Research on Three-Phase Electronic Multifunctional Energy Meter

Guanghua Tong1, Xiaohua Liu1, Xinquan Li1, Guodong Sun2, Jian Mu2, and Liang Liu2

1Xinjiang Institute of State Grid Electric Power Research, Wulumuqi 830000, China
2Yantai Dongfang Wisdom Electric Co., Ltd, Yantai 264003, China

Abstract. A three-phase electronic multi-function smart meter is designed to improve performance, cost performance, accuracy, overload capacity, and electromagnetic compatibility. A measuring meter with conventional power parameters was developed based on the switching power supply and energy metering chip MCU. Users can meet the requirements of anti-theft, power grid harmonic content measurement. This paper provides solutions, implementation schemes and test methods for multi-function power meters. Designing a three-phase electronic multi-function energy meter with high reliability, low cost, high accuracy, and advanced performance.

1. Introduction
In order to accurately and efficiently conduct energy metering and better use of energy to serve the general public, more accurate and more powerful measurement tools are needed. Multi-function electric energy meters with multi-parameter measurement, energy metering, analysis, and control functions are rapidly growing in response to market demand. When the implementation or upgrading of each set of fuel gauge automation systems takes place, the demand for thousands of high-voltage three-phase electronic multi-function electric energy meters will be created with the promotion of electricity metering automation and the popularity of large-user meter reading in China's power system [1, 2]. The demand for tens of thousands of low-voltage three-phase electronic multi-function energy meters will be created when each large-scale meter reading system is implemented.

The power measurement automation technology has made great progress with the continuous development of computer technology and communication technology [3, 4]. The electricity metering automation system requires the use of a hierarchical, distributed and open structure, and must fully consider the comprehensiveness and practicality of the system's functions. It realizes automatic collection, remote transmission and storage, preprocessing, and statistical analysis of electrical energy data to support functions such as the operation of the electricity market, settlement of electricity charges, settlement of ancillary service charges, and calculation of economic compensation. Building a power enterprise data power application platform and fully use the power basic data to achieve statistics and analysis of all categories, all-round, and omni-directional line losses of the entire network, classification, voltage division, sub-line, and subarea [5, 6]. In order to achieve the purpose of improving the efficiency of line loss management and scientific management. At the same time, it provides the decision-making basis for the commercialization of the grid.
2. Integral frame of three-phase electronic multi-function meter
Designing and developing a new three-phase electronic multi-function energy meter to measure conventional power parameters and measure energy, as well as functions such as timing, display, alarm, and instrument self-test. Using the embedded system software and hardware collaborative design method, the basic functions and structural composition based on professional energy metering chip ATT7022B and single chip MSP430F449 system are designed. A reasonable allocation of MSP430F449 resources to complete the design features.

The three-phase electronic multi-function energy meter is mainly composed of a power supply and a management unit, an acquisition unit, a control unit, a display unit, a storage unit, a clock unit, and other units. Power meter block diagram is showed in Figure 1.

![Block diagram of three-phase electronic multi-function energy meter.](image)

Three-phase electronic multi-function energy meter uses a traditional wall-mounted structure. The entire table design uses three circuit boards, namely, power board, CPU board, and LCD liquid crystal display board. The power board mainly realizes the supply of the required power of the entire watch and the transformation of the strong and weak signals. The LCD panel implements various data and parameter display functions of the table. The CPU board mainly implements data acquisition, calculation, and storage. The electric energy meter, short design time, low cost, low power consumption, and reliable products by using the special chips. The voltage of each phase passes through a voltage divider resistor and each phase current passes through the current transformer, which are sent to the dedicated power chip. After the internal A/D conversion and operation processing, the corresponding energy, voltage, current and other data are calculated. Reading data from the MCU, after calculation and sorting and time-sharing processing, get the positive and negative active and negative power data of each rate, and send it to the display, alarm, output and other control units.

3. Hardware design of three-phase electronic multi-function meter
The electromagnetic compatibility of the circuit is fully considered for hardware circuit design of the three-phase electronic multi-function energy meter. A more reliable power meter power supply is designed to improve the lightning strike resistance. The use of serial EEPROM to store data was proposed for simplicity and security. Human-machine interface display is improved with MSP430F449. In addition, a dual power supply circuit for the load alarm circuit and each function module is also designed. Energy meter application schematic shown in Figure 2.
There are different requirements for the voltage input range of the meter, depending on where the meter is installed. Can be divided into 57.7V, 100V and 220V. Power supply for both input ranges of 57.7V and 220V requires a power input range of at least 80% to 90% of the nominal value.

The sampling voltage of the power board output to the CPU board is designed to be 18V. Three-phase electronic multi-function energy meter to withstand 4000V surge electromagnetic compatibility test, 6000V impact insulation voltage test. Because each resistor can withstand 500V voltage, the voltage sampling circuit uses eight RJ24 metal oxide film resistors, the voltage is reduced to 18V through the partial pressure method, and two 30V voltage regulators are used for overvoltage protection at 18V. Current sampling circuit is mainly current protection, using 1N5819.

Eight 1200V high-voltage diodes are used to compose the rectifier circuit to replace the rectifier bridge, convert the AC to DC, and improve the power surge protection capability and reliability of the three-phase electronic multi-function energy meter.

The switching power supply chip uses TOP232P. The chip is manufactured using an improved TOPS witch technology and integrates high-voltage power MOSFETs, PWM control, protection, and other control functions into one CMOS chip. The switching circuit provides four outputs, two 3.3V outputs, 5V outputs, and 5V isolation.

The system uses ATT7022B to complete three-phase energy metering. ATT7022B is a high-precision, suitable for three-phase three-wire and three-phase four-wire energy metering chip.

Selecting MSP430 series one-chip computer MSP430F449 of TI Company as the control core. It is easy to debug and speed up the development progress and future program upgrades, and has a good price. LCD monitors are used as human-machine interfaces to provide users with real-time data information.

4. Software design of three-phase electronic multi-function meter

The software uses the EW430 embedded development system. The system's software design follows a structured, modular, top-down, and step-by-step programming philosophy, which has greatly improved the stability and reliability of the meter. The IAR Embedded Work Platform EW430 was developed specifically for the TI 16-bit microcontroller MSP430 family. It provides a complete development environment for the MSP430 family, supports TI FET drivers, and includes a UML state table and software simulation tools. It is sufficient to meet the design and development of three-phase electronic multifunctional meter software.

The BOOT ROM jumps to the main program entry according to the JTAG debug port pin status, after the MSP430F449 system power-on reset. In the main program, first set the power-failure reset monitoring voltage (2.2V) of the power monitoring circuit, and then determine whether the system is
in the non-debugging state. If the WDT is not set to debug, the WDT is turned off, and then the system cross-border security check is performed. After that, the system is initialized and the main task cycle is entered. It waits for a response to a different interrupt, when the program enters the main task internal loop. Three-phase electronic multi-function meter software flow chart is showed in Figure 3.

**Figure 3.** Flowchart of software design main program.

The main task cycle includes: clear watchdog tasks, system monitoring tasks, communication protocol processing tasks, timing processing tasks, LCD display processing tasks, and event processing tasks. As shown in Figure 4.

**Figure 4.** Meter software design task flow chart.

The data acquisition module mainly realizes the reading of the measurement data. The data security processing is to remove abnormal data, correct the power data, and accumulate the power data, shut off, output power, output the demand, open the interrupt, and handle abnormal events.
5. Three-phase electronic multifunctional meter function debugging

The designed three-phase electronic multi-function energy meter mainly has the following functions:

(1) Measurement function: It can measure and record the forward active, reverse active, forward reactive, reverse reactive energy and maximum demand under the current four rates. It can measure three-phase voltage, current, active power, reactive power, total active power, reactive power, power factor and so on.

(2) Timing function: Internal real-time clock, with a hundred-year clock, with timing function.

(3) Display Function: Various parameters and data can be displayed through the LCD. Wheels can be displayed. The parameters and time of the wheel can be set.

(4) Power-off meter reading function: In the case of power outage, power is supplied from the internal power-off meter reading battery. The meter reading is performed by means of a round-robin button, which is divided into non-contact remote wake-up and manual wake-up.

(5) Self-test function: Power-on self-test. Check the validity of the energy data in the main chip and EEPROM, validity of calibration parameters. The error message is indicated by the LCD code.

The three-phase electronic multi-function meter reference standard is the basis for the design of the meter, and is also a prerequisite for the meter to obtain CMC approval and sales. In the design of three-phase electronic multi-function electricity meters, reference is made to the relevant standards for metering (such as GB/T 17883-1999 0.2S and 0.5S static ac power meter). Test the performance of the meter according to the detailed test methods and procedures of the test standard, so that all indicators of the meter meet the requirements of the standard. Basic error tests include positive active basic error tests, reverse active basic error tests, forward reactive basic error tests, and reverse reactive basic error tests. The method is to add rated voltage under the condition of the laboratory, and to measure the accuracy of the table by changing the size and direction of the current. Because the errors in the forward and backward directions are consistent, only the positive active basic error test results and the reverse reactive basic error test results are listed below.

Table 1. Positive active error.

| Power factor | allowable error % | Electric current Ia% | Actual relative error % | conclusion |
|--------------|-------------------|----------------------|-------------------------|------------|
|              |                   |                      | 01 | 02  | 03  |               |
| 1.0 ±0.5     |                   |                      | 120 | -0.05 | 0.00 | 0.00 | eligible |
|              |                   |                      | 100 | -0.04 | 0.01 | 0.01 | eligible |
|              |                   |                      | 50  | 0.00  | 0.02 | 0.02 | eligible |
|              |                   |                      | 5   | -0.02 | 0.01 | 0.01 | eligible |
| ±1.0 ±1.0    |                   |                      | 1   | -0.08 | -0.01 | -0.01 | eligible |
| 0.5L ±0.6    |                   |                      | 120 | -0.06 | 0.02 | 0.02 | eligible |
|              |                   |                      | 100 | -0.05 | 0.06 | 0.06 | eligible |
|              |                   |                      | 50  | -0.05 | 0.02 | 0.02 | eligible |
|              |                   |                      | 10  | 0.01  | 0.05 | 0.05 | eligible |
| ±1.0 ±1.0    |                   |                      | 2   | 0.02  | 0.06 | 0.06 | eligible |
| 0.8C ±0.6    |                   |                      | 120 | -0.04 | 0.05 | 0.05 | eligible |
|              |                   |                      | 100 | -0.01 | 0.02 | 0.02 | eligible |
|              |                   |                      | 50  | -0.02 | 0.02 | 0.02 | eligible |
|              |                   |                      | 10  | -0.02 | 0.02 | 0.02 | eligible |
| ±1.0 ±1.0    |                   |                      | 2   | -0.06 | -0.03 | -0.03 | eligible |
Table 2. Inverted active error.

| Power factor | allowable error % | Electric current Iₐ% | Actual relative error % | conclusion |
|--------------|-------------------|----------------------|-------------------------|------------|
|              | 1.0               |                      |                         |            |
|              | ±2.0              | 120                  | -0.04                   | eligible   |
|              |                   | 100                  | -0.02                   | eligible   |
|              |                   | 50                   | -0.04                   | eligible   |
|              |                   | 5                    | 0.07                    | eligible   |
|              | ±2.5              | 2                    | -0.06                   | eligible   |
| 0.5L         | ±2.0              | 120                  | -0.03                   | eligible   |
|              |                   | 100                  | -0.01                   | eligible   |
|              |                   | 50                   | -0.02                   | eligible   |
|              |                   | 10                   | 0.20                    | eligible   |
|              | ±2.5              | 5                    | -0.20                   | eligible   |
| 0.5C         | ±2.0              | 120                  | 0.08                    | eligible   |
|              |                   | 100                  | 0.04                    | eligible   |
|              |                   | 50                   | -0.10                   | eligible   |
|              |                   | 10                   | 0.20                    | eligible   |
|              | ±2.5              | 5                    | -0.50                   | eligible   |

It can be seen that the accuracy of the multi-function power meter has reached the design level of 0.5 from the results of the basic error test of active and reactive power. The phase shift caused by the current transformer and its influence on the measurement accuracy can be fully compensated by the AT7022B. The linearity of the current transformer is solved by using a subsection calibration method. It can be seen from the test results that the phase shift and linearity of the current transformer have no effect on the accuracy of the multi-function energy meter. It verifies the accuracy of the design.

6. Conclusion

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