ENERGY ADVISORY COMMITTEE

Loss of Electricity Supply Incident Affecting Southern Sweden and Eastern Denmark on 23 September 2003

This paper informs members of the investigation findings by Svenska Kraftnät (Transmission System Operator of Sweden) and Elkraft (Transmission System Operator of eastern Denmark) concerning the loss of electricity supply incident that affected southern Sweden and eastern Denmark on 23 September 2003[1].

Background

2. In Sweden, the transmission grid (at 400kV and 220kV) is owned and operated by Svenska Kraftnät (SVK), a state-owned grid company serving as the transmission system operator of the Swedish power system. The country has a total installed generation capacity of about 32,000MW. In central and northern Sweden, the transmission grid is interconnected with Norway and Finland at total transfer capacities of about 4,200MW and 1,700MW respectively. The transmission grid in southern Sweden is interconnected with eastern Denmark at a total transfer capacity of about 1,700MW. Sweden is also interconnected with western Denmark, Germany and Poland, each at a total transfer capability of about 600MW.

3. In Denmark, the electricity supply system is divided into two independent systems (i.e. no direct interconnection between the systems), namely the western and eastern systems, which are operated by two independent transmission system operators Eltra and Elkraft respectively. The western system has a total installed generation capacity of about 7,000MW. The eastern system, which covers the city of Copenhagen, has a total installed generation capacity of about 5,200MW. Apart from the above-stated interconnection with southern Sweden, the eastern Danish system is also interconnected with Germany via an interconnector of about 600MW in transfer capacity.

4. In these two countries, planned maintenance outages for some major transmission lines and generators would normally be arranged before the peak

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[1] Based on the investigation reports released by Svenska Kraftnät and Elkraft on 2 October 2003 and 4 November 2003 respectively.

demand in winter. Before the incident, two 400kV transmission lines connecting the power grids in central and southern Sweden were taken out of service for scheduled maintenance works. The Sweden to Germany and Sweden to Poland interconnectors were also taken out of service for annual inspection and some minor works. In eastern Denmark, several 400kV and 132kV transmission lines together the interconnector with Germany were taken out of service for maintenance. Besides, some of the generators in both Sweden and eastern Denmark were taken out of service for overhaul. All these planned maintenance outages had been taken into account by the transmission system operators of these two countries in their operational planning assessment.

The Incident

5. Prior to the incident, the power systems in Sweden and Denmark were operating under stable conditions and well within operational reliability standards. System demands in Sweden and eastern Denmark were at moderate levels of around 15,000MW and 1,850MW respectively. The eastern Danish system was exporting about 400MW of power to southern Sweden at that moment.

The first fault

6. At 12:30 p.m. on 23 September 2003, generating unit no. 3 at the Oskarshamn Nuclear Power Station in southern Sweden tripped due to some technical problems with an internal valve in the feedwater circuit. This reduced some 1,200MW of available generation capacity of the Swedish power system. The loss of a single generating unit was a recognised contingency that the Nordic power system was designed to withstand without causing supply interruption[2]. With automatic activation of reserve generating capacities from other power stations, the power system was stabilised within normal operating limits. Minor voltage drops had occurred in the southern Swedish power grid but it was by no means critical.

The second fault

[2] Although the power system could withstand a single contingency, the spinning reserve capacities available might not be adequate to restore the power system to normal operating state, and hence any further contingency would likely result in supply interruption. According to the reliability standards adopted by the Nordic countries, the transmission system operator is required to bring the power system back to normal operating state within 15 minutes after a single contingency through the activation of standby reserve capacities, if so required.

7. While actions were still being taken to restore the power system to normal conditions, a double busbar fault[3] occurred at 12:35 p.m. (i.e. 5 minutes after the first fault) in Horred Substation (a major 400kV substation) in southern Sweden. The cause of the fault was due to the collapse of a busbar isolator[4] after its joint was broken, and the isolator fell in the direction of an adjacent busbar, causing a short circuit between the two busbars. The fault was detected by the protection devices, which tripped out all connected circuits as designed.

8. As a result of this second fault, four main 400kV transmission lines connected to the said substation were tripped, thus disconnecting two 900MW generating units (at Ringhals Power Station) from the power grid in southern Sweden as well as other important transmission lines between the central and southern part of the Swedish power grid. This resulted in a further loss of about 1,800MW of generation capacity from the Swedish power system and weakening of the transfer capability between the central and southern Swedish power grid.

The blackout

9. The two faults resulted in a total generation loss of about 3,000MW in southern Sweden, and therefore the area had to rely on power imports from central and northern Sweden as well as eastern Denmark to maintain a supply/demand balance. As a result, severe overloading occurred on the remaining transmission lines between central and southern Swedish caused by increased power flow to support the southern Swedish power grid. Moreover, the lack of generation capacities in southern Sweden at that time made it impossible to sustain the system voltage for the power grid, which started to decline. The declined system voltage eventually activated a number of protective devices on the remaining transmission lines between central and southern Sweden, which tripped these circuits thus disconnecting Sweden's southern and central power grids.

10. The drop in system voltage in eastern Denmark was less severe because of the availability of local generation support, hence the power grids of southern Sweden and eastern Denmark remain interconnected but became isolated from the rest of the Nordic power system. With a large generation deficit, the remaining

[3] A busbar is an electrical conductor or conduit at a substation where lines, transformers and other equipment are connected. Depending on the design, a substation can be installed with one or two sets of busbar running in parallel. Since the busbar is installed inside a substation, busbar fault is not as common as other types of faults such as cable damage. Double busbar fault (where a fault occurs between both busbars) is very rare.

[4] An isolator is a switching device in a substation for controlling the electrical connection/disconnection of two electrical points. A busbar isolator is used to control connection/disconnection of equipment to the busbar.

generators within this isolated area were unable to meet demand and support the system voltage. After a very short time, all remaining generators were tripped by their own protective devices, leaving the entire area without electricity supply.

11. The blackout was one of the most severe electricity supply disturbances in the past 20 years for the Nordic power system. System restoration began a few minutes after the blackout with transmission lines/substations re-energized and generating units re-started in accordance with established emergency restoration procedures. Almost all electricity supplies in Sweden and Denmark were resumed by around 7:00 p.m. on the same day, except for a few consumers with their supplies restored only until around 10:00 p.m. owing to special local conditions.

Investigation Findings

12. While the power system is normally designed to withstand a single contingency, according to the reliability standards adopted by the Nordic countries, it is necessary to restore the power system to normal operating state within 15 minutes so that another contingency, if so occurs afterwards, would not cause supply interruption or system breakdown. Investigation findings indicated that the main cause of this blackout incident was a very rare and severe double busbar fault that occurred only a few minutes after the initial loss of the 1,200MW generating unit. The fact that the power system had not yet been returned to normal state after the first fault, and that the power grid was crippled by losing vital transmission lines together with further loss of 1,800MW generation capacity after the second fault, had imposed significant impacts on power system, which were far beyond the degree of severity that the power system was designed to withstand.

Follow Up Actions

13. To minimise the risk of similar incidents in future, the following actions are being considered by the countries concerned:

(a) review the operating and planning specifications and agreements being adopted by Nordel (the Nordic Cooperation between system operators);

(b) analyse the framework of security of supply;

(c) review the system operators' handling of the grid and improve preparedness for major system disturbances in the power system in the light of the experience from this incident; and

(d) examine the entire regime concerning system operation and protection systems.

Observations

14. This incident was caused by a very rare and severe double busbar fault that occurred very shortly after the loss of a major generating unit. The combined faults put burden on the power system that exceeded the level of normal system design and operating reliability standards. Such eventuality could not be adequately catered for in power systems designed with commonly adopted planning criteria.

15. The second fault was related to the mechanical failure of a busbar isolator (in an open type substation[5]), resulting in a double busbar fault at a major transmission substation. In Hong Kong, the design of substation[6] is different and hence a double busbar fault is very unlikely to occur. The incident nevertheless highlights the importance of routine inspection and preventive maintenance of vulnerable points in the power system.

16. Other parts of the Nordic power grid were not affected since the tripping of transmission lines linking central and southern Sweden had isolated the healthy parts of the interconnected power grid from the problem areas. Should the interconnector between southern Sweden and eastern Denmark be intentionally disconnected, eastern Demark might not have been affected and the blackout might be confined to southern Sweden only. According to the investigation, this action would have required some kind of protection system with advanced measuring and controlling capability, which had yet to be fully developed.

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[5] In open type substations, the electricity conducting parts of the switchgear including busbars and isolators are exposed in the open air.

[6] In Hong Kong, almost all transmission substations are installed with gas insulated switchgear with busbars enclosed inside gas-filled insulated chambers. Although there remains a few 132kV transmission substations equipped with open type switchgear, the designs of the busbar isolators are different from the faulted one in the concerned substation in Sweden.

Advice Sought

17. Members are invited to note the content of the paper.

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