Research on Multi-function Power Transmitter of AC Sampling Based on Modbus Protocol

Haifei Si¹,², Xingliu Hu¹, * and Zhen Shi²

¹College of Intelligent Science and Control Engineering, Jinling Institute of Technology, Nanjing, Jiangsu, 211169, China
²College of Automation, Harbin Engineering University, Harbin, Heilongjiang, 150001, China

*Corresponding author

Abstract. It is of great significance for the stability and optimal operation of the power grid to find and control the abnormal conditions in the operation of the distribution system in time. According to the current situation of distribution network and the demand of distribution automation in China, aiming at the problems existing in the cost, accuracy, communication and reliability of distribution monitoring terminal, this paper puts forward a design scheme of distribution monitoring terminal with arm as the control core and high-precision power measurement chip as the data collection core, and designs the serial communication between computer and power transmitter. Communication protocol, and completed the production of the prototype.

Keywords: Distribution monitoring terminal; communication protocol; power transmitter.

1. Introduction

As the last direct user-oriented link in power generation, transformation, transmission and distribution, distribution network plays a very important role in power system and power system automation management. Since the 1970s, many developed countries have started the pilot work of distribution network automation[1]. The distribution monitoring terminal has developed from the early single function, simple communication mode to the current intelligent, miniaturized, multifunctional and has a variety of communication modes[2]. Through the analysis of the application status and development trend of the power consumption transmitter of the distribution monitoring terminal, and from the practical problems encountered in the application of the product in the project, there are some deficiencies in the function and design of the power consumption transmitter of the distribution transformer monitoring terminal in the market at present, mainly manifested in: the most commonly used microprocessors in the power system include 51 series and 96 series etc. The single DSP chip structure has limited functions, small amount of data storage, and does not have the function of remote communication, while the dual CPU structure can realize a variety of functions of the device, but makes the circuit design complex in the selection of electrical measuring devices[3,4]. Although the high-precision synchronous sampling ADC module has high precision and fast conversion speed, its price is relatively expensive and does not carry DSP function increases the calculation workload of main control MCU. In view of the above problems, this paper selects MAXQ3180, a high-precision power measurement chip based on DSP technology and with harmonic measurement function, as the power
data collection core, and LPC2132, a 32-bit single-chip microcomputer with powerful arm technology, as the main control core. Under the premise of low cost, it meets the functional requirements of real-time, accurate and reliable collection of various parameters.

2. Design of the Main Control Board of the Electric Quantity Transmitter

2.1. Composition of Electric Quantity Transmitter

The electric quantity transmitter is composed of input conversion, A/D conversion and parameter calculation, isolation, controller, communication and other units. Its structure is shown in Fig. 1.

![Figure 1. Composition and structure of electric quantity transmitter.](image)

The input conversion unit is mainly composed of current transformer and voltage divider or voltage transformer. Its function is to convert the voltage and current flow to the range suitable for analog-to-digital conversion chip. The analog-to-digital conversion and parameter calculation unit is mainly composed of MAXQ3180 chip and peripheral components. It is the main function part of the power transmitter. It completes the conversion from analog quantity to digital quantity and the calculation of parameters. The isolation unit is mainly composed of optocoupler, which aims to cut off the electrical connection between the input three-phase power grid and the control circuit, and transmit the required information through the optical medium. For safety, the controller is composed of LPC2132 single chip microcomputer, which is the center of the whole transmitter. The main function of the communication unit is level conversion and protocol conversion.

The main control board is the core part of the whole monitoring terminal, which is mainly responsible for receiving the query and control information of the main station; calculating and statistical analyzing the acquisition results of the analog front-end, generating various statistics; detecting the switch status, alarming in case of any abnormality, and controlling the opening and closing of the switch; storing and displaying the data and status information locally. According to the function of the main control board, the main control board can be divided into the following parts:

- **Main Control Module.** The main control module includes the main control CPU, bus expansion, serial expansion and other peripheral circuits.
- **Communication Module.** RS232 communication complying with Modbus communication protocol.
- **Switch Detection and Control Module.** Including switch state acquisition and switch control output.
- **Power Processing.** Power configuration of the whole system.

2.2. Serial Communication Complying with Modbus Protocol

Modbus is a request/reply protocol and provides services specified by function codes. In this design, RTU transmission mode is used. Each 8-bit byte in the message contains two 4-bit hex characters. The maximum Modbus RTU frame is 256 bytes[5,6]. In RTU mode, the idle interval with a time length of at least 3.5 characters separates the message frames. If the idle interval between two characters is greater than 1.5 character time, the message frame is considered incomplete, and the receiving station should discard the message frame. The CRC field is appended to the message as the last field of the message. Since the system is 3.3V system, it is necessary to use SP3232E for RS-232 level conversion. SP3232E is the RS-232 conversion chip of 3V working power supply. ESD protection is added to the chip, which can prevent the surge voltage generated when DB9 is plugged in and out on line from damaging the chip. P0.0 and P0.1 of LPC2132 can be used as serial port communication or general I / O port, so a skip selection function JP1 is added in the circuit board design. When short circuit is used, it is used as serial communication interface, and when disconnected, it is used as general I / O port.

3. Design of Analog Front-End

3.1. Overall Structure of Analog Front-End
The main function of the simulation front-end is to collect the power parameters of the power supply and distribution system. Its overall hardware structure is shown in Fig. 2, including four parts: AC signal conversion circuit, data acquisition, data processing and control, and interface circuit. The weak current signal obtained from the AC signal conversion circuit is sampled and calculated by MAXQ3180 to obtain three-phase current, voltage, active power, reactive power, power factor and frequency and other parameters, which are then transmitted to the main controller LPC2132 through SPI interface[7,8]. LPC2132 receives the control signal from the CPU of the main control board, preliminarily processes the collected data of MAXQ3180, and then sends the result to the main control board according to the self-defined communication protocol. In addition, because there are some errors in the signals obtained by the AC signal conversion circuit, these errors can not be ignored in the high-precision measurement, so LPC2132 control MAXQ3180 is required to complete the accuracy correction.

![Figure 2. Hardware structure of analog front-end.](image)

### 3.2. Analog Front-End Acquisition

MAXQ3180 is a special front-end for measuring electrical parameters. It collects and calculates the multi-phase voltage, current, power, energy and other measurement parameters and power quality parameters of the multi-phase load. The external host reads the calculation results through the SPI bus, and the external host configures the work of MAXQ3180 and monitors its working status through the SPI bus. At the same time, DSP module generates active / reactive electric energy pulse and fundamental / harmonic electric energy. Active and reactive power pulses. Used for accuracy correction of various parameters. After collecting the voltage and current, MAXQ3180 performs the corresponding digital filtering, accumulation and processing calculation to get the measured reading values (such as grid frequency, RMS voltage and current, active and reactive power, etc.), and then the main processor reads these values.

The meter calibration can ensure that the recorded voltage, current, electric energy and power meet the requirements of design standards. Before formal calibration, the basic unit of measurement shall be established first: full amplitude voltage and full amplitude current. The calculated calibration constant is then used to adjust the gain register to produce the required raw current, voltage, energy, and power factor register readings.

Therefore, the three-phase wound asynchronous motor is used to realize the leading and lagging phase shifting of voltage and current in time for calibration, so that the reactive power and power factor can be calibrated.

In Fig. 3, CH1 channel shows voltage waveform, and it can be seen from the figure that the voltage frequency is 50Hz, which is equivalent to the grid voltage waveform; CH2 channel shows current waveform, and it can be seen from the figure that the current frequency is 50Hz. Voltage and current are in phase at this time. If the rotor of the three-phase wire induction motor rotates 90 degrees, the voltage and current will be 180 degrees different in phase.
4. Software Design of the System

4.1. Overall Software Design of the System

The software design of multi-functional electric quantity transmitter mainly includes the design of serial communication protocol and single-chip microcomputer control software. Serial communication protocol is designed to ensure the safety and reliability of data transmission between monitoring computer and multi-function watt-hour meter. The design of MCU control software is mainly to complete the control of MAXQ3180 data acquisition, read the electrical parameters and chip temperature measured by MAXQ3180, receive the command from the monitoring computer, and control the data message from its full duplex serial port to the computer. The monitoring computer software system is the operating platform of the background monitoring, which completes the functions of remote monitoring and information processing of the monitoring computer. The single-chip microcomputer control software block diagram is shown in Fig. 4.
When the system is powered on, the single-chip microcomputer initializes and reads the initialization parameters of MAXQ3180 into the RAM memory of the single-chip microcomputer by EEPROM. Check the IRQ pin of MAXQ3180. MAXQ3180 provides an IRQ signal to connect with the external interrupt 0 of LPC2132, /INTO adopts the low-level trigger, when MAXQ3180 operates normally, the IRQ is high level; when MAXQ3180 is powered on and reset or the abnormal reason is restarted, the IRQ immediately changes to low level, and /INT0 is generated at this time, which is used to trigger the flag bit of MAXQ3180 reset program, and the calibration data can be written into Max after initialization. MAXQ3180: when reading and writing the MAXQ3180 register, there may be errors sometimes. At this time, an error flag will be generated. When the main program checks this FLAG, it will initialize the MAXQ3180. In addition, it can also send the hex 00 01 02 03 compulsory program to initialize the MAXQ3180 through the serial terminal. After that, it will enter the normal operation state, complete the collection and processing of power parameters and the communication with the computer.

4.2. Transmitter Module Serial Communication Design

The purpose of communication with the monitoring computer is to use the computer to operate the power transmitter and realize the function of control and data display, that is, the power transmitter transmits the power parameters to the monitoring computer through the RS232 communication serial port, and the monitoring computer transmits the control command to the power transmitter through the serial port. The processing of RS232 communication module is mainly realized through the serial port of single chip computer.

Modbus protocol is the main slave communication protocol. It can provide handshake signal, error detection, packet retransmission and other functions. In order to ensure the reliability and real-time of the communication, the serial communication protocol of the power transmitter defines the communication format under the framework of Modbus protocol. It is compatible with Modbus protocol and belongs to a subset of it. The frame composition format is as Table 1.

Table 1. Frame structure.

| Slave address | Function code | Data            | CRC   |
|---------------|---------------|-----------------|-------|
| 1 byte        | 1 byte        | 0 to 252 bytes  | 2 bytes |

Figure 4. Main program block diagram.
In this mode, when there is no transmission activation after the time interval of at least 3.5 characters, the communication link is called "idle" state; when the link is in idle state, any transmitted characters detected on the link are regarded as the beginning of the frame; the link enters into "active" state; then, when the time interval exceeds 3.5 characters and there is no transmission character on the link, the frame junction is considered. Beam; when the end of the frame is detected, CRC calculation and verification are performed.

4.3. Calibration Program Design
The calibration procedure is to calculate the errors of MAXQ3180 compared with the standard table in the calibration process, and then store the results in the calibration parameter register corresponding to MAXQ3180. At the same time, the calibration results shall be stored in the internal FLASH of CAT1025 for the initialization of MAXQ3180 after reset. There are many calibration parameters in MAXQ3180. Each type of calibration parameter has its corresponding calibration subroutine. During the calibration process, only one parameter is operated at a time. After each operation, the calibration parameter table in FLASH must be updated.

5. Summary
In this paper, through the exploration of the working principle and design scheme of the power transmitter monitoring terminal, combined with the characteristics of the distribution automation system and the current application status of the power transmitter monitoring terminal, aiming at the design requirements of the power transmitter monitoring terminal on site, the power transmitter monitoring terminal is successfully designed and manufactured. The terminal can collect and process the monitoring data and transmit data in many ways. According to the needs of the terminal, the self defined data communication protocol between the computer and the power transmitter is designed, and the commissioning of the power transmitter is completed. According to the need of system accuracy calibration, a computer software calibration platform is designed for the monitoring terminal of power transmitter, which simplifies the system calibration process and improves the efficiency of calibration.

Acknowledgement
This research was financially supported by the Jiangsu Province’s Natural Science Foundation under Grant BK20171114, Qinglan Projec, Jinling Institute of Technology Talent Introduction Project under Grant Jit-rcyj-201604.

References
[1] Ochoa, Luis Nando, et al. "Embracing an adaptable, flexible posture: ensuring that future European distribution networks are ready for more active roles." IEEE power and energy magazine 14.5 (2016): 16-28.
[2] Hong Y P, Lee W, Kong D W, et al. Kilowatt peak-power wideband active phased-array transmitter[C]/2017 IEEE MTT-S International Microwave Symposium (IMS). IEEE, 2017: 654-657.
[3] Cheng, Shuangshuang, et al. "A wireless monitoring system for a high-power borehole–ground electromagnetic transmitter." Geoscientific Instrumentation, Methods and Data Systems 8.1 (2019): 13-19.
[4] Wang, Meng, et al. "Research Progress in High Power Multi-functional Borehole-Ground Electromagnetic Transmitter for Metal Exploration." Technology and Application of Environmental and Engineering Geophysics. Springer, Singapore, 2017. 151-160.
[5] He, Yanlong, Changzhe Wu, and Xiaolin Huo. "Design of Ultrasonic Liquid Level Sensor Based on STM32 with MODBUS Protocol." 2016 International Symposium on Advances in Electrical, Electronics and Computer Engineering. Atlantis Press, 2016.
[6] Xue, Kaichang, et al. "Constant-current control method of multi-function electromagnetic transmitter." Review of Scientific Instruments 86.2 (2015): 024501.
[7] Baarman, David W., William T. Stoner, and Hai D. Nguyen. "Power supply." U.S. Patent Application No. 15/584,085.

[8] Bonisławski, Michał, and Marcin Holub. "Teaching modern power electronics—Computerized test stand design. "Computer Applications in Engineering Education 26.4 (2018): 928-937.