Analysis Of Fully Automated Feeder Automation in Fault Discrimination and Grid Automation Development

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Abstract. Feeder Automation (FA) emerges as a quintessential instrument for fault diagnostics within electrical distribution networks, markedly diminishing the extent of outage zones and facilitating expedited power reinstatement in unaffected sectors. This role underscores its pivotal contribution to the augmentation of grid automation processes. The paper delineates the foundational theories underpinning fully automated FA, encompassing aspects such as the requisite hardware apparatus, operational paradigms, inherent advantages, research trajectories, applicative contexts, challenges encountered, and future perspectives. Through elucidating the operational mechanics and theoretical underpinnings of two distinct fully automated FA modalities, coupled with case-study analyses, this study asserts the instrumental efficacy and precision of fully automated FA in troubleshooting, positioning it as a principal vector in the evolution of distribution networks. Furthermore, this research proffers novel resolutions to the impediments confronting fully automated FA, offering substantive contributions and insights pivotal for the advancement of grid automation paradigms.

Keywords: Feeder Automation (FA), grid automation, fault analysis.

1. Introduction

With the further development of smart grid, the society as well as the country has higher and higher requirements for automation. The automation function will be prepared with self- learning capability, including modules for automatic billing, fault detection, restoration and feeder reconfiguration, voltage optimization and load transfer and real time pricing (RTP) [1].Traditional manual work has a resource utilization rate is not high, resulting in low efficiency of the entire mechanical system, a person monopoly of the entire machine resources, if you want to multi-pronged, you have to encroach on more human and material resources. It also faces inefficiencies and delays in detecting and correcting errors.

The Feeder automation FA written in this paper can be a good solution to these problems, it is the core application function of distribution automation system, which is an important means to improve the reliability of power supply in distribution network. After the distribution line is put into fully automatic FA operation, when accidental tripping occurs, the FA program can automatically capture the tripping signals of 10kV outgoing switches and the exit action signals of the protection devices in the substation, collect the over-current signals sent from the distribution terminals, quickly analyze the faulty area by combining with the topology of the network frame and automatically complete the isolation of faulty sections and the resumption of power supply of non-faulty sections, the whole process only takes about 1min and requires no manual intervention. The whole process only takes about 1min, without manual intervention [2].

This paper first introduces readers to the theoretical basis of feeder automation, hardware devices, working principle, and its characteristics, mentioning that feeder automation refers to the feeder line between the substation outgoing line to the user's power equipment, and it is based on the DEP-900 Feeder Terminal Unit (FTU) with intelligent in-situ protection, high reliability, high security, and does not have to rely on communication to complete the fault processing of the automatic device. First, the fully automated feeder collects information on the feeder in real time through real-time sensors and analyzes the information. Then, through the state assessment and fault detection of the processed information, the current state of the feeder as well as the existing problems can be determined, and finally a set of appropriate control measures can be formulated based on the fault analysis and assessment. Next, the paper lists the research direction of fully automated FA, the adaptive feeder automation technology of the Chinese Academy of Sciences (CAS) for primary and secondary fusion of complete sets of column-mounted circuit breakers, and the practical scenarios. After that, the two forms of feeder automation, centralized control type and local type (including local automatic control type and intelligent distribution type) were explained, and case studies were made. Finally, the challenges faced by feeder automation are mentioned and their views on how it can be improved are presented.

2. Theoretical Basis

Distribution line (also called feeder line, feeder) is an important part of distribution system, the research of intelligent distribution network is still in the exploratory stage, and feeder automation is the key and core of intelligent distribution network. Feeder automation mainly refers to a technology that automatically detects and cuts off the faulty section after a feeder fault occurs, and then restores normal power supply to the non-faulty section [3]. To realize feeder automation, a reasonable distribution network structure with conditions for ring-fed power supply is required. The operating mechanism of each ring switch, load switch and switch in the street distribution station must have a remote operating function. The ring network switch gear cabinet must be equipped with reliable switching operation power supply and working power supply for FTU and communication equipment; and a reliable communication system that is not affected by the external environment.

2.1. Hardware device

Feeder automation based on DEP-900 Feeder Terminal Unit (FTU). FTU include circuit breakers, load switches, sectional switches, etc. on 10kV lines. Its feeder terminals generally have a main control unit, a battery management unit (responsible for charge/discharge management) and a battery component. Load switches can only cut off the load current, generally used to access the end of the user side, such as column switch. And circuit breaker is the most important electrical equipment in the power system, in addition to the load current, but also can cut off the fault current, and extinguish the arc. Segmented switches are widely used in substation bus and medium-voltage trunks and branches of distribution networks for parallel operation in the case of transferring power from the ring network to the power supply, or for Segmented or dichotomous test-feeding in the case of restoration of power after isolation of faulty segments. The main control unit main is the core of the bus type arc protection system. It mainly serves as the acquisition, measurement, calculation and logic judgment of input quantities, realizes various protections of the system, and communicates with the monitoring master system to upload relevant signals. When alarm conditions are met, an alarm signal is issued, and when trip conditions are met, a trip command is issued to remove the fault. The real-time monitoring of the current and capacity of the battery management unit provides accurate real-time measurement data for the safe and reliable operation of the user's equipment, greatly reduces the chances of over-charging and over-discharging of the battery pack, prolongs the service life of the battery, and thus improves the reliability of the system and the degree of automation. The batteries provide the power for the entire system and ensure its operation.

2.2. Principles of operation

First, the fully automated feeder collects information on the feeder in real time through sensors, including parameters such as current and voltage. This information is processed by digital signals, converted into a data format that can be processed by computers, and transmitted to the monitoring center through the communication network. At the monitoring center, the raw data received is processed and analyzed by a series of algorithms and methods, including differential equations, wavelet transforms, filters, and so on. The purpose of these methods is to clean and optimize the data, eliminate noise and interference, and improve the accuracy and reliability of the data. Next, by performing state estimation and fault detection on the processed data, the current state of the feeder and problems can be determined. State estimation is mainly used to calculate the power, impedance and other information on the feeder by analyzing the trend of current, voltage and other parameters, combined with the model of the power system. Fault detection, on the other hand, analyzes and detects faults in the feeder, such as the problem of over current and over-voltage, based on set fault criteria and rules. Based on the results of state estimation and fault detection, the monitoring center can develop appropriate control strategies and operational measures. For example, when a fault is detected, the faulty section can be automatically isolated and the power supply to the non-faulty area can be quickly restored, thus ensuring the stable and safe operation of the power system. In addition, the control of fully automated feeders is constantly evolving. From the initial no-channel, no-master based re-closer in situ mode, to the local control mode with channels and relying on point-to-point communication between FTU, to the current commonly used remote centralized control mode. The selection of these control methods should be considered in conjunction with the form of the grid structure, the nature of the load, the financial situation, and other factors.

2.3. Characteristic

2.3.1 Intelligent in-situ protection

For fully automatic FA, its intelligent in situ protection relies on real-time monitoring of feeder operation, which is categorized into normal state and accident state monitoring. Normal condition monitoring quantities are mainly voltage magnitude, current, active power, reactive power, power factor, etc. as well as the operating status of switch gear. The monitoring volume is real-time, and the monitoring equipment is generally referred to as a Feeder Terminal Unit (FTU). These quantities can be sent to some level of the distribution SCADA system. The SCADA system is to monitor the equipment remotely through the monitoring terminal. For different devices there are terminals with matching functions, which are roughly divided into DTU (with which the matching device is the ring cabinet), FTU (with which the matching device is the column switch), TTU (with which the matching device is the transformer) and RTU (with which the matching device is the substation outgoing switch when communication equipment is available [4]. In the absence of communication equipment, certain quantities that can be saved or indicated can be selected for monitoring. There are many monitoring points in the distribution network, and those that are necessary should be selected for monitoring to save investment.

2.3.2 High reliability and safety

At the same time, the fully automated FA has high reliability and safety, and in the distribution, network equipped with FTU, it is also possible to accomplish the monitoring in the event of an accident. Fault indicators can be installed at locations where FTU are not installed, and they are usually installed at the entrances of branch lines and large subscribers, with certain anti-interference ability and timing reset function. If the fault indicator has contacts, the fault information can also be sent to a level of the distribution SCADA system via a communication device.

2.3.3 Communication-independent troubleshooting

Intelligent Distributed FA fault processing does not rely on communication with the master station, fault isolation can be accomplished locally, but the results of fault processing need to be uploaded to the master station, and in the process of fault processing, the master station is a bystander that does not participate in the processing process but only collects the results of feeder processing [5]. so there is no requirement for the communication system in the fault handling, so the investment is saved and the effect is fast.

3. Application and Practical Scenario Analysis

3.1. Application scenario

On January 5, the Advanced Distribution System Power Supply Reliability Comprehensive Enhancement Technology Laboratory of the Chinese Academy of Electric Sciences (CAES) carried out a two-fold fusion of complete sets of column circuit breakers with adaptive feeder automation function true type test. Adaptive feeder automation technology of one or two times fusion of complete sets of column circuit breakers came into being, which can automatically realize automatic detection, positioning, isolation and power supply restoration of multi-branch and multi-contact distribution network frames when there are faults through the method of "no-voltage breaking, delayed closing of incoming call", combined with the short-circuit ground fault detection technology and other control strategies, and cooperate with the re-closing of outgoing switches of substations to automatically realize automatic detection, positioning, isolation and power supply restoration of multi-branch and multi-contact distribution network frames when there is a fault, and adaptive to the mode of operation of the system after the transfer of power supply to adapt to the operation of the new type of electric power system on a wide range of occasions [6].

Han Yin feng and other researchers from Ning Bo Power Supply Company of State Grid Zhejiang Province Electric Power Co., Ltd. conducted an optimization study from the perspectives of promoting automation engineering construction, strengthening automation system maintenance (including operation index control, map and model information maintenance, switch state operation, and construction and renovation synchronization), and strengthening the daily application of distribution network scheduling by taking into account the problems of incorrect actions and discontinuous transfer of interactive signals in the current fully automated FA. Optimization study was conducted [7]. Finally, through two years' efforts, the overall success rate of fully automated FA was increased from less than 40% at the beginning of the application to more than 70%, and successfully passed the test of actual cases, with the overall effect of use intact.

The same is for the fully automated FA action incorrect analysis Zhang Kai Di and other researchers from the State Grid Chongqing Bei bei Power Supply Company carried out a detailed analysis, put forward the incorrect action mainly stems from the distribution automation master factors, distribution automation terminal factors and other factors, and through the optimization of the master function, strengthen the terminal management and other effective measures to optimize the problem, and ultimately will be their own A region of the feeder automation correct action rate of 88% or more, and further enhance the effectiveness of the application of power distribution automation utility and the reliability of the distribution network power supply [8].

3.2. Practical scenarios

With the aid of communications, the centralized FA can perform fault location, fault isolation and resumption of power supply to non-faulty areas by the main station based on the fault information transmitted from the distribution automation terminals for fault identification and issuing operation commands to the distribution automation terminals [9]. Centrally controlled FA have greater advantages in transferring supplies in non-faulty areas, with high accuracy and reasonable load deployment. However, the large number of terminals is prone to congestion, and an error at any point in the process will result in failure.

In-place automatic control is based on the re-closer, Segmented switching mode mainly rely on the switch itself to complete the simple automation, which cooperates with the power side of the predecessor switch, in the line with its own unique functional characteristics, in the case of loss of voltage or no current automatically split, to isolate the fault to restore part of the power supply. These switches generally have either a "voltage-time" characteristic or an "over-current pulse counting" characteristic. The voltage-time type is the most common local recloser feeder automation mode. It mainly utilizes the switch's function of "loss of voltage breaking and incoming delayed closing" to isolate the fault and restore power supply to the non-faulted zone automatically by relying on the equipment's own logic judgment function and using the voltage time as a basis for matching with the reclosing of the outgoing switch of the transformer substation. After the substation has tripped, the switch loses voltage to separate, and after the substation has reclosed, the switch closes with an incoming delay, determining the fault location and isolating it according to the voltage holding time before and after closing, and restoring power supply to the non-faulted zone in the direction of the power source at the fault point. This way of working also contributes to its low cost and reliable operation. However, this approach is only suitable for the system is suitable for radial, "hand in hand" ring and multi-segmented multi-connected simple grid distribution network, for more complex grid structure will be slightly more difficult [10]. The key to the application of this system lies in the proper setting of the re-closer and voltage-time type Segmented parameters, which, if improperly set, will not only expand the fault isolation range, but also prolong the time for restoring power supply to the sound area.

Intelligent distributed in situ feeder automation is based on the re-closer mode of in situ feeder automation, adding local fiber optic communication, so that the FTU in the ring network interact with each other, and directly jump on the two sides of the switch nearest to the point of failure within ms level time after the fault, the substation outgoing switch does not need to be tripped, so as to minimize the outage area, and at the same time, the contact switch automatically closes the gate and transfers the power supply. Such an operation principle makes it possible to realize multi-switch series connection without graded difference protection coordination, quickly and accurately realize fault isolation and transfer of power supply, to achieve the purpose of minimizing the scope of power outage and the shortest power outage time. When the protection channel fails, it can automatically switch to the re-closer mode of local feeder automation, which is highly reliable and can be applied to the backbone network with high power supply reliability requirements. Distribution masters and sub-stations may not be involved in the process.

The Comparison between feeder methods is shown in table 1.

Table 1. The Comparison between feeder methods

Comparison Item	Local Feeder Automation		Centralized Feeder Automation
	Recloser	Intelligent Distributed	
Communication Channel	None	Required	Required
Fault Recovery Time	1 to several minutes	Several seconds	Several seconds to several tens of seconds
Control Technology	Local control, independent of communication, through reclosure and segmentation	Local control, between substation and terminal, between terminals	Central control at the main station, achieving global data collection and control in the matching network

Comparison of the above two modes of fully automated FA we can conclude that the recloser in the local feeder automation has the advantages of local control, does not rely on communication, easy to maintain, but its fault processing time is longer usually reaches 1 ~ several minutes, while the intelligent distributed and centralized processing faults in a very timely manner, only a few s to tens of seconds.

4. Challenges and Prospect

4.1. Challenges

The system directly controls Segmented switching without the sensation of causing substation interrupter shocks. However, in fact, in the event of a line fault, the station circuit breaker must undergo a re-closing, the purpose of which is the rapid restoration of power supply for transient faults. If the current-type distribution automation system, in accordance with the above principle, directly isolates the fault, then a large proportion of transient faults will be regarded as permanent faults and be isolated, thus resulting in an expansion of the accident problem.

The controller has a fault confirmation time of 3.5 seconds, this fault time is closely related to various locking relationships, so the re-closing time is generally set to 5 seconds, which is greater than the fault confirmation time of 3.5 seconds. If the re-closer in the substation operates within this fault confirmation time, the feeder equipment on the line will be put into operation without delay, making it impossible for the equipment to determine the point of failure.

Another problem often mentioned in the application of voltage-based equipment is that this mode cannot be used for mixed overhead line and underground cable networks or purely underground cable networks because of the inadvisability of overlapping them. Due to the ground cable faults occur mostly permanent faults, even if the re-closing again, these faults cannot be eliminated, and re-closing again impact line, so the re-closing does not make sense, this time the entire line must be blacked out to search for faults, resulting in human and material losses.

4.2. Prospect

For multiple re-closing and secondary re-closing for the shock caused by the substation I think we should increase the waiting time between each link, in the first re-closing the system should be set to pause time and provide a manual determination of the option, the staff must be in the detection system to determine the state of the substation at this time, the staff to determine the optimal time to send the power, the impact will be minimized. For the problem of hybrid network, if the feeder automation switch is used in the hybrid distribution network, when a line fault occurs, through a re-closing, the Segmented switch can be put into isolation of the fault step by step, and ensure that other normal intervals are quickly restored to the power supply by sending the power to the other normal intervals, and the reliability of the power supply can be greatly improved only through a re-closing.

5. Conclusion

In this paper, the following conclusions are obtained from the research: firstly, the fully automatic FA is used for feeder wiring between substations as well as users, which is built on DEP-900FTU to realize feeder automation, and it is a kind of fully automated system that can find the circuit problems by detecting and comparing with the characteristics of high reliability and high safety.

Secondly, nowadays the society mainly researches on the accuracy and rapidity of its action, and has achieved good research results, which has increased the correct rate of its action to 80%. Furthermore, local feeder automation is more suitable for the control of a certain area, while centralized feeder automation is more inclined to the centralized control of the distribution network. This paper presents some of its own views on the difficulties faced by fully automated feeders, and it is believed that it can provide some help for future grid automation and make the grid automation system more complete.

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