Design of multi-functional intelligent power monitoring instrument.

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Abstract: the real-time detection record of power quality can accurately and quickly analyze the factors that affect the power quality, which is of great significance to improve the national power quality. At present, the electric power monitoring instrument in the market can basically realize the measurement of electric power parameters, but the function is single and the practicability is not strong. So we designed a multi-functional intelligent power monitoring instrument, with three-phase voltage and current detection, harmonic detection, active power and reactive power calculation, electricity calculation, frequency measurement, vector graph, and other functions. The hardware and software design methods of the instrument are described. The window-interpolation FFT algorithm is used to calculate the power parameters, and the sampling frequency can be adjusted in time to reduce the influence of the barrier effect on the system. The test shows that the electric power meter is accurate, small in size, complete in function, simple in operation, and has serial communication function, which is worth popularizing.

1. Introduction

Electricity is a very important secondary energy, which involves all aspects of our modern life, such as lighting, heating, entertainment and industrial production. If there is a problem in the power system, it will have a great impact on life and production. Traditional power monitoring instruments have a single function and can only monitor basic power parameters, and it is difficult to meet the requirements of modern power parameter measurement. To solve the above problems, a smart power monitoring instrument with complete functions, compact size and simple wiring was designed. It can monitor various power parameters such as power, three-phase voltage and current in real time, and can also perform harmonic analysis. Its sampling frequency can be adjusted automatically and it has serial communication function. The following technical indexes are met: the voltage and current error are less than or equal to 0.2%, the frequency error is lower than or minus 0.02Hz, active power, power factor and other parameter errors are below or minus 0.5%, and the design cost is low.

2. Overall design scheme.

The electric power meter to choose the TI company's low power consumption MCU MSP430F249 as its control chip, The chip has a hardware floating-point arithmetic unit that solves the problem of slow and error-prone operations performed by the computer through the software simulator (floating-point arithmetic library) to perform floating-point arithmetic operations, accelerate data processing. A separate power circuit was designed to convert the 220V AC into the instrument's operating voltage to power the meter without the need for an external power supply.

The acquisition circuit uses the MSP430F249 on-chip analog-to-digital converter, which simplifies the circuit design and reduces the size of the entire detector. The TFT liquid crystal display module is
connected so that all important power parameters can be displayed in real time and the display effect is clear. A simple button module has been designed with a total of four buttons for the operator to view various power parameters on site.

For the meter's power measurement function, an EEPROM memory circuit was designed to avoid loss of power parameter power-down. In addition, the instrument has designed the RS-485 communication interface, has the communication function, and has added the unique switch input-output control module, enables the instrument to realize the examination and the control to the other equipment condition. The system structure is shown in Figure 1.

![System structure diagram](image)

**Figure 1** System structure diagram

**System working principle:** The three-phase voltage signal and the three-phase current signal that need to be monitored pass through the signal acquisition circuit, the scaled down analog signals are obtained. The analog signal is converted into a digital signal by an analog-to-digital converter inside the MSP430F249 microcontroller and processed by the FFT algorithm inside the microcontroller. The various parameters obtained after processing are displayed by the liquid crystal display module. The operator can view various data on the liquid crystal display by operating the keys on the instrument. Electrical information will be saved to the storage module in real time to prevent loss of data due to power loss. In addition, an alarm device may be connected near the power monitor, or a warning signal indicating the working status of other devices. Through the meter's digital input and output module to control other equipment or receive signals from other equipment.

3. Hardware system design.

3.1. **Power Module Design.**

The power module is used to power various devices used in the instrument. Among them, MSP430F249 one-chip computer and segment code liquid crystal screen need the power of 3.3V. Signal acquisition circuits, memory circuits, and RS-485 communication interface circuits require ±5V power to maintain normal operation, and 24V voltage is required for relay operation in the digital input/output module. In order to make the whole module size not too bulky, the power module can be designed according to a small switching power supply circuit, as shown in Figure 2.
The working principle of the power supply: 220V AC is connected to the common-mode inductance, the common-mode electromagnetic interference signal is filtered out, and the filtered AC is converted into DC by the rectifier bridge [1]. Direct current is controlled by a high-frequency pulse width modulation signal to switch the switching tube to the primary of the switching transformer [2]. In this way, a plurality of high-frequency low voltages can be induced at the secondary side of the switching transformer. These voltages can be used for load power supply after passing through the filter circuit. In addition, the output voltage needs to be fed back to the PWM signal control switch through a feedback circuit to control the PWM duty cycle so that the voltage can be output stably [3].

3.2. Main Control Module Design

The monitor's control module uses the MSP430F249 microcontroller control circuit as its core, supplemented by a liquid crystal display circuit, a key circuit, an off-chip ROM circuit, a serial communication circuit, and a switch control circuit [4]. Thus, build a complete system.

The chip used in the main control circuit of the power monitor is a MSP430F249 single-chip microcomputer, and the chip has extremely low power consumption and rich on-chip resources [5]. The control circuit includes MSP430F249 minimum system microcontroller, time circuit, digital power supply circuit and off-chip memory circuit. The time circuit is used for the calculation of electrical degrees; the off-chip storage circuit is used for the preservation of parameters such as electrical degrees to prevent loss of data when power-off. The microcontroller needs to leave 4 I/O ports for implementing the button module. The control circuit is shown in Figure 3:
TFT LCD module was selected for liquid crystal display, using ILI9320 driver, 260,000 colors, the display is very good. The module integrates FPC interface circuit, I/O expansion circuit, power supply circuit, TFT control interface circuit, SD interface circuit. When wiring, it only needs to lead out the control line directly from the IO port of the single-chip microcomputer, no need to externally expand any circuit, so that the volume of the entire instrument is further reduced. The power circuit is optional. When the external power supply is 3.3V, you can not use it. The schematic diagram of the connection mode of the liquid crystal module is shown in Figure 4. The control lines and data lines of the SD interface module, the TFT control module, and the IO expansion module are all introduced into the FPC interface circuit and are connected to the control chip via this interface to receive the incoming data and control signals from the chip. When displayed, the screen displays the phase voltage, phase current, power, power factor, harmonics, etc. in turn. The operator can pause the page, view or record data by pressing a key.

In order to enable operators to operate the meter remotely, we designed a serial communication module. The module adopts RS-485 bus mode, with fewer signal lines and efficient and stable data transmission [6]. The differential data receiver SN75LBC184 chip produced by TI company is used as the communication interface chip. This chip integrates high-energy transient grass rope protection device [7], which has a very good effect in preventing lightning impact and electrostatic discharge impact, enabling data Transmission is reliable. When designing, use the method of photoelectric isolation, isolate the one-chip computer and RS-485 communication circuit, prevent mutual interference.
Communication circuit shown in Figure 5, the figure A and B point for the USB interface cable, the computer sends operating signals through the application program, the signal is transmitted through the serial port to the MSP430F249 microcontroller, the microcontroller receives the instruction and then perform the corresponding operation.

The switch control module is used for remote monitoring and remote control. The meter can detect the state of external related equipment through the state of the switch, such as detecting the high level of the external temperature sensor when the temperature changes. It is also possible to issue a switch control signal to control the peripheral devices, such as an external alarm to provide an alarm function. Switch input control as shown in Figure 6. Provides two input digital inputs DI1 and DI2. J1-5 is the power supply connection. The two signals are introduced into the I/O ports J1-23 and J1-24 of the MSP430F249 microcontroller through an opto-isolator. When it is detected that the input value of the switch is low, the photocoupler is turned on, and the corresponding I/O port J1-23 or J1-24 of the one-chip microcomputer receives the low-level signal [8], and performs related processing operations. Switch output control as shown in Figure 7. In output control, relay output is used. When the I/O ports J1-21 and J1-22 of the microcontroller send a high level, the transistors V5 and V4 conduct, which triggers the optocoupler to output a low level. At this time, the relay closes and sends a control signal. The external device receives the signal and performs related operations.

3.3. Collection Module Design

The signals that the instrument needs to collect are three-phase AC voltage signals and three-phase AC current signals. For voltage signals, the design uses high-precision resistors to divide them directly. After the voltage is divided by the resistance, a small AC voltage is obtained. After the signal is amplified and stabilized by the op amp, it can be sent to the on-chip A/D sampling [9]. The circuit diagram is shown in Figure 8. Take phase A as an example. Assuming that the voltage of phase A is \( U_{d} \), the voltage \( U_{a} \) is obtained after the voltage divider of resistors \( R_{1} \) and \( R_{7} \). The formula is:

\[
U_{a} = \frac{R_{7}}{R_{1} + R_{7}} U_{d} \tag{1}
\]

In order to make the sampling voltage not too large, \( U_{a} \) is usually conditioned to a signal with an amplitude of about 1V. It is also possible to change the amplification factor by changing the feedback resistance of the op amp so as to adjust the sampling voltage.
The acquisition of the three-phase current signal is based on the current transformer SCT254FK, which is a precision current transformer with a rated input current of 5A and a rated output current of 2.5mA. The circuit diagram is shown in Figure 9 (C phase). The three-phase current generates a small AC current through the current transformer, which is sent to the operational amplifier. By adjusting the size of the feedback resistor, an AC small voltage signal can be generated at the output of the operational amplifier. Two anti-parallel diodes can protect the operational amplifier. The parallel capacitor on the feedback resistor is used for anti-vibration and filtering. The performance of the op amp directly affects the accuracy and stability of the inductive signal. Therefore, OP07 series precision op amps are used here.

Because the collected signal is a three-phase alternating current signal, both positive and negative amplitudes are available, and MSP430F249 microcontroller on-chip analog-to-digital converter can only collect positive voltage. Therefore, it is necessary to add a bias voltage to the processed three-phase small voltage signal and current signal to raise the amplitude.

4. System software design and data processing
The system software is written in C language, which makes the program structure concise, readable, and efficient. Because of its powerful system and complex program design, it is written in modular form. Each function is written separately, compiled together, and combined into a complete system. Block diagram of the control program shown in Figure 10. First, the MSP430F249 microcontroller is used to initialize various hardware, interfaces, and interrupts involved, such as the on-chip A/D, storage control I/O ports, LCD drive module I/O ports, and key interrupt interfaces. Data acquisition is performed after the initialization is completed, data processing is completed after the entire cycle data is collected, and the processed data is displayed and saved. After that, the sampling frequency is analyzed. If the sampling frequency and the signal frequency are not synchronized, adjust the frequency to acquire the signal again. In this way, the signal is continuously collected and displayed. In general, the interrupt process is interspersed throughout the system, but it is placed last in the block diagram, reflecting the state of the system's first run.
4.1. Frequency Self-regulating Data Acquisition Method

Because the frequency of the signal is affected by the imbalance of the power supply load, it is not a fixed value. If you sample it at a fixed frequency, it is bound to have a serious fence effect. If a phase-locked loop is added to the hardware circuit, although this problem can be solved, it also makes the acquisition system response time longer. We can obtain the real frequency of the signal, through add window interpolation FFT algorithm, adjust the sampling frequency, so that the two remain synchronized, thereby reducing the impact of the fence effect.

The data is acquired through on-chip A/D acquisition of the MSP430F249 microcontroller. There are eight acquisition channels. The signals to be collected are three-phase voltage and three-phase current. Only six acquisition channels are actually used. Since the microcontroller has only one conversion core, it is not possible to collect and convert six signals simultaneously. Therefore, during program design, six signals need to be converted one by one.

4.2. Data Processing Methods

Data processing is the core of this power monitor. Although the data acquired by the A/D chip in a single-chip microcomputer is obtained after hardware filtering, it is inevitably brought into interference. It can be filtered again by software. Here, a common median filtering method is applied. Collect multiple times when collecting data, then sort them and use the median as the final result. After the sampled data is obtained, the power parameters such as voltage, current, frequency, and phase can be quickly and accurately calculated by the windowed interpolation FFT algorithm. The windowing function can reduce the spectral leakage error, and the interpolation algorithm can reduce the barrier effect [10]. In order to
reduce the computational complexity and simplify the program design, the window function can select the typical cosine binomial window, Hanning window.

4.3. Communication Client Software Design
In view of the uncertainty of the installation location of the instrument, in addition to the display of the dial, client software that can be used on a computer is designed to display all data in the power meter and also to detect and issue control signals. Gives the operator a great deal of convenience. The client software and the instrument adopt the form of the upper computer and the lower computer, and the signal is sent by the upper computer (client) as an interrupt signal. In the MSP430F249 microcontroller (lower unit) once detected interrupt, according to different client instructions jump to the corresponding subroutine to perform, and upload the corresponding data to the host computer. The client interface is shown in Figure 11:

![Figure 11 Interface of Power Meter Communication Client Software](image)

5. Test result and analysis
When the monitor is tested, a high-precision three-phase standard source is used to output standard voltage, current, frequency, and other power parameters. The measured value of the monitor is compared with the standard output to obtain a test result. For the convenience of testing, a total of three points were selected for the voltage test, which were 0.25, 0.5, and 1 times the nominal voltage (220.0 V). The current test is similar to the voltage test. We selected 0.2 times, 0.5 times and 1 times the nominal current value (5.0A) as the test point. Test results are shown in Table 1 and Table 2. The active power test selects three test points of 3300W, 825W, 165W (three-phase power). The power factor selects three test points: 1.000, 0.500C, and 0.500L. The frequency selects four test points of 45.0Hz, 50.0Hz, and 55.0Hz. Test results are shown in Table 3.

| Standard value(V) | Measured value(V) |
|-------------------|-------------------|
| Voltage effective value | UA | UB | UC |
| 55.00          | 55.01          | 55.00 | 55.03 |
| 110.0          | 110.1          | 109.9 | 109.8 |
| 220.0          | 220.2          | 220.0 | 220.0 |

| Standard value(A) | Measured value (A) |
|-------------------|-------------------|
| Current effective value | IA | IB | IC |
| 1.000          | 0.999          | 1.002 | 1.001 |
| 2.500          | 2.498          | 2.500 | 2.501 |
| 5.000          | 5.000          | 5.001 | 5.004 |
Table 3 Active power, power factor and frequency test results.

| Active power(W) | Power factor | Frequency(Hz) |
|-----------------|--------------|---------------|
| Standard value  | Measured value | Standard value | Measured value | Standard value | Measured value |
| 3300            | 3302         | 1.000         | 0.999         | 45.00         | 45.02         |
| 825             | 824          | 0.500C        | 0.501         | 50.00         | 50.00         |
| 165             | 165          | 0.500L        | 0.501         | 55.00         | 54.99         |

The test results show that the three-phase voltage accuracy is higher than 0.2%, the three-phase current accuracy is higher than or equal to 0.2%, the technical indicators of frequency, active power and reactive power all meet the design requirements, and meet the power quality voltage deviation standard (GB/T 12325-2008) Grade A accuracy requirements. Moreover, the human-machine interface of the instrument is simple and quick, and the display of the function is complete. This shows that the design of the instrument is reasonable and practical.

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