Design of power parameter monitor system based on Android mobile phone

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Abstract. With the continuous development of power technology, real-time and accurate monitoring of power parameters in the power grid to ensure safe and stable operation of power transmission has become a hot topic of research today. The power parameter measuring instrument can realize multifunctional detection, the overall design and the combination of hardware technology and software technology, connect the mobile phone APP and hardware through WiFi transmission, and display the transmission data in real time on the smart phone terminal. Select STM32F103 as the microprocessor, adopt software synchronous sampling method, control 16-bit high-precision AD conversion chip ADS8556 for AD sampling, and then process the data by discretization method and FFT harmonic analysis algorithm, and finally send the data to The display on the Android mobile phone can realize the measurement of single-phase AC voltage and current RMS value, active power, power factor, frequency and other power parameters, and has a harmonic analysis function. The measurement data is displayed by the smartphone terminal. Tested by a test platform composed of BD-3D multifunction calibrator, the results show that its performance indicators meet the design requirements.

1. Introduction
In recent years, smartphones have become more and more embedded in people's lives, and have become one of the essential items we carry around [1]. In order to enable power maintenance personnel to obtain power parameters and other information more accurately and in real time, this topic abandons the traditional fixed device display and uses the Android mobile phone APP interface display to communicate with the power parameter measurement device in real time. The efficient human-computer interaction method makes Detection of power parameters is more real-time and reliable.

This project uses wireless communication technology, with Cortex-M3 chip as the core data processor, and Android mobile phone as the power parameter display device. Real-time and efficient monitoring of power system parameters such as voltage, current, active power, and harmonic ratio. Among them, wireless communication technology reduces the cost of traditional cable transmission data, improves the reliability of electrical parameter measurement, and the M3 chip improves the efficiency of data processing. The application of the smart phone APP makes the electrical parameter detection more real-time and convenient. This electrical parameter measurement device design scheme adds new scientific power to the maintenance of the power system, and has important practical value and significance for ensuring the safe operation of electrical equipment.
This article first describes the sampling method and its algorithm, then the hardware design and software design of the system, and finally analyzes the experimental results and draws relevant conclusions.

2. Measurement method and data processing algorithm

2.1. Sampling method and selection

The sampling method is divided into synchronous sampling and asynchronous sampling. Asynchronous sampling is simpler and easier to implement than the synchronous sampling circuit, but it will cause serious spectrum leakage, requiring complex windowing and other processing of the data, resulting in complicated programs, and leading to larger measurements when the algorithm is not accurate enough error. So, choose the synchronous sampling method.

Synchronous sampling is divided into software synchronous sampling and hardware synchronous sampling. Hardware synchronous sampling, the circuit is complicated, consumes more resources, and when the harmonic content is large, it is easy to cause the circuit to be unstable, so that a large error will occur as a result. So, this design uses software synchronous sampling. The software synchronously samples the square wave pulse of the signal obtained from the synchronization pulse acquisition circuit, calculates the signal cycle through the timer of the microcontroller, and then calculates the required sampling interval according to the required number of sampling points, and then assigns it to the sampling timer. Realize software synchronous sampling.

2.2. Data processing related algorithms

2.2.1. Fast fourier transform (FFT). Discrete Fourier transform can transform time domain analysis into frequency domain analysis, and it is easier to obtain the amplitude of each harmonic through frequency domain analysis. However, because its operation amount is directly proportional to $N^2$, it is rarely used in actual engineering [2].

On the basis of DFT, the use of FFT (Fast Fourier Transform) algorithm can greatly reduce the amount of calculation. The essence of the FFT algorithm is to continuously decompose the DFT of a long sequence into a DFT of a short sequence, and reduce the amount of DFT operations according to the periodicity and symmetry of the rotation factor [3]. Its periodic expression is as follows:

$$W_N^{kn} = W_N^{(k+N)n} = W_N^{k(N+n)}$$  \hspace{1cm} (1)

$$W_N^{(k+N/2)n} = -W_N^{kn}$$  \hspace{1cm} (2)

2.2.2. Base 4 FFT algorithm. The base 4FFT algorithm divides a sequence of length $N = 4^l$ into four, and represents the N-point DFT as a linear combination of 4 N/4-point DFTs. Then use the symmetry and periodicity of the rotation factor to divide the N/4-point DFT into four, representing the four N/16 point DFT, and repeat this process until it is decomposed into a four point DFT operation [4].

2.2.3. Base 4 FFT algorithm complexity analysis. When calculating DFT $S(k)$ of length $L$ with DFT $S_i(k), i = 0,1,2,3$ of length $L/4$, the basic unit implements the following formula:

$$S(k) = \sum_{l=0}^{3} W_L^l S_i(k)$$

$$S(k + L/4) = \sum_{l=0}^{3} W_L^{(l+L/4)} S_i(k) = \sum_{l=0}^{3} W_L^l (-j)^l S_i(k)$$

$$S(k + 2L/4) = \sum_{l=0}^{3} W_L^{(l+2L/4)} S_i(k) = \sum_{l=0}^{3} W_L^l (-1)^l S_i(k)$$

$$S(k + 3L/4) = \sum_{l=0}^{3} W_L^{(l+3L/4)} S_i(k) = \sum_{l=0}^{3} W_L^l j^l S_i(k)$$  \hspace{1cm} (3)

Equation (3) is a formula for the 4-hour butterfly equation. It can be concluded that the base 4 operation requires 3 complex multiplications and 8 complex additions. Since there are a total of N/4
operation butterflies, the number of complex multiplications and complex additions required for the butterfly operation is 3N/4 times and 2N times, respectively.

In the case of \( N = 4^l \) (\( l \) is a positive integer), the decomposition of the N-point sequence into a four-point sequence requires \( l = \log_4 N \) decomposition. Therefore, the complex multiplication number and the complex addition number required by the base 4 FFT algorithm are respectively.

\[
M_c = \frac{3}{4} N \log_4 N = \frac{3}{8} N \log_2 N \tag{4}
\]
\[
A_c = 2N \log_4 N = N \log_2 N \tag{5}
\]

2.2.4. Closed loop adjustment algorithm. The PID (Proportion Integral Differential) control algorithm is a control method that performs correction based on the output feedback of the control object, and its expression is as follows:

\[
U(t) = K_p [e(t) + \frac{1}{T_i} \int_0^t e(t) dt + \frac{T_d}{T} \frac{de(t)}{dt}] + u_0 \tag{6}
\]

In the above formula, \( K_p \) is the proportional coefficient, \( T_i \) is the integral time constant, \( T_d \) is the differential time constant, \( e(t) \) is the error between the set value and the actual output value, and \( u_0 \) is the actual output value. The first three items represent the proportional, integral, and differential adjustments of the input signal [5]. However, in reality, the computer can only process discrete values and process them as follows:

\[
u(t) \approx u(k)
\]
\[
e(t) \approx e(k)
\]
\[
\int_0^t e(t) dt \approx \sum_{j=0}^{T_i} e(j) \Delta t = T \sum_{j=0}^{T_i} e(j)
\]
\[
\frac{de}{dt} \approx \frac{e(k) - e(k-1)}{\Delta t} = \frac{e(k) - e(k-1)}{T}
\]

Formula (6) can be converted to

\[
u(k) = K_p [e(k) + \frac{T_i}{T} \sum_{j=0}^{T_i} e(j) + \frac{T_d}{T} [e(k) - e(k-1)]] + u_0 \tag{7}
\]

Where \( T \) is the sampling period and \( k \) is the sampling point number.

In this design, the closed-loop adjustment system is mainly to adjust the various disturbances of the output signal in the circuit and reduce the steady-state error. Therefore, the design only selects the proportional control link [6].

3. Hardware design

This topic studies the design of a power parameter measuring system based on an Android phone. The central control processor selects the STM32F103 minimum system board as the control core. The hardware circuit of the system includes voltage sampling circuit, current sampling circuit, signal conditioning circuit, A/D sampling circuit, synchronization frequency acquisition circuit, STM32 minimum system circuit and wireless communication module design circuit [7]. The system block diagram is shown in Figure 1.

Main working principle: The voltage and current sampling circuit obtains the voltage and current that need to be measured through the transformer, and is converted into the voltage that can be input to the AD chip through I/V conversion. After I/V conversion, the signal is filtered through a two-stage active filter circuit to remove most unwanted high-order harmonics, and then input to the AD chip, which is converted into digital signals and input to the single-chip microcomputer for signal processing. It is obtained from the output end of the I/V conversion circuit, and after filtering and hysteretic comparator input to the external interrupt of the microcontroller, the frequency and synchronous sampling time are calculated. After calculating all the power parameters, it is sent to the WiFi chip through the serial port, and then sent to the Android mobile phone APP for display.
4. Software design

4.1. Software framework
The program of the M3 microcontroller of the lower computer mainly includes several modules of configuration initialization, A/D synchronous sampling, 4FFT calculation, power parameter calculation, data processing, and USART3 sending data. Initialize the system first, then start AD sampling, perform 4FFT calculation when the acquisition is complete, and then calculate the value of each power parameter. Considering the interference in the surrounding environment, the design needs to perform median filtering on the data results of the power parameters to make the power parameter results more reliable [8]. After the filtering is completed, the 16-bit floating-point data result is converted into byte-type data storage and sent to the WiFi chip ESP8266 through the USART3 serial communication. The main block diagram is shown in Figure 2.

4.2. UI interface design
The UI interface of this design includes a power parameter display section and a harmonic analysis display section. The power parameter display part has 7 data in total, which can be displayed in a table...
4.3. Data processing
When the time is up, the sampling timer is interrupted, and then the A/D conversion is started. The voltage signal after the I/V conversion is sampled. After collecting a full period of data, it is processed by the base 4 FFT operation. When the value of the sampling period counts N periods, the moving parameters of the N sampling periods are averaged to make the parameters such as the amplitude of the signal more accurate. When doing moving average, it is necessary to sort the electrical parameters obtained from the base 4FFT operation. In order to reduce the system error, the middle part of the data is accumulated and then averaged after sorting; finally, it is passed to the MCU for PID closed-loop control adjustment.

4.4. UDP protocol communication
In this design, the UDP protocol is used for communication. It is necessary to ensure that the server and the client are in the same LAN. After the host computer's UDP server program binds the port number, a communication datagram is created to monitor the client's request. Then establish a dedicated data packet for receiving events, and store the received data packets. Use the getData method to get information about the byte data of the data packet, including the data content, data length, and data offset. The byte array read start position is added to the offset to obtain the byte array without the IP packet header and UDP packet header. Finally, the processed byte array is sent to the main program as additional data through the Intent mechanism.

5. Experimental results and analysis
Use the BD-3D multifunction calibrator to output AC voltage, current, active power and power factor with different amplitudes or change the frequency, add each harmonic to test whether the electrical parameter measurement results meet the requirements, and the data is displayed through the mobile APP. By comparing with the input signal, the difference between the input and output of the electrical parameters is compared and analyzed.

5.1. Effective values of voltage and current
Through the BD-3D multifunction calibrator, the input current is 5A, the frequency is 50Hz, and the voltage effective value range is several sets of AC signals with different amplitudes. Through the BD-3D multifunction calibrator, the input voltage effective value is 220V, the frequency is 50Hz, and the current effective value ranges from 0 to 6A. Several groups of AC signals with different amplitudes. The measurement results of effective voltage and current value were shown in Table 1.

| Standard voltage (U/V) | Voltage measure (U/V) | Relative error value % | Standard current (I/A) | Current measure (I/A) | Relative error value % |
|------------------------|-----------------------|------------------------|------------------------|-----------------------|------------------------|
| 220                    | 220.029               | 0.013                  | 6                      | 6.0009                | 0.015                  |
| 180                    | 179.998               | -0.001                 | 5                      | 5.0010                | 0.020                  |
| 140                    | 140.027               | 0.019                  | 4                      | 4.0010                | 0.025                  |
| 100                    | 100.035               | 0.035                  | 3                      | 3.0007                | 0.023                  |
| 60                     | 60.056                | 0.093                  | 2                      | 2.0009                | 0.045                  |
| 20                     | 20.008                | 0.040                  | 1                      | 1.0003                | 0.030                  |

Table 1. Effective voltage and current value measurement results.
It can be seen from the data in the table that the maximum relative error of the voltage rms value is 0.093%, the maximum relative error of the voltage rms value is 0.045%, and the design requires that the voltage and current rms error is $\leq \pm 0.2\%$, so it meets the design requirements.

5.2. **Effective values of active power and power factor**

The input voltage is 220V through the BD-3D multifunctional calibrator, and the current decreases from 1A to 1A in sequence. The input voltage of BD-3D multifunctional calibrator is 220V, and the current is 5A. The phase angle can be changed, and the input signal of multifunctional calibrator can be compared through the mobile APP display. The measurement results of active power and power factor were shown in Table 2.

| Standard active power (P/W) | Active power measure (P/W) | Relative error value % | Standard power factor (P/W) | Power factor measure (P/W) | Relative error value % |
|----------------------------|----------------------------|------------------------|-----------------------------|----------------------------|------------------------|
| 1099.90                   | 1100.381                   | 0.044                  | 1.000                       | 1.000                      | 0                      |
| 879.974                   | 880.284                    | 0.035                  | 0.9840                      | 0.9845                     | 0.0005                 |
| 659.998                   | 660.295                    | 0.045                  | 0.8660                      | 0.8660                     | 0                      |
| 440.026                   | 440.260                    | 0.053                  | 0.7650                      | 0.7650                     | 0                      |
| 220.018                   | 220.202                    | 0.084                  | 0.6420                      | 0.6420                     | 0                      |
| 109.990                   | 110.105                    | 0.105                  | 0.4990                      | 0.4990                     | 0                      |

It can be seen from the data in the table that the maximum relative error of the active power is 0.105%, and the design requires that the error of the active power measurement is $\leq \pm 0.2\%$. The maximum absolute error of the power factor is 0.0005 less than 0.001, and the error is small, which meets the design requirements.

5.3. **Frequency characteristics and harmonic analysis**

Input the 220V voltage and 5A current through the BD-3D multi-function calibrator, and the frequency is gradually increased from 45-70Hz by 5Hz, and then add the harmonics of the voltage and current harmonic components that are 10%. The related 2-7th harmonic distortion measurement results and the increasing frequency measurement results are shown in Table 3.

| Standard source frequency (Hz) | Frequency measurement (Hz) | Absolute frequency error (Hz) | Harmonic component order | Measured voltage total distortion % | Relative error % | Measured current total distortion % | Relative error % |
|-------------------------------|-----------------------------|-------------------------------|--------------------------|------------------------------------|-----------------|-------------------------------------|-----------------|
| 45                            | 44.998                      | -0.002                        | 2                        | 9.95                               | -0.05           | 10.05                               | 0.05            |
| 50                            | 49.998                      | -0.002                        | 3                        | 9.92                               | -0.08           | 10.11                               | 0.11            |
| 55                            | 54.997                      | -0.003                        | 4                        | 10.00                              | 0.00            | 10.11                               | 0.11            |
| 60                            | 59.996                      | -0.004                        | 5                        | 10.01                              | 0.01            | 10.10                               | 0.10            |
| 65                            | 64.997                      | -0.003                        | 6                        | 9.99                               | -0.01           | 10.10                               | 0.10            |
| 70                            | 69.997                      | -0.003                        | 7                        | 9.98                               | -0.02           | 10.06                               | 0.06            |

As can be seen from the data in the table, the maximum absolute error of the frequency is -0.004, and the frequency measurement error is $\leq 0.005\text{Hz}$. The data meet the design requirements, indicating that the design has good frequency characteristics, and the maximum absolute error of voltage harmonic distortion is -0.08%, the maximum absolute error of current harmonic distortion is -0.11%, and the measurement error is $\leq 0.5\%$, which meets the design requirements.

5.4. **Error analysis**

The error sources of this design mainly include hardware errors and software errors. The analysis of the errors is as follows:
The hardware error mainly comes from the accuracy of the equipment and the welding of the circuit. For example, the resistance changes the resistance value due to the excessive power and it is easy to generate heat. At the same time, the transformer affects the hardware circuit when the environment changes and the input parameters change, making its accuracy will decline. The filter circuit of the hardware circuit uses a second-order active filter. Although it meets the design requirements, increasing the filtering order will reduce the error to a greater extent.

The software errors are mainly periodic errors caused by software synchronous sampling. Each time a signal period is calculated by a timer, the number of pulses is counted by the timer, and there is an excess pulse remainder after dividing by the number of sampling points, causing errors. As for the quantization error of the timer in the software synchronous sampling algorithm, although the corresponding correction has been made in this design, it will still exist.

6. Conclusions
This subject designs and implements a power parameter measurement system based on Android phones, which can measure various electrical parameters in real time and has a harmonic analysis function. Compared with traditional measurement technology, using mobile APP to view is very safe and convenient, and it also improves inspection efficiency. The STM32F103 single-chip microcomputer is used as the main control core. The Android phone interacts with the user to display the electrical parameters intuitively for the user to view and debug. The joint debugging of the hardware module and the software module meets the design requirements. The fundamental 4FFT algorithm and PID adjustment algorithm applied in this paper are the key to achieving this design requirement. Harmonic analysis of current and voltage signals is performed. The electrical parameters and the proportion of each harmonic are clearly and dynamically displayed on the mobile phone interface. The characteristics of traditional test output electric parameter display are incomplete, low precision, and poor stability.

The design has its high-precision measurement display, APP interface for flexible viewing of personnel, and efficient wireless data transmission. It can meet the needs of various users. At the same time, it provides a research basis for remote monitoring of power parameters, and realizes the transfer from fixed instrumentation display to smart phone terminal display, which greatly facilitates the user's operation and has high application value.

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