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Automatic Monitoring and Control System of Distribution Network Transformer Energy Consumption Based on Single-Chip Microcomputer

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Abstract:
Distribution network transformers are widely used in power systems. Aiming at the problem that high energy consumption is easy to lead to energy waste, an automatic detection and control system of energy consumption of distribution network transformer based on single-chip microcomputer technology is proposed. The control center of the system design is a single-chip microcomputer, which calculates the transformer load through the multi-function meter, and sets the corresponding gear adjustment threshold to adjust the capacity of the transformer, so as to reduce losses and save energy. After case verification, this method can greatly improve the energy-saving effect of distribution network transformers, and at the same time operate stably and reliably.

Keywords: Single-chip microcomputer, distribution network transformers, load loss, GPRS DTU module, communication

INTRODUCTION

At present, the total energy consumption of transformers accounts for about 10% of the overall power generation, and there are two methods to monitor the energy consumption of transformers now. (1) Monitoring the load power in the power demand side area need compare the losses of different operation types through the energy saving function, and then adjust the transformer ratio in terms of the actual operation situation. Although this can save energy and reduce costs, there are some defects such as insufficient energy saving, long switching period, insufficient intelligent switching, and complex operation. (2) Combined with the microcontroller monitoring and the control of energy consumption of transformer in the distribution network, different parameters of transformer operation are controlled in real time. At the same time, the capacity of the transformer can be automatically adjusted through the change of transformer load, so as to reduce costs and increase efficiency and save energy.

CONTROL SYSTEM DESIGN

The microcontroller is used as the monitoring and control center to collect the load data of the transformer during operation [1, 2]. The load data is analyzed and the gear corresponding to the transformer capacity is shifted, so as to reasonably distribute the electric energy and control the energy consumption of the distribution network transformer. The overall flow chart of automatic detection and control of the distribution network transformer combined with the microcontroller is shown in Figure 1.

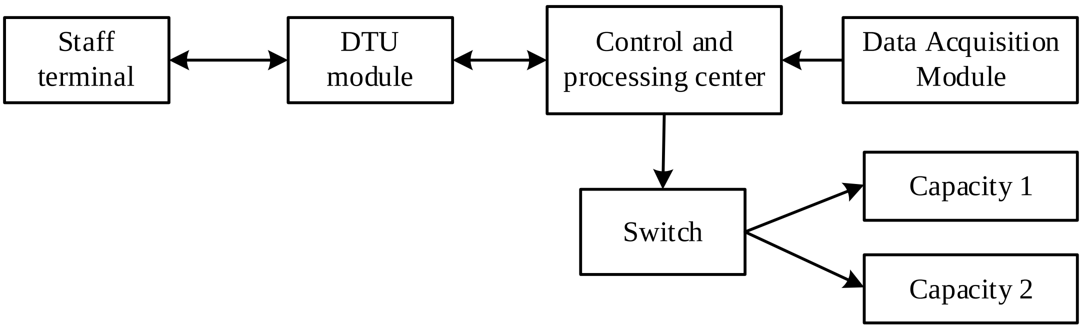

Figure 1. Schematic diagram of automatic detection and control system

The system collects the operating parameters of distribution network transformers through the data acquisition module, transmits the data information to the control center, compares it with the given threshold, and judges whether it is necessary to adjust the gear by comparison. If the gear needs to be shifted, the control center instructs and the instruction switch accepts it and switches accordingly [3].

The control center is connected to the GPRS DTU module, which communicates with transformers in real time, so as to know the data information in time [4-6]. At the same time, the GPRS DTU module can be used for alternative manual intervention to shift gears to ensure the stable and safe operation of the system.

And the time-specific lag margin is set to reduce the number of gear shift and the energy consumption of transformers. When the high gear is shifted to the low gear, the delay time is 30min; When the low gear is shifted to the high gear, the delay time is 0.5min.

SYSTEM HARDWARE DESIGN

Data Information Acquisition Module

The multifunctional electronic electric energy meter is used as a module for collecting system data, collecting real-time information and calculating load power and real-time electricity quantity [7].

The schematic diagram of the specific working principle of the multifunctional meter is shown in Figure 2.

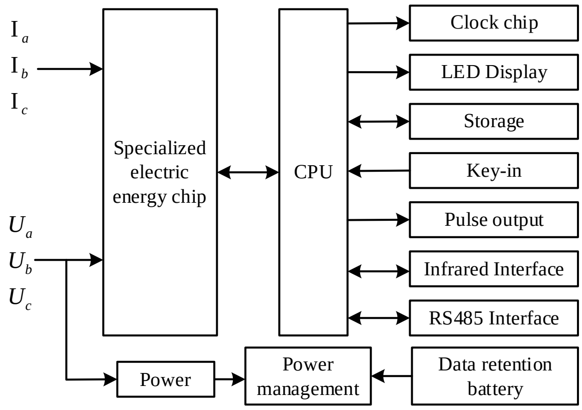

Figure 2. Schematic diagram of the working principle of the multifunctional meter

In Figure 2, the distribution network voltage is divided by resistors, and the current is sampled by current transformers and voltage transformers to be transmitted to the power chip. Through A/D conversion, the analog quantity is converted into corresponding digital quantity, and then transmitted to CPU for further analysis and calculation. CPU can read the data collected by the power chip, and process other output and input data at the same time, as well as realize time-sharing accounting. In terms of the corresponding time period, the maximum demand and the active energy are measured. The corresponding LCD display can display the data obtained by operation acquisition [8].

The multifunctional meter communicates with other circuit devices through RS485 interface or infrared interface. At the same time, the changes of different parameters in the operation process are monitored in real time, and recorded and stored.

Control Processing Center

In designing the system, the STC89C52 microcontroller was selected because it can be compatible with the MCS51 instruction system and Flash ROM can be erased and rewritable. Besides, the number of bidirectional I/O ports is 32, and 3 internal RAM, with the specification of 256×8bit, as well as the 6-bit programmable counter interrupts, 2 serial interrupts, 2 external interrupt sources, 2 read-write interrupt lines, with the 0-24MHz clock frequency, and the Level-3 encryption bit. And it also features low-power consumption idle and power-down modes, and includes programmable UART serial ports. The chip can set the corresponding wake-up and sleep functions through software [9-11].

GPRS DTU

GPRS DTU module is the corresponding wireless transmission module, through which the data information of distribution network transformers can be transmitted accurately and timely. When applying the GPRS DTU module, it is necessary to set the relevant parameters of the GPRS DTU module first, so as to ensure the reliable transmission of data information [12].

First of all, the transmission rate during communication is set to 38400bit/s by AT+IPR=38400 instruction. The initial default value of such value in the GPRS DTU module is 9600bit/s, which can be adjusted in light of the actual situation.

The second is to set the network as a Monternet. The adopted instruction is AT+CGD CONT=1, “IP”“CMNET”, and the access gateway corresponding to GPRS is changed through this instruction.

The third is to set up a mobile terminal, and the instruction adopted is AT+CGCLASS= “B”. Through this instruction, a Class B mobile terminal is set, and different services are monitored simultaneously through the mobile terminal. However, it is impossible to run multiple services at the same time by, intelligently selecting one of GSM voice communication and GPRS service to run at any time.

The fourth is to test the GPRS service and activate it through AT+CGACT=1. When ERROR is displayed after returning, it indicates that the GPRS service is not activated. It is necessary to confirm the service opening of the SIM card and check whether the antenna of the GPRS module is installed correctly. The GPRS service has been successfully activated in case of displaying OK after running.

Gear Shift

Closing or disconnecting the corresponding AC contactor so that the motor rotates counterclockwise or clockwise, thus shift the low-capacity or high-capacity gears of the transformer. The system designs two AC contactors, C1 and C2, and the specific schematic diagram of switch wiring for gear shift is shown in Figure 3.

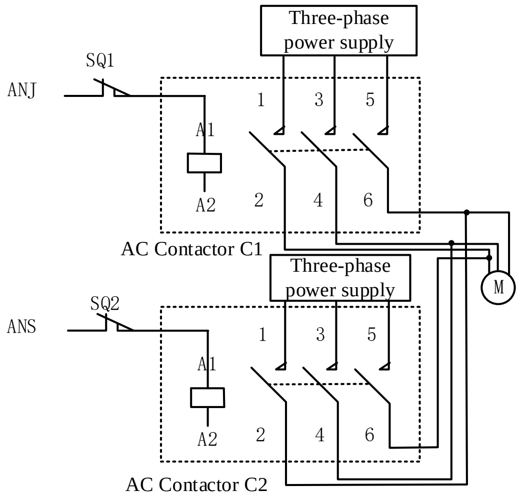

Figure 3. Schematic diagram of gear shift

In Figure 3, ANS refers to the capacity-raising button, i.e., the high-gear button. When the ANS high-gear button is pressed, the C1 AC contactor is electrically closed, and the motor rotates clockwise. After successful gear shifting, the normally closed contact of the travel switch is disconnected, and the power supply of the control line loses power, so that the C1 AC contactor loses power, and the motor no longer rotates, as well as the normally open contact of the travel switch is closed. Therefore, the transformer changes to a high-capacity state. At this time, the low-voltage side is connected in parallel and the high-voltage side is connected in triangles.

ANJ refers to the capacity reduction button, i.e., the low-gear button. When the ANJ low-gear button is pressed, the C2 AC contactor is electrically closed and the motor rotates counterclockwise. After successful gear shifting, the normally closed contact of the travel switch is disconnected, and the power supply of the corresponding control circuit loses power, so that the C2 AC contactor loses power, and the motor no longer rotates, as well as the normally open contact of the travel switch is closed. Therefore, the transformer changes to a low capacity state. At this time, the low voltage side is connected in series and the high voltage side is connected in a star shape.

Adjustable Capacity Design of Transformers

The transformer in the distribution network is improved to ensure that it can adjust its capacity in terms of the load. When the transformer is of high capacity, the winding is connected with the delta connection; while the transformer is of low capacity, the winding with the star connection.

Since the number of turns of large-capacity coil and small-capacity coil is certain, the design of conductor cross-section needs to be based on the large-capacity coil. In this case, large-capacity coils are connected with the delta connection and small-capacity coils with the star connection. The capacity expression can be expressed as Formula (1) and Formula (2).

$$S_\Delta = 3 I_\Delta U_\Delta \tag{1}$$
$$S_Y = 3 I_Y U_Y \tag{2}$$

In formulas (1) and (2), the high capacity of the adjustable transformer in the distribution network is SΔ, and the low capacity SY. The phase current at high capacity is represented by IΔ; the phase current at low capacity by IY; the phase voltage at high capacity UΔ; and the corresponding phase voltage at low capacity by UY.

Under the condition of high capacity and low capacity, the corresponding short-circuit impedance of the distribution network transformer can be obtained by Formula (3) and Formula (4).

$$U_{\Delta k} \propto I_{\Delta} \times N_{\Delta}/e_{t\Delta} = I_{\Delta} \times N_{\Delta}^2/U_{\Delta} \quad (3)$$

$$U_{Yk} \propto I_{Y} \times N_{Y}/e_{tY} = I_{Y} \times N_{Y}^2/U_{Y} \quad (4)$$

In formulas (3) and (4), the short-circuit impedance of the transformer at high capacity is represented by UΔk, and the short-circuit impedance at low capacity is UYk. The number of turns of the high-voltage coil at high capacity is NΔ, and the corresponding number of turns at low capacity is NY. The turn potential table at high capacity is shown as etΔ, and the turn potential table at low capacity as etY.

In the above formula, UY=$\frac{U_{\Delta}}{\sqrt{3}}$, and Formula (2) can be expressed in the form of Formula (5).

$$S_Y = 3I_YU_Y = 3I_Y \times \frac{U_{\Delta}}{\sqrt{3}} \quad (5)$$

At the same time, $N_{\Delta} = N_Y$, Formula (4) can be expressed in the form of Formula (6).

$$U_{Yk} \propto I_Y \times N_Y/e_{tY} = I_Y \times N_Y^2/(U_{\Delta}/\sqrt{3}) \quad (6)$$

When under the 630kVA transformer capacity, the short-circuit impedance is usually 4%, so $U_{Yk} = U_{\Delta k}$, and it can derive the Formula (7).

$$I_Y = \frac{I_{\Delta}}{\sqrt{3}} \quad (7)$$

Formula (8) can be derived from Formula (7) and Formula (5).

$$S_Y = 3I_YU_Y = 3\frac{I_{\Delta}}{\sqrt{3}} \times \frac{U_{\Delta}}{\sqrt{3}} = I_{\Delta} \times U_{\Delta} \quad (8)$$

From Formula (1) and Formula (8), Formula (9) can be derived.

$$S_{\Delta} = 3S_Y \quad (9)$$

In Formula (9), when the low capacity of transformers is about 33.3% of the high capacity, the short-circuit impedance can be relatively consistent.

Since the number of turns of high-capacity high-voltage coils and low-capacity high-voltage coils should be equal, and the high-capacity phase current is 1.732 times that of low-capacity phase current. Therefore, for the number of turns of low voltage coils, the number of high-capacity coils should be 0.577 times that of low-capacity coils. A low-voltage winding consists of three parts, of which the cross-sectional areas of the first part and the second part should be 0.5 times that of the third part, which should be 0.27 times the total turns of the low-voltage coil, and the first part and the second part should be 0.73 times the total turns through parallel connection. The schematic diagram of transformer connection at different capacities can be shown as Figure 4.

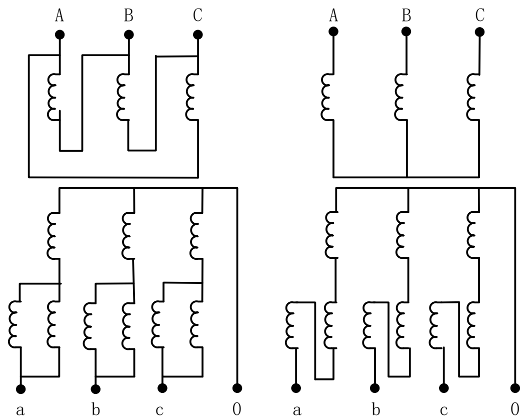

Figure 4. Schematic diagram of transformer connection at different capacities

When the transformer is shifting gears, it is necessary to change the phase voltage on the high voltage side into 0.577 times the previous value and the turns on the low voltage side into 1.73 times the previous number.

In terms of Formula (10), when the number of turns of the high-voltage coil is constant, the increase of turns of the low-voltage coil will lead to the decrease of the corresponding magnetic flux density of the transformer core and the decrease of the loss of the silicon steel sheet, resulting in the decrease of no-load current and no-load loss. Usually, when the transformer is low-cylinder grain, the no-load current can be reduced to 70% of the general loss, and the no-load loss to 30% of the general loss.

$$\frac{U_l}{U_h} = \frac{N_l}{N_h} \tag{10}$$

RESULTS TEST AND ANALYSIS

Gear Shift Test

The STC89C52 microcontroller can be expanded with two serial ports to connect a GPRS DTU module and a multifunctional meter. When connecting, both work in time sharing through the RS485 standard. During the test, the UART interface of the microcontroller and RS485 interface of the multifunctional meter are connected through a MAX485 converter. The microcontroller reads power data through a RXD pin. The connection between the multifunctional meter and the microcontroller can be shown in Figure 5.

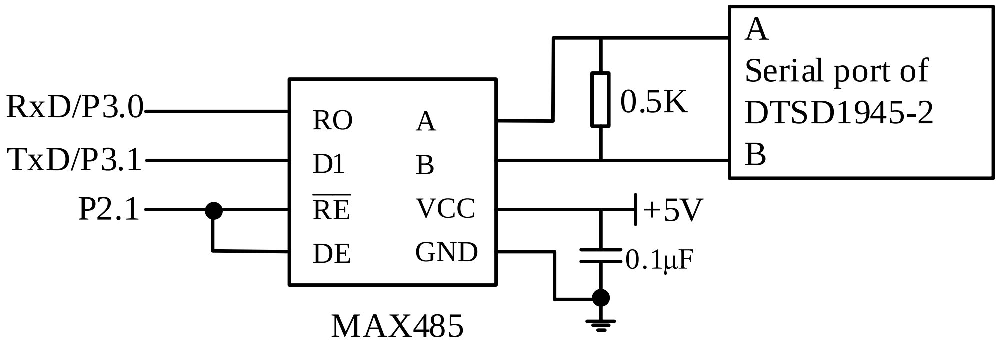

Figure 5. Connection diagram of the Multifunctional meter and the microcontroller pin

In the actual test, the transformer capacity specification is set at 630/200kVA, where 630kVA is high capacity and 200kVA is low capacity. The control output of the microcontroller selects pin P2.0, and the relay behind controls the two corresponding high and low gear shifting buttons respectively. The threshold value of the corresponding power of the controller is set to 180kVA. In actual monitoring, the time-lag margin of shifting from high capacity to low capacity is set to 30s, and that for shifting from low capacity to high capacity is set to 5s. The lag time of shifting from low capacity to high capacity should be as small as possible under the premise of actual situation, so as to reduce the occurrence of overload.

The test takes the electricity consumption of a certain community as the test subject. The collection of power data is completed by a multifunctional electric meter. The electricity load of the community in one day is shown in Figure 6.

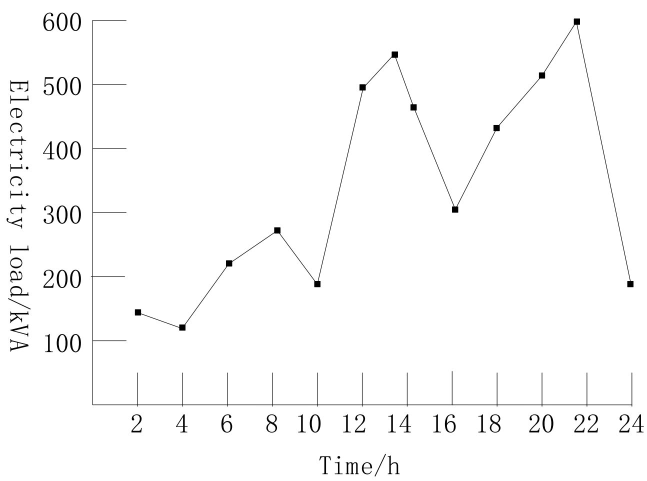

Figure 6. The electricity load of the community in one day

In Figure 6, the load of the community is usually the smallest from 03:00 to 04:00, the peak power load from 12:00 to 13:00, and the maximum power load in one day from 21:00 to 22:00.

The energy consumption of improved system transformer is compared with that of conventional distribution network transformer, such as Figure 7.

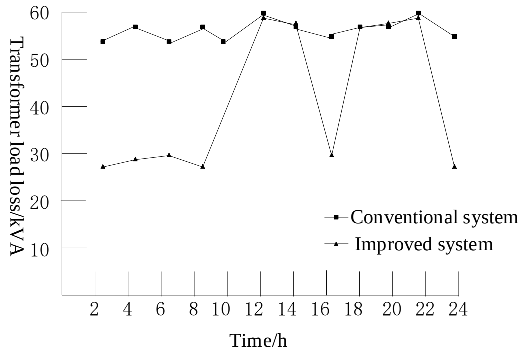

Figure 7. Comparison of transformer load losses

In Figure 7, the percentage of low-gear transformer after improvement is close to 52%. The improved system can monitor and automatically control the energy consumption of distribution network transformers in real time to reduce the energy consumption of transformer system.

GPRS DTU Module and System Comparison

The bidirectional communication between mobile terminal and microcontroller is realized by the GPRS DTU module. The interface between the GPRS DTU module and the microcontroller is the RS485 serial port. Usually, depending on the corresponding threshold can carry out the corresponding gear shift. When it is impossible to shift the gear automatically under special circumstances, the staff can also perform through the GPRS DTU module to peer and instruct the microcontroller to shift gears. The pin connection diagram of the GPRS DTU module can be shown as Figure 8.

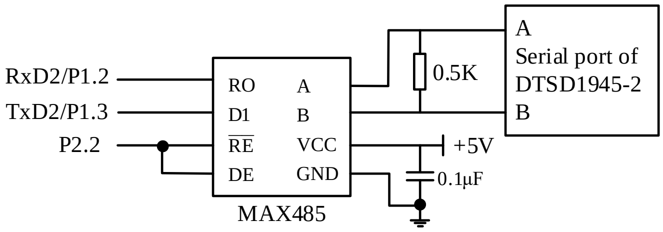

Figure 8. Schematic diagram of the GPRS DTU module pin connection

In Figure 8, the GPRS DTU module is connected to the serial port 2 corresponding to the microcontroller through RS485, with a total of 7 data bits, which are verified by means of an even parity, and the bit rate is 9.6kbit.s.

By setting the above parameters, the improved transformer monitoring and control system is compared with the conventional transformer system. Without considering other factors, the comparison results of the percentage of households without power failure in a quarter are shown in Figure 9.

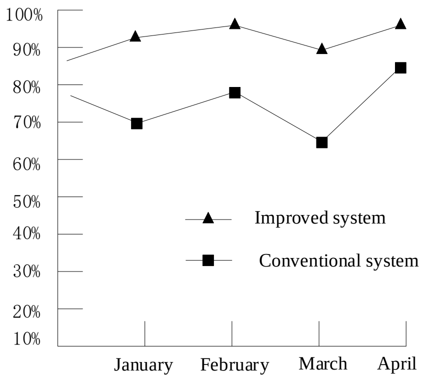

Figure 9. Proportion of households without power failure

By combining the STC89C52 microcontroller, it is used as a control center to receive the real-time data of transformer operation, analyze and calculate it at the same time, and give corresponding control instructions in terms of the results. The GPRS DTU module is used as te communication module. The example verifies that the energy consumption of transformers can greatly save energy. In the case of low power load, the transformer can shift the corresponding gear based on the power load, to ensure the corresponding power demand and less loss, so as to ensure the power system to maximize energy savings and stable and reliable operation.

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