

MAJOR STORMS – MAIN CAUSES, CONSEQUENCES AND CRISIS MANAGEMENT

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ABSTRACT

A major storm hit the Nordic countries at Christmas 2011 causing devastating damages of power lines and long-lasting interruptions for lots of customers. This paper gives a comparison of the main consequences and it addresses improvements in crisis management from previous storms. The paper also gives examples of indicators to monitor vulnerabilities related to extraordinary weather events.

INTRODUCTION

Major storms hit Norway, Sweden and Finland at Christmas 2011, affecting 200 DSOs and about 1.7 million customers suffered from interruptions. The vast majority was reconnected within 24 hours, but some customers were without electricity for several days and up to weeks due to devastating damages of power lines, communication lines and roads.

Dagmar was the strongest storm in Norway since 1992, when a quite similar storm hit almost the same parts of Norway on New Year Day. Dagmar also caused wide-area interruptions in Finland and Sweden, however, affecting Sweden to a lesser degree than by the major storms Gudrun (2005) and Per (2007). Such extraordinary or exceptional events causing wide-area interruptions with severe impact on society are also referred to as major events, blackouts or high impact low probability (HILP) events [1-4].

Learning from major events is important to identify vulnerabilities and improve the emergency preparedness. Extraordinary weather events tend to be an expensive experience for network companies. The high societal impact and lessons learnt have also increased the awareness of politicians and energy regulators, triggering changes in the quality of supply (QoS) regulation. Many European countries have introduced quality incentives like penalty and compensation schemes [1].

This paper gives a comparison of Dagmar in Norway, Sweden and Finland, as far as information is available. The paper addresses improvements in crisis management from previous storms to Dagmar. Furthermore, it addresses indicators to monitor vulnerabilities as part of the emergency preparedness dealing with weather related extraordinary events. Examples of indicators are given.

THE STORM DAGMAR

The storm started in North-Western and inner parts of Norway on Christmas Day. It lasted for 4 days and caused interruptions for about 570 000 end-users. Dagmar also hit the middle part of Sweden and most of the country in Finland, resulting in interruptions for 530 000 end-users in Sweden and 600 000 end-users in Finland, respectively. In Sweden the storm is referred to as "Dagmar" from 25 - 26 December and "Johannes" from 27 - 28 December, while in Finland the storm is referred to as "Tapani" 26 December and as "Hannu" 27 December. For simplicity, the events are presented as a single storm, named "Dagmar" hereafter.

Dagmar hit a large area and many DSOs were affected; 76 in Norway, 72 in Sweden and 55 in Finland. The interruption duration varied from a few hours up to several days. While MV distribution accounts for about 95 % of the total interruption duration, the longest durations were in the LV network, about 10 days in Norway and 25 days in Sweden and Finland. In Finland some end-users suffered from interruptions even longer. Most of the damages during the storm were in all three countries on power lines in the distribution network, caused by extensive tree-fall and strong winds which also hampered the repair and restoration work. The repair cost after Dagmar was about 18 MEUR in Norway and more than 30 MEUR in Finland. Table 1 gives a comparison of the consequences.

The storm Gudrun (2005) triggered the "Gudrun laws" in Sweden, stating for example maximum interruption duration of 24 hours and plans for securing the power lines against tree-fall. Risk and vulnerability analyses are mandatory in both Sweden and Norway [see e.g. 5]. In all three countries there is an incentive based regulation in terms of a penalty scheme based on customers' costs of interruptions, and a direct compensation is paid for very long interruptions (> 12 hours) [1, 6-8]. For the latter part, the amount increases in steps according to the duration. In Finland and Sweden, the compensation is based on a percentage of the annual system service fee. As can be seen by Table 1, the storm Dagmar caused an interruption cost of 446 MEUR and a compensation of 47 MEUR in Finland. These cost elements were significantly higher than in Norway, where the corresponding costs amounted to 57 MEUR and 14 MEUR, respectively. The differences are partly due to the variation in interruption durations and partly to different cost rates.

Table 1 Comparison of consequences during the storm Dagmar (2011) in Norway, Sweden and Finland, respectively

Country	Number of end-users affected (interrupted)	Energy not supplied (MWh)	Stipulated/average interruption duration	Longest interruption duration	Main causes	Customer interruption costs	Compensation for very long interruptions > 12 hrs	Repair costs
Norway	570 000	17 275	15 hours	10 days	Storm, extensive tree-fall	57 MEUR	14 MEUR	18 MEUR
Sweden	530 000	-	18 hours	25 days	Storm, extensive tree-fall	-	180 000 customers (all 2011)	-
Finland	600 000	13 649	11 hours	several weeks	Storm, extensive tree-fall	446 MEUR	47 MEUR	30 MEUR

Information about the cost figures in Sweden is not available. The amounts of interruption costs and compensation payments as a result of Dagmar, added up to several times the normal amounts on a yearly basis for some of the affected network companies in Norway. Hence, there has been a discussion following Dagmar whether these financial arrangements should be applied during extraordinary events or not.

EXTRAORDINARY WEATHER EVENTS AND VULNERABILITY INDICATORS

Storms are threats that can lead to unwanted events in the power system, and may develop into extraordinary events characterized by low probability and high impact. Such weather related events typically hit large geographical areas, causing long-lasting interruptions for many end-users and needs for extensive repair of the power system. A similar event, as Dagmar, happened in Norway twenty years earlier on New Year Day (1st of January 1992) more or less in the same parts of the country. In Sweden the storm Gudrun in 2005 has been the most disastrous event in later years affecting 730 000 end-users, some of them up to 35 days. In Finland the storms Janika in 2001 and Asta in 2010 are the largest similar events. Also during these events the main causes were strong winds and extensive tree-fall.

The consequence of an interruption is not only dependent on the duration, but also the amount of disconnected load, indicating the affected area and customers. Figure 1 shows the consequences after historical weather related events in the Nordic countries in addition to Dagmar. The figure shows that Dagmar caused a large amount of disconnected load in both Norway and Finland, quite similar to Gudrun in Sweden in 2005, but Gudrun caused much longer duration. The Gudrun event in Norway is also included to show that although the same storm, it caused rather limited consequences in Norway and is not regarded as an extraordinary event.

The power grid is vulnerable to natural hazards of such extent even if it is designed for and usually robust towards

weather related stress. Previous weather related events contribute to increase the understanding of such events, to identify vulnerabilities and improve the network companies' emergency preparedness. Power systems' vulnerability to extraordinary events is defined to be an expression of the problems the system faces to maintain its function when exposed to threats and the problems the system faces to resume its activities after the event occurred. Vulnerability is composed by susceptibility and coping capacity, which are internal characteristics of the system [9].

Identification of critical assets and indicators for monitoring vulnerabilities are important in the dealing with extraordinary events. Indicators give information about different characteristics of the power system, and how vulnerable it is towards threats.

Thus, vulnerability indicators give information about the susceptibility and coping capacity and provide insight into the risk related to extraordinary events. However, vulnerability can only be seen in relation to threats and indicators should also cover threats that the system is exposed to. Finally, the criticality for society has to be considered to assess the potential of severe consequences [9]. Important indicators for extraordinary events related to storms are e.g., the quality of vegetation management, technical condition of the grid and knowledge and experience of the working staff.

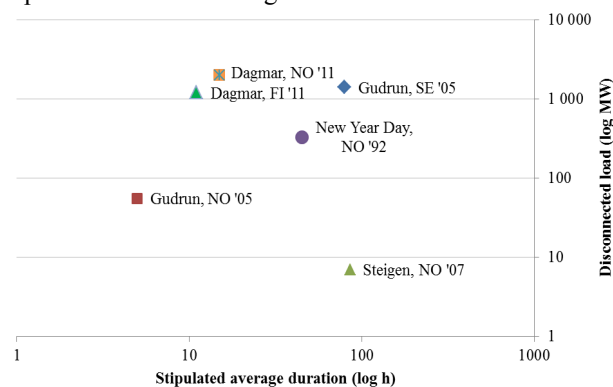


Figure 1 Consequence diagram for extraordinary historical weather events, based on [10].

Table 2 Examples of vulnerability indicators for the regional network in Steigen, based on [9]

Threat	Indicator for threat	Indicator for susceptibility	Indicator for coping capacity	Indicator for criticality
Storm	Wind prognosis (speed, direction, duration)	Location in the terrain, how exposed to wind?	Competence on repair of 66 kV power lines	Location of critical loads Types of end-users Temperature
Loading degree	Percentage loading compared to nominal values	Technical condition of 66 kV power lines	Availability of spare parts, and transport for repair of power lines	
	Increase in loading degree	Competence on condition evaluation	Availability of communication systems and reserve generating units	
		Competence on risk and vulnerability analysis		

A case study has been carried out as an example of identifying vulnerability indicators for weather related threats like storms. The study is based on the event in Steigen in Norway in 2007 (shown in Figure 1).

Steigen is a small community located far north in Norway (latitude 68°) in a coastal area exposed to wind and icing. The community has less than 3000 inhabitants and is normally supplied by a single 66 kV overhead line while there is another line on hot stand-by. The stand-by line can be connected if the main line fails.

Both lines are routed in a coastal area with harsh weather conditions, making them exposed to failures and bad conditions for repair work. In the actual event in January 2007 Steigen lost its power supply for nearly 6 days (see Figure 1) due to failures and breakdown of both the 66 kV lines. Extreme weather conditions and lack of daylight delayed repair considerably.

The event was triggered by heavy storm while icing was a contributing cause. This led to breakage of the line itself and damage of several pylons. The reserve line turned out to be unable to cover the load when it was connected, resulting in overheating and three subsequent line breakages. The post event fault analysis showed that these faults were caused by ageing and poor technical condition. In a risk and vulnerability analysis it can be identified that overlapping faults of both lines supplying Steigen represent a critical outage since the whole community will be affected. There is no local generation in this area, and Steigen is therefore vulnerable to the loss of both lines. If such an event happens in winter the temperature might be a critical factor. In this case it can also be noted that the weather conditions as well as seasonal lack of daylight might threaten the coping capacity in terms of delayed repair and extended duration of the blackout compared to for instance in summer time. Indicators are proposed for the threats 'storm' and 'loading degree' and examples are presented in Table 2.

The critical assets in this case are the two 66 kV overhead lines. Appropriate susceptibility indicators are therefore the technical condition of 66 kV power lines itself as well as the competence on condition evaluation. The technical

condition is an important susceptibility towards both threats 'storm' and 'loading degree'. Correspondingly, an appropriate indicator for coping capacity is the competence on repair of 66 kV lines as well as availability of spare parts and transport for repair of the overhead lines. Other indicators for the coping capacity are of a more general character, such as availability of communication systems and reserve generating units. From Table 2 it can be observed that the indicators for the criticality (consequences to society) are independent of the threat.

The case study revealed that the part of the main power line where the fault was located (crossing a mountain-top) was particularly exposed to strong winds. Access to the line for repair work was only possible by helicopter at this time of the year (January), and the coping capacity was hampered by the bad weather, lots of snow and lack of daylight. Thus, to provide a vulnerability indicator capable of monitoring the vulnerability of critical overhead lines, it is important to identify the exposure to for instance strong winds and the access to the lines for repair and other factors of importance for the coping capacity. In this way it is possible to identify and monitor those parts of the critical lines which are the most vulnerable. The framework for indicator development is explained in [9, 11].

IMPROVEMENTS AND MAIN CHALLENGES

The storm Dagmar revealed the power lines' vulnerability towards weather related stresses, emphasizing the importance of including extraordinary events in asset management. The main challenges are, except for power lines' susceptibility to tree-fall, related to the dependencies between power supply, commercial communication systems and transportation, especially during crisis management and restoration work. The introduction of smart grid technologies will enhance these dependencies even more. It is also expected that there will be more extreme weather in the future and society's dependency on uninterrupted electricity is increasing. It can be observed that the coping capacity is improved, comparing the Dagmar event with previous major storm events such as the New Year Day (1992) in Norway, and Gudrun (2005) and Per (2007) in Sweden, as well as Janika (2001) and Asta (2010) in

Finland. This is indicated by the reduced duration of the interruptions. For instance, during the New Year Day storm in Norway 81 % of the end-users were reconnected within 24 hours compared to 94 % during Dagmar. Similar figures in Sweden were 53 % during Gudrun compared to almost 90 % during Dagmar. For many years the quality of supply regulation is gradually intensified in all three countries, by introduction of e.g., functional requirements and incentives for improvements through penalty schemes and compensation arrangements. This has resulted in reliability increasing measures such as:

- More sectionalisers in the network
- More automation and remote control
- Cabling of the distribution networks
- Better design criteria and condition monitoring
- Better vegetation management.

While better vegetation management directly affects the susceptibility to storms, other improvements made of particular relevance for extraordinary events are:

- Early warning of extreme weather
- Risk and vulnerability analyses
- Improved emergency preparedness (e.g. cooperation between network companies and with rescue authorities)
- More practicing and learning from past events.

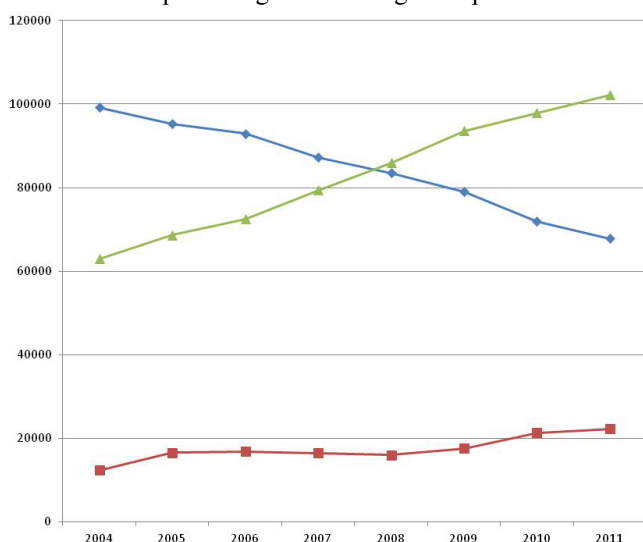


Figure 2 The development of km MV cables in Sweden 2004 – 2011. Blue: km uninsulated overhead line, red: km insulated overhead line, green: km underground cable.

In Sweden extensive line clearance programs are carried out in addition to cabling of the distribution network. Both measures have already shown to decrease the networks' susceptibility towards storms. Figure 2 shows the development of km MV cables since 2004. It can be noted that from 2008 the amount of km underground cables exceeds the amount of km uninsulated overhead lines. In 2011 the share of cables was > 50 %. There has also been a slight increase in the amount of insulated overhead lines.

CONCLUSIONS

Dagmar is one of the strongest storms that have hit the Nordic countries the last twenty years with regard to wide-area interruptions. It caused devastating damages in the power grid and affected a large amount of both end-users and DSOs in Norway, Sweden and Finland, resulting in hundreds of million Euros in societal costs. Over the last twenty years the quality of supply regulation is gradually intensified and the emergency preparedness and crisis management has improved. Extraordinary events like Dagmar and Gudrun have revealed the power lines' vulnerability towards weather related stresses. More extreme weather can be expected in the future, and the challenges will still be significant. The paper gives examples of vulnerability indicators relevant for extraordinary events to be used in asset management for monitoring the grid. Such indicators may contribute to prevent and limit the impact of major storms as well as other threats.

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