Study on Optimal Operation Mode of One-key Sequence Control in Substation

Yang Wang 1, Hengxuan Li 2, Shiping E 1, Kanjun Zhang 2, Qianchen Chen 3, Xin Hu 4*, Shang Cao 4 and Xiaotong Luo 4

1 State Grid Hubei Electric Power Co., Ltd., Wuhan 430077, Hubei Province, China
2 Electric Power Research Institute, State Grid Hubei Electric Power Co., Ltd., Wuhan 430077, Hubei Province, China
3 Wuhan Haomai Power Automation Technology Co., Wuhan 430074, Hubei Province, China
4 State Key Laboratory of Advanced Electromagnetic Engineering and Technology, Huazhong University of Science &Technology, Wuhan 430074, Hubei Province, China

Email: m201871569@hust.edu.cn
TEL:19818936965

Abstract. At present, some substations have carried out sequential control pilot applications, but there are generally problems such as inconsistent operation methods, narrow operation coverage, incomplete typical functions, and complicated manual intervention links. The article constructs a multi-objective comprehensive evaluation model of operation mode based on the one-key sequential control operation mode of different application scenarios. This article establishes the weights of various indicators including operation efficiency, economic benefits and other factors, conducts a comprehensive evaluation and proposes an optimal operation mode. Through actual cases, the article also analyzes the functional transformation scheme of one-key sequence control technology of intelligent substation.

1. Introduction
With the continuous improvement of the requirements for the safe operation and service quality of the power grid, the workload of substation operation inspection has increased significantly. It is necessary to improve the automation and intelligence of power grid. Sequential control is an effective way. Sequential control refers to the process of completing the operation of a series of circuit breakers and disconnectors and changing the operation state of the system according to the pre-defined operation logic and five-prevention locking rules automatically. Substation sequence control can help operators perform complex operation tasks, convert traditional operation tickets into task tickets, and reduce operation difficulty. Without additional manual intervention or operation, it can greatly improve operation efficiency, reduce the risk of mis-operation, maximize the power supply reliability of the substation, and shorten the outage time caused by manual operation. The case in Reference [1] shows that there are substations that have carried out pilot application of sequence control but costs a lot of manpower and material resources. The application of sequence control in Reference [2] has very narrow operation coverage. Reference [3] indicates the problems such as inconsistent operation mode, narrow operation coverage, incomplete typical functions, and complex manual intervention links.
An important key factor affecting the promotion and application of sequence control operations is that there is currently no unified operation mode, covering two aspects: 1) There is no unified system architecture at the technical level, resulting in lack of guidance during construction; 2) The corresponding management model has not been established, resulting in a low degree of practicality in operation. Therefore, this paper conducts research on the one-key sequence control operation mode, formulates a unified system architecture, and proposes a management mode suitable for one-key sequence control operation, which can lay foundation for the popularization and application of one-key sequence control.

2. Framework of sequential control system

2.1. Functional structure

As shown in Figure 1, the functional architecture of Sequential control is divided into four levels: scheduling layer, functional application layer, Platform support and Terminal / sub-station [4].

Scheduling layer: Users of the control function include the controller and licensed substation operation and maintenance personnel. The controller or substation operation and maintenance personnel carry out the control operation by regulating the master man-machine workstation.

Functional application layer: The sequential control function is composed of scheduling instruction application, operation application and sequential control application. The scheduling instruction application has the functions of writing, auditing, checking and executing the dispatching order; The application of sequence control operation ticket has the function of automatically generating sequence control operation ticket according to the scheduling sequence control instructions and conducting safety verification; Sequential control application has the functions of programmed execution, locking signal automatic judgment, operation equipment position automatic identification and video linkage.

Platform support: Sequential control function is based on basic platform. The support platform mainly includes SCADA primary model, substation secondary model, process management, error proof calibration and so on.

Terminal/sub-station: The control system automatically sends the control command to the substation remote motivation through the dispatching data network. The substation terminal completes the control operation process and the real-time acquisition and upload of remote communication and telemetry information according to the traditional remote control execution process.

Figure 1. Scheduling control system architecture.
2.2. Scheduling sequential control mode
The remote network authorities communicate forwarding between the dispatching station and the monitoring system module of sequential control operation service, providing the dispatching remote sequential control channel between the dispatching master station and the monitoring system [5].

The plant terminal configures the sequential operation service module in the monitoring system. Sequential control operation service module functions include: 1) interaction with the master station; 2) Calling the existing typical tickets of the monitoring system; 3) interaction with the monitoring system with five defenses and SCADA to realize remote sequential control operation.

The plant and station monitoring system has the function of programmed operation (one-click sequential control). It changes the traditional manual filling operation mode of switching operation, which is tedious, repetitive and easy to mis-operate, into one-click sequential control operation mode, and promotes the transformation of substation operation and maintenance mode from the traditional on-site inspection to remote operation and maintenance. So as to reduce duplication of labor, reduce the risk of mis-operation and substation operation and maintenance costs, and improve the efficiency of substation work, increase the benefit of power grid enterprises.

3. Compilation model of sequential control optimal operation mode
Substation one-click sequence control system can realize one-click sequence control operation of substation main equipment state conversion. At present, there is no unified operation mode, and there is no unified system architecture at the technical level, which leads to the lack of guidance in construction. In view of this problem, this paper constructs the model of one-click sequence control operation ticket in substation, which includes operation object, current equipment state, target equipment state, operation task name, operation project, operation condition, target state and so on. It should be debugged and verified before the substation is put into operation.

![Flowchart of sequence control operation](image)

Figure 2. Flowchart of sequence control operation.

According to the requirements of sequential control operation, all running states of interval devices and the corresponding judgment conditions of each state should be defined. After the device state definition, the paper defines the sequence control process when switching between each device state,
namely sequence control operation ticket. The definition of sequence control process is divided into two types [6]:

1) One ticket requires setting the original device state and final device state of the operation ticket.
2) Secondary ticket does not require setting the original and final equipment states of the operation ticket.

The flow chart for the station side sequence control operation is shown in Figure 2. According to the actual operation object and operation mode, define the task description, action type, execution condition and confirmation condition. The graphical interface configuration tool is provided to edit and maintain the sequence control operation ticket information of each device. The order tickets need to be tested and accepted by the operator before they are enabled.

After the dispatcher clicks a device on the topology graph and selects the target state of the operation, the system combines the current running state of the device and the selected target state to intelligently generate the operation tasks and steps. When dispatching tickets, the system supports the automatic generation of secondary equipment operation terms by associating primary equipment operation.

3.1. Objective function
Considering staffing, operation and maintenance, construction cost and other factors, carry out the multi-objective comprehensive evaluation of operation mode, and propose the optimal operation mode. This paper adopts multiple objective functions for planning.

1) Minimizing manual checking items in sequential control operation
As is known to all, programmed operation is an automatic process. In order to ensure the consistency of programmed operation, manual intervention is avoided as far as possible in the operation process. In the programmed operation ticket, use $\Psi$ to indicate the manual intervention operation steps (e.g. dividing and closing operation mechanisms to operate the power supply air switch, and disconnect the temporary grounding wire).

$$f_1 = \min \sum \Psi(\alpha, \beta)$$

Where: $\alpha, \beta$ represent original device state and final device state of all the equipment.

2) Minimizing construction and maintenance costs
Intelligent substation has optical transformer, online monitoring, intelligent video monitoring, intelligent patrol and other equipment. In the process of compiling the sequence control operation ticket, the existing intelligent equipment can be fully utilized to reduce the construction and operation maintenance costs, and the construction and operation maintenance costs can be used and expressed respectively.

$$f_2 = \min \sum (X(\alpha, \beta) + T(\alpha, \beta))$$

Where $X, T$ represent construction and operation maintenance costs.

Finally, the total objective function after normalization is as follows:

$$f = \sum_{i=1}^{4} \lambda_i \frac{f_i}{f_i^*}$$

Where $f_i, f_i^*, \lambda_i$ are the calculated value, optimal value and weight of the i-th objective function respectively.

3.2. Description of constraint conditions
By deploying a sequence control host and an intelligent error prevention host at the substation and transforming the 'double confirmation' of the isolation switch [7] [8], the sequential control realize the conversion operation between the three states of substation equipment 'operation, hot standby and cold standby. At present, the second auxiliary criterion of 'double confirmation' of disconnector mainly includes video confirmation, travel switch and displacement sensor [9]. Due to the technical limitation of the second auxiliary criterion, it is difficult to ensure the reliability of open disconnector opening
and closing position judgment, and priority is given to the one-key Shunt transformation of GIS substation. Specific constraint conditions can refer to chapter 5.

4. Remote centralized shunt communication networking and information security protection
Under the optimal operation mode, the communication network and information security protection scheme of remote centralized sequential control are proposed to ensure the safety and reliability of information transmission in the operation process.

4.1. Communication network of sequential control
The substation deploys a sequence control host, an independent intelligent error prevention host, a knife-lock state acquisition device, an open control device, a pressure plate state acquisition device, a ground wire state acquisition device and an operation and inspection gateway (standby) [10]. The independent intelligent error prevention host and the sequence control host have built-in error prevention logic to achieve double sets of error proof checking. The communication network is closed for the scheduling data communication channel and can also communicate with the sequence control host. The operation and inspection network provides a channel for remote key order control of the control mechanism.

In Figure 3, ① and ② represent the two ways of obtaining data by the sequential control host: ① represents the data of the measurement and control device obtained by the communication network shutdown (original); ② represents the acquisition of data from the protection measurement and control device (original). Method ① is more optimized and more efficient than method ②.

![Figure 3. Communication network of sequential control operation.](image-url)

4.2. Information security protection—error proofing
The sequence control host is responsible for the collection and processing of data in the station. It should have the functions of one-click sequence control, anti-misoperation locking, operation monitoring, operation and control of the equipment in the station [11] [12]. The anti-misoperation locking is the
The principle of using two sets of anti-misoperation mechanism verification in the process of simulation preview and instruction execution. One set is the built-in anti-misoperation logic locking of the sequence control host, and the other set is the anti-misoperation logic verification of the independent intelligent anti-misoperation host to prevent misoperation.

The intelligent error proof host obtains the information of the whole station equipment state and the pressing board state and can add the pressing board state to the error proof verification. The intelligent error proof host performs the whole process error proof checking of the operation ticket according to the simulation preview instruction of the host and returns the checking results to the host. When the key sequence control operation is executed, the intelligent error prevention host performs one-step error prevention check on each step control instruction sent by the sequence control host and returns the check results to the sequence control host.

5. Case analysis

5.1. The solution to the Model of Optimal Operation

Taking a 110 kV substation as an example, this paper introduces several key links in the preparation and implementation of the one-key sequence control transformation project. After comprehensive and detailed field investigation, the following major constraint conditions are as follows:

1) The control circuit and signal circuit of the 110 kV GIS disconnector in the substation are co-cable. The cable should be re-laid between the GIS control cabinet and the corresponding measurement and control screen. 2) This transformation needs to add a sequential control host screen, and there is no suitable location in the station. At first, it is determined to be placed between the original master console and the 1P screen cabinet. The mobile master console needs to cooperate with the UPS power line and network line at the bottom of the mobile. The cable length margin is not included in the design consideration, resulting in the temporary change of the screen cabinet. 3) in order to avoid delayed shutdown and power recovery, it requires full consideration on when to shut down the old device to make way for the new intelligent error prevention machine and a key sequence control host. 4) The 110 kV GIS equipment and the main transformer switch of the station have the defect on the one-click sequence control, which needs to be combined with power outage.

| Table 1. Sequence control operation sheet of No.1 transformer bay (HV side) |
|--------------------------------------------------|
| **Operational task:** No. 1 main transformer (high-voltage side) from running to hot standby |
| 1 | close 4 × 12 neutral point switch |
| 2 | disconnect 603 circuit breaker |
| **Operational task:** No. 1 main transformer (high-voltage side) from hot standby to Cold standby |
| 1 | Open 6301 disconnector |
| **Operational task:** No. 1 main transformer (high-voltage side) from Cold standby to hot standby |
| 1 | Close the 6301 disconnector |
| 2 | Close the 4×12 knife gate |
| **Operational task:** No. 1 main transformer (high-voltage side) from hot standby to running |
| 1 | close 603 circuit breaker |

For equipment operation conditions and sequence control operation tickets, it is necessary to combine the actual situation of substation equipment. 1) According to the operation mode issued by the control center, when the No. 1 main transformer is in normal operation, its neutral point knife gate should be in position. Therefore, in the hot standby state, the neutral point switch position should not be one of the
operating conditions. Before operating 603 circuit breaker (the main transformer high voltage side circuit breaker), close 4×12 neutral point switch. 2) Since there are no signals such as the input/exit of the remote control pressure plate of the ‘xxx measurement and control device and the input/exit of the fast divider switch of the ‘xxx control power supply in the variable telecontrol and background signal library, the state of such secondary components is not written into the sequence control program as the operating conditions, and it requires maintenance personnel.

According to constraint conditions above, list formulas (1) – (3), and the programming model of the optimal operation mode can be solved by the integer programming method to obtain the transformation target scheme of the distribution network project, as shown in Table 1.

5.2. Technical route for sequential control transformation

![Flow chart](Figure 4. The flow chart of one key sequence control transformation for substations.)

Key sequence control transformation is a systematic project, which is divided into two stages: project preparation and project implementation. The project preparation stage focuses on six tasks: site exploration, equipment operation conditions (i.e. equipment status) definition, sequence control operation ticket preparation, operation confirmation conditions (i.e. double confirmation criteria) preparation, construction three measures preparation, work ticket and acceptance card preparation. The project implementation stage is divided into the non-stop stage and the power outage stage. The non-stop stage mainly includes the equipment installation, platform construction and remote control preset. The power outage stage mainly includes the access, debugging and acceptance. The specific workflow is shown in Figure 4.
6. Conclusion
This paper conducts an in-depth analysis of sequence control and proposes a multi-objective comprehensive evaluation method for optimal operation mode based on factors such as operation and maintenance, construction costs. Through the research of one-key sequence control communication network and information security protection technology, the paper also ensures the safety and reliability of information transmission in the operation process. Through actual cases, the article also analyzes the functional transformation scheme of one-key sequence control technology of intelligent substation.

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