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Research on Distributed Protection in Switch Stations Based on GOOSE

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Abstract. The application of IEC61850 standard and the development of smart terminal unit (STU) technology provide a powerful platform for secondary protection research of distribution network. Aiming at the problems of override trip in the protection of the incoming line and feeders on traditional 10kV switching stations, a scheme combining distributed voltage loss protection and overcurrent protection is proposed. The smart terminal unit collects and processes the operation data, realizes data exchange through GOOSE network communication, and cooperates to realize the protection function of the switch stations. In this paper, a protection logic diagram based on the GOOSE mechanism is constructed, which realizes the protection function of feeder lines fault lockout incoming line breakers and the bus line fault lockout busbar automatic transfer switch.

1. Preface

The traditional protection technology for switch stations can be divided into local control methods (such as current protection) and centralized control methods according to the protection device layout structure. The local control method only uses the information of the installation location of the protection device, is easy to implement, and moving fast, but the information used is limited and the protection performance is not perfect. The centralized control mode is mainly based on the primary station, which can integrate global information, optimize control, and improve protection performance. However, there are many links involved, low reliability, and slow protection response. On the other hand, from the perspective of the protection principle, the traditional three-stage current protection is mainly used for the switch stations. Since the three-stage protection is achieved according to the current setting grading and the action time grading, it has its inherent defects, and it is prone to problems such as override trip. In the literature 1, the ultra-short incoming lines and feeder lines current protection of the switch stations in the urban power grid is improved, but the information used for the protection implementation is limited to the local information of the protection installation, and the protection performance is not perfect^[1]. In the literature 2, the incoming lines and feeder lines protection of the switch stations based on the GOOSE mechanism is studied, and the GOOSE action logic diagram is constructed. However, the protection implementation principle is still based on the traditional three-stage current protection^[2]. Under different operating modes and different fault types of the distribution network, the protection current value has a problem of setting difficulty.



With the promulgation and application of the IEC61850 standard, it laid the foundation for the application of distributed current protection technology. The IEC61850 standard enables intelligent terminals to implement interworking between devices according to a unified data model, and also enables interoperability between intelligent terminals of different manufacturers. The automation system based on IEC61850 standard can realize GOOSE function. The intelligent terminal can exchange real-time data through GOOSE network communication quickly. The real-time data transmission time is generally less than 10ms, which can guarantee the response speed of distributed protection technology^[3,4].

In addition, the rapid development of smart terminal unit (STU) technology provides a realistic path for the application of distributed protection technology. STU uses high-performance digital signal processor (DSP), microprocessor (MCU), large-scale field programmable logic array (FPGA), etc., with powerful data storage and data processing capabilities^[5]. Its main functions include: collecting and processing operational data, exchanging data with relevant STUs in distributed protection, and then obtaining fault information, acting on circuit breaker tripping or issuing warning information to realize protection control function. STU's interface circuit design meets modularity and standardization and can be flexibly selected according to engineering demands.

2. Structure and protection of the switch station

In order to save the 10kV substation outlet corridor and solve the problem of insufficient spacing of the power distribution equipment, the switch station is widely used at the exit of the 10kV substation. It generally adopts the main bus form of a single bus bar or a single bus bar segment, and generally two power sources are incoming.

When two power supplies are used, the power supply comes from different substations or different busbars of the same substation. The number of feeders is from 3 to 5. Figure 1 shows the main wiring diagram of a typical single busbar section switch station. When the bus coupling switch is closed, the switch station is in the parallel running state, and when the bus coupling switch is disconnected, switch station is in the divided operating state. When the switch station is in normal operation, the bus-coupled switch is in the open state, and the bus-coupled switch is configured with the busbar automatic transfer switch (BATS) device.

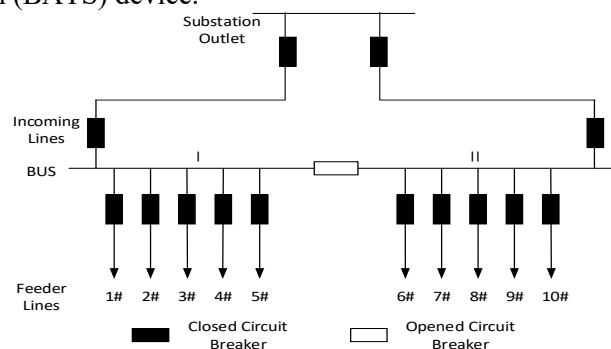


Figure 1. The Structure of Switch Station

The functions to be implemented by the protection of switch station are:

a) When the incoming line fault occurs, the upper substation outlet circuit breaker trips. After the reclosing, if it is a permanent fault, it is put into the BATS device and is powered by the standby incoming line.

b) When the busbar fault occurs in the switch station, it will be tripped by the incoming circuit breaker, and the BATS device will be blocked to realize the isolation of the fault area and ensure the power supply in the non-faulty area.

c) When the feeders fault occurs, the incoming line protection is blocked to prevent the override trip, and the faulty circuit is tripped by the action of the circuit breaker on the feeder line branch.

3. Distributed protection principle of switch station

The distributed protection system consists of a substation outlet circuit breaker, an incoming line circuit breaker, a feeder line branch circuit breaker, a smart terminal unit (STU), and a GOOSE communication network for exchanging fault detection information between STUs. For the protection system of the switch station system, the traditional protection system focuses on the combination of current setting difference and time level difference^[3], while the distributed protection system focuses on the cooperation between STUs. STU obtains local measurement data for local processing. At the same time, based on GOOSE networked communication, the measurement and control data of other relevant STU transmissions are received, thereby synthesizing the information of each site, judging the fault-related situation and making a decision to realize the protection function. As shown in Figure 2, the distributed protection system of switch station, in which the substation outlet circuit breaker protection devices STU1 and STU2 are equipped with overcurrent protection, and the incoming line circuit breaker protection devices STU3 and STU4 are equipped with voltage loss protection and overcurrent protection, and the line protection device for feeder lines branches STU5~STU10 are equipped with overcurrent protection, and the busbar protection device STU0 is equipped with overcurrent protection and BATS function.

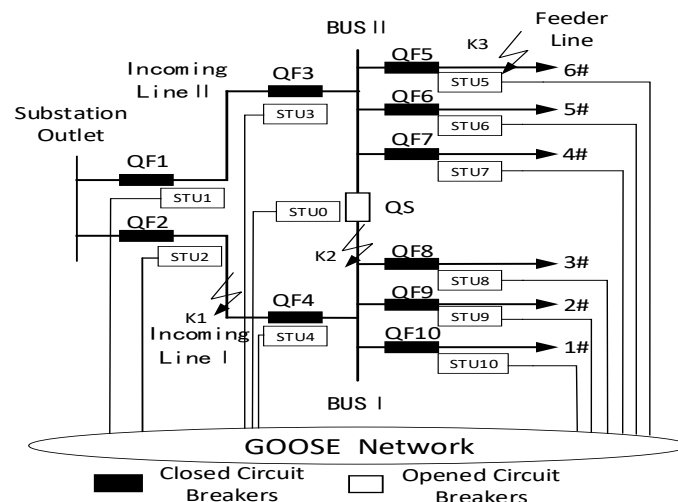


Figure 2.The Distributed Protection System of Switch Station

According to the installation position, the distributed current protection of switch stations can be divided into incoming line protection and feeder line protection. When a fault occurs at different locations on the line, the protection action is as follows:

1) When the incoming line K1 fault, the protection device STU2 detects that the fault current is started, and other protections are not activated. After a short delay, the STU2 can receive no other protection start information through the GOOSE network, then it is judged as the incoming line fault, QF2 disconnect. After the QF2 is disconnected, the reclosing is performed. If it is a transient fault, the STU2 detects that the fault current disappears. In the case of a permanent failure, STU2 immediately jumps off. At this time, STU4 detects that the incoming line 1 is no voltage, the voltage loss protection is activated, and simultaneously sends a GOOSE message to STU0. If STU3 detects that there is voltage in the incoming line 2, STU0 cannot receive the STU3 loss-of-voltage protection start information, and puts in preparation BATS function, QS switch is closed. If STU3 detects that there is no voltage in incoming line 2, the voltage loss protection is started, and STU0 receives the STU3 voltage loss protection start information, then the STU4 and STU3 information is combined to make a judgment, and the BATS function is blocked.

2) When the bus K2 fails, the protection device STU2 detects the fault current start, STU4 detects that the fault current is also started, and STU8, STU9, and STU10 do not start, it is judged as the bus fault. STU2 receives the STU4 overcurrent start message within a short delay, and then judges to be an out-of-zone fault and lock-up protection. STU4 acts directly on the trip and the QF4 switch is off. At

the same time, the GOOSE message is sent to STU0, and the BATS is locked.

3) When the fault occurs at the feeder line K3, the protection devices STU1, STU3, and STU5 detect that the fault current is started, and it is determined that the feeder branch 6# is faulty. After a short delay, STU1 receives the overcurrent blocking signal of STU3, STU3 receives the overcurrent blocking signal of STU5, judges that an out-of-zone fault occurs, and the blocking protection, STU5 acts on the trip, and QF5 switch is off.

4. Incoming and feeder line protection setting in switch stations

4.1. Incoming and feeder line protection setting

The traditional switch station local protection and micro-computer protection adopt three-stage current protection, and the current setting and action time are matched in the limit of the upper and lower protection devices. The intelligent level is not high, and the protection delay near the power supply is too long. The number of protection stages increases, and the protection setting is complicated. The distributed protection developed by the protection platform based on STU, GOOSE network communication and distributed interaction greatly simplifies the protection setting of switch stations.

The distributed protection of the switch station adopts the principle of combining the voltage loss protection and the overcurrent protection to improve the protection performance. The setting of the voltage loss protection is 70% of the rated voltage, and the action time limit is set according to the time of avoiding the reclosing of the substation outlet circuit breaker. When the substation outlet circuit breaker is unsuccessful and jumps off, the incoming line voltage is rapidly reduced and the voltage loss protection is started.

For the overcurrent protection of the distributed structure, the networked communication and logic judgment are used to judge the fault information, and the current setting can reflect the fault information. Therefore, the current III protection is used as the primary protection and backup protection, no need to install current quick-break or time-limited current quick-break protection. The current setting of the current III protection is set according to the maximum load current. When the current III segment protection is used as the main protection of the incoming line, the current at the end of the two-phase short circuit at the end of the line is verified by the minimum operation mode, and the sensitivity coefficient K_{sen} is taken as 1.5. If the sensitivity factor is not met, it can be adjusted by extending the line protection range.

4.2 Protection time performance calculation

For the implementation process of distributed protection, the delays generated by each link include: fault current detection time T_0 , generally less than 20ms; GOOSE message command transmission time T_1 , is about 10ms; circuit breaker disconnect fault current time T_2 , Generally less than 70ms; the time T_3 of the incoming circuit breaker reclosing is 300ms; the delay of the current III protection T_4 should avoid the transmission time of the GOOSE message and the logical judgment time of the STU, is about 30ms; The protection time under different line fault conditions is:

a) When the incoming line fails, the substation outlet circuit breaker completes a reclosing by $T_0+T_4+T_2+T_3=20+30+70+300=420\text{ms}$.

b) When the busbar line fails, the incoming line circuit breaker cuts off the fault by $T_0+T_4+T_2=20+30+70=120\text{ms}$.

c) When the outgoing branch line fails, the outgoing branch circuit breaker cuts off the fault by $T_0+T_4+T_2=20+30+70=120\text{ms}$.

5. Protection action logic based on GOOSE mechanism

5.1 The incoming line fault protection logic in switch stations

As shown in Figure 3, when the incoming line I of switch station fails, STU2 detects that the overcurrent information is activated, and STU4, STU8, STU9, and STU10 are not started. After a

delay of 10ms, STU2 does not receive the GOOSE message initiated by other STUs, and it is determined that the incoming line has a fault, so it directly acts on the substation exit breaker QF2 to trip. After a reclosing of QF2, if it is a permanent fault, it will jump again to achieve isolation of the fault incoming line. At this point, the incoming line I loses power, the incoming line voltage drops to 70% of the rated voltage, the STU4 loss of voltage protection starts, and sends a GOOSE message to STU0. after 10ms delay, if STU0 does not receive the loss from STU3 When the voltage protection start signal is sent, the bus-connected circuit breaker QS closing message is sent to the STU4 to lock the voltage loss protection, and at the same time, the circuit breaker QS is closed and put into the BATS device. If STU0 receives the STU3's voltage loss protection start signal within 10ms delay, it will lock the BATS device.

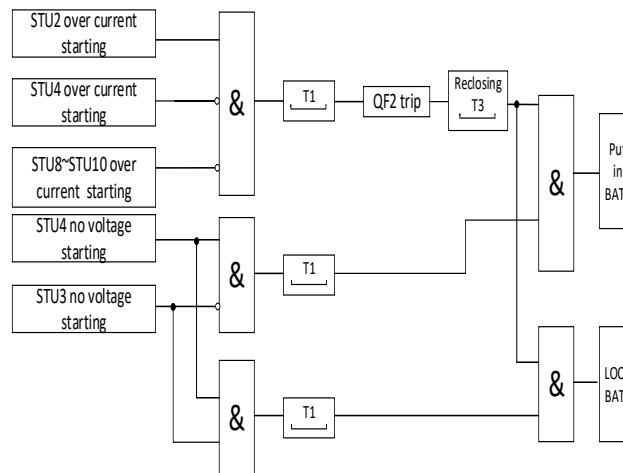


Figure 3. The Incoming Line Fault Protection Logic in Switch Stations

5.2 Bus fault protection logic in switch stations

When the bus I fails, STU2 and STU4 detect that the overcurrent information is activated, and STU8, STU9, and STU10 are not started. After 10ms delay, STU2 receives the GOOSE message from the STU4 overcurrent start, and blocks QF2 protection. When STU4 does not receive the startup information of the STU8~STU10, it is determined that the bus I has a fault, directly acts on the QF4 trip, isolates the faulty bus, and blocks the BATS device. When QF4 is opened, STU4 sends a GOOSE message to STU2 to cancel the blocking. As shown in Figure 4:

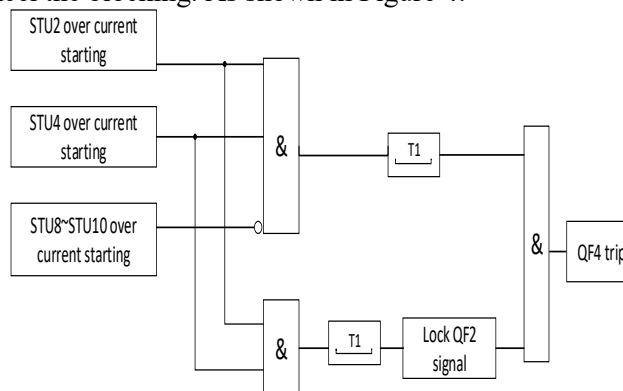


Figure 4. Bus Fault Protection Logic In Switch Stations

5.3 Feeder branch fault protection logic in switch station

When the feeder branch of the switch station is faulty, the protection logic is as shown in Figure 5. STU2 and STU4 detect that the overcurrent information is started, and the branch line 3# (such as

STU8) detects that the fault current is also started. After 10ms GOOSE message transmission delay, STU2 receives STU4 startup information and locks protection. At the same time, STU4 receives the STU8 start information and locks the protection. It determines that the feeder branch 3# has failed, and directly acts on the feeder branch breaker QF8 to trip and cut off the faulty line. When QF8 trips, STU8 sends a GOOSE message to STU2 and STU4 to cancel the lock.

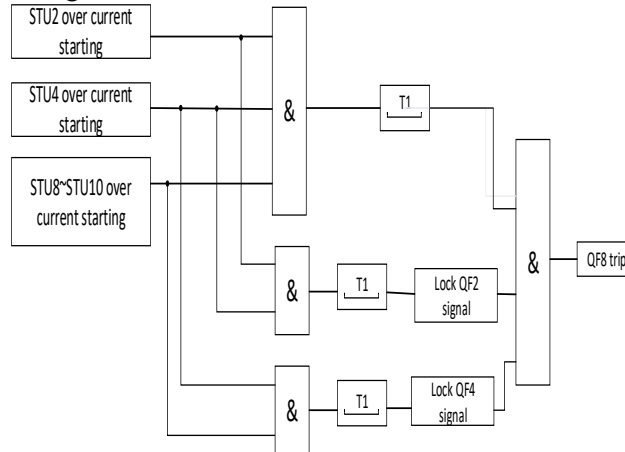


Figure 5. Feeder Branch Fault Protection Logic in Switch Station

6.Setting Examples

The structure of the switch station with distributed protection is shown in Figure 6. The 10kV incoming line includes the incoming line 1 and the incoming line 2, both of which are introduced by the 110kV low-voltage side busbar, which is used for hybrid power supply of overhead line and cables. The length of the overhead line is 1.3km. The length of cable is 0.7km. Single bus segmentation structure is adopted. The number of feeder line for the busbar I segment and the busbar segment II are four. Among them, the 4# feeder and the 8# feeder are connected to the transformer, and the load capacity is 30kVA.

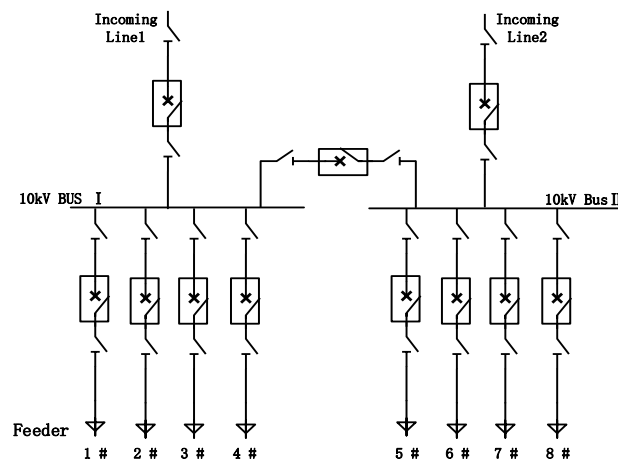


Figure 6. The Structure of The Switch Station

Feeder lines data are shown in Table 1:

Table 1. Feeder Lines Data

Feeder Number	1#	2#	3#	4#	5#	6#	7#	8#
Load Capacity (kVA)	500	630	1000	30	630	630	315	30
Rated Current(A)	28.9	36.4	57.7	—	36.4	36.4	18.2	—
Cable Length(km)	0.23	0.7	0.3	—	0.6	0.53	0.48	—

Taking the reference capacity $S_b=100\text{MVA}$ and the reference voltage $U_d=10.5\text{kV}$, the reference current $I_d=5.5\text{kA}$, and the maximum incoming line load current is 207 A. The 10kV bus short-circuit impedance standard value $X_{max}=0.4193$, $X_{min}=0.8581$. When in the maximum operating mode, the short-circuit current of the II section busbar is: three-phase short circuit 6.3kA, two-phase short circuit 5.46kA, and the short-circuit current for feeder line (for example, 1#): three-phase short circuit 0.62kA, two-phase short circuit 0.54kA. When in the minimum operation mode, the short-circuit current of the II section busbar is: three-phase short circuit 4.11kA and two-phase short circuit 3.63kA; the short-circuit current at the end of 1# feeder is: three-phase 0.59kA, two-phase 0.51kA.

a) Incoming line overcurrent protection setting:

$$I_{dz} = \frac{k_k}{k_{fh}} I_{fmax} = 1.3 \times 207 / 0.95 = 283\text{A} \quad (1)$$

Among them, K_k is the reliability coefficient, which is 1.3; K_{fh} is the protection return coefficient, which is 0.95.

When the line overcurrent protection is used as the main protection of the line, the current value of the two-phase short circuit at the end of the line is checked in the minimum operation mode, and the protection sensitivity is:

$$K_{sen} = \frac{I_{min}^{(2)}}{I_{Dz}} = 3630 / 283 = 12.8 > 1.5 \quad (2)$$

Therefore, the requirements are met.

When the incoming line overcurrent protection is used as the backup protection for the feeder line, the current value of the two-phase short circuit at the end of the feeder line is checked in the minimum operating mode. Taking the 1# feeder line as an example, the protection sensitivity is:

$$K_{sen} = \frac{I_{L1 min}^{(2)}}{I_{Dz}} = 510 / 283 = 1.8 > 1.2 \quad (3)$$

Therefore, the requirements are met.

b) Feeder line overcurrent protection setting (take 1# as an example)

$$I_{dz} = \frac{k_k}{k_{fh}} I_{fmax} = 1.3 \times 28.9 / 0.95 = 40\text{A} \quad (4)$$

Among them, K_k is the reliability coefficient, which is 1.3; K_{fh} is the protection return coefficient, which is 0.95.

When the feeder line overcurrent protection is used as the main protection of the line, the current value of the two-phase short circuit at the end of the line is checked in the minimum operation mode, and the protection sensitivity is:

$$K_{sen} = \frac{I_{min}^{(2)}}{I_{Dz}} = 510 / 40 = 12.7 > 1.5 \quad (5)$$

Therefore, the requirements are met.

7. Conclusion

The distributed protection method based on GOOSE networked communication and logic judgment can greatly simplify the protection setting of the switch station, and can effectively solve the problem of multi-level coordination setting difficulty in the protection of traditional switch station, especially in the case of the cascading of the switch station, it is possible to effectively solve the problem of the override trip in the protection.

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