

The Distribution System Multi-criterion Relay Technology Based on GOOSE

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Abstract

GOOSE message of smart substation can transmit switch quantity and analog quantity, each IED connected in the GOOSE network can choose as subscribers or publishers to receive or publish data in order to achieve the station information sharing and equipment interoperability. In this paper, a new multi-criterion bus protection technology is proposed which is based on the cross-bay transmission of switch quantity by GOOSE network and combines smart substation construction requirements and the technical characteristics of the GOOSE protocol. This technology can solve protection action dead zone, sensitivity and other issues which cannot be solved by traditional differential protection. An information fusion multi-criterion single-phase ground protection technology is also proposed. It's based on the cross-bay transmission of analog quantity by GOOSE network. Compared with the traditional ground protection technology, this technology uses more branches' zero-sequence information. So it can solve the insufficiency of criterion, poor reliability and sensitivity of protection action. Results show that using the new technologies can make the bus protection action speed time less than 20ms and there is no action dead zone. The new technologies also can improve the rapidity and sensitivity of the single-phase ground protection.

Key words: multi-criterion relay, GOOSE, bus protection, single-phase ground protection

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1. Introduction

In the power distribution system, the occurring probability of bus faults and one-phase-to-ground faults is high. Because there are many outgoing lines in the power system and its structure is complex. Due to the high cost, complexity of the secondary circuit, the limit of switchgear's volume and other reasons, there's no bus protection for traditional power distribution network [1]. Selective ground protecting is the important protection for indirectly grounded power system. In the use of single-phase ground protection, sometimes the misoperation and mistrip of switches occurs, influenced by the distributed capacitance of power grid. Therefore, how to set up effective protection, to improve the reliability of the power distribution system has been the focus and difficulty of the study. Theoretically GOOSE can be used to transmit analog quantity and state quantity [2]. So using GOOSE information can provide new solutions for bus protection and ground fault protection. But there is a few literatures on this area. In the building process of the smart substation, some countries (such as China) rule that the control unit, protection device, merging unit should be combined by bays in the 66/35kV substation and below according to the standards. In this substation's network structure, there's no SV (Sample Values) process layer network, so the relay protection based on information sharing of sampled values through process layer network is impossible. In this case, the relay protection technology on the GOOSE message interaction becomes particularly necessary.

2. The Technology of GOOSE

The ACSI, SCSM and other technology realize information sharing and interoperability of substation intelligent electronic devices. The GOOSE technology is a fast, efficient and reliable communication method. In smart substation IEDs are connected by GOOSE network.

Every IED can choose as a subscriber or publisher to receive or publish data in order to achieve the station information sharing [3].

GOOSE use dataset to organize data exchange. Theoretically GOOSE can be used to transmit analog quantity and state quantity. Due to the GOOSE transmission mechanism, when use GOOSE to transmit real-time sampled values, there exist synchronization problem and transmission dead zone problem. If you do not set the dead zone, GOOSE will always be high-density transmission. This may cause packet storm. But if you set the dead zone, this may generate imbalance quantity which has an impact on the judgment of protection, and the frequent switching of the dead zone will also affect the fast message transmission speed. At present the GOOSE technology is mainly used to transfer switch signal, applications developed for the transmission of small variation of voltage and current amplitude or phase signal are so less.

The GOOSE technology is the key technology of smart substation communication system [4]. In substation applications, using GOOSE can reduce the secondary cables. The secondary devices can exchange switch quantity and analog quantity simply through switches, this can reduce the redundant cross-cell connections. Therefore, all kinds of advanced substation functions can be realized only by the GOOSE network configuration. And once the communication network is established, the GOOSE network can be flexibly configured as long as there is enough hardware bandwidth. What's more, GOOSE network has high reliability. When there're broken links, there're alarms.

3. Bus Protection based on GOOSE'S Switch Signal Transmission

Generally the 10kV bus do not equip the bus protection, when bus fault happens, it relies on the backup protection of transformer to remove the faults. This scheme needs the timing difference coordination of main transformer's low voltage side protection and the 10kV outgoing line's protection. Thus, the bus short circuit fault can't be removed quickly by the main transformer backup protection. This may expand the accident area, have a severe impact on the main transformer, especially damage the cabinet equipment badly, and even threat the operating personnel safety. In view of this, equipping the 10kV bus protection economically and reasonably is absolutely necessary.

3.1. Scheme of Bus Protection based on GOOSE's Switch Signal Transmission

The conventional bus protection needs protection device to get the current value of each branch. This needs to increase the number of cables, which makes the secondary circuit complex, increases the investment and increases workload of field construction. An economic, reliable and operable scheme of 10 kV bus protection based on the smart substation GOOSE technology is proposed. The structure is shown in Figure 1.

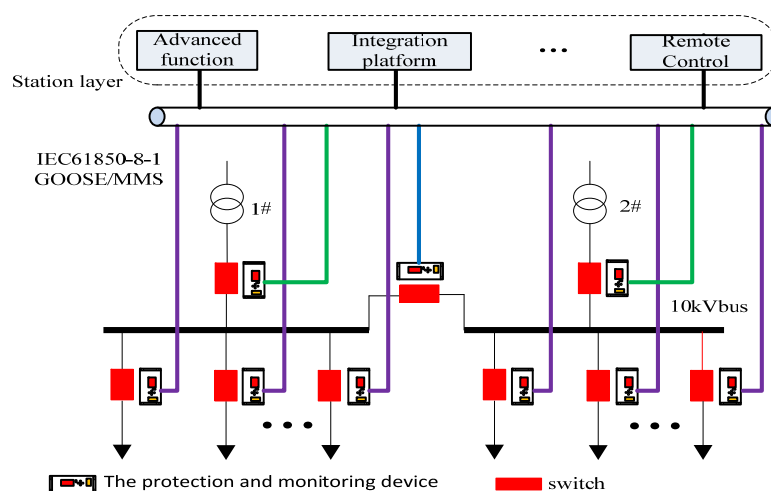


Figure 1. 10 kV Bus Protection Scheme

The protection and monitoring device of each bay makes the protection judge independently and shares information through the bay layer network. If there's a short-circuit fault, the GOOSE message which contains fault information is multicast through a fiber optic switch. Each device in both sides of the bus can receive the message and makes comprehensive judgments by analyzing the sharing fault information. In this way, bus fault can be removed immediately. In this scheme, there are no additional deceives. The bus protection function disperses to each bay, sending the trip command independently. This ensures that the bus protection acts rapidly, selectivity and reliability.

3.2. Theory of Bus Protection

Protection devices are generally equipped with a start element. Starting elements are used to block the protection output in normal and start the whole protection, unblock the protection output in the event of a fault. In normal, protection and monitoring devices collect the data of the three-phase current and do real-time protection computing. When there's short-circuit fault, the protection is started and the protection and monitoring device sends the multicast GOOSE message that the short-circuit protection has been started. The protection device which protects the incoming line of the bus starts the delay timer at the same time the start element is started. If in the delay time, the device does not receive the fault GOOSE information multicasted by the bus's outgoing lines protection devices, it judges the fault as bus fault and send trip signal; otherwise, it judges as outgoing line failure, and blocks the trip output. The switching of incoming line still does protection computing in the delay time. If the fault is removed in the delay time, the device sets the "local signal" to "0", so it cannot send trip signal no matter whether it receives the fault GOOSE information or not. This can prevent misoperation [5]. The bus protection logic is shown in Figure 2.

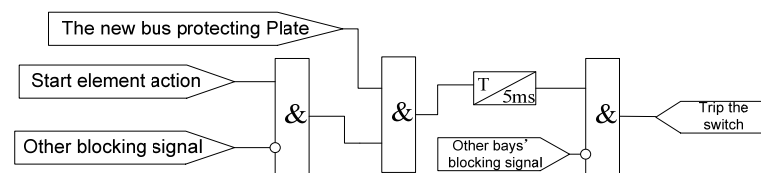


Figure 2. The Bus Protection Logic

The break variable is widely used as a start-up criterion. Usually choose the break variable of the phase current value as a start element, If the phase current break variable is over the setting threshold value and phase current values change from small to big, The protection and monitoring device starts up phase current waveform record and generates the virtual switch's state change information which means the fault current flows through the switch. And the device sends the information by GOOSE message multicast at the same time records the phase current waveform. The phase current waveform can be uploaded actively by the protection and monitoring device or be uploaded by the way of summoning. The break variable of phase current can be expressed as follows,

$$\Delta i_k = \left\| i_k - i_{k-N} \right\| - \left\| i_{k-N} - i_{k-2N} \right\| \quad (1)$$

Where, Δi_k is the calculated current value at the k-th moment, i_k is the sampled current value at the k-th moment, N is the total sampling number in one frequency cycle.

The current changes obviously when faults happen. This characteristic can be used by the break variable start element. In the steady-state case, the current only contains the fundamental and harmonic, there must be that Δi_k equals zero, when a failure occurs, the current contains not only the fundamental frequency component but also the power frequency component and the transient component, so Δi_k cannot equal zero. It can be judged as outgoing line faults if:

$$\Delta i_k \geq k \times i_e \quad (2)$$

Where k is coefficient, i_e is the rated current of the circuit breaker. Both of them can be set. Using the multiple consecutive computing is the way to improve reliability, like continuously calculating Δi_k , Δi_{k+1} and Δi_{k+2} . When faults occur, the start element starts and fault information multicasts. If the incoming line's protection and monitoring device does not receive the outgoing line's fault information in a delay time (assuming 5ms), it judges the fault as the bus fault and issue a trip command.

Using the start element, the computing just needs 1/4 cycle sampling so it can be judged in 5 milliseconds. The delay of GOOSE message transmission which contains failure information is less than 4 milliseconds, even in the case that the network load is every heavy. And the time from when the bus fault happens to when the trip command is issued is not greater than 15 milliseconds, even in extreme cases.

4. Single-phase Grounding Protection based on Analog Transmitted by GOOSE

At present, in the small current grounding system, the neutral point ungrounded system or via arc suppression coil grounding system is widely used in the low voltage distribution network. Single-phase grounding fault is a common fault type in the small current grounding system [6]. According to the statistics, in the small current grounding system, the grounding fault probability, in 35kV power grid accounted for about 10%, in 10kV power grid accounted for about 90%. When Single-phase ground fault happens in the small current grounding system, weak fault current, unstable ground fault feature, changing load conditions and system operating mode make the problem that the ground protection sometimes mistakenly act, which is difficult to solve [7].

The existing ground fault protection based on a single device which only obtains its own line sampling signal, unable to obtain additional branch information, that result in faults information are not comprehensive and the failure criterion is not sufficient. So the ground fault protection reliability is not high enough. The single-phase ground protection based on smart substation information sharing feature can make full use of each branch information for fault diagnosis, which greatly improve the transverse selectivity and reliability of grounding protection.

4.1. Single-phase Grounding Protection Scheme

The single-phase grounding protection scheme is shown in Figure 1, each protection and measuring-control device in bay levels monitors the voltage and current of each branch. When single-phase grounding fault occurs, if the zero-sequence voltage and zero-sequence current are detected greater than the setting value, the protection and measuring-control device will start the ground protection module. Each protection and measuring-control device collects the zero-sequence full current information independently, makes Fourier transform on the information, obtains zero sequence full current fundamental values, packages each branch zero sequence full current fundamental real part and imaginary part and multicasts in the form of GOOSE message. Each protection and measuring-control device can receive all branches' GOOSE messages which solve the sampling information sharing problem in the no process layer SV (sampled values) network. According to the received fault information, the protection and measuring-control device judge the fault line comprehensively by the zero sequence full current power direction principle, and the fault branch protection and measuring-control device will give out a tripping command and break the fault branch.

According to MMS: ISO 9506-2: 2003, There are four main data types about GOOSE message: Boolean, String, 32-bit Integer and UTC time type [8], the corresponding Application Primitive Tag encoding 0x83(BOOLEAN), X84(BIT-STRING), 0x85(INTEGER), 0x91(UTC time). The amplitude which protection and measuring-control device have calculated is encoded with GOOSE message by string instead of floating-point number. Specific coding is shown in Table 1.

Table 1. Coding Format of GOOSE Message

numDatSetEntriesINT32U		Tag=8ah
		Length≤4
Tag of GOOSE		Numbers
		Tag=abh
GOOSE1	Tag of GOOSE1	Tag=a2
	Length of GOOSE1	Length
	Amplitude	Tag=84H
		Length=1
Bit-string		
GOOSE2

This scheme realized the information sharing by multicasting GOOSE messages [9-10]. Each protection and measuring-controlling device can get the fault information of all the branches on the bus, compute the fault line comprehensively by the zero sequence full current power direction principle, overcome the shortcomings of the traditional protection devices which judge only by its own branch voltage and current information and those protection devices cannot cooperate. This scheme constructs multi-criterion protection under the no process layer network, greatly improving the lateral selectivity and reliability of single-phase grounding protection.

4.2. Principle of Zero Sequence Full Current Power Direction

On the basis of the analysis of the existing ground fault protection principles, the premise of information sharing, zero sequence full current power direction principle is put forward. In small current grounding system, when single-phase grounding fault occurs, with the reference of zero-sequence voltage vector, the non-fault line zero sequence full current vector falls in the first quadrant, and the fault branch zero-sequence full current vector falls in the third quadrant for the neutral point ungrounded system; however, non-fault line zero-sequence full current vector falls in the first quadrant and the fault line zero-sequence full current vector falls in the second quadrant or the third quadrant for the neutral point via arc suppression coil grounded system. Considering the transformer angular deviation, those zero sequence full current vectors of the fault branch mentioned above might fall in the fourth quadrant.

Principle of zero sequence full current power direction shows in Figure 3. The solid line represents neutral point ungrounded system, dashed line represents the neutral point via arc suppression coil grounded system.

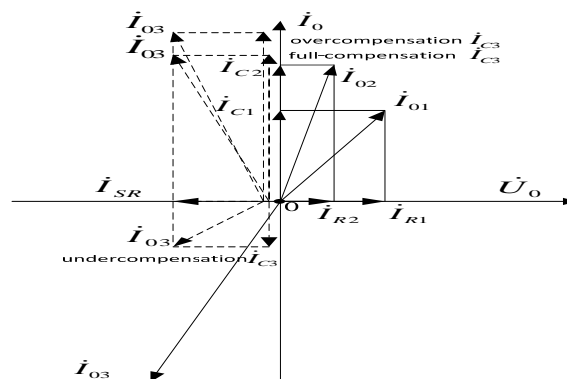


Figure 3. Principle Diagram of the Direction of Zero Sequence Full Current Power

Therefore, according to the active power and reactive power of each branch, for a line L_i , if $P_i > 0, Q_i > 0$, which means that zero sequence full current vector falls in the first quadrant, according to the principle of zero sequence full current power direction, L_i is a non-fault line. If line L_i does not fall in the first quadrant, it must be a fault line. However, in practical

applications, due to the effects of transformer angle deviation, maybe there are several branches outside the first quadrant protection and measuring-control device will judge that the single-phase ground fault has happened on more than one line. Here we assume that the transformer angle deviation is in the same direction. When the protection device measures that there are several lines outside the first quadrant, the branch which has the largest vector angle between zero sequence full current vector and zero sequence voltage is most likely the fault branch. In other words, according to the direction of the Q_i , P_i and the size of the $\tan \theta_i = \frac{Q_i}{P_i}$,

fault branch can be judged.

The zero-sequence full current power direction principle can no longer distinguish whether it is the neutral point ungrounded system or the neutral point via arc suppression coil grounded system. The fault line can be accurately judged by the active and reactive power. Based on the information sharing, protection and measuring-control device can make full use of all branch fault information and focus on comprehensive judgment, which overcomes the shortcomings of the single fault information judgment and traditional protection independent judgment.

5. Conclusion

Using the technology of GOOSE can realize the substation information sharing. In order to let the substations have the function of GOOSE transmission, the traditional protection device just adds the communication module which can enable them to send and receive GOOSE messages and the fiber optic cables. We can see it is low cost and easy to extend the protection functions. The new multi-criterion bus protection technology which is based on the cross-bay transmission of switch quantity by GOOSE network can solve protection action dead zone, sensitivity and other issues which cannot be solved by traditional differential protection. The new multi-criterion single-phase ground protection technology is based on the cross-bay transmission of analog quantity by GOOSE network. This technology uses more branches' zero-sequence information and it can solve the insufficiency of criterion, poor reliability and sensitivity of protection action. In addition, some other substation functions like anti-misoperation, sequential control, VQC and so on can also use GOOSE to realize.

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