Analysis Of Typical Power Grid Blackout Accidents And Suggestions For Countermeasures

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Abstract. The prevention and control of power grid blackout has become an important research content of the modern power industry and government departments. This paper collects and compares 160 influential international large-area blackouts since 1960, summarizes and analyzes the main causes, common problems and developing Process. Combined with the operation of China's power grid, the main risk sources of large-scale blackouts and the recovery process are summarized. Based on the lessons of international blackout accidents, some specific suggestions and countermeasures are put forward from four aspects, such as strengthening risk management and operation control of large power grid, which can provide useful reference for the safe operation of large power grids above provincial level.

1. Introduction
How to effectively prevent, control and response to large-scale power grid blackouts, has become an important research content of the modern power industry and the relevant regulatory bodies and government department[1][2]. Blackouts have occurred in many countries in the world in recent years. According to incomplete statistics, 28 major blackouts have occurred globally, including 6 in the United States, 2 in Europe and 0 in mainland China[3]. Since 2015, China has become the largest power grid in the world with the largest installed capacity, the highest voltage level and the strongest resource allocation capacity. On the other hand, some new risk sources that affect the safety of power grid have appeared. In some way, the new risks threatened the safe operation of the power grid are increasing, the risk of large-scale blackouts always exists.

The main causes, common problems and developing process of blackouts are summarized based on 160 cases of blackouts in the world since 1960. Further, combined with the operation of China's power grid, this paper analyzes and introduces the risk sources of blackouts and the main process of handling and recovering. Finally, some specific suggestions and countermeasures are put forward by drawing lessons from international blackout accidents, such as strengthening risk management and control of large power grid, establishing reliable the three-defense-line, operating important equipment safe, controlling network safety management, improving emergency response capacity. It can provide useful reference for the safe operation of large power grids above provincial level.
2. Review of major international blackouts
Modern power systems are equipped with relay protection and safety control devices, so some simple accidents do not easily lead to large-scale blackouts. Looking back on the typical cases since 1960, the reason of large-scale blackouts is not a simple factor, but a series of adverse events and many accidental factors. Set up samples of typical blackout cases since 1960, the main causes can be classified and analyzed, and summed up the rules and lessons. Since the middle of the last century, the power grids have entered the era of large generator, high voltage and large-scale interconnection. The loss and influence caused by the blackout are increasing day by day, and the importance of the safety to the large power grid is becoming more and more prominent. Based on the statistics of load loss, the proportion of affected users, the duration and the severity of blackouts, 160 blackout cases in the world since 1960 are selected to establish samples. The occurrences of international blackouts in different years is shown in Figure 1.

Fig. 1. International blackout occurrences in different years since 1960

(1) From the perspective of time dimension, the international blackout occurrences are on the rise after 1960, the regions where the blackouts occurred tend to be more scattered after 1990, 120 of the 160 blackout cases are occurred after 2000.

(2) From the perspective of regional dimension, North America is the region with frequent blackouts. 62 blackout cases are occurred in the United States and Canada, including 45 in the United States and 17 in Canada. Power grids in Western Europe, Russia, as well as developing countries such as Brazil and India, also suffered from blackouts.

(3) From the perspective of load loss statistics dimension, 28 blackout cases of more than 8000MW and 37 blackout cases of more than 5000MW are occurred.

(4) From the perspective of recovery time dimension, about 80% of the accidents can be recovered in a few hours after the accident. However, if serious natural disasters cause large-scale damage to the power grid, the recovery process usually takes days or weeks.

3. Analysis on the causes and developing process of blackout
Many causes may lead to large-area blackout, such as natural disasters, unreasonable grid structure, insufficient standby capacity at peak load, unreasonable relay protection and safety control settings, improper grid dispatching management and disposal, network attacks, equipment failures, etc. The specific reasons (as shown in Table1.) and typical cases are as follows:

Natural disaster, such as typhoon, earthquake, ice disaster, etc, often causes large-scale damage to power grid equipment, resulting in large-area blackout\(^4\). Key equipment failure, such as key lines, key transformer and important protection and control equipment, etc, may lead to major or above accidents, resulting in a large-area blackout\(^5\). Misoperation and improper handling of dispatching may also lead to large-scale blackout\(^6\)\(^-\)\(^7\). Serious imbalance of generation and consumption caused by various reasons may lead to large-area blackout. Computer and control system failure due to network attack and other reasons, which will lead to the fatal damage of power generation system and power grid system.
Table 1. Analysis of the initial cause of blackout

| Initial cause     | Times | Proportion |
|-------------------|-------|------------|
| Key equipment     | 77    | 48.12%     |
| Natural disaster  | 49    | 30.62%     |
| Error control     | 15    | 9.38%      |
| External damage   | 8     | 5.00%      |
| Supply imbalance  | 7     | 4.38%      |
| Network attack    | 4     | 2.50%      |

A large number of cases show that the blackout is not a simple event, but a complex process of dynamic development and multiple factors. According to the basic law of power system operation, the common process leading to blackout is described as follows:

1) Transmission line cascading failures. Some key line trip causes a wide range of power flow transfer, and the other tie-line flow control is not timely, may lead to the interlocking trip of the grid connection channel and worsen the operation condition of the power grid.

2) Power angle stability failure. The important tie-line chain loses, the system impedance increases, and the power angle stability margin decreases, when the stability limit is exceeded, the system will lose synchronization, which will lead to system disconnection and unit shutdown.

3) Frequency stability failure. After disconnection, the power generation and consumption of the system are seriously unbalanced, and the frequency deviation exceeds the allowable value. If measures are not taken in time the system frequency will further deteriorate until it collapses, causing a blackout.

4) Voltage stability failure. After a series of accidents, the power angle stability may not be damaged, but the bus voltage of some hub substations is seriously reduced. If the adjustment is not timely, the voltage collapse will be caused, probable resulting in large-area blackout.

4. Risk sources in operation safety of large power grid

China has a vast territory and complex geographical conditions. The frequency and intensity of natural disasters such as typhoon, rainstorm, ice and snow, lightning, earthquake, etc, are on the rise. In addition, the risk brought by dense transmission channel needs to be paid more attention. Disasters may cause multiple lines jumping at the same time, which has a huge impact on the system and seriously threatens the safety of the system.

With the rapid growth of new energy installation, the proportion of thermal power unit has further increased, nuclear power units have been put into operation, and the proportion of units undertaking peak load regulation tasks has continued to decline. During the accident, it is easy to large-scale off grid due to abnormal voltage or frequency, leading to cascading failure.

Power supply, power grid and load are all connected with a large number of power electronic equipment. The trend of power electronic is obvious. After failure, the equipment cascading reaction aggravates the complexity of the system and greatly increases the difficulty of control. In the grid connection of wind power, photovoltaic and other new energy, power electronic technology plays a very important role, mainly including inverter, solar charger, matrix frequency converter, active filter, etc. Many functions of the stability control system, intelligent equipment, DC control and protection system are realized through software logic, and the hidden danger tends to be more hidden.

In the market mode, the allocation mode of power grid from plan to market, the decision-making of power plan is decentralized. With the increase of market entities, the transaction frequency and the number of transactions increase, which puts forward higher requirements for the technical support system.
5. Ensure the safety of large power grid and prevent blackout

5.1 Strengthen risk management and control of large power grid

Strengthen the awareness of power grid risk and actively carry out power grid risk assessment. Strengthen the outage plan, power generation plan, safety management and control and multiple outage check of large power grid, strictly control all kinds of risks that may cause the outage. According to the change of power grid operation mode, carry out the troubleshooting of power grid safety risks, deeply study the characteristics of AC-DC hybrid power grid and the operation mechanism of large power grid, timely improve the stability control strategy, and effectively strengthen the weak points of power grid operation. Strengthen the real-time control and regulation capacity of power grid operation, implement the integrated control of power grids at all levels, strictly control the power flow of important sections, and prohibit the operation beyond the stability limit and equipment capacity. Strengthen the coordinated control of the source-network-load, strengthen the safety management and technical supervision of the grid involved in the wind power plant, speed up the construction of the precise load cutting system, and improve the power grid balance control and system regulation capacity. Solve the short circuit current constraint. The short-circuit current problem has become a prominent problem restricting the safety of interconnected large-scale power grid. There are contradictions between reducing short circuit and improving the transmission capacity of power grid. It is necessary to comprehensively consider the reasonable grid structure planning, carry out the technical research and engineering application of larger breaking capacity circuit breakers, and increase the short-circuit current flexible suppression technology research to improve the safety of power grid.

5.2 Strengthen the construction of three-defense-line

Strengthen the operation management, implement the requirements of "four characteristics" (rapidity, reliability, sensitivity and selectivity) of relay protection, and ensure the reliable operation of equipment in the network. Strengthen equipment maintenance, operation management, implementation of anti-accident measures and management of automatic safety devices, deepen the troubleshooting of "three-defence-line" hidden dangers, and eliminate hidden dangers against power grid safety. Strengthen the safety control equipment management. Part of the transmission capacity of UHV depends on the safety control equipment, which is forced to become the necessary measure for the safe operation of power grid in the transitional period. Regularly carry out safety control equipment inspection, accelerate the construction of safety control procedure system, realize standardized design, standardized management and modular inspection of safety control equipment. According to the change of power grid operation mode, carry out the troubleshooting of power grid safety risks, deeply study the characteristics of AC-DC hybrid power grid and the operation mechanism of large power grid, timely improve the stability control strategy. Improve the intelligent substation relay protection reliability level. The development of some new technologies ignores the requirements of "four characteristics" of relay protection, which may lead to incorrect operation of protection and threaten the safe and stable operation of large power grid. Improve the operation reliability of merging unit, intelligent terminal and other equipment. Strengthen the research of operation mechanism, prevent multiple protections from incorrect action or locking due to single component failure, and eliminate the possibility of causing major accidents. Strengthen the research on the influence of the characteristic change of the large power grid on the DC control protection. With the expansion of UHVDC scale and the strengthening of coupling, the DC fault characteristics such as commutation failure, restart, equipment over-voltage become new constraints for the safe operation of power grid. Increase professional coordination and linkage, rely on the actual demand of power grid operation, timely adjust the DC control and protection function design, and improve the adaptability of UHVDC protection.
5.3 **Strengthen the operation and safety level of important equipment**

Strengthen the whole process safety management of equipment. Strictly implement the requirements of major anti-accident measures of power grid, and improve the intrinsic safety level of equipment. Increase the investigation and treatment of hidden dangers of important equipment and ultra-high voltage equipment, and effectively improve the health level of ultra-high voltage and key equipment. Strengthen the research on the operation characteristics of the equipment. Carry out the special improvement work in time. Carry out troubleshooting of anti-misoperation of substation circuit breakers, regularly check the anti-short-circuit ability of transformers with 220 kV and above, improve the reliability of cable operation, and practically implement measures to prevent full stop of substation. Strengthen the management of abnormal handling ability. Carry out the treatment of special hidden dangers such as station AC / DC power supply and intelligent station SCD. Strengthen operation and maintenance inspection, and strictly prevent pollution flashover, external short circuit fault, flood and cold etc. Carry out comprehensive control of electrical fires, accelerate the remediation of fire safety hazards, and improve the fire-fighting capacity of substations. Comprehensively strengthen the protection of power facilities. Focusing on the protection of key transmission channels and important power facilities. Carry out risk assessment of important transmission channels and implement management and control measures for risks at different levels. During the continuous period of heavy load and power grid risks, such as summer and winter, equipment operation and maintenance guarantee shall be strengthened, risk management and control measures shall be implemented to ensure safe and reliable operation of high power.

5.4 **Strengthen the management and control level of network security**

Enhance the network safety awareness of all staff and strengthen the network security management. Implement the responsibility of network security, carry out the publicity and implementation of network security law, strengthen the network security training, and improve the network security awareness and technical skills of the whole staff. Strengthen network and information security control. Strengthen the unified management of network security, and form a network security management and control mechanism for each of them. Implement the requirements of network security "three synchronization" (synchronous planning, synchronous construction and synchronous operation), and strengthen the safety management and control of project construction process. Strengthen the network security audit and improve the management level of network information system operation and maintenance. Improve the network and information security system. Strengthen the network security cooperation with government departments, establish the network security information sharing mechanism, enhance the ability of network security technicians, carry out the network security early warning, monitoring, analysis and drilling work in a normal way, and improve the collaborative handling ability of network security events. Improve the level of network security technology protection. Strengthen the information security management of the external network system, strengthen the technical supervision of the network related parts of the power monitoring system, carry out the normalization of the network safety risks, carry out the research on the network security of the new information communication technology, accurately grasp the trend and it’s safety risks, and take the initiative to prevent and resolve the network security risks.

6. **Conclusion**

‘Safety first, prevention in priority and comprehensive renovation’ is the safety consistent policy of China's power grid. The prevention of power grid blackout has become one of the primary tasks of the country, energy industry and power enterprises. To form a working system and mechanism between government-enterprise, adhere to the unified dispatching management mode, adhere to the source control and hidden danger investigation, and adhere to the intrinsic safety construction of the power grid. It’s necessary to implement comprehensive renovation to ensure the safe operation of the power grid and prevent large-scale blackout, such as development planning, infrastructure construction, marketing management, dispatching operation, etc. These specific suggestions and countermeasures
are put forward from four aspects, which can provide useful reference for the safe operation of large power grids above provincial level.

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