Realization of Sequential Control Function Based on Bay Level Equipment in Smart Substation

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Abstract. In view of the problem of low reliability and automation of advanced application functions such as sequential control in smart substation, the logic configuration mode of sequential control is analyzed based on the principle of logic virtual circuit of bay level equipment in smart substation, and the realization of sequential control function based on bay level equipment is proposed. This method improves the operational reliability and configuration flexibility of sequential control, and fundamentally solves the technical application problem, so as to improve the intelligent level of power grid.

1. Introduction

In recent years, with the development of Intelligent Electronic Device (IED) technology of intelligent substation (hereinafter referred to as intelligent station) and the application of IEC61850 network communication technology, the substation has changed from traditional integrated automation to intelligent electronic device system integration technology. The intelligent level of the intelligent station interval layer device is significantly improved, the interconnection between the interval layer devices and the realization of the anti-mislocking function, on the basis of which the whole process of the substation primary equipment operation control and sequence control is automatically executed, which becomes a technological development. The inevitability [1-6].

The sequential control is an automatic operation mode in which the intelligent device simulates the manual operation process and the steps. At present, the intelligent station sequential control is generally configured with the same complete logic for determining the status of the primary device at the site control device and the remote monitoring primary station. The remote control operation mode realizes the operation control of the sequential control. On the other hand, due to the monitoring capability of the intelligent station interval layer device, generally only has the function of measuring and executing the operation instruction, and the automatic sequence operation and the step sequence control function without logic comprehensive judgment are difficult to realize complete anti-misoperation locking operation. The control function increases the logic configuration complexity of the station control layer and the remote implementation of sequential control, and the operational reliability and automation degree need to be further improved.

Based on the principle of logical virtual loop of intelligent station interval layer device, this paper analyzes the logical configuration mode of sequential control, and proposes a method based on intelligent station interval layer device sequential control function to improve the reliability and configuration flexibility of sequential control operation. Restrict the application of sequential control technology and improve the level of intelligent grid.
2. Logic Virtual Loop

The network in smart substation follows the application structure of ‘three-layer two-network, configured by interval’, and is arranged in three layers according to the station control layer, the interval layer and the process layer, as shown in Figure 1.

According to the system engineering configuration, each system function is mostly completed by multiple links, multiple components or multiple devices. The traditional circuit cable can be used to treat the communication link and data exchange channel between the IEDs as virtual connections. Referring to the system device integration and functional composition, the IED configuration logic can be considered as a virtual implementation of a device/device function. According to a function of the system, from the function input to the output, the IED configuration and the communication link between the configurations are regarded as the virtual loop. For example, the protection function virtual circuit of Figure 1 can be composed of an AC input port, a MU AC sampling configuration, an SV virtual link, a protection device configuration, a GOOSE virtual link, a smart terminal configuration, and a digital output port.

Taking the operation of separate CB as an example by the station control layer device, the control logic receives the operation command of the station control device through the ‘Operation separate CB’ communication point, as shown in Figure 2, and is connected to the ‘separate CB’ terminal on the field side via the internal connection to execute the output.

Wherein, the ‘separate CB’ logic point of the interval layer measurement and control device can be connected to the corresponding communication point of the intelligent terminal according to the

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**Figure 1.** System structure and function virtual loop.

**Figure 2.** Virtual circuit and virtual terminal for measurement and control IED device.
communication point according to IEC61850, and the latter performs the output; if the measurement and control IED and the intelligent terminal are regarded as the overall device, then ‘separate CB’ can be output on-site through component connections. Therefore, the logical connection points through which the devices are associated by information can be expressed as ‘virtual terminals’ to function as logical connections between devices.

3. Analysis for Sequence Control Configuration

3.1. Sequence control technology features

The sequence control is a programmatic automatic operation mode realized by the relevant IED device to simulate the manual operation steps and processes under the effective monitoring of the dispatching remote or station operators. Sequential control simulates the sequence of manually operating equipment and includes all the elements involved in operational and equipment safety during manual operations.

In practical applications, sequential control includes both technical implementation and operational safety management. The technical implementation of sequential control logic configuration, sequential operation, step control and monitoring model reflects the technical capabilities of the system and its IED. On the other hand, the sequential control of the operational ticket form expresses the operational safety management method. The effective and reliable implementation of the substation sequence control function, the associated monitoring method, the anti-misoperation locking and step control technology, the anti-misoperation and the operation ticket management, etc., involve the comprehensive application of the combination of the technical implementation mode and the safety management mode.

The common sequential control mode is based on the remote signal, telemetry and remote control capabilities of substation bay level equipment, and is implemented independently at the station control level. Usually in the station control layer of the substation, each method adopts the method of comprehensive calculation and judgment of remote signal and telemetry signal to perform step control and monitoring, and adopts a series of automatic remote control operations to realize the sequential control of the primary equipment.

3.2. Sequence control mode for logic configuration of station control layer

Based on the virtual loop of the interval measurement and control equipment, the station control layer equipment simulates the manual operation to realize the traditional sequential control application strategy for cutting off the line load, as shown in Figure 3.

![Figure 3. Interval programmed virtual loop and sequential control.](image)

The order in which the line load is manually cut off: Disconnect the circuit breaker CB, check that the CB has been disconnected, and disconnect the isolating switch DS.

The logic of the execution process is as follows:
(1) If the circuit breaker ‘CB has been closed’ =1, the ‘Operation Separate CB’ =1 command can be issued, and the circuit breaker is tripped through the ‘Separate CB’ command;

(2) The circuit breaker ‘CB has been divided’ = 1 and ‘voltage sampling’ <set value, then the virtual terminal ‘allow DS to separate’ = 1, the expression can be separated by the isolation switch DS operation;

(3) When the monitoring receives ‘Allow DS separation’ =1, it can issue the ‘Operation Separate DS’=1 command, and disconnect the isolation switch through the ‘separate DS’ command;

(4) According to the monitoring, the circuit breaker ‘CB has been divided’ = 1 and the isolating switch ‘DS has been divided’ = 1, to judge the automatic operation to end normally.

Through the mentioned above automatic operation logic, combined with the analysis of interval measurement and control equipment, in the current sequential control mode, the same false lockout logic operation in the station monitoring, remote monitoring, five defenses and other equipment in a large number of repeated configuration, increasing the complexity of the system And maintenance difficulty, reducing operational reliability and system stability, and is not conducive to subsequent system addition, transformation and safe operation.

Moreover, the operation instructions of each primary device are sent by the station control device, which is essentially ‘remote control batch processing’, and the reliability is lower if the remote control is scheduled. And if the network of the station control layer is in faulty, there is no operation means between the station control layer and the remote side.

Therefore, simplifying the complexity of logic configuration, improving monitoring mode, improving monitoring and unattended reliability are all necessary requirements for technological development and feasibility.

4. Sequence Control Based on Interval Function Virtual Loop

4.1. Programmatic Control Model

For the problems for sequential control of the station control layer, the same part of the station control equipment and the remote control logic can be configured to the measurement and control device, and the solution of the virtual circuit of the measurement and control device and the interval program control is realized.

Figure 3 shows the virtual loop structure of the monitoring based on the program control capability of the measurement and control device itself to realize the sequential control of the device. The model is suitable for the remote.

As can be seen from the measurement and control device of Fig 3, the automatic operation process of cutting off the line load can be started, monitored and stopped in the ‘operation display circuit’ of the device. The operation mode of the cut load line is as follows:

(1) When ‘Allow sequence operation’=0, ‘Sequence operation’=1 will not start the load shedding process, and it is forbidden to operate the isolating switch;

(2) ‘Allow sequence operation ‘= 1 and ‘Operation display loop’ sets ‘Sequence operation ‘= 1, start the line load shedding process;

(3) The first step of operation, automatically set ‘separate CB’ = 1, to perform a trip circuit breaker;

(4) Safe check: If the circuit breaker has tripped ‘CB divided’=1 and ‘voltage sampling’ <set value, then ‘allow DS minute’=1, the disconnector can be operated;

(5) The second step operation, delay T time, automatically set ‘separate DS’ = 1, automatic disconnect the isolating switch;

(6) End of automatic control: ‘DS has been divided’=1, the isolating switch has been disconnected.

4.2. Sequence control process monitoring based on interval control

Based on the interval control logic virtual terminal, the background database can be monitored via a network communication connection, and then connected to the display interface through data mapping, as shown in Fig 3.
It can be seen from Fig. 4 that the monitoring background does not need too complicated judgment logic, and only needs to issue a ‘start’ operation command through the interface, as shown in ①, through the ‘sequence operation’ and the database ‘sequence operation’. The mapping relationship can be started by inputting the virtual terminal through the ‘sequence operation’ of the network connection measurement and control device to start the sequence control of the measurement and control device. And through the measurement and control device each output virtual terminal, real-time monitoring of the entire operation process, as shown in ②,③.

The timing diagram for the sequence control function is as follows:

**Figure 4.** Time diagram for sequence control operation.

The time diagram for sequence control operation of the bay level device is shown in Figure 4. In Figure 4, let t1 = 0, t1 is the start time of the sequence device step-by-step operation, t1’ is the time when the circuit breaker leaves the closing position, t2 is the time when the step-one operation is completed, and t3 is the comparator To the sequence of the second step of the anti-error check to trigger the timing of the step control timer, t4 is the effective output time of the sequence control operation, t4’ is the time when the isolation switch leaves the closing position, t5 is The smooth operation of the bay level device 4 is operated by the monitoring station to be the monitoring end time of the inactive state.

In Figure 4, T1’ is the absolute time difference between the start of the sequence control step and the comparator to determine that the voltage transformer has no voltage; T is the fixed value of the step timer, T = t4 - t3; T1’ is shun The control start step 2 operation is to the monitoring end time when the compliant operation is switched from valid to invalid, T1’=T5-T4. Referring to Fig. 3 and FIG. 4, the sequence of the sequence device operation and the step control is as follows:

1. Time t1=0: When the pass condition is allowed to be in the valid state, the received pass-through operation is changed from invalid to valid state, and the operation output of the sequence step is valid, and the step-by-step operation state is changed from invalid to valid.
2. At t1’ time: the circuit breaker closing position becomes invalid, the voltage sampling value begins to decrease, the pass permission becomes invalid, and the operation output of the sequence step is invalid. The operation state of the step sequence is effectively changed to Invalid state.
3. At time t2: the position of the circuit breaker is changed to the effective state, and the operation of the step sequence is completed, and the process is changed from invalid to valid.
4. At time t3: the effective state of the circuit breaker separation position is unchanged, the voltage sampling value is lower than the comparator limit value, and the sequence control second error prevention operation verification is changed from invalid to valid state.
5. At time t4: there is no change in the effective state of the compliant operation, the operation output of the sequence control step 2 is valid, and the operation state of the second step is changed from invalid to valid.
6. Time t4’: The isolation switch closing position becomes invalid.
(7) At time t5: the position of the isolation switch is changed to the effective state, the operation of the second step is changed from the invalid to the active state, and the smooth operation is changed from the valid to the invalid state, and the output of the sequence control is invalid. The second operational state is changed from valid to inactive.

In summary, the application method of the virtual loop technology is oriented to the station domain control and the regional control, and the means for initiating the sequence operation by the interval layer is added, which is suitable for real-time monitoring of the equipment in the substation and the dispatching end; The overall security of the system can effectively improve the automation level and support the development requirements of integrated monitoring.

5. Conclusion
Based on the analysis of the characteristics of the virtual loop and sequence control technology, combined with the virtual loop logic configuration method of the interval IED device function, the virtual loop function mode optimization such as operation monitoring and operation control is used to study the sequence control model applicable to remote and local monitoring.

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