The Reason Analysis of Holland Blackout on March 27, 2015 and Lessons for Hunan Power Grid

Meng Xiang, Dongzhen Yu, Wenlin Wang, Jian Zuo, Yangwu Shen, and Xiaoqian Xie

***Abstract*—On March 27, 2015, technical faults occurred in a Dutch substation, and the chain reaction followed by lead to blackout in a large area of Holland. The blackout caused serious consequences on the north area of Holland (including the capital Amsterdam). This paper briefly introduces the current status of Holland power grid, and reviews the time sequence of the blackout. The main causes of the Holland blackout are analyzed preliminarily. Based on this study, the paper presents the revelations for Hunan power grid, such as the dynamic security check and evaluation deficiencies, lack of accident response capability, protection and stability control being set incorrectly, and grid construction lagging behind demands. The relevant recommendations are proposed to avoid the blackout and protect the security and stability of the grid.**

***Index Terms*—Dutch grid, blackout, accident analysis, grid security.**

I. Introduction

On March 27, 2015 at 9:37 am (Holland local time), a technical failure occurred in high-voltage substation Diemen (“Diemen” for short), located 11km southeast of Amsterdam. This failure resulted in a complete failure of Diemen station, and other chain reaction, eventually led to a large-scale blackout in North Holland. About 1 million households were affected by this outage, mainly in a large part of North Holland and a small part of Flevoland, including the capital Amsterdam. At 3 pm, most of power system had returned to normal. The last failure on the grid took place in 1997.

This blackout has exposed many problems and attracted a great deal of international attention, power industry and researchers all over the word have begun to discuss the accident cause. This paper briefly introduces the current status of Dutch grid, reviews the time sequence of the blackout, and preliminarily analyzes the main causes of this outage. Based on above analysis and combined the current situation of Hunan power grid, this paper summaries the experiences and lessons, and proposes some related suggestions.

II. Background Introduction

A. Holland Power Grid

Tennet, the operator of Holland power grid, is Europe's fifth largest independent grid operator. Its operating range includes the whole Holland, as well as a part of Germany’s 110kV main gird and above. Tennet controls 21000 km grid lines and 250 transformer substation, services more than 41 million people, with a frequency of 50Hz. As shown in Fig. 1, in northeastern Europe power grid, Holland power grid play the role of hub and nod, it has 3 Internet channel with Germany, 2 with Belgium and 1 with UK.

At present, Holland power grid takes the 380kV and 220kV ring network as the main framework, 150kV and 110kV sub network as the regional framework. The frame diagram of Holland power grid at 110kV and above (by October 31, 2014) is shown in Fig. 2.

1) Tennet connected Holland to UK (BritNed) through 260-km-long HVDC cable, with 1000MW transmission capacity.
2) Holland and Belgium are connected through 380kV AC line (ELIA), with 1501MW transmission limit under normal circumstances.
3) Holland and Germany are connected through 380kV AC line (AMPRION, TenneT and GmbH, etc), with 2449MW transmission limit under normal circumstances.
4) Holland and Norway are connected through DC line (StatNett), with 700MW transmission limit.

B. Brief Introduction of the High-Voltage Substation Diemen

Diemen is a 380kV substation, built in 1970, located 11 km away from Amsterdam. Diemen is installed with four 380/150kV transformers, three of them has a capacity of 450MVA, one 500MVA, the total change capacity 1850MVA. 4 transformers in Diemen are installed with 45MVar shunt compensator at 50kV side, with the compensation capacity of 180MVar; two sets of capacitors are installed at the 380kV high voltage side, with the capacity of 150MVar.

150kV bus of Diemen is connected to 150kV transmission network in Noord-Holland area and a natural gas power station, Diemen and Oostzaan substation consitutes the important 380kV Power Supply for Noord-Holland area (including Amsterdam). Therefore, Diemen is an important hub substation, with 4-circuit 380kV outlet connected to three 380kV substation. The information about 4-circuit 380kV outlet is showed in Table I.

III. Occurrence of Holland Blackout

According to Tennet’s reports. in the morning of March 27, 2015, both halves of Diemen(lines and transformers)has been connected for a short period at a normal changeover.

At 9:37, a short circuit occurred in Diemen, after the two

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parts had been switched off automatically, resulting in a complete failure of Diemen station.

At 9:41, Tennet sent the “Abnormal” alerts to the whole power grid, and pointed out the fault time starting at 9:37. Due to the exit operation of Diemen, a large-scale blackout happened in most areas of Noord-Holland (including Amsterdam) and part of Flevoland.

At 10:40, Diemen restored electric power supply, and gradually regained the power supply to the users of the above areas.

At 11:19, Tennet removed “Abnormal” alarm.

At 11:20, the entire 150 kV network was available again.

Parallel via the underlying Liander households and businesses energized again at the regional networks to build the 150 kV network. This was already 14:30.

Due to the wide affected range of railway traffic, it was not until 3 pm that the whole system has been restored. Around one million households were affected by the outage, one of the largest in the Netherlands in recent years. The last failure on the grid took place in 1997.

Fig. 1. The Dutch transmission grid.

TABLE I: 4-CIRCUIT 380KV OUTLET OF DIEMEN SUBSTATION

Line	Line length of each circuit /km	Circuit number	Total length /km	Normal transmission capacity (each circuit) /MVA	Maximum design total transmission capacity /MVA
Diemen-Lelystad	51.8	2	103.6	1645	1975
Krimpen-Diemen	57.3	1	57.3	1645	1975
Oostzaan-Diemen	15.3	1	15.3	1900	1975

IV. CAUSE ANALYSIS OF HOLLAND BLACKOUT UNITS

As an important hub substation for supplying and driving the local load in Amsterdam and other important place, Diemen station is redundant, which means that if one half of the station fails, the other half will automatically take over the transmission of electricity. In this failure, short circuit fault and voltage failure accident occurred when Diemen doing normal changeover operation, resulting in a complete failure of Diemen station.

From Fig. 1 it appears that Noord-Holland (include Amsterdam and other important loads) is just powered by two 380kV substation, Diemen and Oostzaan (Beverwijk is powered by Oostzaan). On the one hand, Diemen’s complete failure is likely to result in the overload of Oostzaan-Krimpen transmission lines or the overload trip in Oostzaan substation, and Noord-Holland will lose all 380kV power. Because of the less power supply access to the

150kV gird in Noord-Holland, It is almost certain that there will be a large area blackout in the Noord-Holland area. On the other hand, because Flevoland is powered by Lelystad substation which is connected to Diemen, if Diemen fails, the power supply of Flevoland will be affected, causing power cuts in part of Flevoland.

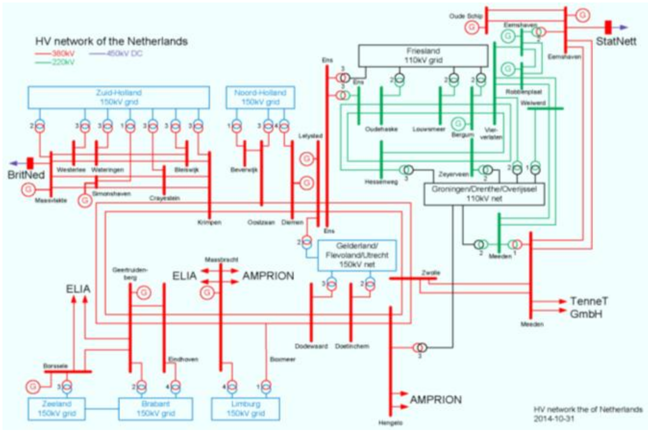

Fig. 2. High voltage network of the Netherlands.

This analysis coincides with the declaration from local operator, both of them agree that the outage was caused by power grid overloading. From the blackout range perspective, Oostzaan-Krimpen lines, Oostzaan substation and Lelystad substation were all affected by Diemen failure, resulting in the blackout of most Noord-Holland and parts of Levoland.

On 12 June, 2015, a research report was published in TenneT official website, it included more detailed analysis: In the week prior to the break at Diemen station，a work carried out on the secondary installation of the field Krimpen a / d IJssel white (KIJ W). To confirm the result of the work, it was decided to conduct a test on Friday, March 27, 2015, during the changeover. Changeover is a usual procedure, during this time, the two rail systems are not separately secured for a short time. In order to keep the supply of the 380 kV just as high as possible, it was necessary to turn on parallel rail separator B first rail before the operation of separator A could be tested (the specific installation location of rail separator A and B does not describe in the report). This is one of the phases had no galvanic contact with the rail system, resulting in that separator B was not taken in its end position. So it's unable to perform next switching operations. The visual inspection led to the present employees to the conclusion that rail separator B was in the correct position, and that rail separator B was turned on just because of a fault in secondary system but not the mechanical breakdown. This observation and the fact that the separator previously functioned well two days ago, the bypass has been performed and rail separator A could be tested immediately afterwards, though one of three phases of rail separator B had not come into its final position At 9:37 am, when operators performed the operation on rail separator A, break arc appeared on one phase of it because of the real state of rail separator B (under normal condition, the current flowing through rail separator A should be transferred to rail separator B). In addition, the arc has been made under the influence of a strong westerly, resulting in short circuit with another phase. This has subsequently led to the complete failure in Diemen. In accident survey reports, TenneT summed up the power failure as a result of the combination of a technical failure and human actions.

V. Processing Strategy of Holland Blackout

Immediately after the break, TenneT had addressed the following issues:

1) Determining the priority in restoring the network 150kV and 380kV, so the impact could be minimized;
2) Communication and coordination with other emergency organizations;
3) Communication internally and externally through various media, so that everyone could be as informed as possible;
4) The start of two trials (internal and external) to the cause of the malfunction and break.

The following recommendations are put forward to minimize the chance of recurrence:

1) Technical: dig the underlying cause for the failure of the drive of the rail separator, and research whether this failure could be predicted, for example, by changing the maintenance policy.
2) People: consider how the general level of knowledge can be raised regarding work instructions for all persons with such authority
3) Operation: consider how to analyze whether the applied instruction is sufficiently clear, complete and appropriate

VI. Revelation to Hunan Grid on Safe Operation

A. *Pay Attention to the Stable and Safe Dynamic Verification and Evaluation*

In the stable and safe checking, only N-1 and N-2 would be checked. In this failure, from the point of operation, it's N-8 which led to the complete failure in Diemen. It's still unknown whether Tennet did the simulation on the influence of Diemen's complete failure on other substation and line.

Although the complete failure of substation is a small probability event, as an extremely important load-center substation, it's necessary to analyze the reason why the fault happened in Diemen. It's recommended that system analysts pay attention to the analysis of invisible system failure, deepen the research on cascading failure and strengthen the study of isolated island stable operation. For instance, in 17 running 500kV transformer substations and switching stations of Hunan province, there are 10 substations which have 4-circuit outlet or above, doing assessment on such small probability event as the 500kV load-center substation outage is necessary.

B. *Organize Fault Preview and Prevention for Eliminating Defects*

In this blackout failure, the blasting fuse is the changeover fault in Diemen, this process is also a test of operator's professional quality and capability in handling accident. At present, although intelligent substation becomes more and more widespread, the ability to recognize abnormal signal and duly handle the emergency failure is still very important for turning the scale when accident happens.

To improve substation operator's analytical skill and ability to deal with emergency accidents and abnormal operation, this paper proposes Electric Power Company of Hunan Province("Hunan grid" for short) to organize anti-accident exercise. Combined with the characteristics of power grid operation, the exercise should involve the emergency processing of major safety accident, whole substation power failure and main transformer accident, to observe their analytical skill and processing capacity and lay the foundation of emergency processing. The last large-scale blackout in Hunan happened in 2008 because of the ice disaster. We should draw lessons from the past, strengthen the construction of emergency mechanism and platform, draw up black-start scheme and revise it yearly, enhance black-start exercise, bring more power plant of load centre into the range of black-start power source [1]-[3].

The other blasting fuse of the blackout failure is the mechanical failure of rail separator. Therefore, improving equipment's operational reliability, discovering and preventing hidden danger early are important for ensuring a continuous supply of electricity. It's recommended to implement circuit checking regulation simultaneously on operating equipment maintainer and operator during summer and the Spring Festival, changing passive defects elimination into initiative preventative. Through the above measures, abnormal condition can be discovered early by experienced maintainer, and the failure can be prevented.

C. Set Relay Protection and SCS Reasonably

From the perspective of relay protection, Diemen, a transformer substation with multi-circuit outlets, would not complete fail due to the protection action, unless there are some unreasonable designs in protection logic, or maloperation and miss operation on protection devices. Therefore, the Holland blackout also exposed the weakness of the relay protection and SCS (Safety Control System).

As the first defense line of electric power system, the correct operation of relay protection device plays an important role in ensuring the safe and stable operation of power system. The department in charge of substation and power plant should take multiple measures to strengthen relay protection device operation management, relay setting calculation and technological supervision, establish and improve anti-accident measures, close study countermeasures against maloperation under large-scale flow transferring, strictly check the test of newly installed or repaired relay protection device in grid reform and upgrading, do scheduled check, pre-test, and routine maintenance.to make the best use of relay protection in power grid operation.

In addition, we should strengthen the second defense line of power grid security, SCS. In this outage. If all the parts had cooperated to cut off partial loads quickly, further damage could be limited. So there must have been some problems in Diemen's Safety-Stability Control Strategy, for example, control measures were not decisive and drastic enough. In the future, Hunan grid will be a complex AC / DC hybrid power grid with high dependence on SCS. If the SCS of UHV transmission line didn't operate reliably, large-area temporary stability failure would happen. It is recommended that SCS reformation adheres to the "optimization and simplification" principle, considers complex conditions, strengthens the test and measures for avoiding act-error and act-refuse, to improve SCS reliability continually [4].

D. Strengthen Infrastructure Construction and Rational Planning

According to the online report of the European Electricity Transmission System, the transmission capacity of European power grid is close to the limit, about 1/3 of the planned project has been lagged, the lack of transmission capacity and investment have become the major barrier to building EU unified power market.

From Fig. 2 we can see, Amsterdam and other important load are powered only by two 380kV substation (Diemen and Oostzaan) with few 380kV power supply, this blackout happened on account of the line overload due to Diemen exiting flow transferring. In order to weaken the dependence of Randstad and other regions on Diemen, Tenne T has begun to build the Randstad 380 kV Northern Ring connection in 2007, which will be completed in 2018 in prediction. If the complete failure happens in Diemen again, this "strong grid" will reduce the damage to northern areas.

On the one hand, electric power is the pillar of economic, Hunan grid should make every effort to promote grid infrastructure construction as a priority in boosting economic development, strengthen the coordinated development of power grid and power supply with appropriately advance of power grid, to avoid electrical socket and restriction from the construction lagging of electric power, build a strong and stable grid to maximum meet the power demand of businesses and residents.

On the other hand, the reasonable structure of power grid is the objective condition to ensure the safe operation and avoid large-area blackout. In Hunan power system planning, the receiving-end grid should be close-connected and the power supply should be distributed reasonably as much as possible; electromagnetic circuit network need to be opened firmly under the premise of ensuring the reliability of power supply; conditions should be created in order to promote the level of UHVDC isolated operation, and reduce the risk of flow transferring after DC fault [5], [6].

E. Strengthen Safety Education and Training

In this failure, one of the main reasons is that station did switching action on the basis of an incorrect interpreted visual observation and past operating record.

Hunan grid should learn from the Holland blackout, strengthen training and safety education, implement the responsibility system for safe production, refine operation procedures and standards, to avoid such incidents happening again. When abnormal situation occurs, operators must not blindly believe experience and operate forcefully. Instead, they should make deep analysis of new complex and difficult problems, operate in strict accordance with rules and regulations, to avoid the further expansion in accident.

VII. Conclusion

This article has introduced the background, causes and process of "3-27" Holland blackout in detail, and analyzed the reason for this accident. Taking this as a warning, Hunan power grid should pay more attention to the stable and safe dynamic verification and evaluation, develop effective emergency and recovery measures, organize defect elimination, improve safety and stability integrated defense system, strengthen basic infrastructure construction and rational planning, strengthen safety education and training, to reduce the risk of occurring blackouts in Hunan power grid through all the efforts.

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