Design of AC Load Analysis System Based on Single-chip Microcomputer

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Abstract. A high-precision data sampling AC load analysis system is designed based on the core of ARM cortex M3 microcontroller named NXP LPC1500. The hardware composition, circuit design of each hardware part and the software design of the system are discussed in detail. The voltage, frequency, energy (W-h), harmonic current and current curve are also added into the analysis system. The circuit diagram of the functional part of the main circuit is provide, and the flow chart of the software design for the microcontroller are given. The experimental data show that the system works stably and reliably in actual application.

Keywords: AC load, LPC1500 ADC, power electronics, power factor analysis.

1. Introduction

An AC load analyzer is commonly used to measure the load current and power consumption of instruments and household appliances [1]. Le [2] proposed a power management system composed of intelligent instrument and PC protection device to collect the electrical parameters and switch signals. Zhao [3] presented a measuring system at engineering frequency based on MCU. A power transformer test device based on AVR MCU modeled ATmega128 was designed in Wen [4] to test the Load and no-load experiments. Dong [5] put forward a method to obtain the power frequency in PMU based on the influence of the low frequency interference on the calculation of the line frequency parameters. A method is proposed to calculate the sequence parameters of transmission lines based on the decomposition of the induced voltage (current) into positive, negative and zero sequence in [6]. Tang [7] designed a power factor intelligent compensation device based on MCU to determine different circuit compensation parameters according to the change of load power factor to achieve the purpose of intelligent compensation and electricity saving.

The system proposed in this paper is designed for the power monitoring needs of power systems, industrial and mining enterprises, public facilities, and intelligent buildings to analyze and detect the electricity of various types of instruments and electrical equipment. The current, effective power, apparent power and power factor will be measured and furthermore the voltage, frequency, energy (W-h), harmonic current and current curve are also added into measurement items.

The organization of the article is as follows: In Section 2, the configuration of analysis system is given and microcontroller, ADC, power supply and display section are selected. Then, in Section 3, the system functions including sampling and refreshing, normal mode, as well as harmonics and calibration
are designed. The control program and the running process are provided in Section 4. Some experiments are conducted in Section 5 to validate the effectiveness of the proposed method, and the performance is satisfied. Finally, the conclusion is presented in Section 6.

2. System composition
The configuration of the AC Load Analysis System Based on Microcontroller is shown in Fig. 1.

Figure 1. Hardware structure block diagram

2.1. Microcontroller
According to the measurement index, the microcontroller should have two input channels, namely the input voltage and the load current, to measure the required parameters. The measured data are not only the waveform, but also the phase angle between the two input channels. The input channels need to be sampled simultaneously, so two ADCs are required. A microcontroller modeled NXP LPC1519 is selected as the main controller.

The LPC1519 microcontroller combines all the functions required for high-precision sensorless BLDC control, and is optimized for fast, high-precision motor control. It can controls two motors simultaneously with flexible and simple configuration. This microcontroller, Arm Cortex-M3 processor which consists of two 12-bit, 12-channel, 2 ms / s ADCs and an on-chip quadrature encoder interface (QEI) is used to achieve high-precision control of sensor and sensorless BLDC combination. Four on-chip comparators are applied to realize the fast response overcurrent / voltage monitoring and protection. Four SCTimer / PWM timers provide 28 PWM channels for the timing subsystem and tightly coupled simulation in order to minimize the CPU load. So that it is exactly suitable for industrial applications such as digital power supplies and instruments which require real-time control and high accuracy data sampling.

2.2. ADC
For the current detection channel, the 12-bit resolution is insufficient because the load current ranges from a few milliamps to 10 amps and the current is constantly changing. Therefore, an external 16-bit ADC is used for the current channel and an integrated 12-bit ADC is used for the voltage channel.

The AD7685 is selected for the current channel in this system. The AD7685 is a 16-bit, charge redistribution, successive approximation analog-to-digital converter (ADC) which uses a single 2.3 V to 5.5 V power supply (VDD)[8]. The AD7685 contains a low-power, high-speed, 16-bit sampling ADC with no missing codes, an internal conversion clock, and a multifunctional serial interface port. It also integrates a low-noise, wide-bandwidth, short-aperture delay sampling holder. The analog input voltage difference between IN+ and IN-, ranging from 0 V to REF is sampled by AD7685 when the CNV pin is on the rising edge. The reference voltage (REF) is provided externally and can be set up to the supply voltage [9]. The ADC and MCU connection diagram is shown in Fig. 2.
2.3. Power supply
A simple capacitor step-down converter will be selected as the auxiliary power supply because the total current consumption of the microcontroller, analog circuits and LCDC in the overall system design is generally 10 mA. It should be noted that this type of power supply has a risk of electric shock and requires separate insulation because the load circuit is not isolated from the AC input. However, the current detection circuit does not need to be isolated from the AC line, so that the number of large components such as isolation transformers and directly which use a current detection resistor to detect the load current can be eliminated.

2.4. Display section
A 128x128 dot TFT-LCD module (ZY-FGDI442701V1) is selected in the display section for advantage of low power consumption, but information much better than the character LCD can be displayed by the full color graphical display. The backlight circuit is separate from the LCDC, so it can in series with the power supply to reduce the supply current of the circuit, and a small step-down capacitor can be used.

3. System functions

3.1. Sampling and refreshing

Two input signals including current and voltage is acquire at a sampling frequency of 16 ksps, which are completed by a 16 kHz square wave of SCT. The rising edge of the square wave is used to trigger the external ADC and the internal ADC. It also generates an interrupt on the falling edge to read the conversion result. The number of samples per cycle varies with the input frequency, which will make the subsequent process, especially harmonic analysis process becomes very simple while fix to a constant number. In this system, the collected samples are resampled at 128 samples per cycle and stored.
in the waveform buffer. Most data processes are done by using resampled data. Raw sampling data is only used for frequency and W-h measurements that require continuous processing.

3.2. Normal mode

Current, effective power, apparent power, power factor and voltage are calculated at the period of the resampled waveform. The waveform is stored into the buffer by using 8-cycle-average method in order to filter out noise components, thus the values is updated several times per second. In addition to these items, energy consumption (W-h), frequency and measurement duration are also displayed. Frequency is measured in inverse form from the number of samples in 64 cycles. The frequency resolution becomes to 2.44 MHz under a 50 Hz input frequency.

3.3. Harmonics and Calibration

A DFT processing is applied to capture the current waveform and display the value of the harmonic components. One waveform period is suitable for 128 \((2^n)\) samples through the resampling process, therefore DFT can be done without a windowing. Gain errors will not be generated and the frequency resolution will not be reduced during the period of analysis.

A separate power supply is required during the process of flash programming and calibration because the circuit is non-isolated. It must be powered by a 9V battery connected to TP6 and GND. When P0_13 is set low and powered on, it will enter the calibration mode. The calibrated data is stored in EEPROM.

4. Software design

For LPC1500 series microcontrollers, the most commonly used programming languages are C and C++. This system’s software is written using IAR programing software. The main functions of this system include voltage and current of current display, average voltage and current of the AC line connected to the system, frequency detection of the AC line, real-time power factor display which is used to calculate and display the power factor of the current consumer, the voltage and current waveform display applied to display the average voltage and current waveforms of the AC lines connected to the system which is convenient for users to identify the type of connected load.

The running process of this system is described as follows:

1. Initialize the external ADC and internal ADC at startup, and start sampling.
2. The microcontroller detects the rising edge of the input voltage through the internal ADC.
3. Reset the address pointer of the buffer when the rising edge arrives and start recording new data, thus the data in the form of a waveform will be displayed on the screen.
4. Average value of the data is achieves and various numerical calculations is performed after repeating the recording process multiple times.

Analysis system software flowchart is shown in Fig. 4.
5. Experimental result
Experiments are performed in this system to test the SMPS without PFC and the results are shown in Fig. 5. It can be achieved that the input current has a high peak-to-average ratio due to the charging current flowing to the input capacitor at the peak of the input voltage. It is concluded that the waveform in the form of a pulse contains many odd harmonic currents, which results in a poor power factor.

6. Conclusion
This data acquisition designed in this system makes full use of the high performance and data processing capabilities of the LPC1519 microcontroller to achieve the data acquisition of voltage and current data for AC loads, voltage and current waveforms display and the real-time calculation of power factors. Satisfied results in the practical application of AC load analysis has been obtained.
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