Review on Methods of Wide Area Backup Protection in Electrical Power System

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Abstract—Thanks to wide area measurement system, the introduction of the whole electrical power system information into wide area backup protection methods has made up the severe deficiency that some incorrect judgments made by traditional backup protective devices when the transmission line overload occurs are only based on local measuring data, which may cause incorrect operation of protective relays. The deficiency of traditional backup protection has deteriorated the operating condition of the power system and has accelerated process of cascading trips. The current methods of wide area backup protection can be possibly designed for optimal strategies from the point of the whole system. In this paper, according to the different designing principles, methods of wide area backup protection are classified into five categories and are listed in detail based on the present research progress. Advantages and disadvantages of these methods in practical application are summarized. At last, the existing problems and possible studying directions of wide area backup protection methods are pointed out.

Keywords-power system; wide area backup protection; wide area measurement system; overload; cascading trips

I. INTRODUCTION

With the interconnection of power networks, the topology structure is becoming more complex and the operating control is becoming more difficult. Transmission lines are operating close to their limit. Thus relay protection is of great significance to the security and stability of the power system [1-2]. When transmission lines are heavily loaded and there is any fault, if the protective devices can operate correctly, reliably and quickly, the fault will be cleared in time, so that the system's operating condition will not be deteriorated.

Traditional backup protection has its own deficiency that the only utilization of local measuring data may bring about the incorrect judgement [3-4]. For example, after the faulted transmission line is removed, power flow on it will be transferred to other connected lines. If these lines are heavily loaded, non-faulted overload may occur caused by the transferred power flow. Traditional zone 3 backup relays will operate to remove overloaded lines according to their setting principles, worsening the system's operating condition. Because of the introduction of the whole power system information from wide area measurement system, wide area backup protection can overcome the deficiency of traditional backup protection. The protection scheme can be designed for optimal controlling strategy from the whole power system's view of point, thus the cascading trips can be prevented beforehand and the stable and safe operation of power system can be guaranteed.

In this paper, based on the current research process and the different designing principles, the methods of wide area backup protection are mainly classified into the following five categories: wide area current differential backup protection, wide area fault directional comparison principles, transferred flow identification based wide area backup protection, adaptive scheme based on wide area information, and expert decision system for wide area backup protection. The paper classifies and analyzes the five different methods of wide area backup protection in detail. The advantages and disadvantages of them on operating performances, sensitivities, fault tolerances and coordination with the main protections are summarized respectively. Moreover, the existing unresolved problems in practical application and the technical perspective of the development of wide area backup protection methods in the future are pointed out.

The paper is organized as follows. In the next section, several recent well-known blackouts in the world are listed for the presentation of reasons and lessons learned from them. Section 3 introduces the current research situation of the five categories of wide area backup protection methods. The features of them are summarized in detail. The point of view in practical application is proposed. In Section 4, the problems of the existing wide area backup protection methods to be solved and possible developing directions in the next few years are concluded.

II. REASONS AND LESSONS FROM WELL-KNOWN BLACKOUTS

It is difficult to avoid power system fault. If backup protection can identify the abnormal condition of power system accurately and can diagnose the conditions properly, the system status deterioration will be curbed effectively. The rapidly and reliably removing the faulted line when the main protection rejects to operate, and blocking relays tripping when overload occurs, cascading trips under condition of heavy load will be prevented effectively.

According to statistics of recent 17 years by National Electric Reliability Council, reasons of 63 percent of well-known power system blackouts are related to incorrect operation of protective relays [5-10], such as interconnected North America power grid blackout on August 14, 2003, central China power grid blackout on July 1, 2006, western Europe power grid blackout on November 4, 2006 and India blackouts occurred on July 30 and July 31, 2012. After faulted lines are removed by main protection, power flow on them will be transferred to those connected lines. The transferred power flow may result in overload, which cannot be distinguished between internal fault by traditional backup protection [11-12]. Backup protection will operate to remove the overloaded lines according to the original design principles rather than block relays in time, accelerating the collapse of power system.

As the possibility of failure of substation DC power supply cannot be ignored, the role of the remote backup protection for the adjacent electrical components is essential [13]. At the beginning of the blackout, the range of the accident is not very big, and the cost to take measures is not very high. So if we can take corresponding measures in time, the expansion of the blackout may be prevented effectively.

In recent years, with the rapid development of modern communication and digital technology, wide area measurement system arises for power system relay protection. Wide area measurement system can collect the electrical synchronous phase information and can update it every 20-50 millisecond [14-16], creating the conditions for the power system dynamic control. Therefore the protection scheme can be designed for optimal controlling strategy from the whole power system's view of point.

III. PRESENT SITUATION OF WIDE AREA BACKUP PROTECTION METHODS

The concept of Wide Area Protection is first presented by Swedish scholars Bertil Ingelsson in 1997. Compared with traditional stability control strategy, wide area protection involves a wider range of information acquisition and control strategy implementation. Since 1998, a lot of scholars at home and abroad started the wide-area backup protection research.

According to current research process, the methods of wide area backup protection are mainly classified into the following five categories: wide area current differential backup protection, wide area fault directional comparison principles, transferred flow identification based wide area backup protection, adaptive scheme based on wide area information, and expert decision system for wide area backup protection. All kinds of methods are reviewed and compared as follows:

A. Wide area current differential backup protection

Wide area current differential backup protection is based on kirchhoff's current law. By measuring current differential quantity, the fault point is located in the internal area or the external area. Traditional current differential backup protection only reflects the internal fault of an electrical component, while wide area current differential backup protection extends the protective area to the adjacent area, providing the rapid main protection as well as the short-delaying and good-selective backup protection.

The earliest research related to wide area current differential backup protection can be found in the literatures [17-18]. The literatures make use of the dedicated optical network to transfer synchronized current date marked by Global Positioning System to make up wide area current differential backup protection system. This scheme can effectively shorten the operating delay of backup protection, but due to the fixed partition for protective areas, the adaptability of the scheme to power system operation mode changes is limited. Literatures [19-20] use kirchhoff's current law to check or reconstruct measuring date at protective devices, and introduce tripping priorities to decide relays tripping order. The method removes those breakers first whose date was error or lost to determine the position of the faulted component, effectively improving the conditions that errors may occur in data transmission process. The wide area current differential backup protection principle in literature [21] quickly locates the fault and removes the faulted components by partitioning the protective ranges and associated domains of intelligent electronic devices installed at the circuit breaker points. Factors influence the performance of wide area backup protection include the error of current transformers, the reliability and the operating way of the transmission channels. A large amount of data transmission makes it very complex to design the communication system of the wide area current differential backup protection.

B. Wide area fault directional comparison principles

A wide area protection algorithm based on direction comparison is proposed in literature [22]. The algorithm adopts substation centralized structure. According to the main devices/direction element of the substation and transmission lines, the matrices are created to identify the specific faulted components combined with faulted direction information. The algorithm is limited by direction element discriminant, so its accuracy may be reduced under the conditions of power swing or power converse.

Literature [23] utilizes the positive sequence component element, negative sequence component element and virtual quantity direction element for make up disadvantages of the former elements as the basic protection elements. The cooperating relationship is discussed based on the three elements' operating characteristics. Then the logical relationship of the complex component is presented to reflect all kinds of faults and to avoid dead zone of protection exit in case of three-phase short circuit fault.

C. Transferred flow identification based wide area backup protection

As the number of nodes in the modern interconnected power grid is very large, power flow calculation is very huge and complex. Power flow transferring involves multiple components. In order to satisfy the real-time control in emergency, the introduction of wide area information is essential to identify internal fault or the transferred power flow in a short time [24], so that the incorrect operation of backup protection will be prevented and effective measures to eliminate the influence of flow transferring will be taken to ensure the safe and reliable operation of the power system.

On the basis of analyzing the defects of traditional backup protection, literature [25] puts forward a new flow transferring identification method based on WAMS. Through comparison between the estimated power flow and the measured power flow, the result of transmission line overload is determined. If it is resulted from flow transferring, the backup protection will be blocked on time and relevant measures will be taken for power service restoration. Literature [26] studies the power flow transferring identification method taking consideration of transient process. The introduction of changes in power flow caused by the generator and load of the power grid can effectively reduce the possible errors in power flow distribution calculation.

D. Adaptive scheme based on wide area information

Traditional relay protection makes the protective settings according to the worst condition of the power system. It is very difficult to satisfy the demands on selectivity, rapidity, sensitivity and reliability at the same time. In order to improve the performance of the existing protection and to adapt to all kinds of power system operating modes [27], scholars at home and abroad carry out the studies on adaptive protective scheme based on wide area information, which can adjust the setting values in real time in terms of changes in the system topological structure.

Literature [28] lists the factors influencing the relay protection setting calculation, including the calculating speed, efficiency, accuracy and others. The literature also lists the situations that leads to the complex calculation of the protective settings, such as repeatedly breaking a circuit, finding errors under the worst operating conditions of the power system, the improper selection of protective delays and so on. Ideas are presented to solve the problems that the setting calculation ranges are partitioned based on the disturbed area, and circular protective setting calculation is carried out in the calculating zones. Literature [29] proposes an adaptive scheme based on port equivalent algorithm. The method tracks the apparent impedance in the real time after the overload occurs, and analyzes the principles of fault calculation and values setting. Then the method gives constraints to prevent the incorrect operation of backup protection and to keep the fault identification function in the meantime, realizing the adaptive adjustment of backup protection.

E. Expert decision system for wide area backup protection

In this method, when the monitoring system detects the transmission line fault, the expert system will start the reasoning process to locate fault and to issue a tripping signal. The decision rules of expert system is divided into two levels: the first level is responsible for identifying the internal fault and issuing the tripping signal; the second level make decisions according to the fault-influencing area, whose priority is lower than the first level. The expert decision system for wide area backup protection can cooperate with the main protection to realize the accurate, rapid, intelligent identification of internal fault and to solve the problem that the trip delay is not short enough. On the other hand, the expert system may demand better communication reliability.

Doctor Tan presents the centralized structure of expert system for wide area backup protection [30-31]. Through acquisition of identification results of four zones in fault adjacent area, the fault is accurately located and isolated according to the decision principles. The utilization of the expert system can reduce the bad impact of circuit breaker failure on the backup protection. Literature [32] studies the grid based expert decision system for wide area backup protection. Combined with the advantages of grid platform, the expert system invokes the electrical quantities such as the network topological structure, the relay operation information, and the circuit breaker switch state by the wan conveniently to complete inference and decision-making process. At the same time, using the parallel and distributed computing ability, the system can quickly and accurately complete the data processing and analysis, speeding up the fault location and shortening the delay time of the protection.

IV. CONCLUSIONS

Wide area backup protection can improve the performance of traditional protection on configuration, principles and implementation. It can also simplify the setting calculation, and can eliminate some factors that endanger the safe and stable operation of power grid such as mismatch between protections and incorrect operation in case of overload. Thanks to the introduction of the whole system information, it is possible to set up the optimal control strategies from the global perspective.

This paper classifies the methods of wide area backup protection into five categories based on the different designing principles: wide area current differential backup protection, adaptive scheme based on wide area information, transferred flow identification based wide area backup protection, wide area fault directional comparison principles and expert decision system for wide area backup protection. The unresolved problems existing in the study of wide area backup protection methods are considered as follows:

i) The process of wide area backup protection research at present is still at the theoretical stage, in which the emphasis is laid on the specific problems rather than the overall planning and implementation.

ii) Categories of methods have not pointed out their applicable environments of power grid yet, such as voltage grades, the system structures, configuration requirements, economical and technological conditions, etc.

iii) The promotion of wide area measurement system and digital substation technology may bring changes in data source and communication requirements of wide area backup protection. Lack of consideration on differences from traditional supervisor control and data acquisition system, the communication structure and configuration applied to various wide area backup protection algorithm deserve to be improved.

As the focus and the direction of modern power system relay protection research in the future, wide area backup protection should overcome the above shortcomings gradually. Planning from the whole perspective is essential for guaranteeing the sound coordination between control center and protective units. In order to optimize the fault identification and isolation of the whole power system, data from different positions should be marked its weight or priority explicitly for the next determination by wide area backup protection. Applicable environments of all kinds of wide area backup protection methods, including communication configuration, voltage grades, the system structures, economical and technological conditions, need full consideration to satisfy the requirements of the speed, precision of protective data transmission and the reliability and stability of power system relay protection. As the process of research is pushed forward, the existing problems of wide area backup protection methods will be solved. More advanced research results will come out to improve the performances of wide area backup protection.

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