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FUTURE-PROOFING SUBSTATION SAFETY: ADVANCES IN MALOPERATION PREVENTION TECHNOLOGIES

Xiao Ming Wang
Anhui Nanrui Jiyuan Power Grid Technology Co., Ltd., Hefei, Anhui Province, China

Abstract:
Substations play a crucial role in the electrical power infrastructure, and ensuring their reliable operation is of paramount importance. Recent substation accidents and failures have raised significant concerns regarding the safety and stability of the power supply. To address these challenges, the majority of domestic power system substations have adopted intelligent preventing maloperation protection systems. While these systems have proven effective in enhancing safety, certain operational issues persist, such as real-time monitoring of operation ticket implementation and tracking of location data for relevant power equipment and facilities. These limitations can lead to operational inefficiencies and reduced stability and reliability of the power system. In response to these challenges, there is a growing need for a high-performance substation integrated smart preventing mal-operation system. This system would not only provide real-time monitoring and tracking capabilities but also significantly reduce operational pressure on substation operators by simplifying complex tasks within the power system. The research and design of such a system are vital to improving the overall safety and efficiency of substation operations. This paper aims to address the existing problems in substation operation and design a comprehensive integrated smart preventing mal-operation system that leverages advanced technology to enhance operational performance and safeguard the power supply.

Keywords: Substation, Preventing Maloperation, Smart System, Safety, Power Infrastructure

1. Introduction

There are many electrical equipment in the substation, the current substation accident situation is in a frequent state, the safety situation is facing serious challenges[1]. In order to avoid many serious failures, the domestic power system substations at this stage basically take the form of intelligent preventing maloperation protection system[2]. However, during the operation of the substation, there are still certain problems, such as the monitoring system can not effectively obtain the implementation status of the operation ticket in real time and the operation period can not monitor the relevant power equipment and facilities and other location data in real time. In order to avoid the omission of items during the execution of the reversing action, the operation efficiency and stability reliability of the power system are greatly reduced, and the operators are also subject to greater operational pressure due to the complex power system. Therefore, a high-performance substation integrated smart preventing mal-operation system needs to be researched and designed.

Usually, integrated smart preventing mal-operation system have the following two advantages [3-4]: simple operation mechanism; low cost and good economy; 2 main defects exist in the practical application process of power system substations, one is the need for staff to circulate the data, the specific location data of power equipment cannot be updated in real time, reducing the efficiency of the reversing operation and lengthening the downtime of the equipment. The other is that the lockout is easy to be broken and complicated to operate; while other systems and intelligent anti-mistake lockout system have less compatibility, and both operation and operation are difficult, difficult to expand, the background machine data and the location information of the field equipment are not connected, etc.

Based on the structural design and operation method of the preventing mal-operation systems [5-6], the software program is used for the design of the building blocks of the intelligent units, as well as for the design and adjustment of the operation mode of the power equipment and signal data, and the control and adjustment of the operation tickets through the database. For the study and design of the analog operating system, the core of which is the operation authority control mode, data query, and automatic recording, as a way to complete the conversion of secondary blocking lines and data acquisition. Adopting the environment of intelligent system, the data in the control system is transmitted to the preventing mal-operation simulator through the analog disk and supporting parameter contents, while relying on the smart-key to complete the deployment of preventing mal-operation monitoring of substation facilities in the power system. The smart-key, electric encoded lock, mechanical encoded lock, software, smart preventing mal-operation host and simulator are effectively combined to set the lockout device as the important core of the system, so that they can work together to complete the construction of a fully monitored and integrated automation station.

In this paper, the error-proof system of substation integrated system is studied. The "fast topology analysis algorithm" is used to capture the equipment charged operation in real time based on the substation primary wiring diagram and operation mode, and then the wireless network mode is built in the substation to connect the smart-key with the smart preventing mal-operation host in real time, and the real-time communication is realized between the smart preventing mal-operation host and the smartkey and the field locks to integrate the preventing mal-operation, lock control, access control, ground state management and other error prevention measures in real time. It integrates preventing mal-operation, lock control, access control, ground state management and other preventing mal-operation measures, realizes comprehensive coverage of substation preventing mal-operation measures to make real-time locking logic judgment and real-time preventing mal-operation, and controls the operation process of smart-key in real time according to the judgment result, which effectively improves the accuracy and efficiency of the work of operation personnel.

2. Substation integrated smart preventing mal-operation system architecture

A system that uses computer, measurement and control and communication technologies to automatically preventing mal-operation by collecting real-time information on the status of equipment such as circuit breakers, disconnect switches and ground wires, and realizing the function of remote (sequence control) and local operation error prevention.The substation integrated smart preventing maloperation system contains smart preventing mal-operation host, smart-key, preventing mal-operation locking device, smart grounding module and other equipment, as a function of independent supervision system positioning, its architecture design, independent of the substation monitoring system, while following the overall architecture requirements of the State Grid smart substation, taking into account the construction requirements of the centralized control station equipment monitoring system. The architecture design is independent of the substation monitoring system and follows the requirements of the overall architecture of the State Grid smart substation, taking into account the requirements of the construction of the equipment monitoring system of the centralized control station, in which the wireless access meets the security protection requirements of the Security Protection Program of the Smart IOT

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System of the State Grid Co.The specific architecture diagram is shown in Figure 1.

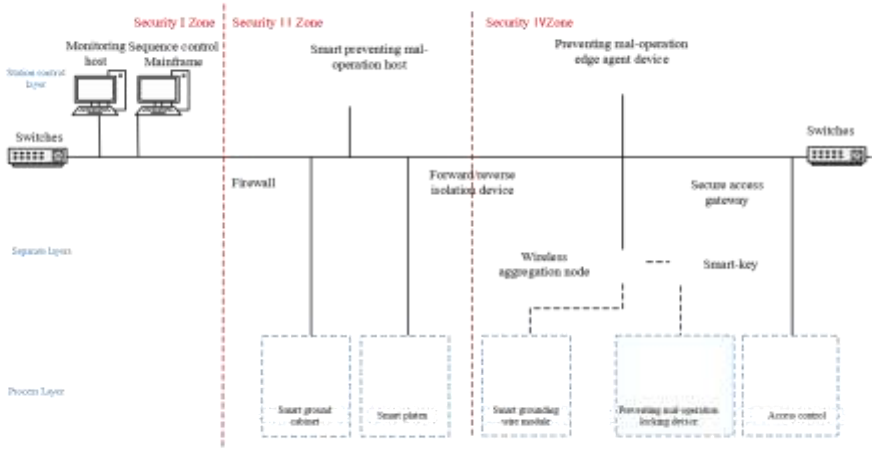

Figure 1: Substation integrated smart preventing mal-operation system architecture

3. Topology preventing mal-operation analysis method for substation integrated smart preventing mal-operation system

3.1 Topology preventing mal-operation principle

The topology preventing mal-operation of the integrated smart preventing mal-operation system of the substation describes that the anti-blocking of device operation is achieved through the topological connection between electrical devices [7]. The mutual topological connection relationship and thus the interlocked devices are searched, and when the topology preventing mal-operation based blocking rules are extracted and determined, they are able to self-adapt to changes in the topology of the power grid and apply to different types of electrical equipment. The following are included:

(1) Electrical island: the electrical combination formed by the interconnected electrical devices in the power system.

(2) Grounding island: If there is a grounding isolation cutter in the island in the closed position or a grounding wire is installed next to some equipment in the island, the island is defined as a grounding island.

(3) Live island: When there are active components such as generators or other power sources in the electrical island, the electrical island is defined as a live island.

(4) Logical bus: a number of nodes are directly connected through multiple switches and isolation cutters, indicating the connection between connected equipment, if the logical bus and the physical bus have obvious differences, the logical bus can be referred to as the bus.

(5) Connected branch: the two ends of the electrical equipment nodes connected to each other through the path.

3.2 Topology preventing mal-operation rules

The logic rules of topology preventing mal-operation in power systems are mainly for operable devices. The main operable devices in the system are three types, which are switches, isolation cutters and grounding cutters.

The Topology preventing mal-operation logic rules of the switch mainly address the case of mistakenly dividing and closing the switch. Figure 2 is used as an example to illustrate the Topology preventing mal-operation logic rules of the switch.

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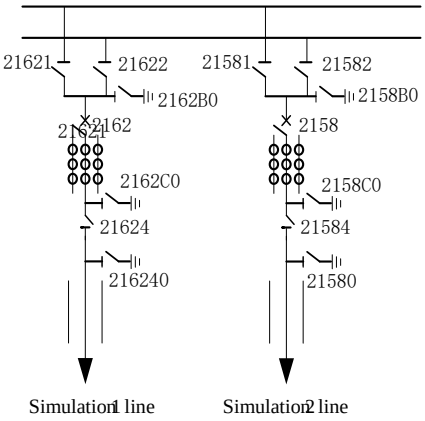

Figure 2: Substation integrated smart preventing mal-operation system architecture

If the original task is to switch 2158 to overhaul work, the switch should be operated with the switch number checked to prevent misoperation of the switch 2162. Compared with the topology preventing mal-operation logic rules of the switch, thetopology preventing mal-operation logic rules of the isolation switch are relatively more complicated, and the rules are divided into two categories, including avoiding closing the isolation switch with a grounding switch and preventing splitting and closing the isolation switch with a load. The following is the description of the topology preventing mal-operation rules with Figure 2 as an example.

(1) If any of the nodes directly connected to the isolation gate belong to any grounding island, it is prohibited to operate the isolation gate. In Figure 2, when either 2158B0 and 2158C0 grounding gate is closed, both ends of 2158 switch belong to the grounding island, therefore, one end of 21581, 21582 and 21584 gates belong to the grounding island. Therefore, it is forbidden to close 21581, 21582 and 21584 isolated cutters when any of 2158B0 and 2158C0 grounding cutters are not pulled open, so as to avoid closing isolated cutters with grounding cutters.

(2) According to the principle of forbidding to open and close the disconnector with load, if there is any switch directly connected to the disconnector in the closed position, it is forbidden to open and close the disconnector. If there is no switch directly connected to the disconnector, further search is required until a switch is found that is indirectly connected to the disconnector. In Figure 2, switch 2158 is directly connected to three disconnectors 21581, 21582 and 21584. When the state of switch 2158 is in the closed position, operation of the three disconnectors is prohibited.

(3) Topology of grounding cutter gate preventing mal-operation. According to the topological analysis of the power system, the power grid can be divided into live islands and grounding islands. If one node of any grounding gate is judged to be a live island, it is strictly forbidden to close the grounding gate to avoid the grounding gate from being closed with electricity. As shown in Figure 2, if the 2158 switch is in the closed position or the 21581, 21582, 21584 isolation gate is in the closed position, the equipment is running with power, the nodes of 2158B0, 2158C0, 215840 belong to the live island, then it is strictly prohibited to perform the corresponding closed operation on the 2158B0, 2158C0, 215840 grounding gate.

4. Wireless network-based substation integrated smart preventing mal-operation system

The substation integrated smart preventing mal-operation system uses the latest wireless communication technology of short-range wireless communication to realize wireless digital communication, which can make the preventing mal-operation operation more intelligent. It can allow multiple services to operate together and multiple operation tickets of reversing gates to be completed at a unified time [8]. The system can support tens of thousands of network nodes and is very expandable to meet the needs of various applications of power preventing mal-operation system. The comprehensive integrated smart preventing mal-operation system can also be extended to be compatible with the ground bank management system, power inspection system and intelligent key management

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system, so that each system can be fully applied optimally and the comprehensiveness of error prevention operation can be ensured.

4.1 Substation integrated smart preventing mal-operation system single station architecture diagram

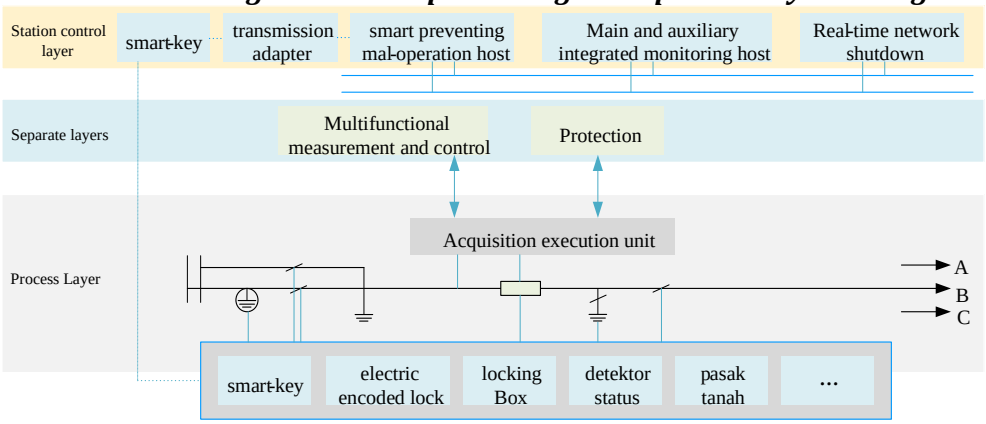

Figure 3: Substation integrated smart preventing mal-operation system architecture

The integrated smart preventing mal-operation system has the functions of remote operation (including sequence control) preventing mal-operation verification and transmission adapter, and the system architecture is shown in Figure 3.

It is deployed at the station control layer, in which the smart preventing mal-operation host is connected to the station control layer network through the station control layer and the smart-key operation sequence generation. They are installed on the primary equipment body or the auxiliary equipment related to the primary equipment to realize the function of forcible lockout for in-place operation.

4.2 Substation integrated smart preventing mal-operation system single station architecture diagram

The operation logic is prepared in advance by the wireless key within the integrated smart preventing mal-operation system based on the operation rules and primary wiring, which is also solidified in the system program and the smart preventing mal-operation host repository. The operator can complete the simulation trial operation in the integrated simulation screen and graphic operation ticket expert system through the content of the specific operation, and then the preventing mal-operation mainframe realizes the self-determination of each operation through the expert system, and if the operation meets the standard specification of "preventing mal-operation", then it will enter the next stage of operation; if it does not meet the standard, then the number and name of the misoperation equipment will be set. If it does not meet the standard, the number and name of the misoperation equipment will be prompted by voice to indicate the wrong operation type, so that the operator can finish the correction of the wrong content.

At the stage of executing the reversing action, the smart-key will display the contents of the reversing operation, and the smart-key can be deployed to the preventing mal-operation locking device at this time, and the effective detection of the operation target can be realized by relying on the coding head. If the detection is passed, the smart-key will transmit the instruction of operation execution by voice and open the locking mechanism, and then the reversing action can be executed. If a wrong operation is performed, the smart-key will send out a warning about the error by voice, and display the information about the wrong equipment and the correct equipment on the monitor screen to achieve the purpose of forced lockout, which can ensure the correctness of the operation process and improve the skill level of the operator. After completing the operation content, the smart-key will rely on the wireless network to transfer the operation content online to the smart preventing mal-operation host, and at the same time update the display status of the equipment in the graphical simulation system of the smart preventing mal-operation host at one time. If the wireless network fails, the smart-key automatically stores the information of the reversing operation

and then transmits it back to update the display status of the primary equipment on the preventing mal-operation mainframe through the communication adapter.

4.3 Substation integrated smart preventing mal-operation system function

1) Online judgment of error-proof logic: After thesmart-key executes each action, the operation data can be transmitted to smart preventing mal-operation host online by the wireless network, so that the data in the field and the data parameters in the smart preventing mal-operation host can be guaranteed to be the same. The smart preventing mal-operation host executes the corresponding operation tickets based on the real-time status parameters of the equipment, and completes the logical determination of them based on the online telemetry and telematics deployed in the back-end system. If it does not meet the standard, the smart preventing mal-operation host will issue a ban command and suspend the action of the smart-key, so that it can effectively avoid the misoperation of the power equipment caused by the inappropriate operation and misoperation.

2) Real-time tracking of operation process: During the operation process, the computer within the wireless network coverage can receive the operation ticket issued by the smart preventing mal-operation host online in real time. In each process executed by the smart-key, each action data will be transmitted to the smart preventing mal-operation host relying on the wireless network, and this smart preventing mal-operation host will realize the online alignment of all primary equipment relying on the online telemetry and telematics in the background system, and display the execution information of each process to the smart preventing mal-operation host, so that it is convenient for the operators to know the specific status of the site in real time and online.

3) Real-time lockout operation function: When operating, the smart-key will rely on the wireless network to obtain the operation ticket sent by the smart preventing mal-operation host and display the current operation content according to the preset process, the operator executes the unlocking action through the equipment number and name pointed out by the smart-key. If the smart-key is deployed to the coded lock, if the online locking logic meets the requirements, it is necessary to open the locking component to make the operator execute the operation of reversing the equipment; if the lock code does not meet the requirements, the system at this time will stop the execution of the operation and pop up the warning page to the main interface of the smart preventing mal-operation host, display the reason for stopping the execution of the operation and display the data related to the smart-key.

4) With the self-healing function of wireless network: Based on the LoRa wireless network technology, a self-healing and self-configuration function module is deployed. If the node equipment in the network fails, the other stable operating equipment will be redeployed according to the form of dynamic deployment, and a new network structure will be formed to ensure the effective transmission of information by other nodes, and the network wound healing can be completed to ensure the data interaction function of the wireless network. Healing, to ensure the data interaction function of the wireless network, greatly improving the robustness of the preventing mal-operation system.

5) Multi-task parallel operation function: The wireless key is able to realize the parallel operation of multi-tasking in many forms of the integrated intelligent preventing mal-operation system, that is, it can realize the simultaneous operation of multiple operators. The smart preventing mal-operation host can be in the standard of preventing mal-operation, and complete the multi-task collaborative operation. In the online operation stage, the system can ensure the parallel operation of several smart-key, and also effectively monitor the operation process of each smart-key.

5. Conclusions

This paper analyzes the urgent need for online preventing mal-operation transformation, the characteristics and transformation effect of integrated smart preventing mal-operation system in the context of the current substation accident situation is in a frequent state and the safety situation is facing serious challenges. With scientific and reasonable design and operation, it can effectively enhance the anti-mistake lockout and full preventing mal-

operation lockout coverage of power equipment and components. Therefore, it can effectively avoid the occurrence of defects in the previous preventing maloperation systems and intelligent substation systems with seam connections. And in the design process, a variety of forms of fault analysis, in each level of the implementation of the action stage, if there is a misoperation can be emergency stop operation, this multi-layer protection, greatly improving the overall stability.

Through the introduction of LoRa communication technology, the introduction of telemetry and telematics as real-time preventing mal-operation evidence, completely solving the problem of equipment's false variable position "topology preventing mal-operation"; the purpose of "free networking, network self-healing", improving the robustness of the system; can establish intelligent detection and analysis module, real-time monitoring of the health conditions of the anti-equipment, to achieve "timely investigation" of the causes of failure, to ensure the reliability of the system. The new grounding device can upload the grounding information to the background monitoring machine in real time to achieve the purpose of real-time monitoring.

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