Research on Relay Protection Technology Based on Smart Grid

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Abstract. Smart grid is a new direction for the development of my country's power industry. Relay protection, as the first line of defense to ensure the safe operation of the power grid, needs to actively adapt to the power grid reform. The thesis first introduces the related technologies of relay protection, and proposes a fault diagnosis method for distribution network based on the characteristics of the sequence information of relay protection. Finally, the simulation of electromagnetic transient and diagnosis method is carried out on the PSCAD platform, and the results of calculation examples verify the accuracy and effectiveness of the diagnosis method.

Keywords: Smart grid, relay protection, timing information characteristics, fault diagnosis technology.

1. Introduction
Since the advent of overcurrent relays in power systems, a century has passed. Traditional protective relaying principles were developed before the 1930s, and were based on the measurement of power frequency signals in fault detection. With the advancement of modern technology, in the field of power system protection, microprocessor-based digital relays are gradually replacing traditional relays. At the same time, many new protection concepts and solutions have emerged. The development of smart grids in China has the following characteristics: in terms of power generation, coal-fired thermal power units account for the main proportion of installed power generation capacity in China, while the gap between the supply and demand of primary fossil energy and serious environmental pollution are becoming increasingly prominent, and it is necessary to actively develop wind power, solar energy, etc. Renewable energy power, optimize the energy supply structure, reduce the pressure of energy saving and emission reduction; in terms of power transmission, China’s energy and load are distributed in reverse, and the energy centre and the load centre are thousands of kilometres apart. It is necessary to build an ultra-high voltage cross-regional transmission network. Realize the optimal allocation of energy resources and improve economic benefits; in terms of power distribution, with the access of distributed power sources, the distribution network has changed from a single power supply mode to a multi-power supply mode, and the power flow distribution has undergone great changes. The promotion of smart power services the two-way interaction between the power grid and users has been increased, and the way of power consumption has changed [1]. The common feature of adaptive, artificial intelligence, transient, wide-area, integrated protection, and newly developed protection based on parameter identification is...
intelligent protection. With the progress of modern technology, especially the overall development of smart grids, the future development direction of relay protection will be intelligent protection based on high-performance computer technology and advanced communication networks.

2. Introduction to Relay Protection Technology

2.1. Analysis of protection scheme
Since the traditional distribution network is mostly a single power radial structure, its protection configuration is relatively simple. At present, there are mainly two configuration schemes for relay protection in domestic distribution network:

2.1.1. Adopt the traditional three-stage current protection scheme. Instantaneous current quick-break protection, time-limited current quick-break protection and overcurrent protection. Among them, the current quick-break protection is set according to the maximum short-circuit current that flows through the protection when the end of the line is short-circuited, and the instantaneous action removes the fault, but it cannot protect the entire length of the line; the time-limited current quick-break protection is sensitive and has sufficient sensitivity when the end of the line fails. The principle of setting in coordination with the instantaneous current protection of adjacent lines can protect the entire length of the line; the overcurrent protection is set in accordance with the principle of avoiding the maximum load current of the line and cooperating with the overcurrent protection of adjacent lines to protect the line and phase the full length of the adjacent line. In addition, for terminal lines that do not need to cooperate with adjacent lines, the current quick-break protection is set in accordance with the principle of sufficient sensitivity for short-circuit at the end of the line to protect the entire length of the line [2].

2.1.2. Adopt inverse time limit overcurrent protection scheme. Inverse time overcurrent protection is a kind of protection related to the protection action time limit and the short-circuit current in the protected circuit. The greater the short-circuit current, the shorter the protection action time limit, that is, the protection action time limit is short when a near fault occurs, and when a slightly distant fault occurs the protection action time limit is short, and the action time limit is longer in the case of a remote fault. The protection can meet the requirements of quick action and selectivity at the same time, and it is widely used in the relay protection of the distribution network.

2.2. Wide area protection

2.2.1. Wide area centralized type. As shown in Figure 1, the wide-area centralized decision-making host is located in a central station of the system, and its coverage is the entire regional power grid. The number of plants and stations included can reach dozens or more. With the protected equipment as the basic unit, through direct concentration all information is used for fault judgment. This mode has the largest information concentration, the most comprehensive fault detection angle, and the highest requirements for protecting the host's security and processing capabilities.
2.2.2. IED is distributed. Figure 2 shows the distributed structure of the IED. The decision-making unit of this mode is the IED components distributed at each protected device. Each IED collects local information and interacts with the relevant IED to complete the protection function. The advantage of this mode is that the protection structure is flexible, the adaptability is strong, and the dependence on a single decision-making element is low, but its disadvantages are the large amount of information exchange, complex protection configuration, and high requirements for communication conditions.

2.2.3. The mode of station area concentration and regional distribution. Figure 3 shows the mode of station domain concentration and regional distribution. This mode includes both station domain protection functions and regional protection functions. The station domain protection realizes the backup protection function of the components in the station. The station domain master set in each plant station centralizes the information of each component of the station, and each station serves as a regional protection substation to form a distributed system. The area protection is mainly aimed at the failure of
the connection line between the stations, and the judgment is made by the interaction information of the relevant station domain host, and at the same time, it provides the remote backup function for the components in the station. Compared with the wide-area centralized mode, the coordinated mode of the station area has lower requirements on the computing power and security of the main station, short communication delay, and high correlation of the exchange information; compared with the distributed IED, its information exchange mechanism for judging the fault is simple, and the repetitive work of fault identification is less, which is conducive to the development of the backup protection in the direction of simplified configuration [3]. The mode of coordination between station area and area has advantages in rationality and feasibility, and is currently a relatively ideal way to constitute a wide-area backup protection system.

![Diagram](image)

**Figure 3.** The mode of site concentration and regional distribution

### 3. Relay protection failure analysis and timing relationship model

A line failure will generally cause the current in the line to exceed the setting value of the current protection. In order to ensure that the relay protection device can reliably remove the fault, and taking into account the short line length in the radial distribution network, each section of the line is equipped with three sections Type current protection. In the three-stage current protection, instantaneous current quick-break protection (current section I), time-limited current quick-break protection (current section II) and definite overcurrent protection (current section III) cooperate with each other in time. Let 

\[ T_{i,I}, T_{i,II}, T_{i,III} \]

denote the protection delays of protection i, current section I, current section II, and current section III respectively. For protection i, there is \( T_{i,I} \leq T_{i,II} \leq T_{i,III} \). The relationship between the action time of the current protection and the fault current and the three-stage setting value is shown in Figure 4.
3.1. Time series relationship model

After a fault occurs, first the three-stage current protection is activated, and after the corresponding protection delay, one of the protections is tripped according to the coordination relationship, and the circuit breaker is activated at the same time. After the action time limit of the circuit breaker, the circuit breaker is finally tripped and recorded by SOE. Upload relevant information in the form [4]. Therefore, according to the evolution process of the fault in the distribution network, without considering the time error in the information transmission, the SOE information has the time sequence relationship shown in formula (1).

\[ t_{BRK} = t_s + \Delta T_{RP} + \Delta T_{BRK} \]  

In the formula: \( t_{BRK} \) is the circuit breaker tripping time in the SOE information; \( t_s \) is the protection start time; \( \Delta T_{RP} \) is the corresponding protection action time delay; \( \Delta T_{BRK} \) is the circuit breaker action time limit. Since the process from the occurrence of the fault to the protection start can be ignored, the formula (1) is used to obtain the calculation formula of the fault time \( t_{fault} \), as shown in the formula (2).

\[ t_{fault} \approx t_s = t_{BRK} - \Delta T_{RP} - \Delta T_{BRK} \]  

3.2. Fault location judgment rule based on protection cooperation

The time limit characteristics of the above current protection show that when both the circuit breaker and the protection are operating correctly and the synchronous SOE information is accurately uploaded, the protection start-up situation is related to the location of the fault [5]. According to the protection cooperation relationship, the fault location can be initially determined, as shown in Table 1.

| Protection action | Fault location |
|-------------------|----------------|
| Upper level II, III, this level I, II, III | Within the backup protection range of the upper stage II section of the line |
| Upper level III, this level I, II, III | Outside the backup protection range of the upper-level section II of this level line, and within the range of the current level section I |
| Upper level III, this level II, III | Outside the protection scope of section I of this level line |
Whether the first stage of the line protection is activated or not can initially determine the location of the fault. If the first stage is activated, the fault occurs within the protection range of the current line I, otherwise it is outside the protection range of the current line I. When section I of this line is started, the start of section III and section II of the upper protection can further reduce the range of fault locations. If the upper protection stage II is activated, it means that the fault occurred in the upper stage II backup protection range of the line, otherwise it is outside the upper stage II backup protection range and within the current stage I protection range [6]. Taking into account the protection error action and information loss in the fault diagnosis, for any protection, suppose the probability of the fault current flowing but the fault information being missed is $p_M$, and the probability of not reporting the fault information without the fault current being $P_e$. Because the probability of refusal and disoperation is relatively small, this paper only considers a protection disoperation or refusal and improves the fault location judgment rule.

4. Example simulation analysis

4.1. Circuit breaker refuses to operate

 Modify the MATLAB calculation program to delete all the conditions that trigger the start of the line 7 circuit breaker. At this time, the line 7 circuit breaker will always refuse to operate. When the simulation is set to 1s, a three-phase short-circuit ground fault occurs on line 7, and the fault point is 2km away from the head end of line 7. The received SOE information is shown in Table 2.

| Circuit breaker action | Protection action |
|------------------------|------------------|
| Line 5 circuit breaker trips at 1.658s | Protection 5 current II section protection trip |
|                        | Protection 5 current III section protection trip |
|                        | Protection 7 current stage I protection trip |
|                        | Protection 7 current stage II protection trip |
|                        | Protection 7 current III section protection trip |

The diagnosis result can be obtained through the traditional decision table: the fault area is in line 7, the fault time is $1.658-0.04-0.6=1.018$s, and the fault location is within the range of line 5 backup protection section II.

4.2. Loss of protection correct action information

Modify the MATLAB calculation program to delete the protection action information of line 7 current II and III. When the simulation is set to 1s, a three-phase short-circuit ground fault occurs on line 7. The fault point is 2km away from the head of line 7. The received SOE information is shown in Table 3:

| Circuit breaker action | Protection action |
|------------------------|------------------|
| Line 7 circuit breaker trips at 1.098s | Protection 5 current II section protection trip |
|                        | Protection 5 current III section protection trip |
|                        | Protection 7 current stage I protection trip |

5. Conclusion

Based on the analysis of the development process of relay protection, this paper analyses the characteristics and research status of today's intelligent protection. Explain the development direction of intelligent protection through an integrated wide-area relay protection scheme based on transient measurement. The scheme consists of integrated protection relays equipped with multiple transient protection modules and wide-area relay protection devices to form a relay network. The wide-area relay protection device receives and compares the signals from the integrated protection devices of each
substation to determine the location of the fault and makes a trip decision to send to the corresponding substation for execution, thereby realizing the wide-area integrated protection of the power grid.

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