Design of current protection and automatic reclosing system based on programmable logic controller

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Abstract. Current protection is the most typical relay protection mode for 35kV and below power lines. With the continuous expansion of medium-low voltage distribution network, line current protection has become an important guarantee for reliable operation of the power grid. In order to find a better current protection scheme, this paper proposed the use of programmable logic controller (PLC) to realize three-stage current protection and automatic reclosing of medium-low voltage lines. This design covered the overall design of system structure and function, the hardware design of PLC's peripheral modules and interface circuit, and the software design of the ladder diagram programming. In addition, remote communication technology was introduced, achieving upper computer's configuration monitoring of on-site data. It was verified by the simulation experiment that the system design realized the anticipated function successfully. It can satisfy basic requirements of distribution system's protection and has high reliability in power line's three-stage current protection.

1. Introduction

Current protection is the most typical relay protection mode for 35kV and below power lines. Due to the wide distribution and high failure rate of medium and low voltage lines [1], it is necessary to find a superior current protection scheme with greater reliability, functional characteristics and cost effectiveness, thus ensuring secure operation of power system.

Traditional three-stage current protection device is composed of electromagnetic relays, which have obvious disadvantages such as poor reliability, complicated wiring, large device size and short service life [2, 3]. With the rapid development of protection technology, single-chip microcomputer has been widely used in current protection and reclosing systems, and microcomputer protection device has quickly become the mainstream of current protection and reclosing devices. However, the programming and debugging of microcomputer protection is more complicated, making it hard for workers to learn and master.

In order to make up for shortcomings of the above two protection methods, this paper proposed a new current protection and reclosing implementation scheme—using PLC to design a three-stage current protection and automatic reclosing system. The PLC protection system combines the powerful control functions of microcomputer protection with the simple and easy-to-understand features of traditional electromagnetic relay protection, which can better meet the control requirements of line current protection [4].

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2. Overall Design

2.1. System Structure

The PLC protection system designed in this paper conforms to the common rule of relay protection installation constitution, which includes three parts: measurement, logic and execution [5]. The structure diagram is shown below:

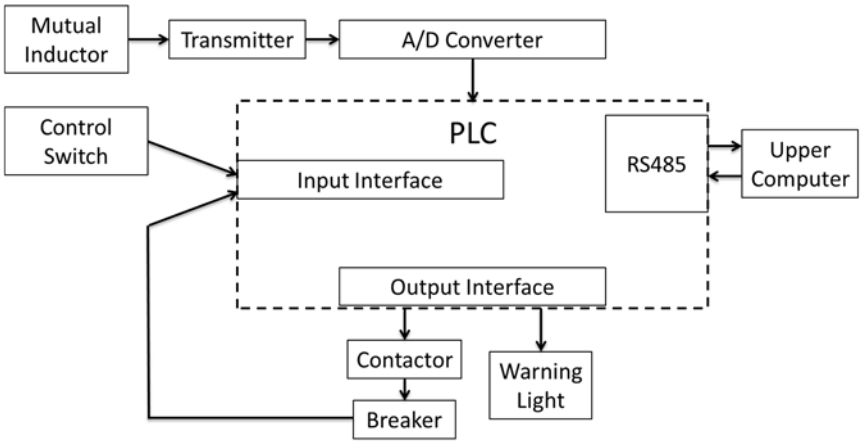


Figure 1. Structure diagram of protection system based on PLC.

As shown in Figure 1, the installation is mainly composed of measurement and acquisition circuit, A/D module for converting analog current values into digital form, logic element (PLC), buttons and switches for issuing control command, drive circuit for controlling circuit breaker, communication circuit, and so forth.

2.2. Working Process

The way this system works is as follows:

Current mutual inductor detects the AC current signal of power lines and sends it to transmitter, which converts its received signal linearly into 4~20mA DC standard signal. After that, the signal is fed into an A/D converter and transferred linearly into digital signal, which can be identified by the CPU of the programmable controller.

PLC determines whether to start current protection according to the magnitude of this digital signal, and if it starts, PLC also needs to determine whether to perform reclosing according to the actual working condition of power lines.

Finally, the judgment results are embodied in state changes of output contacts of PLC [6], thereby driving the contactor to control circuit breakers to operate correspondingly, and in the meanwhile generating corresponding displays and warning messages on the upper computer.

3. The Hardware Design of System

Based on the signal transformation process, the hardware design was divided into designs of four sub-circuits: current acquisition, A/D conversion, PLC, and drive circuit.

3.1. Current Acquisition Circuit

Current acquisition circuit includes current mutual inductor and transmitter.

The mutual inductor reduces the large current in lines on the primary side line to a small current value that can be used for measurement and protection; and it also acts as an electrical isolation [7, 8].

The transmitter linearly converts the input current into a standard 4-20 mA industrial signal and then transmits it to the A/D converter.

3.2. A/D Converter

It converts the continuously changing analog signal outputted by the transmitter into digital signal and then sends it to PLC. The analog input module of PLC is essentially an integrated multi-channel A/D converter.

3.3. PLC

With microprocessor as the core, PLC is a kind of new automatic control device where there is a series of internal programmable storage. It is the central part of protection system.

3.4. Drive Circuit

As a result of the weak drive capability of PLC's output contacts, PLC cannot directly drive the tripping and closing coils of circuit breakers. Therefore, contactors are used in this paper as the drive circuit for expanding the contact capacity.

4. The Software Design of System

Software design is the most crucial part for the system's function implementation. This part mainly includes two aspects - PLC ladder program design and configuration monitoring interface design. The former controls circuit breakers to trip or close, and the latter realizes remote display and operation function via the upper computer.

4.1. PLC Ladder Program Design

Composed of contacts, coils and box commands, ladder diagram is the most widely-used PLC programming language. The contacts represent input conditions, and the coils represent output results, which is similar to traditional relay control diagram so it is intuitive and easy for workers to understand and master.

Structured programming is adopted in this paper. The PLC program consists of five subroutines, which complete initialization, module check, current sampling, tripping, and closing.

The program judges the operating state of the system according to line current value and external operation instructions, and accordingly completes the tripping and closing control of circuit breakers. Note that there are many factors to be considered for automatic reclosing. When the following four conditions occur, the reclosing should not be started: manual closing on the fault lines, manual tripping, reclosing manually blocked, and tripping again due to the permanent fault.

4.2. Remote Monitoring Design

To satisfy the automation requirements of power system, the man-machine monitoring interface is drawn by configuration software on the upper computer of the substation, and telecommunication technology is applied to realize the telemetry, remote signaling, remote control and remote adjustment of the current protection system [9].

Since PLC can carry out data transmission with the main control unit of the substation by way of computer communication mode, PLC is used as the lower unit, and the microcomputer equipped with configuration software is used as the upper unit. If the lower unit finds any abnormality, it immediately issues an alarm on the remote monitoring interface of the upper computer, so that the on-duty personnel can find and handle the problem in time, greatly shortening the inspection time, effectively avoiding the expansion of the fault, and ensuring the safe and stable operation of the power distribution system.

5. Simulation Experiments and Results

In the simulation experiments, the coils with different resistance values were used to simulate the line impedance and load. Wires were connected between the resistance wires of coils and the ground line to simulate short-circuit faults at different positions of the line. The specifications of current mutual inductor and transmitter were selected according to the experimental current range; the model selection of PLC and A/D convertor was S7-200 and EM235 respectively; the circuit breakers in the experimental

circuit were simulated by AC contactors; the software tools adopted in the experiments were STEP 7-MicroWIN V4.0 and Kingview 6.55.

The experimental process was as follows:

(1) At the beginning, the main contacts of contactors had not been closed yet, and the current values the upper computer monitored were 0.000A.

(2) Press the remote manual closing button, the corresponding contactor instantaneously pulled in, the monitoring current values were normal operating current value of lines; when the manual tripping button was pressed, the contactor instantly tripped and did not automatically get reclosed, and the monitoring current values were reduced to zeros.

(3) Under normal operation of the system, the transient short-circuit faults were simulated repeatedly in different positions of the line, the contactors tripped according to the current threshold and time delay based on protection setting calculation. The experimental results were identical to theoretical analysis results.

(4) When the remote reclosing block switch was turned on and the faults were simulated as described above, the corresponding contactor tripped and no longer got reclosed.

(5) Set the reclosing mode switch to post-acceleration mode and simulate a permanent short-circuit fault in the rear of the line. The contactors would trip after a time delay for the first time; since the fault still existed after reclosing, the contactors instantaneously tripped and no longer got reclosed.

(6) Set the reclosing mode switch to pre-acceleration mode and simulate a permanent short-circuit fault in the rear of the line. The contactors would trip instantaneously for the first time; since the fault still existed after reclosing, the contactors tripped after a time delay and no longer got reclosed.

(7) When remote manual closing button was pressed at the same time as a line failure was simulated, the contactors tripped and no longer got reclosed.

During experiments, the alarming window on the upper computer monitoring interface would record corresponding information according to changes of the line operation, as shown in Figure 2. Simulation experiments showed that this current protection and reclosing system design was feasible. Because the system has the characteristics of high reliability, low cost, good convenience, it possesses great engineering practical value.

Date	Time	Warning Content
2016/5/31	19:19:50…	Automatic tripping
2016/5/31	19:19:50…	QF1 switched off
2016/5/31	19:19:38…	Post-acceleration mode chosen
2016/5/31	19:19:35…	Automatic reclosing started
2016/5/31	19:19:35…	QF1 switched on
2016/5/31	19:19:33…	Automatic tripping
2016/5/31	19:19:33…	QF1 switched off
2016/5/31	19:19:04…	QF1 switched on
2016/5/31	19:19:04…	QF1 manual closing order
2016/5/31	19:18:57…	QF2 switched on
2016/5/31	19:18:56…	QF2 manual closing order

Figure 2. Information records on the alarming window of King view.

6. Conclusion

This paper presented a new current protection and automatic reclosing system design method based on programmable controller. The system not only has a relatively complete circuit breaker controlling function, but also realizes the integration of protection, control, measurement and data communication. PLC realizes the relay protection of lines and the tripping and closing control of circuit breakers, and the communication technology is introduced to realize the centralized monitoring and remote operation of the system by relevant technician, which is helpful to construct a superior current protection system

with high automation level and great reliability and realize information management. Therefore, the application of PLC-based current protection in power distribution systems is promising.

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