The Hardware Design of Power Quality Online Monitoring Device Based on MCU

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Abstract: In recent years, the power grid and its load structure has undergone great changes. Especially the interference of a large number of non-linear and impact loads have caused voltage waveform distortion, voltage fluctuations, and a series of power quality problems. Therefore, extensive attention has been paid on the research of power quality on-line monitoring device. This paper focuses on the power quality monitoring device hardware, and designs a MCU system, which is based on C8051F340, as the device's handle control core. Then on this basis, we design sensor unit, sampling trigger unit, analog-to-digital conversion unit etc, and actually make and weld PCB. As for software, under the Keil µVision4 development circumstances, the author uses C language to develop MCU's control, computing, communication, and other programs of lower computer. Actual test results has proved the design's rationality, and the installation's various functions and indexes can meet the requirements of power quality online monitoring.

Introduction

With the development of society, science and technology and national industry, electric energy has important influence on the country's progress and the industry's development. In the modern society, electric load growth rapidly, especially the sustained growth of nonlinear and impact load. A lot of power electronic devices and the application of nonlinear devices in power system, such as arc furnace, subway, high-speed rail has caused serious impact on power quality.

Therefore, developing a new type of power quality monitoring system (PQMS) which is low cost, easy to use, and can analyze, census，and display power quality indexes is very necessary and imperative. It will have great significance on the safe and reliability of electricity supply and industrial production, and the economic operation. It will also speed up power as a commodity quality standardization process, improve the management efficiency of electric power department on power quality, improve power quality, provide reliable basis for perfecting electricity market system, and promote the formation of the Chinese power market.

Based on the above analysis, the design will build a system with MCU + industrial PC server as the core. It will be applied to power quality analysis, real-time monitoring and accurate analysis for the power grid measure, in order to improve the power quality.

The Design of Monitoring Device Hardware

The design uses a system architecture which includes MCU + industrial PC server. The hardware block diagram of the site monitoring is shown in figure 1. The system is mainly consists of a sensor unit, a data acquisition unit, MCU control unit, USB unit and the IPC unit, etc.

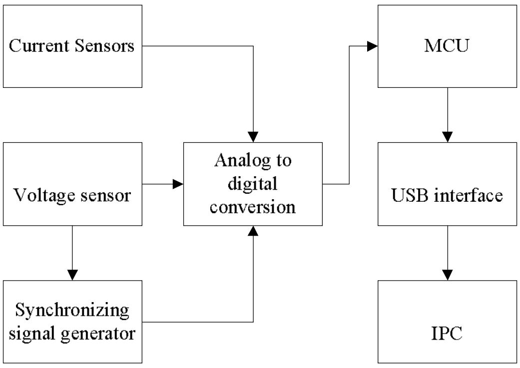

Fig.1 Field monitoring device hardware diagram

Three-phase voltage and current respectively flow into the voltage, current sensors, and then into the analog to digital converter for each channel. While the output signal of the three-phase voltage sensor flow into the sync signal generator, and then it can generator and send the synchronous sampling trigger signal to AD converter, in order to complete the voltage and current sampling. After the ADC conversion is complete, the processor reads data by parallel data bus. Then follow the instructions set in advance, calculate various types of power quality indicators and transfer to the PC by the USB interface. The user can check the basic monitoring information by buttons and display. They can also examine the raw data by PC hard disk.

The MCU Unit Design Based on the C8051F340. The device of the single chip micro-controller uses mixed signals on a chip system MCU C8051F340, which is designed and manufactured by American Silicon Laboratories Inc [1,2]. C8051F340 MCU has full speed USB interface, and a built-in USB cache and protocol, which greatly reduces the difficulty of the USB control interface and control program development. And C8051F340 has enhanced UART (two) and enhanced SPI serial interface GPRS module and RS232 interface serial communication requirements. In addition, 8051 compatible micro-controller kernel (up to 48 MIPS), with high speed and assembly line structure, can satisfy the coordination of many real-time control tasks. Therefore, C8051F340 MCU can meet the design requirements of the micro-controller. C8051F340 micro-controller system is shown in Figure 2.

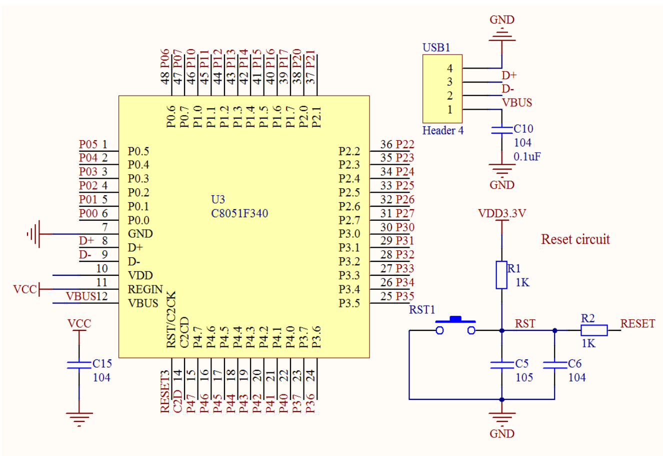

Fig. 2 C8051F340 system diagram

The Design of Sensor Unit. Phase voltage sampling uses a voltage transformer (PT), current sampling uses a current transformer (CT) isolated transformation, in order to ensure the system is safe and reliable. Voltage and current sensor is the key part of ensuring measurement accuracy. In order to ensure the accuracy of the harmonic measurement, voltage and current transformers should have a uniform frequency response within the frequency range of 50Hz ~ 2500Hz. In this paper, the design uses high-precision electromagnetic isolation sensors which are producted by Mianyang weblogs Electronics Co., Ltd.

The Design of Sampling Trigger Unit. Using phase-locked frequency multiplication technology can achieve synchronous sampling, in order to prevent spectral leakage and frequency aliasing happening [3,4]. Harmonic analysis of the number of the article is up to 32 times, and the phase-locked frequency technology is 2N times the sampling frequency of the fundamental frequency of the measured signal, where N is the minimum selectable 6, and the sampling frequency is 64 times of the fundamental voltage signal. When the fundamental frequency is 50Hz, the sampling frequency is 3200Hz.

Since the output signal of the voltage sensor is an analog signal, it can not be directly used as an input signal for phase-locked frequency multiplier circuit. Therefore, it is necessary to convert the AC sinusoidal signal to square wave signal by the zero-crossing comparator. The square wave signal has the same frequency as the fundamental wave and can be used as the input signal of phase-locked frequency multiplier circuit, shown in Figure 3. U_{a_OUT}, U_{b_OUT} and U_{c_OUT} are tracking voltage output signal of the three-phase voltage sensor, and the input signal of the add and subtract multiplier circuit constituted by LM358. The relationship between the three-phase input signal and the output voltage U_{OUT} of LM358 is:

$$U_{OUT} = U_{a\_OUT} + U_{b\_OUT} - U_{c\_OUT} \tag{1}$$

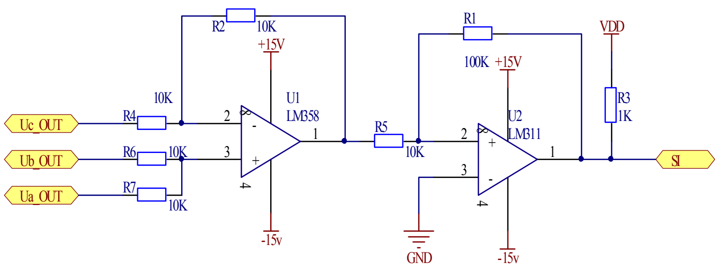

Fig.3 Sampling trigger circuit design

Figure 3 shows that U_{OUT} is synthesised by three-phase voltage signal. When the system occurs to single-phase or two-phase fault, U_{OUT} is not zero. It is more reliable than using single-phase voltage as the synchronous circuit input signal. Under the condition of three-phase symmetrical operation, the amplitude of U_{OUT} is 2 times larger than U_{c_OUT}, and the Anti-interference performance is more stronger. LM311 as a zero-crossing comparator can convert the analog signal which contains frequency information to square wave signal which is as the same frequency as fundamental wave. To prevent the zero fluctuation caused by interference, LM311 is set to zero-crossing comparator. After LM311 produces square wave which is samed as fundamental frequency, phase-locked frequency multiplier circuit generate synchronization interval signal. This article designs synchronize sampling trigger circuit of system, shown in Figure 4.

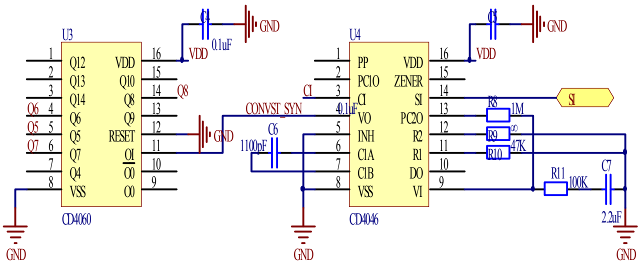

Fig.4 PLL frequency multiplier circuit diagram

CD4046 is COMS PLL chip. CD4060 is 14 levels binary serial counter which used as a divider [5]. SI is the fundamental frequency of the signal generated by LM311. CONVST_SYN is output signal. The other input signal CI of the phase comparator is also the output signal of the frequency divider. When different CD4060 output terminals connect to the CI, which changes the frequency division factor of the frequency divider. The output of the PLL will produce different frequencies multiples. The design of this paper, which connect CI to Q5, Q6, Q7 and Q8 respectively to generate four synchronization signal, 32-fold, 64-fold, 128-fold and 256-fold.

The Design of Analog to Digital Conversion Unit. This paper selects AD7606 bipolar AD-converter. AD7606 is the new generation of 16-bit, 8-channel, simultaneous sampling, bipolar input, and single-supply AD-converter, producted by ADI Company [6]. CONVST_A and CONVST_B are the sample and trigger pins of AD7606. They can control four channels and be connected together to trigger eight channel sampling simultaneously. The design of this paper is that C8051F340 control eight channel sample simultaneously in order to ensure accurate measurement. Since the data read control pin and chip select pin of AD7606 is connected to the chip IO ports of C8051F340, the chip data ports of AD7606 are connected to the IO of C8051F340, and the data read operation is very convenient.

The design of monitoring device software

Design of MCU Main Program. Keil C51 is the development system producted by US Keil Software company. This system is compatible micro-controller C language for 51 series. This company released Keil µVision4 on February 2009. C8051F340 build environment is Keil µVision4. C8051F340 program is composed of main program and subroutine. The main program is responsible for each function subprogram reasonably organized together in the timing process. Subroutines primarily is responsible for achieving all kinds of functions, such as interrupts, initialization, sampling and so on. MCU's main program flow chart shown in Figure 5, which includes several parts:

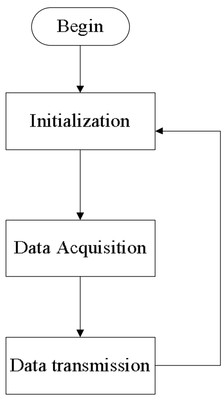

Fig.5 The main program block diagram

First power micro-controller, the program restart after press a reset button. Initialization consists of a micro-controller IO port configuration, system clock initialization, watchdog settings, interrupt settings, USB transfer settings, AD conversion start initialization. Call data acquisition subroutine. Read AD conversion completion data. Call the USB transmission program, the read data will be sent to the PC.

Data Collection Process Subroutine. We can judge the AD7606 data conversion whether is beginning by setting the MCU external interrupt. The rising edge of the signal BUSY is the interrupt trigger signal. Interrupt flag is cleared off after entering the interrupt. Turning off the interrupt prevent other factors affecting the data collection and send. Through a for loop, the data of AD7606 can being read out and stored in a byte array. Calling USB send subroutine, send the data stored in the array to the PC, and open data acquisition interruption, waiting for an interrupt trigger.

C8051F340 USB Data Transfer Routine Processes. Before the device making the USB communication, USB clock must first initialize, and then initial the USB interface including setting PID, VID, the device description information, enable the USB API interrupt [14]. After the setup is completed you can send data at any time. The system calls Block_Write() function in data acquisition interrupt. The initialization of USB clock, interface and API interrupt are all written in the main program initialization.

Test results and analysis

The test uses a three-phase precision test power simulate the secondary side of 110kV substation PT / CT. Start the monitoring and analysis software, and enter a password login. First set voltage level, current level, PT / CT ratio and other parameters. The test can set data record custom criteria such as voltage, current, harmonic ratio limits and so on according to need.

Frequency Measurement Accuracy Test. This article uses JCD4060 sophisticated testing three-phase power regulator output frequency on the frequency measurement tests. Use Tektronix TDS2012C digital oscilloscope and the monitoring device developed in this paper to simultaneously test the voltage signal of measuring power. Test data and absolute error as shown in Table 1. f_{OSC} and f_{PQMS} are respectively oscilloscope measurements and monitoring device measurements.

Tab.1 Frequency measurement test table

f_{OSC}/Hz	49.998	49.995	49.999	49.994
f_{PQMS}/Hz	49.991	49.990	49.995	49.995
Absolute error /Hz	0.007	0.005	0.004	0.001

As shown in Table 1, the max absolute frequency measurement of the monitoring device and TDS2012C oscilloscope is 0.005Hz. Meet the national standard's accuracy requirements of GB / T 19862-2005 *General requirements for power quality monitoring equipment in the frequency deviation* is less than 0.01Hz.

Voltage Measurement Accuracy Test. Since the JCD4060 test power's display precision is three and a half. It's not sufficient as a reference for voltage measurement accuracy test of the monitoring device. The display of the four semi-voltmeter test victory licensing VC86E is used be as a voltage measurement reference. Three-phase voltage measurement test data, and the relative error are as shown in Table 2.

Tab.2 Three-phase voltage measurement test table

Supply voltage /V	Monitoring device measurement value /V			Relative error /%		
	A	B	C	A	B	C
120.00	120.16	119.99	120.18	0.13	-0.01	0.15
110.00	110.13	109.95	110.15	0.12	-0.05	0.14
100.00	100.09	99.99	100.12	0.09	-0.01	0.12
90.00	90.07	89.96	90.08	0.08	-0.04	0.09
80.00	80.02	79.87	80.09	0.03	-0.04	0.11
60.00	60.07	60.00	60.05	0.12	0	0.08
40.00	40.05	39.95	40.04	0.13	-0.13	0.10
20.00	19.98	19.97	20.02	-0.10	-0.15	0.10

As can be seen from Table 2, the relative measurement error of three-phase voltages distribute between -0.15% to 0.15%. Meet the precision of the national standard GB / T 19862-2005 *General requirements for power quality monitoring equipment in the voltage deviation* is less than 0.5%. Reach the 0.2% accuracy.

Conclusion

This paper completed the MCU system design, which is based on the C8051F340, as the core of the system hardware controller. Then on this basis, the author designed sensor unit, sampling trigger unit, analog-to-digital conversion unit etc, and actually made and welded PCB. The author uses C language to develop MCU's control, computing, communication, and other programs of lower computer. Testing the frequency, voltage, harmonics measurement accuracy and other functions in the laboratory. Actual test results has proved the design's rationality, and the installation's various functions and indexes can meet the requirements of power quality online monitoring.

References

[1] Silicon Labs, C8051F34X Data Manual [Z], www.silabs.com, 2008

[2] Lei Zhu, The design for low-cost data acquisition based on C8051F340 [J], Foreign electronic components, 2008(4): 6-8. In Chinese.

[3] Guangyu Du, Xiaoqiao Chen, Zhongtian Wan, Application for locked multiplier and quasi-synchronous sampling method in the measurement of harmonics [J], Wuhan University (Engineering Science) , 2001(5): 39-44. In Chinese.

[4] Haisheng Yu, Songfeng Pan, Herong Wu, The electrical parameter measurement based on complex sequence FFT and the principle of phase lock [J], Grid technology, 2000(3): 59-61. In Chinese.

[5] Dahua Zhang, PLL IC CD4046 and its application in automation instruments [J], Industrial Measurement, 2003(6): 30-32. In Chinese.

[6] Keyong Yu, Jianjun Sun, The application of the new generation of 16 bit 8-channel simultaneous sampling ADC-AD7606 in the smart power grid. In Chinese.