.

The identification of multi-purpose electrical appliances needs more complex comparison, because some of the electrical parameters of the two kinds of electrical appliances are not simple additions, and some of the parameters are larger or smaller than those in theory. This requires that at the beginning of the design, some redundancy should be considered, and the identification can not be judged directly
according to the previous parameters. The redundancy design should be adjusted according to the actual measurement parameters to achieve different situations. Perfect recognition results. Finally, the screen will display the recognition results, if it is a variety of electrical appliances, it will also show the overlap of electrical appliances, if it is not recognized electrical appliances, the screen will also display unknown electrical appliances.

![Flow chart of identification program](image)

**Figure 8.** Flow chart of identification program

4. Debugging of Single-Phase Electrical Appliance Analysis and Monitoring System
The figure below is the hardware system, the main controller with display screen, electric energy measurement module and electrical outlet.

![System in kind](image)

**Figure 9.** System in kind
4.1. Functional debugging of electric energy metering circuit.
The upper computer software is connected with the electric energy metering circuit through serial port to TTL level circuit. After the system is powered on, the upper computer sends instructions, and the module receives the corresponding instructions and sends corresponding data. The upper computer sends inquiry message frame when inquiring information. The order of instruction is device address, function code, data information code and check code. Address codes represent the hardware address of slave devices; Functional codes are functional instructions, that is, what the command register does, such as function codes 03 or 04, which require the registers to return data; Data segments contain additional information that needs to be executed by registers; Check codes are a way to provide information integrity checking. The message query instructions designed in this paper adopt CRC16 calibration rules. If the host sends 0103 00 4800 0645 DE, the received data is shown in Figure 10. Through the algorithm analysis, the data meaning is obtained, and the correct electrical parameters are displayed. The actual measurement of the meter proves that the parameters are correct, and the test of the electric energy measurement module is successful.

Figure 10. Upper Computer Software Receiving Diagram

4.2. Calibration and debugging of electric energy metering circuit.
Calibration procedures, power on the start of correction, before not corrected as shown in Figure 11, the parameters are inaccurate, almost all scrambled code. After correction, as shown in Figure 12, the detailed parameters can be seen in Table 2. Its voltage returns to normal value, current and power factor correction returns to 0, and power factor circuit has its own loss, measured at 1W. From this we can know that the calibration and debugging is successful.

Figure 11. Pre correction chart
Figure 12. Corrected chart
Table 2. Electrical parameters before and after correction

| Parameter | Before Correction | After Correction |
|-----------|-------------------|------------------|
| Voltage (V) | 210 | 227 |
| Current (A) | 3.008 | 0.000 |
| Power (W) | 451 | 1 |
| cosΦ | 3.997 | 0.000 |

4.3. System Accuracy Testing.
In order to test the measurement accuracy of the system, this paper designs and assembles an electrical appliance, which is composed of a 1K resistor and an LED lamp and powered by 5V. Specific measurement parameters can be seen in Table 3. The measured current is 0.011 A. The minimum precision of the visible current can be up to 1 mA. The system accuracy is adequate.

Figure 13. Minimum Electrical Test Chart

Table 3. Minimum test electrical parameter table

| Parameter       | Value   |
|-----------------|---------|
| Voltage (V)     | 227     |
| Current (A)     | 0.011   |
| Power (W)       | 1       |
| Power factor    | 0.401   |

4.4. Debugging of system learning mode.

Figure 14. Debugging of learning mode
The following three kinds of electrical appliances are studied and tested: a hair dryer, a desk lamp and a charging treasure. The physical objects are shown in figure (a), (b), (c). First of all, study the desk lamp, (d) for learning mode lights, electrical identification is No. 1. Then learn the hairdryer, figure (e) for learning mode lights up, electrical identification number 2. Then learn Charge Treasure, (f) for learning mode lights up, electrical identification number 3. Specific parameters can be seen in Table 4. Learning mode debugging is successful, electrical appliances are successfully learned.

**Table 4. Learn Electrical Parameters Table of Electrical Appliances**

|                   | Table Lamp | Hair drier | Portable battery |
|-------------------|------------|------------|------------------|
| Voltage (V)       | 224        | 222        | 222              |
| Power (W)         | 40         | 126        | 13               |
| Power factor      | 0.997      | 0.497      | 0.575            |
| Identification Number | 1       | 2          | 3                |

4.5. System Recognition Mode Debugging.

In recognition mode, the learning mode is turned off and the learning mode indicator is turned off. In Fig. 15, the visible indicator lights are turned off, i.e. enter the cyclic recognition mode. From left to right, they are desk lamp recognition, hairdryer recognition, charging treasure recognition, desk lamp and hairdryer recognition as well as three kinds of electrical appliances recognition at the same time. Table 5 clearly shows the specific parameters on the screen from left to right. Fig. 16 is the nameplate of electrical appliances. Charging Bao input power is about 10W, measured 13W; bulb rating is 40W, measured 40W; hairdryer rating power is 1000W, measured power is 126W in one-stop mode. Through analysis, it is concluded that the electrical parameters used by electrical appliances at the same time are not simply the superposition of two electrical parameters to be identified. Design adds great difficulty. According to the debugging results, the recognition pattern design is successful.

**Table 5. Electrical Apparatus Identification Model Electrical Apparatus Parameters Table**

|                   | Table Lamp | Hair drier | Portable battery | Table lamp and hairdryer | Three kinds of appliances |
|-------------------|------------|------------|------------------|--------------------------|-------------------------|
| Voltage (V)       | 224        | 222        | 222              | 222                      | 225                     |
| Current (A)       | 0.179      | 1.139      | 0.100            | 1.278                    | 1.337                   |
| Power (W)         | 40         | 126        | 13               | 153                      | 168                     |
| Power factor      | 0.997      | 0.498      | 0.575            | 0.539                    | 0.558                   |
| Identification number | 1       | 2          | 3                | 1+2                      | 1+2+3                   |
5. Summary
The core of this paper is the study and identification of electrical appliances. First of all, the study of electrical appliances, which parameters to learn and under what conditions to learn are all issues to be considered. So the setting of this paper is to learn the parameters under the rated working state of the electrical appliances. Then in the process of identification, electrical appliances work in AC circuit, fluctuation is inevitable, but for identification, real-time comparison of each parameter, if the fluctuation range is large, this data does not match, it will not be recognized. The program design in this paper has greater redundancy and flexibility. In order to avoid the identification gap being too large, its elastic range has been tested repeatedly, which can solve this problem well.

Acknowledgments
Science and Technology Development Plan Project of Changshu No. CR201711

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