Nordel

GRID DISTURBANCE AND FAULT STATISTICS

2008

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1 Introduction

This report is an overview of the Danish, Finnish, Icelandic, Norwegian and Swedish transmission grid disturbance statistics for the year 2008. The report is made according to Nordel's guidelines for disturbance statistics [1] and it includes the faults causing disturbances in the 100–400 kV grids. Transmission System Operators providing the statistical data are *Energinet.dk* in Denmark, *Fingrid Oyj* in Finland, *Landsnet* in Iceland, *Statnett SF* in Norway and *Svenska Kraftnät* in Sweden.

Nordel's Guidelines for the Classification of Grid Disturbances [1] were prepared during the years 1999–2000 and have been used since 2000. When the guidelines were introduced, the statistics were expanded to contain various charts that exclusively include the period 2000–2008. Therefore, there are tables in this report that include data only for the period 2000–2008. In those cases where data for the previous 10 years was available, the period 1999–2008 has been used.

The statistics can be found at Nordel's website www.nordel.org. The guidelines and Nordel disturbance statistics were in the "Scandinavian" language until 2005. In 2007, however, the guidelines were translated into English and the report for 2006 was the first set of statistics to be written in English. The structure of these statistics is similar to the 2006 statistics.

This summary can be seen as a part of Nordic co-operation that aims to use the combined experience from the five countries regarding the design and operation of their respective power systems. The material in the statistics covers the main systems and associated network devices with the 100 kV voltage level as the minimum. Control equipment and installations for reactive compensation are also included in the statistics.

Despite common guidelines, there are very slight differences in interpretations between different countries and companies. These differences may have a minor effect on the statistical material and are considered to be of little significance. Nevertheless, users should – partly because of these differences, but also because of the different countries' or transmission and power companies' maintenance and general policies – use the appropriate published average values. Values that concern control equipment and unspecified faults or causes should be used with wider margins than other values.

Although the classification of disturbances and faults in high voltage direct current (HVDC) installations is described in the guidelines, Nordel does not have any statistics related to HVDC devices. Therefore, CIGRE statistics for HVDC devices should be used. The publications of CIGRE can be found at www.cigre.org.

In Chapter 2 the statistics are summarised, covering the consequences of disturbances in the form of energy not supplied (ENS) and covering the total number of disturbances in the Nordic power system. In addition, each Transmission System Operator has presented the two most important issues from the year 2008.

In Chapter 3 disturbances are discussed. The focus is on the analysis and allocation of causes of disturbances. The division of disturbances during the year 2008 for each country is presented; for example, the consequences of the disturbances in the form of energy not supplied.

Chapter 4 presents tables and figures of energy not supplied for each country.

In Chapter 5 faults in different components are discussed. A summary of all the faults is followed by the presentation of more detailed statistics.

Chapter 6 covers outages in the various power system units. This part of the statistics starts from the year 2000.

There are no common disturbance statistics for voltage levels lower than 100 kV. Appendix 3 presents the relevant contact persons for these statistics.

1.1 Contact persons

Each country is represented by at least one contact person, responsible for his/her country's statistical information. The relevant contact person can provide additional information concerning Nordel's disturbance statistics. The relevant contact information is given in Appendix 2.

1.2 Guidelines of the statistics

The scope and definitions of Nordel's disturbance statistics are presented in more detail in Nordel's Guidelines for the Classification of Grid Disturbances [1].

1.3 Voltage levels in the Nordel network

The Nordic main grid is in Figure 1. Voltage levels of the network in the Nordic countries are presented in Table 1.1. In the statistics, voltage levels are grouped according to the table.

Figure 1 The Nordic main grid.

Table 1.1 Voltage levels in the Nordel network

Nominal voltage level kV	Statis-tical voltage U (kV)	Denmark U_N kV	Denmark P %	Finland U_N kV	Finland P %	Iceland U_N kV	Iceland P %	Norway U_N kV	Norway P %	Sweden U_N kV	Sweden P %
≥400	**400**	400	100	400	100	-	-	420	100	400	100
220–300	**220**	220	100	220	100	220	100	300	88	220	100
220–300	**220**	-	-	-	-	-	-	250	4	-	-
220–300	**220**	-	-	-	-	-	-	220	8	-	-
110–150	**132**	150	63	110	100	132	100	132	98	130	100
110–150	**132**	132	37	-	-	-	-	110	2	-	-

U – statistical (designated) voltage, U_N – nominal voltage

P – Percentage of the grid at the respective nominal voltage level for each statistical voltage.

The following tables use the 132, 220 and 400 kV values to represent the nominal voltages, in accordance with Table 1.1.

1.4 Scope and limitations of the statistics

Table 1.2 presents the coverage of the statistics in each country. The percentage of the grid is estimated according to the length of lines included in the statistics material.

Table 1.2 Percentage of national networks included in the statistics

Voltage level	Denmark	Finland	Iceland	Norway	Sweden
400 kV	100%	100%	-	100%	100%
220 kV	100%	100%	100%	100%	100%
132 kV	100%	88%	100%	100%	100%

The network statistics of each country, except Iceland, cover data from several grid owners and the representation of their statistics is not fully consistent.

Finland: The data includes approximately 88% of Finnish 110 kV lines and approximately 55% of 110/20 kV transformers.

Iceland: The network statistics cover the whole 220kV and 132kV transmission grid. There is only one transmission company in Iceland.

Norway: A large part of the 132 kV network is resonant earthed but is combined with a solid earthed network in these statistics.

2 Summary

In 2008 the energy not supplied (ENS) due to faults in the Nordic main grid was quite low. ENS was 4.83 GWh, which is somewhat higher than 4.70 GWh in 2007, but still lower than average. The ten-year annual average of energy not supplied during the 1999–2008 period in the Nordel area was 8.20 GWh. The corresponding average value for each country is presented in brackets in the following paragraphs. The following paragraphs also present the number of disturbances for each country as well as the number of disturbances that caused energy not supplied in 2008. The corresponding annual averages are from the periods 1999–2008 and 2002–2008, respectively. In addition, the two most important issues in 2008 defined by each Transmission System Operator are also presented in the summaries.

2.1 Summary for Denmark

In Denmark, the energy not supplied for the year 2008 was 10 MWh (10-year average 958 MWh). The number of grid disturbances was 38 (10-year average 80). In 2008, 7 of those 38 disturbances caused ENS. On average 4 disturbances per year caused ENS during 2002–2008. In 2008, 73% of ENS occurred in April. The high value was caused by two disturbances which occurred on the 20th and the 24th of April.

The disturbance on the 20th of April was due to an open contact in the busbar protection system in a 150 kV substation which caused a busbar trip and ENS of 7 minutes. The open contact was detected when a fault occurred on a neighbouring overhead line. The reason of the open contact was a human mistake due to maintenance of the substations protection devices earlier the same year.

The disturbance on the 24th of April was due to a malfunction of a circuit breaker and a missing operation from the protection system. The circuit breaker was located in a shunt reactor feeder on a 150kV substation. After a manual *open command* one of the circuit breaker poles did not open. Because of the low value of generated zero sequence current, the breaker failure protection system was not able to detect the current. This resulted in a circuit breaker explosion and a busbar trip which caused ENS for 19 minutes.

2.2 Summary for Finland

For Finland the energy not supplied in 2008 was 149 MWh (10-year average 191 MWh). The number of grid disturbances was 330 (10-year average 277) and 53 of them caused ENS. On average 52 disturbances per year caused ENS in 2002–2008. In 2008, 33 % of ENS occurred due to operation and maintenance. Most of the disturbances were caused by lightning and occurred during the summer months.

The percentage of unknown disturbances rose to 58% in 2008 from 52% in 2007. Almost all of the unknown disturbances occurred in 110 kV lines.

50% of ENS was caused by only 4 disturbances. The highest amount of ENS (30 MWh) in a single disturbance was caused by a current transformer explosion. It caused a power cut for 60 000 people lasting as long as 44 minutes.

2.3 Summary for Iceland

For Iceland, the energy not supplied in 2008 was 1798 MWh (10-year average 759 MWh). The total number of disturbances was 43 (10-year average 47), of which 18 led to ENS. On average there have been 27 disturbances per year that caused ENS in 2002–2008.

In Iceland, over 80% of ENS occurred in January due to bad weather. Two of the disturbances caused by bad weather in January were relatively significant. One was located in a switching station for the power station Sigalda and was caused by a block of ice falling from a tower onto high voltage equipment. This disturbance resulted in several tripped lines and ENS for the power intensive industry. The other disturbance was located on a radial transmission line in the west fjords in Iceland and was caused by strong wind.

2.4 Summary for Norway

For Norway, the energy not supplied for 2008 was 1243 MWh (10-year average 2559 MWh). The number of grid disturbances was 253 (10-year average 345), which is less than during any other year since 1999.

In 2008, the biggest contributor to ENS was an operation and maintenance fault close to a liquefied petroleum gas (LPG) terminal. It alone caused more than 2/3 of the total ENS. A cable fault over the Oslofjord limited the supply of electricity to the market for a lengthy duration.

2.5 Summary for Sweden

In Sweden, the energy not supplied in 2008 was 1634 MWh (10-year average 3731 MWh). The total number of disturbances was 490 (10-year average 649) and 121 of those caused ENS. On average there have been 131 disturbances per year that have caused ENS in 2002–2008. The amount of ENS was relatively low.

The number of transformer faults at the 132 kV level is still significantly higher compared to the other countries. The reason could be age distribution or different maintenance strategies or difference in fault classification for different utilities.

3 Disturbances

This chapter includes an overview of disturbances in the Nordel countries. In addition, Chapter 3 presents the connection between disturbances, energy not supplied, fault causes and division during the year, together with the development of number of disturbances over the ten-year period 1999–2008. It is important to note the difference between a disturbance and a fault. A disturbance may consist of a single fault but it can also contain many faults, typically consisting of an initial fault followed by some secondary faults.

Definition of a grid disturbance:
Outages, forced or unintended disconnection or failed reconnection as a result of faults in the power grid [1, 2].

3.1 Annual number of disturbances during the period 1999–2008

The number of disturbances during the year 2008 in the Nordic main grid was 1154, which is clearly lower than the 10-year average of 1398. The number of grid disturbances cannot be used directly for comparative purposes between countries, because of big differences between external conditions in the transmission networks of Nordel countries.

Table 3.1 presents the sum of disturbances during the year 2008 for the complete 100–400 kV grid in each respective country. Figure 3.1 shows the development of the number of disturbances in each respective country during the period 1999–2008.

Table 3.1 Number of grid disturbances in 2008

Year 2008	**Denmark**	**Finland**	**Iceland**	**Norway**	**Sweden**
Number of disturbances	38	330	43	253	490

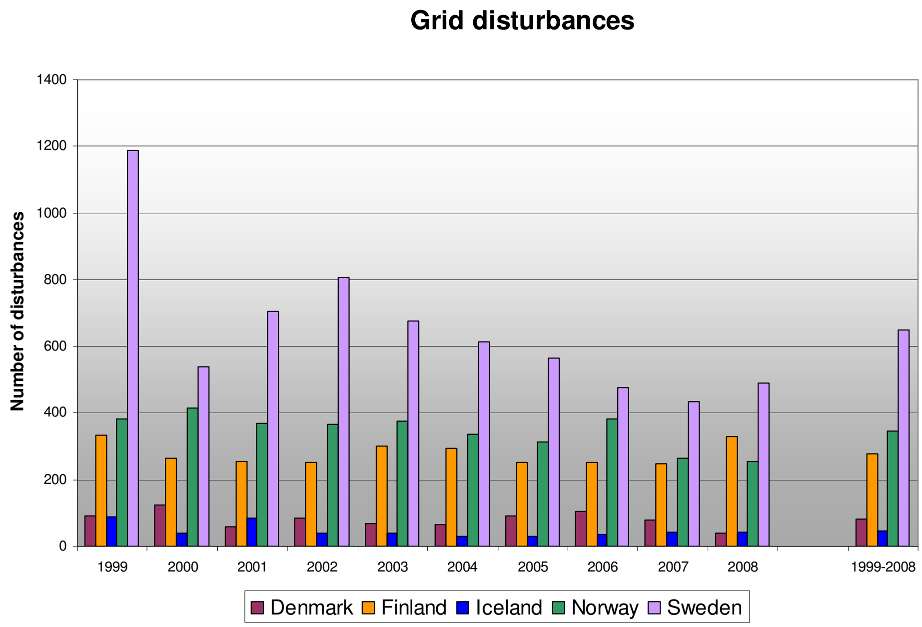

Figure 3.1 Number of grid disturbances in each Nordel country during the period 1999–2008.

3.2 Disturbances divided according to month

Figure 3.2 presents the percentage distribution of grid disturbances according to month in different countries. The figure shows the distribution both in the year 2008 and the average values during the period 2000–2008.

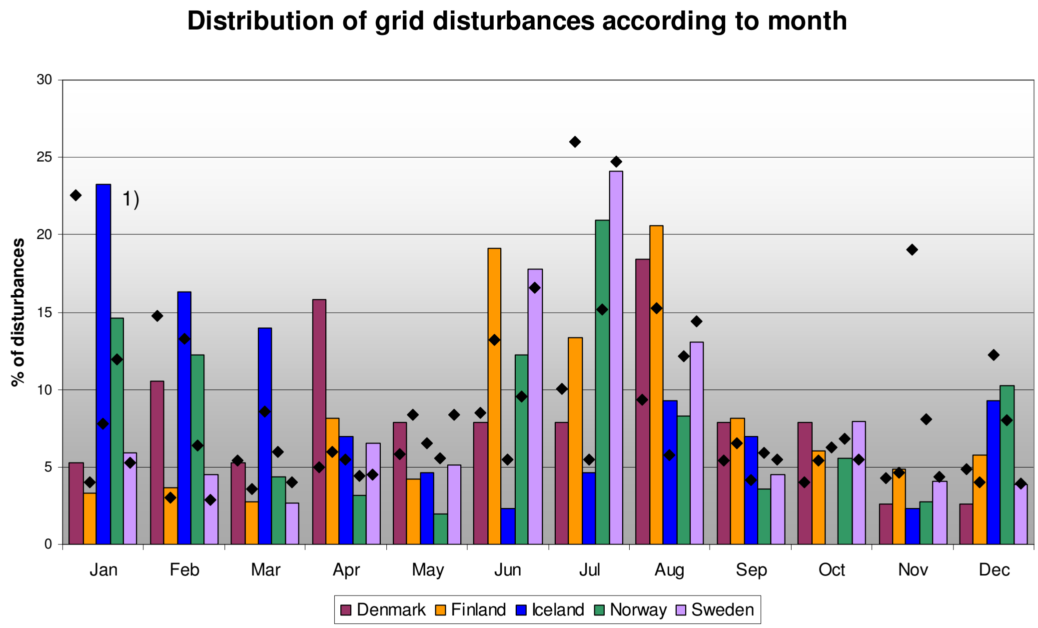

Figure 3.2 Percentage distribution of grid disturbances according to month for each country in 2008 and during the period 2000–2008. The columns correspond to the year 2008 and the black markers to the period 2000–2008.

[1)] In Iceland, the highest number of disturbances in 2008 occurred in January. Two of them were relatively significant. One was located in a switching station for the power station Sigalda and was caused by a block of ice falling from a tower onto high voltage equipment. This disturbance resulted in several tripped lines and ENS for power intensive industry. The other disturbance was located on a radial transmission line in the west fjords in Iceland and was caused by strong wind.

Table 3.2 and Table 3.3 present the numerical values behind Figure 3.2. The numbers in the tables are sums of all the disturbances in the 100–400 kV networks. For all countries, except Iceland, the number of disturbances is usually greatest during the summer period. This is caused by lightning strikes during the summer.

Table 3.2 Percentage distribution of grid disturbances per month for each country in 2008

Country	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Denmark	5	11	5	16	8	8	8	18	8	8	3	3
Finland	3	4	3	8	4	19	13	21	8	6	5	6
Iceland	23	16	14	7	5	2	5	9	7	0	2	9
Norway	15	12	4	3	2	12	21	8	4	6	3	10
Sweden	6	4	3	7	5	18	24	13	4	8	4	4
Nordel	8	7	4	7	4	16	19	14	6	7	4	6

Table 3.3 Percentage division of grid disturbances during the years 2000–2008

Country	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Denmark	23	15	5	5	6	8	10	9	5	4	4	5
Finland	4	3	4	6	8	13	26	15	7	5	5	4
Iceland	8	13	9	5	7	5	5	6	4	6	19	12
Norway	12	6	6	4	6	10	15	12	6	7	8	8
Sweden	5	3	4	4	8	17	25	14	6	5	4	4
Nordel	8	5	5	5	7	13	21	13	6	6	6	5

3.3 Disturbances divided according to cause

There are some minor scale differences in the definitions of fault causes and disturbances between countries. Some countries use up to 40 different options and others differentiate between initiating and underlying causes. The exact definitions are listed in Section 5.2.9 in the guidelines [1]. Nordel's statistics use seven different options for fault causes and list the initiating cause of the event as the starting point. An overview of the causes of grid disturbances and energy not supplied in each country is presented in Table 3.4.

Each country or company that participates in the Nordel statistics has its own more detailed way of gathering data according to fault cause. Nordel's guidelines [1] describe how each fault cause relates to Nordel's cause allocation.

Table 3.4 Grouping of grid disturbances and energy not supplied (ENS) by cause

Cause	**Country**	**Percentage distribution of disturbances**		**Percentage distribution of ENS**[1)]	
		2008	2000–2008	2008	2000–2008
Lightning	Denmark	32	17	11	0
	Finland	25	35	1	9
	Iceland	2	2	1	1
	Norway	31	23	4	6
	Sweden	34	42	14	11
Other environmental causes	Denmark	0	32	0	0
	Finland	4	4	0	12
	Iceland	37	40	89	51
	Norway	22	18	1	27
	Sweden	4	4	3	6
External influences	Denmark	24	13	27	0
	Finland	2	3	20	8
	Iceland	2	1	0	0
	Norway	1	2	0	2
	Sweden	4	3	16	2
Operation and maintenance	Denmark	5	13	0	4
	Finland	7	6	33	26
	Iceland	9	11	2	22
	Norway	10	15	72	17
	Sweden	7	7	3	12
Technical equipment	Denmark	13	10	0	11
	Finland	3	4	4	25
	Iceland	30	23	8	18
	Norway	19	23	20	35
	Sweden	17	16	27	48
Other	Denmark	8	5	55	84
	Finland	2	8	21	14
	Iceland	19	17	0	6
	Norway	8	15	1	13
	Sweden	9	9	15	17
Unknown	Denmark	18	9	7	0
	Finland[2)]	58	41	21	7
	Iceland	0	5	0	2
	Norway	9	6	1	1
	Sweden	26	18	23	4

[1)] Calculation of energy not supplied varies between different countries and is presented in Appendix 1.

[2)] Most of the Finnish unknown disturbances probably have other natural phenomenon or external influence as their cause.

In Figure 3.3, disturbances for all voltage levels are identified in terms of the initial fault.

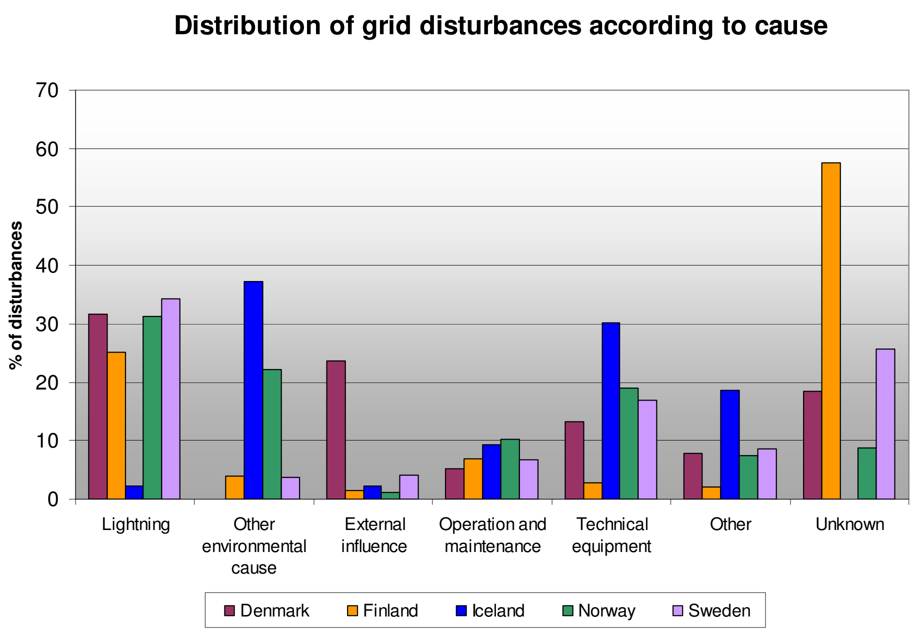

Figure 3.3 Percentage distribution of grid disturbances according to cause in 2008.

A large number of disturbances with unknown cause probably have their real cause in the categories *other environmental cause* and *lightning*.

4 Energy not supplied (ENS)

This chapter presents an overview of energy not supplied in the Nordel countries. One should notice that the amount of energy not supplied is always an estimation. The accuracy of the estimation varies between companies in different countries and so does the calculation method for energy not supplied, as can be seen in Appendix 1.

Definition of energy not supplied:
The estimated energy which would have been supplied to end users if no interruption and no transmission restrictions had occurred [1, 2].

4.1 Energy not supplied (ENS) divided according to voltage level

Table 4.1 shows the amount of energy not supplied in the five countries and also its division according to voltage level.

Table 4.1 Energy not supplied (ENS) according to the voltage level of the initiating fault

Country	**ENS MWh 2008**	**ENS divided into different voltage levels during the period 2000–2008 (%)**			
		132 kV	**220 kV**	**400 kV**	**Other[2)]**
Denmark	9.6	5.1	0.0	94.9 [1)]	0.0
Finland	149.4	95.8	2.1	0.4	1.7
Iceland	1797.8	38.7	61.3	0.0	0.0
Norway	1243.4	39.0	33.7	7.1	20.1
Sweden	1633.5	48.1	6.3	34.4 [1)]	11.2
Nordel	4833.8	39.5	19.4	29.8	11.2

[1)] The high values for the 400 kV share of energy not supplied in Denmark and Sweden are the result of a major disturbance in Southern Sweden on the 23rd of September in 2003.
[2)] The category *other* contains energy not supplied from system faults, auxiliary equipment, lower voltage level networks and the connections to foreign countries, etc.

In Figure 4.1 and Figure 4.2, energy not supplied is summarised according to the different voltage levels for the year 2008 and for the period 1999–2008, respectively. Voltage level refers to the initiating fault of the respective disturbance.

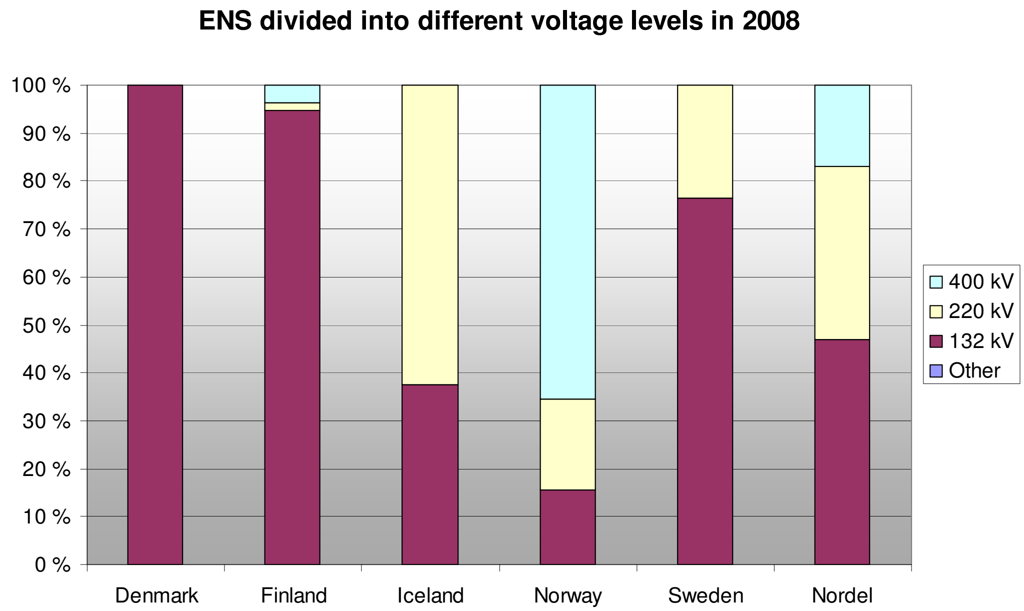

Figure 4.1 Energy not supplied (ENS) in terms of the voltage level of the initiating fault in 2008.

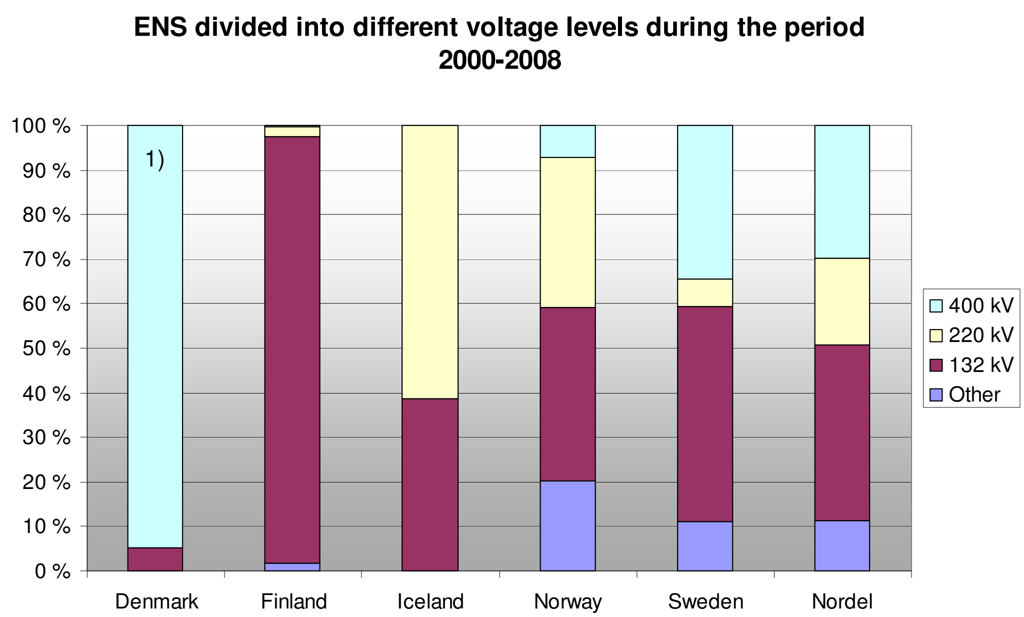

Figure 4.2 Energy not supplied (ENS) in terms of the voltage level of the initiating fault during the period 2000–2008.

1) The large amount of energy not supplied at 400 kV grid in Denmark is a consequence of the big disturbance in Southern Sweden and Zealand on the 23rd of September in 2003. That disturbance caused 88% of the total amount of energy not supplied at the 400 kV level during that year.

4.2 Energy not supplied (ENS) and total consumption

Table 4.2 shows the energy not supplied in relation to the total consumption of energy in each respective country and also its division according to installation.

Table 4.2 Energy not supplied (ENS) according to installation

Country	Total consumption GWh 2008	ENS MWh 2008	ENS / consumption Ppm 2008	ENS / consumption Ppm 1999–2008	ENS divided according to installation during the period 1999–2008 (%) Overhead line	Cable	Stations	Other
Denmark	33790	9.6	0.3	27.6	11.8	0.0	4.5	83.7
Finland	86900	149.4	1.7	2.5	29.4	0.0	52.0	18.6
Iceland	16467	1797.8	109.2	79.7	37.9	1.1	45.2	15.8
Norway	124819	1243.4	10.0	21.1	34.0	0.4	42.9	22.6
Sweden	144000	1633.5	11.3	26.0	16.3	9.1	64.5	10.1
Nordel	405976	4833.8	11.9	21.3	23.6	4.4	48.7	23.3

Ppm (parts per million) is ENS as a proportional value of the consumed energy, which is calculated: ENS (MWh) × 10^6 / consumption (MWh).

Figure 4.3 presents the development of energy not supplied during the period 1999–2008. One should note that there is a considerable difference from year to year, which depends on occasional events, such as storms. These events have a significant effect on each country's yearly statistics.

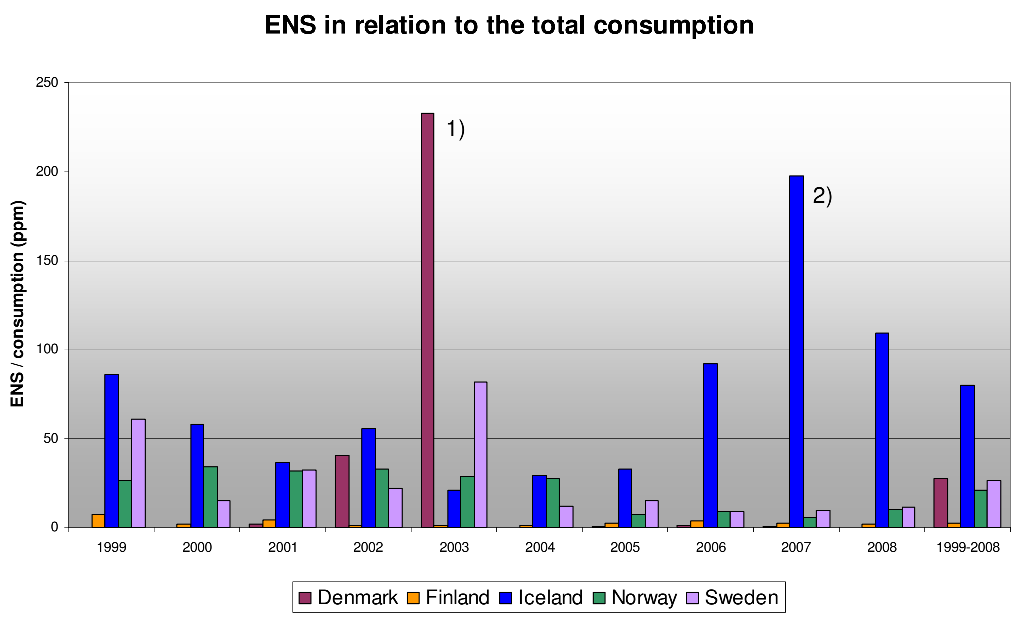

Figure 4.3 Energy not supplied (ENS) / consumption (ppm).

[1)] The large amount of energy not supplied in Denmark is a consequence of the major disturbance in Southern Sweden on the 23rd of September in 2003 that caused the whole of Zealand to lose its power.
[2)] An unusual number of disturbances, which had an influence on the power intensive industry, caused the high value of energy not supplied during 2007 in Iceland.

4.3 Energy not supplied (ENS) divided according to month

Figure 4.4 presents the distribution of energy not supplied according to month in the respective countries.

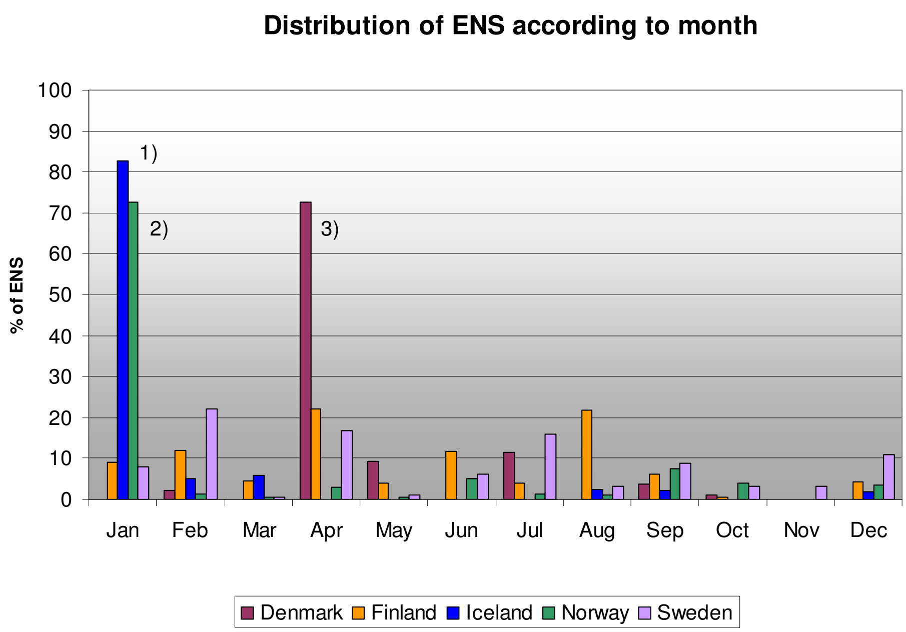

Figure 4.4 Percentage distribution of energy not supplied (ENS) according to month in 2008.

[1)] The high value of ENS for Norway in January was caused by one major operation and maintenance fault, which had 768.71 MWh of ENS.
[2)] In Iceland, the high value of ENS in January was mainly caused by two relatively significant disturbances. One was due to a block of ice falling from a tower onto high voltage equipment. The other was due to strong wind.
[3)] For Denmark, the high value of ENS in April was caused by two disturbances that occurred on the 20th and 24th of April. One was due to an open contact in the busbar protection system in a 150 kV substation. The other was due to a malfunction of a circuit breaker and a missing operation from the protection system.

4.4 Energy not supplied (ENS) divided according to cause

Figure 4.5 presents the distribution of energy not supplied according to cause in different countries.

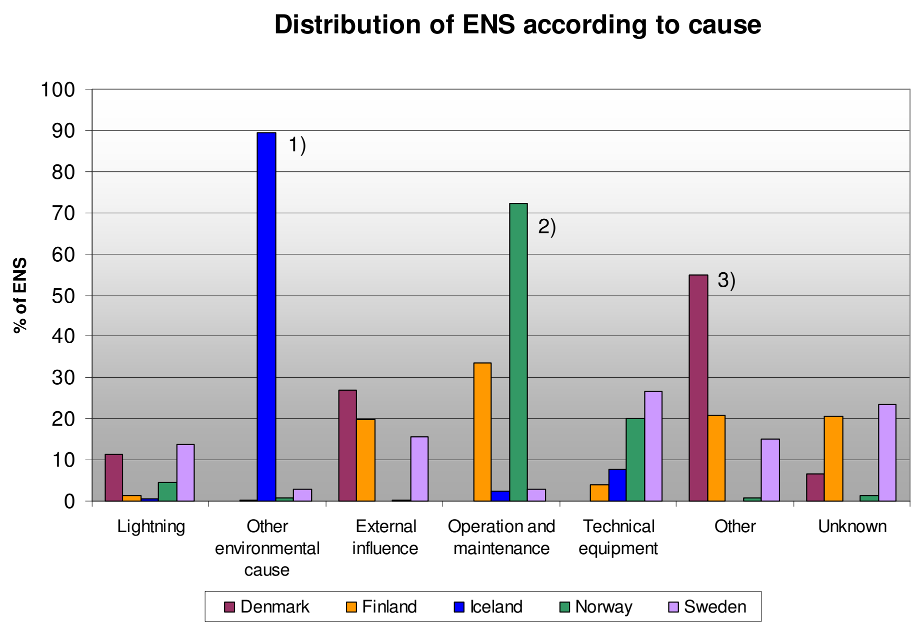

Figure 4.5 Percentage distribution of energy not supplied (ENS) according to cause in 2008.

1) For Iceland, the high value of ENS in the category *other environmental cause* was due to bad weather in January.

2) Norway had in January an operation and maintenance fault, which caused 768.71 MWh of ENS.

3) For Denmark, the high value of ENS in the category *other* was caused by two disturbances which occurred on the 20th and the 24th of April.

4.5 Energy not supplied (ENS) divided according to component

Table 4.3 shows the amount of energy not supplied in 2008 and the annual average for the period 2001–2008. Table 4.4 shows the distribution of energy not supplied according to component.

Table 4.3 Energy not supplied (ENS) in 2008 and the annual average for the period 2001–2008

	Denmark		**Finland**		**Iceland**		**Norway**		**Sweden**		**Nordel**	
Time period	2008	2001–2008	2008	2001–2008	2008	2001–2008	2008	2001–2008	2008	2001–2008	2008	2001–2008
ENS (MWh)	10	1197	149	170	1798	819	1243	2276	1634	3537	4834	7999

Table 4.4 Percentage distribution of energy not supplied in terms of component

Fault location	Denmark		Finland		Iceland		Norway		Sweden		Nordel	
	2008	2001–2008	2008	2001–2008	2008	2001–2008	2008	2001–2008	2008	2001–2008	2008	2001–2008
Overhead line	11.4	0.4	33.0	37.5	32.7	36.4	66.4	30.9	21.9	16.1	37.7	20.5
Cable	0.0	0.0	0.0	0.0	4.6	1.3	0.0	0.5	7.8	11.0	4.3	5.1
Sum of line faults	11.4	0.4	33.0	37.5	37.3	37.7	66.4	31.4	29.6	27.1	42.0	25.6
Power transformer	0.0	0.6	0.0	2.3	0.0	0.2	0.7	0.7	12.9	11.2	4.6	5.3
Instrument transformer	0.0	0.0	19.8	6.7	0.0	0.0	4.7	4.0	6.7	2.7	4.1	2.5
Circuit breaker	45.6	3.5	0.0	4.9	0.1	4.3	4.7	1.4	3.5	1.8	2.5	2.3
Disconnector	0.0	0.2	0.0	0.8	0.0	14.8	8.3	5.0	9.2	40.8	5.2	21.0
Surge arrester and spark gap	0.0	0.0	9.2	4.3	0.0	0.0	0.2	2.5	0.0	0.2	0.3	0.9
Busbar	0.0	0.2	5.2	5.0	24.1	9.3	0.0	1.6	0.9	1.6	9.4	2.3
Control equipment	36.3	11.4	32.1	26.1	2.5	12.3	11.8	28.1	5.9	4.2	7.0	13.4
Common ancillary equipment	0.0	0.0	0.0	1.4	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1
Other substation faults	6.6	0.0	0.0	1.3	0.0	0.0	3.1	2.0	21.5	3.4	8.1	2.1
Sum of substation faults	88.6	15.9	66.3	52.8	26.7	40.9	33.6	45.5	60.6	65.9	41.3	49.8
Shunt capacitor	0.0	0.0	0.0	0.0	5.5	4.2	0.0	0.0	0.0	1.2	2.0	1.0
Series capacitor	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Reactor	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SVC and statcom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Synchronous compensator	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sum of compen-sation faults	0.0	0.0	0.0	0.0	5.5	4.2	0.0	0.0	0.0	1.2	2.0	1.0
System fault	0.0	83.8	0.0	0.0	30.5	17.2	0.0	7.6	4.2	0.7	12.8	16.8
Faults in adjoining statistical area	0.0	0.0	0.6	9.7	0.0	0.0	0.0	15.5	5.7	5.1	1.9	6.9
Unknown	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sum of other faults	0.0	83.8	0.6	9.7	30.5	17.2	0.0	23.1	9.8	5.8	14.7	23.6

One should notice that some countries register the total number of energy not supplied in a disturbance in terms of the initiating fault, which can give the wrong picture.

5 Faults in power system components

Faults in a component imply that it may not perform its function properly. Faults can have many causes, for example, manufacturing defects or insufficient maintenance by the user. In this chapter, the fault statistics in different grid components are presented. One should take note of both the causes and consequences of the fault when analysing the fault frequencies of different devices. For example, overhead lines normally have more faults than cables. On the other hand, cables normally have considerably longer repair times than overhead lines.

Definition of a component fault:
The inability of a component to perform its required function [3].

First an overview of all faults registered in the component groups used in the Nordel statistics is given. More detailed statistics relating to each specific component group are then presented. Ten-year average values have been used for components that have data for 10-year periods. For some components there is data only from the year 2000. In the calculation of ten-year averages, the annual variation in the number of components has been taken into consideration. The averages are therefore calculated on the basis of the number of components with the number of faults for each time period. This chapter also presents fault trend curves for some components. The trend curves show the variation in fault frequencies of consecutive 5-year periods. These curves are divided into 220–400 kV and 132 kV voltage levels for all the components except for cables, which are not divided. Readers who need more detailed data should use the national statistics.

5.1 Overview of all faults

Table 5.1 presents the number of faults and disturbances during 2008. For Iceland, the fault statistics cover data from *Landsnet*, the only transmission company in Iceland. For the other four countries, the Transmission System Operators collect data from several grid owners and the representation of their statistics is not fully consistent.

Table 5.1 Number of faults and grid disturbances in 2008

	Denmark	**Finland**	**Iceland**	**Norway**	**Sweden**
Number of faults in 2008	49	345	64	305	499
Number of disturbances in 2008	38	330	43	253	490
Fault/disturbance ratio in 2008	1.29	1.05	1.49	1.21	1.02
The average fault/disturbance ratio during 2000–2008	1.17	1.14	1.25	1.32	1.13

5.1.1 Overview of faults divided according to voltage level

The division of faults and energy not supplied in terms of voltage level and country is presented in Table 5.2. In addition, the table shows the line length and the number of power transformers in order to give a view of the grid size in each country. One should note that the number of faults includes all faults, not just faults in lines and power transformers.

Table 5.2 Faults in different countries in terms of voltage level

Voltage	Country	Size of the grid		Number of faults		ENS[2] (MWh)	
		Number of power transformers	Length of lines in km[1]	2008	2000–2008 (annual average)	2008	2000–2008 (annual average)
400 kV	Denmark	23	1537	3	10.4	0.0	365.7
	Finland	51	4443	17	21.3	5.4	0.6
	Iceland	0	0	-	-	-	-
	Norway	64	2708	44	58.6	814.8	164.6
	Sweden	63	10653	96	124.1	0.0	1166.1
220 kV	Denmark	2	105	0	0.7	0.0	0.0
	Finland	24	2400	13	24.1	2.5	3.6
	Iceland	32	868	28	17.1	1124.9	481.4
	Norway	271	6165	90	111.9	236.3	855.2
	Sweden	102	4332	61	65.6	384.4	212.5
132 kV	Denmark	238	4305	44	78.3	9.6	54.2
	Finland	814	15422	307	228.6	141.5	159.5
	Iceland	60	1347	36	34.4	673.0	304.2
	Norway	724	10677	171	190.9	192.4	1069.4
	Sweden	756	15860	316	386.8	1249.1	1631.0

[1] Length of lines is the sum of the length of cables and overhead lines.

[2] Calculation of energy not supplied (ENS) varies between countries.

Table 5.3 shows the number of faults classified according to the component groups used in the Nordel statistics for each respective country. One should note that not all countries have every type of equipment in their network, for example, SVCs or statcom installations. The distribution of the number of components can also vary from country to country, so one should be careful when comparing countries. Note that faults that begin outside the Nordel statistics' voltage range (typically from networks with voltages lower than 100 kV) but that nevertheless have an influence on the Nordel statistic area are included in the statistics.

Table 5.3 Percentage division of faults according to component

Fault location	**Denmark**		**Finland**		**Iceland**		**Norway**		**Sweden**		**Nordel**	
	2008	2000–2008	2008	2000–2008	2008	2000–2008	2008	2000–2008	2008	2000–2008	2008	2000–2008
Overhead line	50.0	60.9	81.2	73.8	25.3	38.9	55.4	38.8	47.9	56.6	57.5	54.4
Cable	4.3	2.3	0.0	0.0	2.7	0.6	2.0	0.7	1.8	0.5	1.5	0.6
Sum of line faults	54.3	63.2	81.2	73.8	28.0	39.5	57.4	39.6	49.7	57.1	59.0	54.9
Power transformer	0.0	3.6	0.9	0.7	2.7	3.0	2.0	1.7	5.0	5.5	2.8	3.3
Instrument transformer	2.2	0.6	0.9	0.4	0.0	0.4	1.6	1.8	1.2	0.9	1.2	1.0
Circuit breaker	8.7	5.6	0.0	1.4	1.3	6.6	1.6	3.3	3.0	3.8	2.0	3.4
Disconnector	0.0	1.6	0.3	0.6	0.0	0.2	2.6	1.4	0.6	0.7	0.9	0.9
Surge arresters and spark gap	0.0	0.5	0.3	0.2	0.0	0.4	1.3	1.1	0.0	0.2	0.4	0.5
Busbar	0.0	0.5	0.6	0.4	1.3	0.8	0.3	1.2	1.0	1.0	0.7	0.9
Control equipment	28.3	13.5	12.2	11.7	34.7	26.5	24.3	31.1	7.8	12.0	15.3	18.1
Common ancillary equipment	0.0	0.4	0.0	0.3	0.0	0.0	1.0	1.0	0.4	0.8	0.4	0.7
Other substation faults	2.2	2.4	0.3	1.0	10.7	8.0	6.6	4.5	19.1	2.6	9.9	3.0
Sum of substation faults	41.3	28.7	15.4	16.8	50.7	45.9	41.3	47.1	38.2	27.5	33.6	31.9
Shunt capacitor	0.0	0.1	0.0	0.9	5.3	1.6	0.0	1.3	0.8	0.7	0.6	0.9
Series capacitor	0.0	0.0	0.9	0.4	0.0	0.2	0.0	0.0	0.6	1.1	0.5	0.6
Reactor	0.0	1.7	0.0	0.4	0.0	0.0	0.3	0.5	0.8	1.0	0.4	0.7
SVC and statcom	0.0	0.1	0.0	0.0	0.0	0.0	1.0	1.0	1.2	1.0	0.7	0.7
Synchronous compensator	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	1.0	0.4	0.4	0.4
Sum of compen-sation faults	0.0	1.9	0.9	1.8	5.3	1.8	1.3	3.6	4.4	4.2	2.6	3.3
System fault	0.0	2.6	0.3	0.1	16.0	12.2	0.0	1.8	3.2	3.6	2.3	2.7
Faults in adjoining statistical area	4.3	3.5	2.3	4.1	0.0	0.0	0.0	7.9	4.4	4.5	2.5	5.2
Unknown	0.0	0.1	0.0	3.5	0.0	0.6	0.0	0.0	0.0	3.0	0.0	2.0
Sum of other faults	4.3	6.2	2.6	7.6	16.0	12.8	0.0	9.7	7.6	11.2	4.8	9.8

5.2 Faults in overhead lines

Overhead lines constitute a very large part of the Nordel transmission grid. Therefore, the tables in this section show the division of faults in 2008 as well as the ten-year period 1999–2008. Faults divided by cause during the ten-year period are also given. Along with the tables, the annual division of faults during the period 1999–2008 is presented graphically for all voltage levels. Figure 5.4 and Figure 5.5 present the trend of faults for overhead lines. With the help of the trend curve, it may be possible to determine the trend of faults also in the future.

5.2.1 400 kV overhead lines

Table 5.4 Division of faults according to cause for 400 kV overhead lines

Country	Line km	Number of faults	Number of faults per 100 km		Faults divided by cause during the period 1999–2008 (%)								
	2008	2008	2008	1999–2008	Lightning	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown	1-phase faults	Permanent faults
Denmark	1228	1	0.08	0.40	19.1	61.7	6.4	4.3	6.3	2.1	0.0	51.0	6.5
Finland	4443	8	0.18	0.24	76.5	8.2	0.0	3.1	2.0	4.1	6.1	51.0	4.1
Norway	2683	22	0.82	1.09	23.2	68.5	0.4	0.4	2.6	2.2	2.6	65.2	8.2
Sweden	10645	33	0.31	0.36	48.7	24.6	1.6	1.3	3.1	1.0	19.6	83.8	8.7
Nordel	18999	64	0.34	0.43	41.8	39.6	1.3	1.4	3.0	1.9	11.1	71.6	7.8

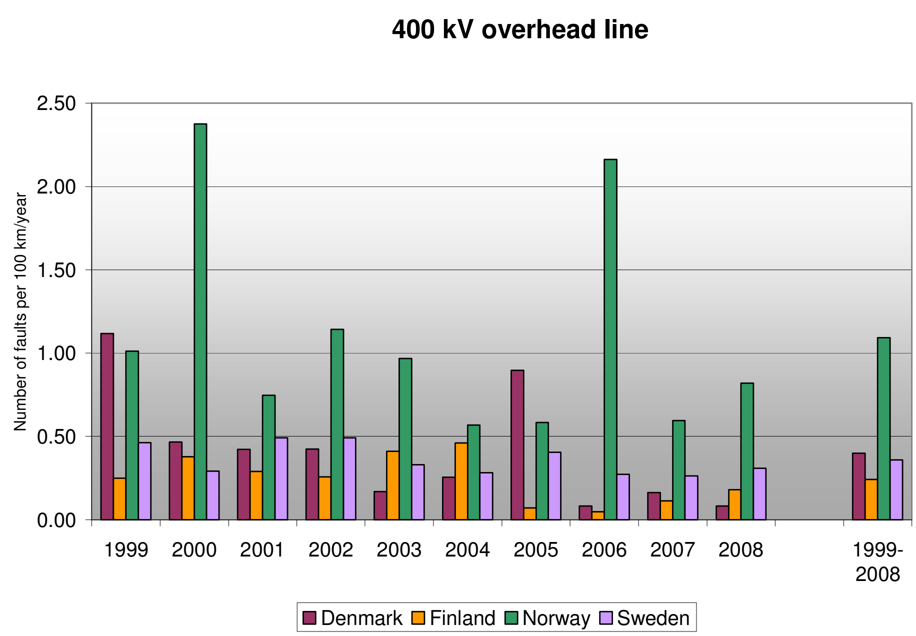

Figure 5.1 Annual division of faults during the period 1999–2008.

5.2.2 220 kV overhead lines

Table 5.5 Division of faults according to cause for 220 kV overhead lines

Country	Line km 2008	Number of faults 2008	Number of faults per 100 km 2008	Number of faults per 100 km 1999–2008	Faults divided by cause during the period 1999–2008 (%) Lightning	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown	1-phase faults	Permanent faults
Denmark	105	0	0.00	0.48	40.0	20.0	20.0	0.0	0.0	0.0	20.0	80.0	0.0
Finland	2400	12	0.50	0.70	43.1	3.6	3.6	0.6	0.6	1.2	47.4	68.0	3.5
Iceland	867	4	0.46	0.43	34.5	44.8	0.0	0.0	20.7	0.0	0.0	48.3	24.1
Norway	5715	35	0.61	0.68	56.4	32.1	1.0	0.3	2.6	1.3	6.4	58.9	13.8
Sweden	4117	35	0.85	0.88	70.6	5.5	3.4	3.9	3.1	0.5	12.9	53.3	10.0
Nordel	13204	86	0.65	0.73	58.9	17.1	2.5	1.7	3.0	0.9	15.9	58.1	10.8

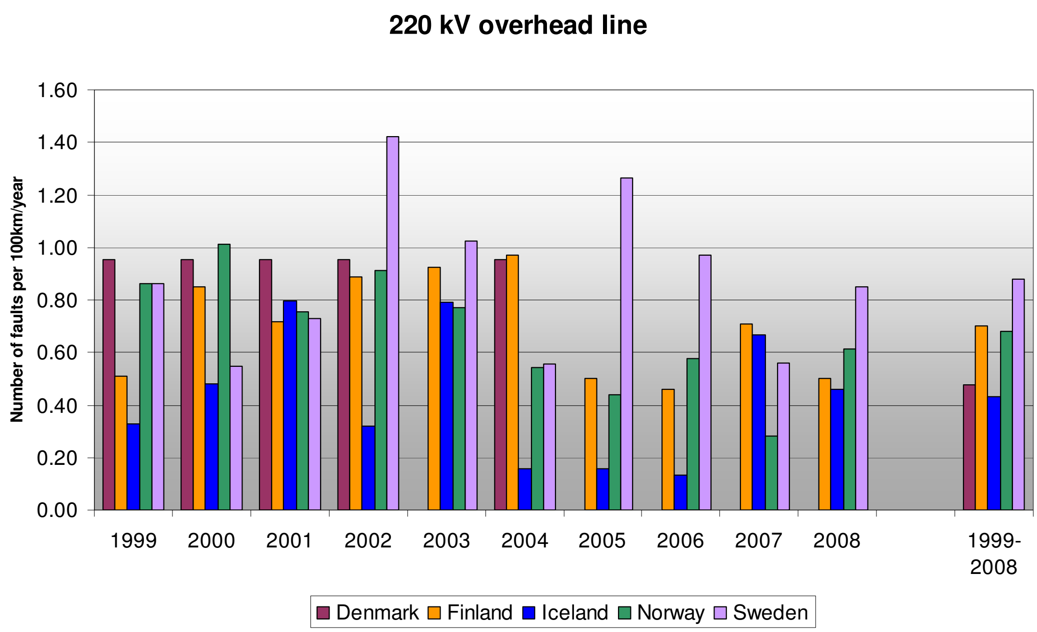

Figure 5.2 Annual division of faults during the period 1999–2008.

5.2.3 132 kV overhead lines

Table 5.6 Division of faults according to cause for 132 kV overhead lines

Country	Line km 2008	Number of faults 2008	Number of faults per 100 km 2008	Number of faults per 100 km 1999–2008	Faults divided by cause during the period 1999–2008 (%) Lightning	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown	1-phase faults	Permanent faults
Denmark	3669	22	0.60	1.32	22.1	47.5	17.2	2.3	1.0	3.2	6.7	46.4	4.9
Finland	15296	260	1.70	1.85	41.6	3.9	1.9	1.4	0.5	0.8	49.8	76.5	2.5
Iceland	1293	15	1.16	1.46	2.2	89.4	2.2	1.1	4.5	0.0	0.6	43.6	13.4
Norway	10475	112	1.07	1.09	57.2	27.5	3.0	0.5	6.3	4.0	1.5	25 [1)]	16.8
Sweden	15645	172	1.10	2.30	62.9	4.6	3.0	1.8	2.3	2.0	23.4	41.5	5.4
Nordel	46378	581	1.25	1.74	51.2	13.6	3.7	1.5	2.4	2.0	25.6	49.3	6.6

[1)] The Norwegian grid includes a resonant earthed system, which has an effect on the low number of single-phase earth faults in Norway.

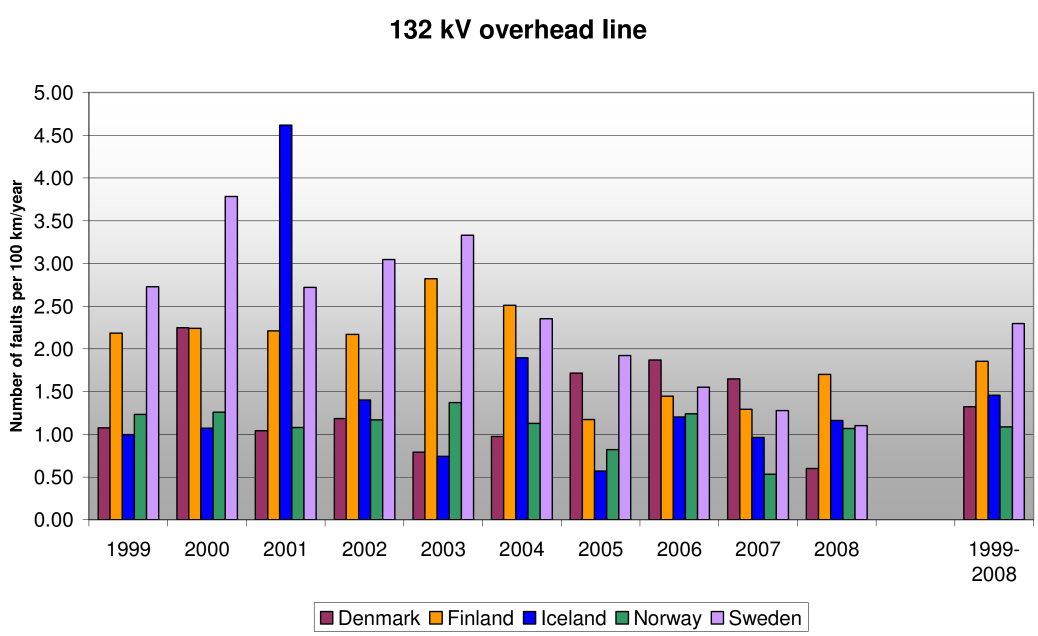

Figure 5.3 Annual division of faults during the period 1999–2008.

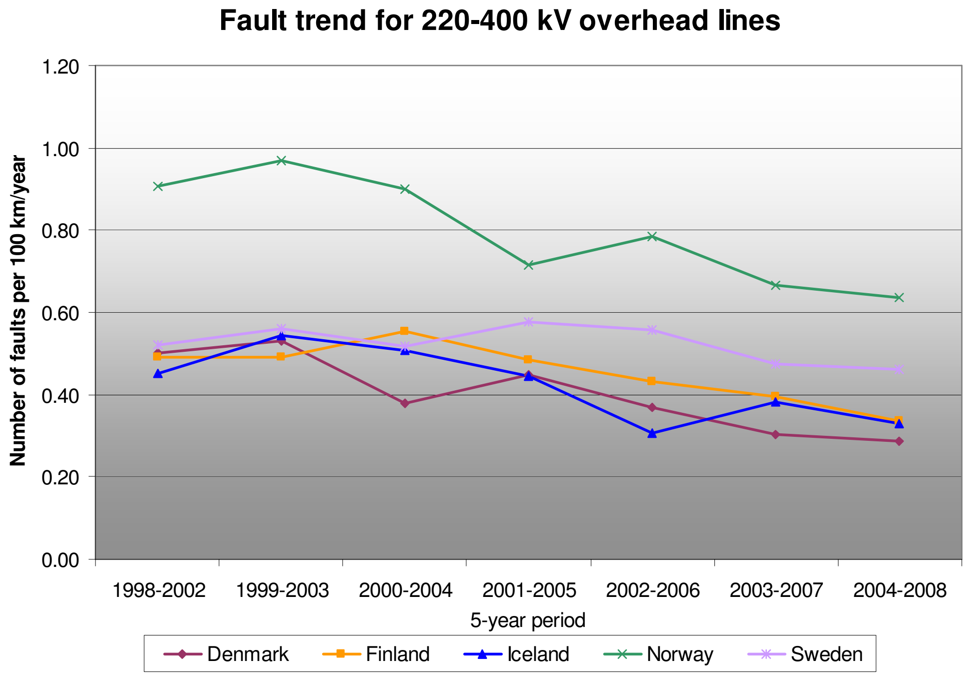

Figure 5.4 Fault trend for overhead lines at voltage level 220–400 kV.

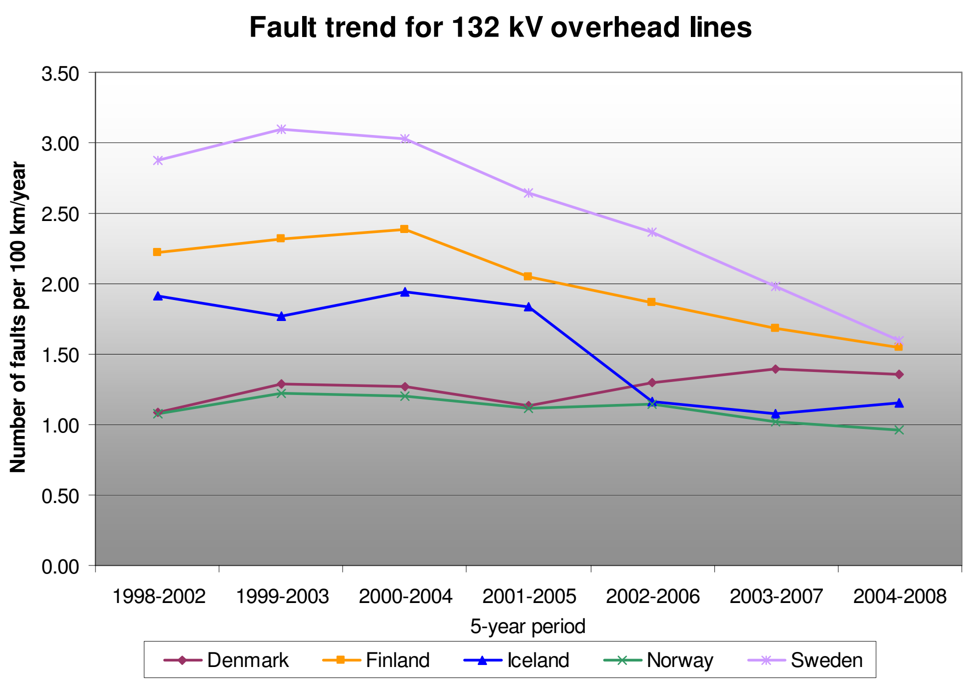

Figure 5.5 Fault trend for overhead lines at voltage level 132 kV.

Figure 5.4 and Figure 5.5 present faults divided by line length at different voltage levels. The trend curve is proportioned to line length in order to get comparable results between countries.

5.3 Faults in cables

The tables in this section present faults in cables at each respective voltage level, with fault division for the year 2008 and for the period 1999–2008. In addition, the division of faults according to cause is given for the whole ten-year period. The annual division of faults during the period 1999–2008 is presented graphically for 132 kV cables. Figure 5.7 presents the trend of faults for cables. With due caution, the trend curve can be used to estimate the likely fault frequencies in the future.

5.3.1 400 kV cables

Table 5.7 Division of faults according to cause for 400 kV cables

Country	Line km 2008	Number of faults 2008	Number of faults per 100 km		Faults divided by cause during the period 1999–2008 (%)						
			2008	1999–2008	Lightning	Other environmental cause	External influence	Operation and maintenance	Technical equipment	Other	Unknown
Denmark	309	0	0.00	0.28	0.0	0.0	0.0	25.0	25.0	25.0	25.0
Norway	25	2	8.00	0.81	0.0	0.0	0.0	0.0	50.0	50.0	0.0
Sweden	8	0	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nordel	342	2	0.58	0.35	0.0	0.0	0.0	16.7	33.3	33.3	16.7

5.3.2 220 kV cables

Table 5.8 Division of faults according to cause for 220 kV cables

Country	Line km 2008	Number of faults 2008	Number of faults per 100 km		Faults divided by cause during the period 1999–2008 (%)						
			2008	1999–2008	Lightning	Other environmental cause	External influence	Operation and maintenance	Technical equipment	Other	Unknown
Norway	450	0	0.00	0.10	0.0	33.3	0.0	33.3	33.3	0.0	0.0
Sweden	215	0	0.00	0.89	0.0	0.0	0.0	11.1	77.8	0.0	11.1
Nordel	665	0	0.00	0.30	0.0	8.3	0.0	16.7	66.7	0.0	8.3

5.3.3 132 kV cables

Table 5.9 Division of faults according to cause for 132 kV cables

Country	Line km 2008	Number of faults 2008	Number of faults per 100 km 2008	Number of faults per 100 km 1999–2008	Faults divided by cause during the period 1999–2008 (%) Lightning	Other environmental cause	External influence	Operation and maintenance	Technical equipment	Other	Unknown
Denmark	636	2	0.31	0.32	0.0	0.0	43.7	18.7	25.0	12.5	0.0
Finland	126	0	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Iceland	54	2	3.72	0.83	0.0	0.0	0.0	0.0	100.0	0.0	0.0
Norway[1)]	202	4	1.98	1.44	0.0	0.0	11.1	18.5	55.6	11.1	3.7
Sweden	215	9	4.19	0.87	0.0	0.0	19.0	14.3	28.6	19.0	19.0
Nordel	1232	17	1.38	0.66	0.0	0.0	20.9	16.4	41.8	13.4	7.5

[1)] Cables in Norway include resonant earthed cables.

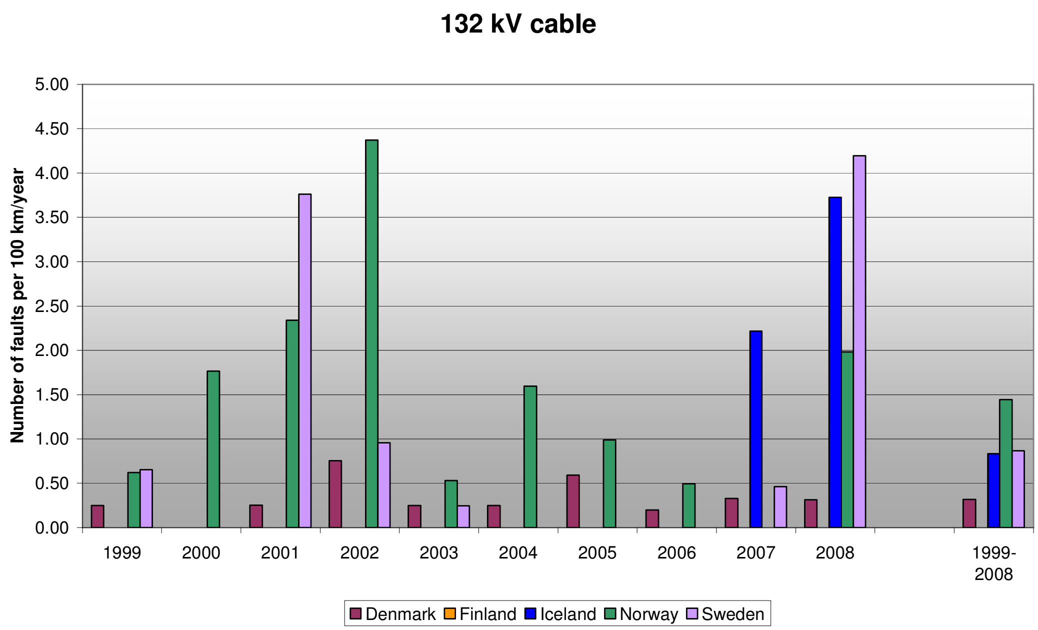

Figure 5.6 Annual division of faults during the period 1999–2008.

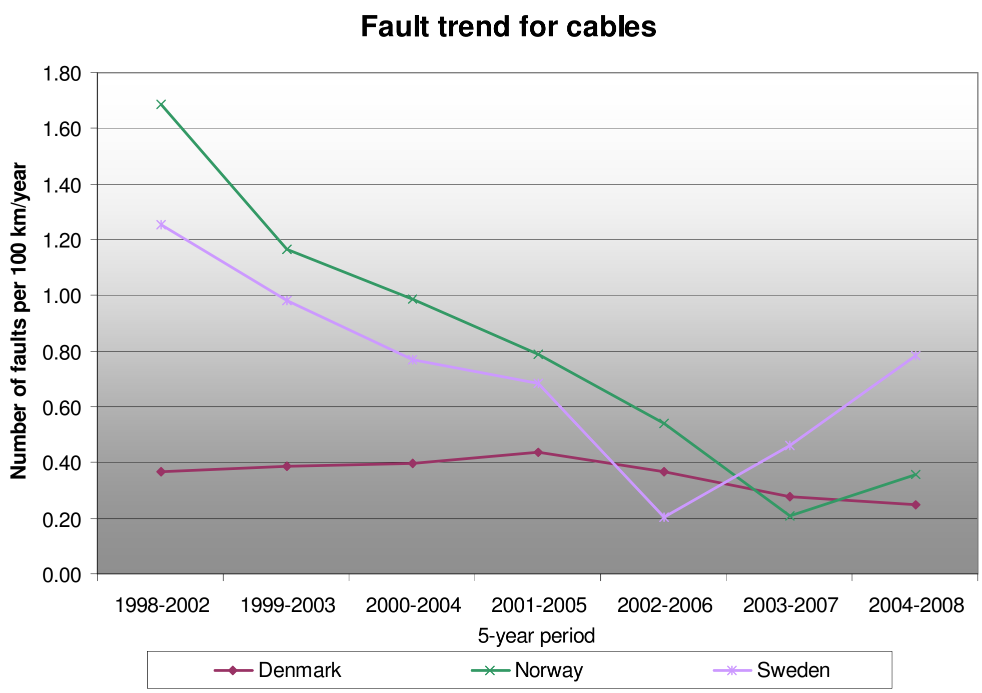

Figure 5.7 Fault trend for cables at all voltage level.

Figure 5.7 presents the fault trend for Denmark, Norway and Sweden only due to the low number of cables in Finland and Iceland.

5.4 Faults in power transformers

The tables in this section present the faults division for the year 2008 and for the period 1999–2008 in power transformers at each respective voltage level. The division of faults according to cause during the ten-year period is also presented. The annual division of faults during the period 1999–2008 is presented graphically for all voltage levels. Figure 5.11 and Figure 5.12 present the trend of faults for power transformers, which also allows the trend to be estimated in the future. For power transformers the rated voltage of the winding with the highest voltage is stated [1, Section 6.2]. Each transformer is counted only once.

5.4.1 400 kV power transformers

Table 5.10 Division of faults according to cause for 400 kV power transformers

Country	Number of devices 2008	Number of faults 2008	Number of faults per 100 devices 2008	Number of faults per 100 devices 1999–2008	Faults divided by cause during the period 1999–2008 (%) Lightning	Other environmental cause	External influence	Operation and maintenance	Technical equipment	Other	Unknown
Denmark	23	0	0.00	3.18 [1)]	14.3	14.3	0.0	14.3	14.3	0.0	42.9
Finland	51	0	0.00	2.06	0.0	22.2	0.0	11.1	44.4	11.1	11.1
Norway	64	1	1.56	0.81	0.0	0.0	0.0	20.0	80.0	0.0	0.0
Sweden	63	1	1.59	1.46	14.1	0.0	0.0	28.6	43.0	14.3	0.0
Nordel	201	2	1.00	1.57	8.5	8.6	0.0	20.0	42.9	8.6	11.4

[1)] The high number of faults in Denmark was caused by a transformer that inflicted three out of the seven faults registered during the period 2001–2005.

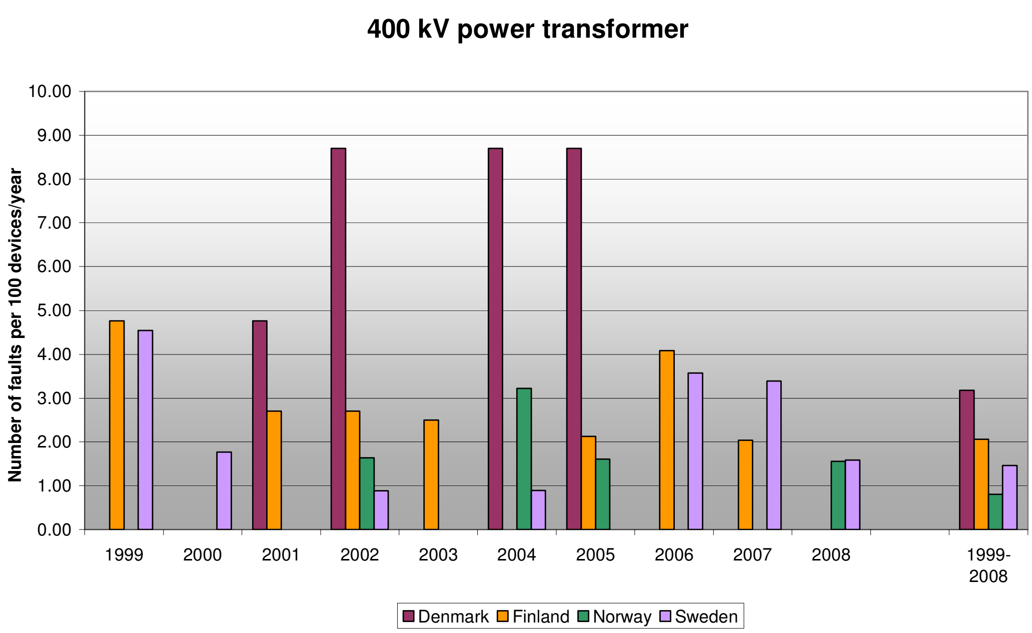

Figure 5.8 Annual division of faults during the period 1999–2008.

5.4.2 220 kV power transformers

Table 5.11 Division of faults according to cause for 220 kV power transformers

Country	Number of devices 2008	Number of faults 2008	Number of faults per 100 devices		Faults divided by cause during the period 1999–2008 (%)						
			2008	1999–2008	Lightning	Other environmental cause	External influence	Operation and maintenance	Technical equipment	Other	Unknown
Denmark	2	0	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Finland	24	0	0.00	1.75	0.0	0.0	0.0	0.0	25.0	0.0	75.0
Iceland	32	2	6.25	3.53	0.0	0.0	0.0	11.1	77.8	0.0	11.1
Norway	271	2	0.74	1.29	5.7	0.0	2.9	25.7	45.7	17.2	2.9
Sweden	102	1	0.98	2.92	30.6	5.6	8.3	19.4	22.2	5.6	8.3
Nordel	431	5	1.16	1.89	15.5	2.4	4.8	20.2	38.1	9.6	9.5

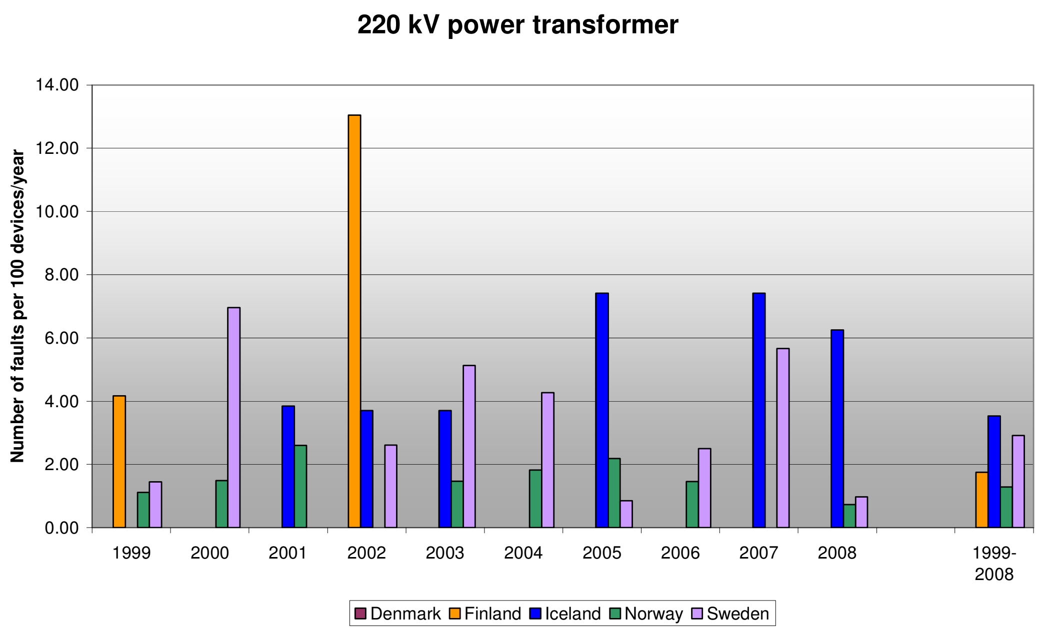

Figure 5.9 Annual division of faults during the period 1999–2008.

5.4.3 132 kV power transformers

Table 5.12 Division of faults according to cause for 132 kV power transformers

Country	Number of devices 2008	Number of faults 2008	Number of faults per 100 devices 2008	Number of faults per 100 devices 1999–2008	Faults divided by cause during the period 1999–2008 (%) Lightning	Other environmental cause	External influence	Operation and maintenance	Technical equipment	Other	Unknown
Denmark	238	0	0.00	0.94	4.2	8.3	4.2	29.2	25.0	4.2	25.0
Finland	814	3	0.37	0.37	0.0	10.0	10.0	10.0	20.0	0.0	50.0
Iceland	60	0	0.00	0.96	0.0	0.0	0.0	50.0	25.0	0.0	25.0
Norway	724	3	0.41	0.52	2.7	5.4	5.4	21.7	48.5	13.6	2.7
Sweden[1)]	756	23	3.04	5.27	17.5	3.8	3.2	16.2	27.2	14.3	17.8
Nordel	2592	29	1.12	2.08	14.6	4.4	3.6	17.7	28.9	13.1	17.7

[1)] The high number of faults shown for Sweden during the period 1999–2004 was caused by misinterpretation of Nordel's guidelines [1]. The old data is not corrected for Table 5.12, Figure 5.10 or Figure 5.12.

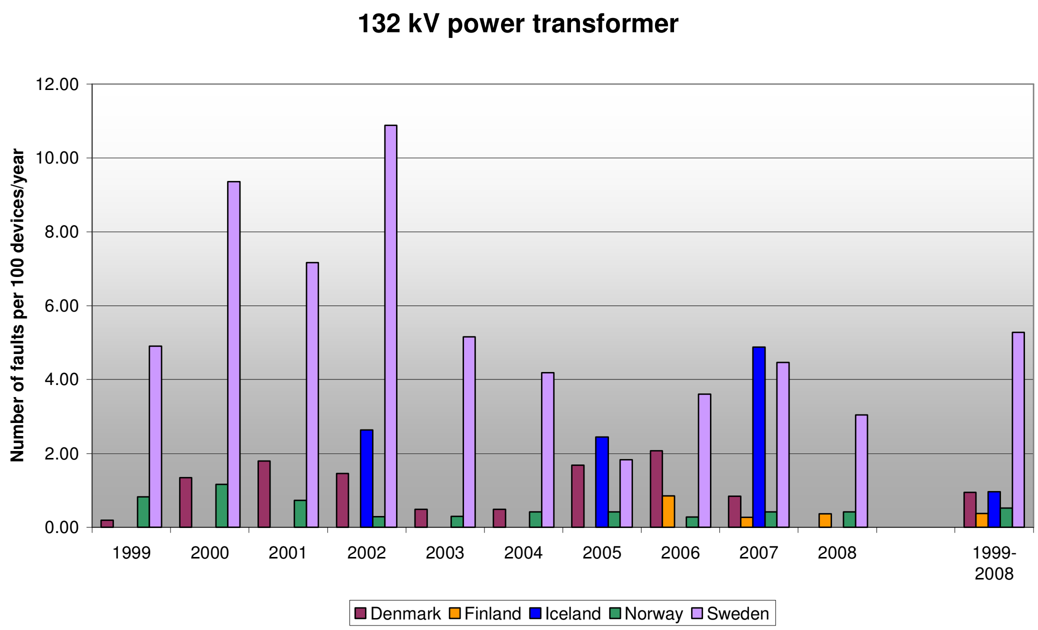

Figure 5.10 Annual division of faults during the period 1999–2008.

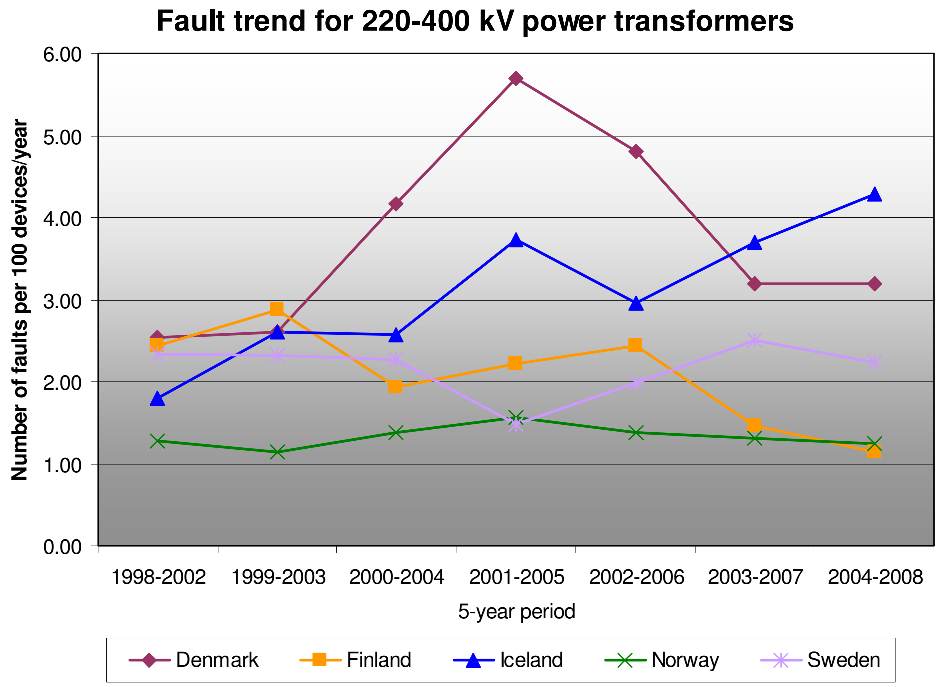

Figure 5.11 Fault trend for power transformers at voltage level 220–400 kV.

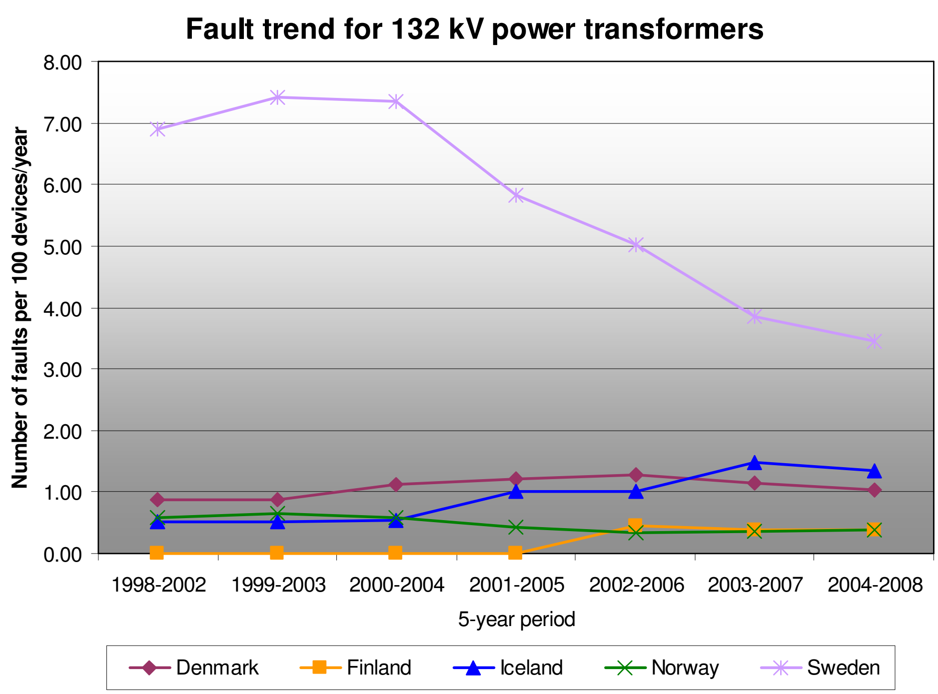

Figure 5.12 Fault trend for power transformers at voltage level 132 kV.

5.5 Faults in instrument transformers

The tables in this section present the faults in instrument transformers for the year 2008 and for the period 1999–2008 at each respective voltage level. In addition, the division of faults according to cause during the ten-year period is presented. Figure 5.13 and Figure 5.14 present the trend of faults for instrument transformers. Both current and voltage transformers are included among instrument transformers. A 3-phase instrument transformer is treated as one unit. If a single-phase transformer is installed, it is also treated as a single unit.

5.5.1 400 kV instrument transformers

Table 5.13 Division of faults according to cause for 400 kV instrument transformers

Country	Number of devices 2008	Number of faults 2008	Number of faults per 100 devices		Faults divided by cause during the period 1999–2008 (%)						
			2008	1999–2008	Lightning	Other environmental cause	External influence	Operation and maintenance	Technical equipment	Other	Unknown
Denmark	533	0	0.00	0.05	0.0	100.0	0.0	0.0	0.0	0.0	0.0
Finland	378	0	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Norway	930	0	0.00	0.13	0.0	10.0	0.0	10.0	30.0	40.0	10.0
Sweden	934	0	0.00	0.10	8.3	0.0	0.0	16.7	66.7	0.0	8.3
Nordel	2775	0	0.00	0.09	4.2	12.5	0.0	12.5	45.8	16.7	8.3

5.5.2 220 kV instrument transformers

Table 5.14 Division of faults according to cause for 220 kV instrument transformers

Country	Number of devices 2008	Number of faults 2008	Number of faults per 100 devices		Faults divided by cause during the period 1999–2008 (%)						
			2008	1999–2008	Lightning	Other environmental cause	External influence	Operation and maintenance	Technical equipment	Other	Unknown
Denmark	12	0	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Finland	140	0	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Iceland	444	0	0.00	0.03	0.0	0.0	0.0	0.0	100.0	0.0	0.0
Norway	2805	2	0.07	0.09	8.3	8.3	0.0	0.0	54.2	20.8	8.3
Sweden	1054	3	0.28	0.08	0.0	0.0	0.0	9.1	90.9	0.0	0.0
Nordel	4455	5	0.11	0.08	5.6	5.6	0.0	2.8	66.7	13.9	5.6

5.5.3 132 kV instrument transformers

Table 5.15 Division of faults according to cause for 132 kV instrument transformers

Country	Number of devices 2008	Number of faults 2008	Number of faults per 100 devices		Faults divided by cause during the period 1999–2008 (%)						
			2008	1999–2008	Lightning	Other environmental cause	External influence	Operation and maintenance	Technical equipment	Other	Unknown
Denmark	4441	1	0.02	0.01	0.0	20.0	0.0	20.0	40.0	0.0	20.0
Finland	1805	3	0.17	0.06	22.2	0.0	11.1	0.0	55.6	11.1	0.0
Iceland	637	0	0.00	0.02	0.0	0.0	0.0	0.0	100.0	0.0	0.0
Norway	7768	3	0.04	0.06	10.6	0.0	0.0	8.5	51.1	19.1	10.6
Sweden	4835	3	0.06	0.07	22.5	2.5	0.0	7.5	50.0	12.5	5.0
Nordel	19486	10	0.05	0.05	15.7	2.0	1.0	7.8	51.0	14.7	7.8

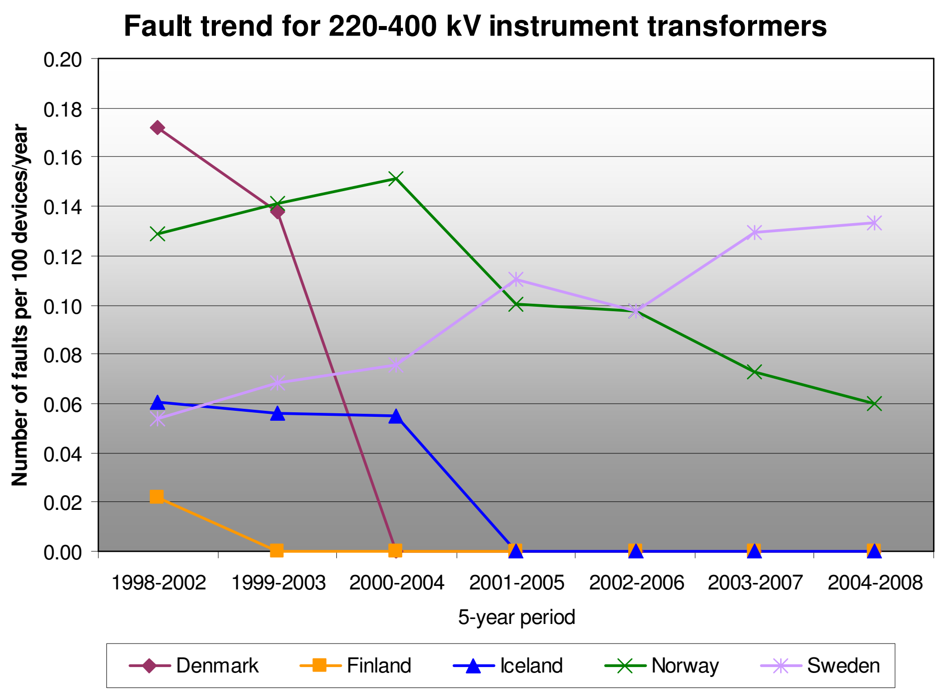

Figure 5.13 Fault trend for instrument transformers at voltage level 220–400 kV.

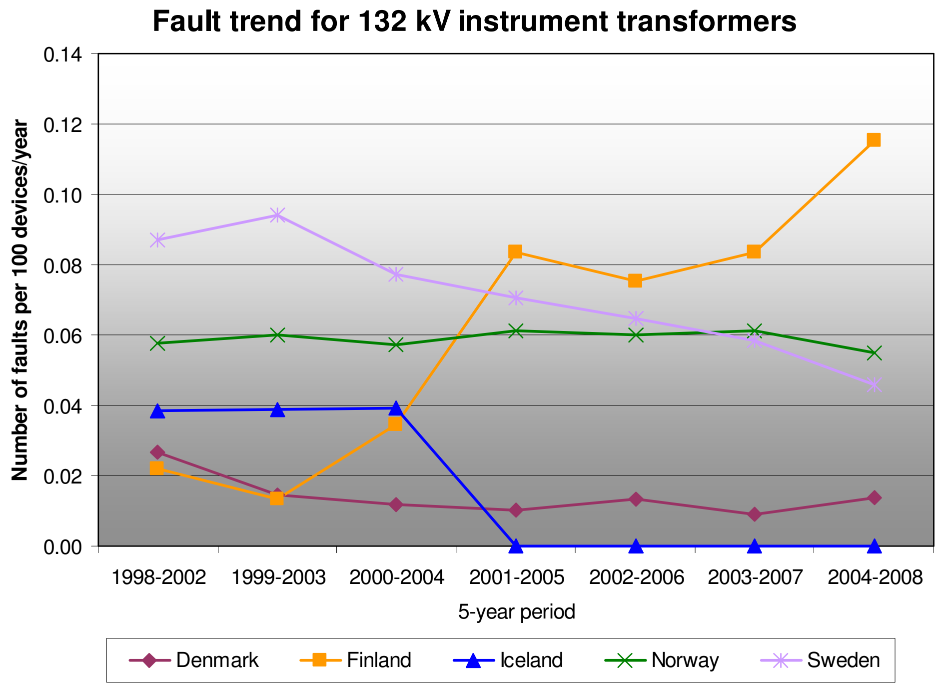

Figure 5.14 Fault trend for instrument transformers at voltage level 132 kV.

5.6 Faults in circuit breakers

The tables in this section present circuit breaker faults for the year 2008 and for the period 1999–2008 at each respective voltage level. The division of faults according to cause during the ten-year period is also presented. Figure 5.15 and Figure 5.15 present the trend of faults for circuit breakers.

One should note that a significant part of the faults are caused by shunt reactor circuit breakers, which usually operate very often compared to other circuit breakers. Disturbances caused by erroneous circuit breaker operations are registered as faults in circuit breakers, with operation and maintenance as their cause.

5.6.1 400 kV circuit breakers

Table 5.16 Division of faults according to cause for 400 kV circuit breakers

Country	Number of devices 2008	Number of faults 2008	Number of faults per 100 devices 2008	Number of faults per 100 devices 1999–2008	Faults divided by cause during the period 1999–2008 (%) Lightning	Other environmental cause	External influence	Operation and maintenance	Technical equipment	Other	Unknown
Denmark	149	1	0.67	0.72	0.0	11.1	11.1	11.1	55.6	11.1	0.0
Finland	220	0	0.00	0.33	0.0	0.0	16.7	16.7	66.7	0.0	0.0
Norway	262	1	0.38	0.98	0.0	0.0	0.0	33.3	54.2	4.2	8.3
Sweden[1)]	438	12	2.74	2.01	0.0	2.4	0.0	2.4	77.6	11.8	5.9
Nordel	1069	14	1.31	1.27	0.0	2.4	1.6	9.7	71.0	9.7	5.6

[1)] For Sweden, the breaker failures at the 400 kV level most often occurred in breakers used to switch the reactors. This is the reason for the high number of circuit breaker faults in Sweden, because a reactor breaker is operated significantly more often than a line breaker.

5.6.2 220 kV circuit breakers

Table 5.17 Division of faults according to cause for 220 kV circuit breakers

Country	Number of devices 2008	Number of faults 2008	Number of faults per 100 devices 2008	Number of faults per 100 devices 1999–2008	Faults divided by cause during the period 1999–2008 (%) Lightning	Other environmental cause	External influence	Operation and maintenance	Technical equipment	Other	Unknown
Denmark	2	0	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Finland	93	0	0.00	0.43	0.0	0.0	0.0	0.0	75.0	25.0	0.0
Iceland	79	0	0.00	3.86	0.0	8.0	0.0	8.0	72.0	0.0	12.0
Norway	724	1	0.14	0.84	1.7	0.0	0.0	32.2	56.0	5.1	5.1
Sweden	413	0	0.00	0.55	4.8	0.0	0.0	19.0	71.4	0.0	4.8
Nordel	1311	1	0.08	0.88	1.8	1.8	0.0	22.9	63.3	3.7	6.4

5.6.3 132 kV circuit breakers

Table 5.18 Division of faults according to cause for 132 kV circuit breakers

Country	Number of devices 2008	Number of faults 2008	Number of faults per 100 devices 2008	Number of faults per 100 devices 1999–2008	Faults divided by cause during the period 1999–2008 (%) Lightning	Other environmental cause	External influence	Operation and maintenance	Technical equipment	Other	Unknown
Denmark	812	3	0.37	0.59	0.0	8.1	2.1	32.7	45.0	12.2	0.0
Finland	2535	0	0.00	0.24	25.9	7.4	0.0	22.2	37.0	3.7	3.7
Iceland	142	1	0.70	0.68	0.0	0.0	0.0	12.5	75.0	0.0	12.5
Norway	2119	3	0.14	0.37	2.7	0.0	0.0	51.4	39.2	2.7	4.1
Sweden	1900	3	0.16	0.93	23.6	2.1	2.1	17.1	43.6	3.6	7.9
Nordel	7508	10	0.13	0.53	14.1	3.0	1.4	28.5	43.0	4.7	5.4

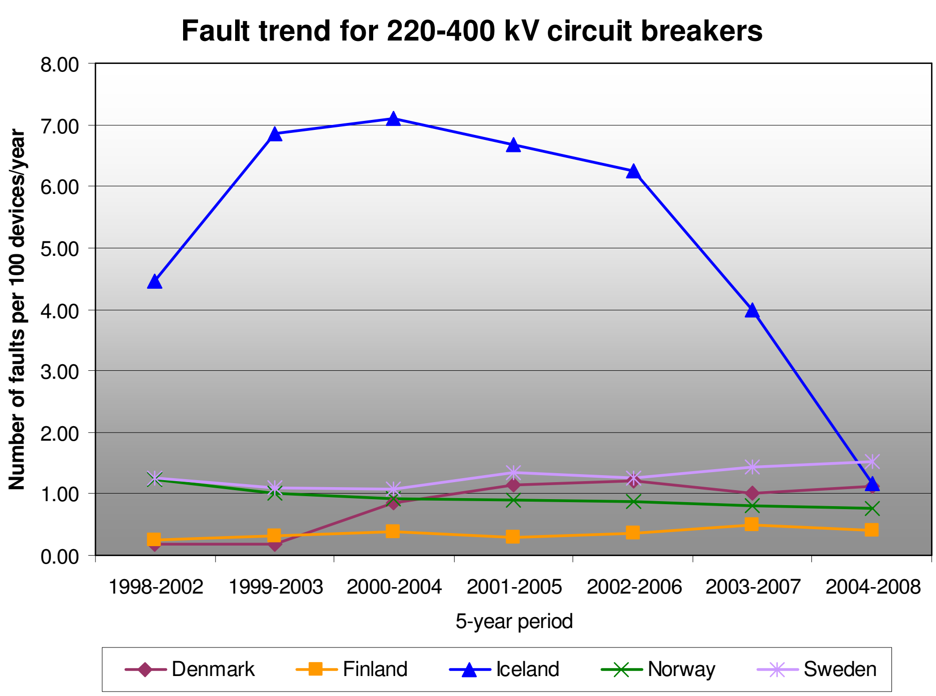

Figure 5.15 Fault trend for circuit breakers at voltage level 220–400 kV.

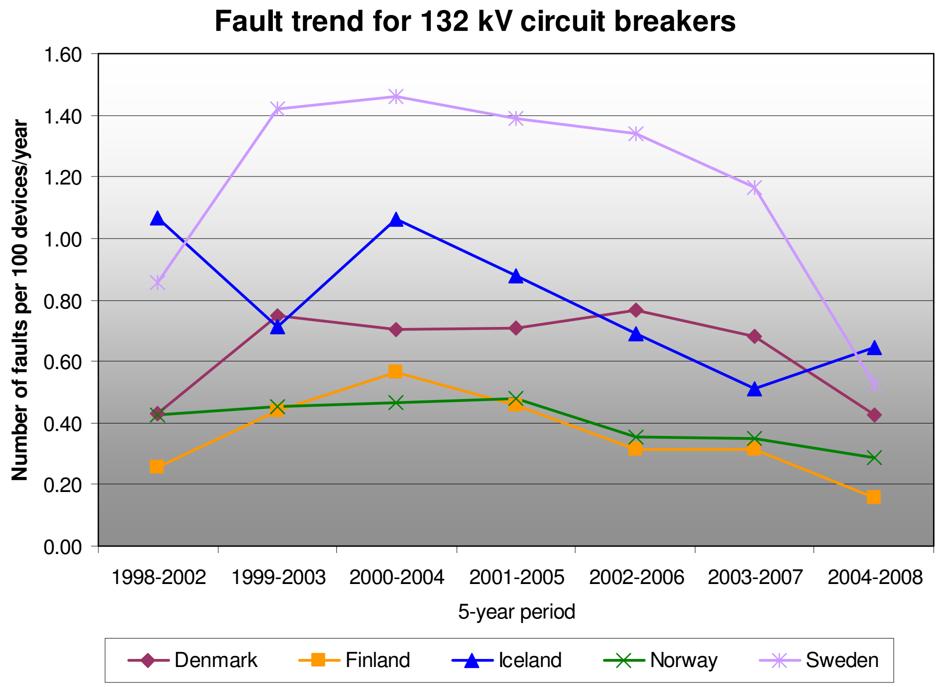

Figure 5.16 Fault trend for circuit breakers at voltage level 132 kV.

5.7 Faults in control equipment

The tables in this section present faults in control equipment at each respective voltage level for the year 2008 and for the period 1999–2008. In addition, the division of faults according to cause during the ten-year period is presented.

It may be uncertain whether a fault really is registered in the control equipment or in the actual component in cases where some parts of the control system are integrated in the component. Faults in control equipment that is integrated in another installation will normally be counted as faults in that installation. This definition has not been applied in all the countries. Nordel's guidelines of these statistics [1] can be used to obtain more detailed definitions.

5.7.1 400 kV control equipment

Table 5.19 Division of faults according to cause for 400 kV control equipment

Country	Number of devices 2008	Number of faults 2008	Number of faults per 100 devices 2008	Number of faults per 100 devices 1999–2008	Faults divided by cause during the period 1999–2008 (%) Lightning	Other environmental cause	External influence	Operation and maintenance	Technical equipment	Other	Unknown
Denmark	149	1	0.67	2.19	4.0	0.0	4.0	28.0	28.0	20.0	16.0
Finland	220	6	2.73	5.86	0.0	0.0	0.0	36.4	12.2	39.3	12.1
Norway	261	11	4.21	11.31	0.0	0.7	0.4	29.9	40.4	12.1	16.5
Sweden	439	28	6.38	11.90	0.4	0.6	0.3	12.6	80.4	3.8	1.9
Nordel	1069	46	4.30	9.39	0.3	0.6	0.4	21.3	58.0	11.2	8.2

5.7.2 220 kV control equipment

Table 5.20 Division of faults according to cause for 220 kV control equipment

Country	Number of devices 2008	Number of faults 2008	Number of faults per 100 devices 2008	Number of faults per 100 devices 1999–2008	Faults divided by cause during the period 1999–2008 (%) Lightning	Other environmental cause	External influence	Operation and maintenance	Technical equipment	Other	Unknown
Denmark	2	0	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Finland	93	0	0.00	5.60	0.0	0.0	0.0	42.3	46.2	5.8	5.8
Iceland	79	11	13.92	12.52	3.7	9.9	0.0	32.1	50.6	3.7	0.0
Norway	721	31	4.30	8.54	0.5	0.8	0.5	31.8	40.2	8.7	17.4
Sweden	407	10	2.46	4.22	0.0	0.0	1.8	33.1	52.7	9.5	3.0
Nordel	1302	52	3.99	7.14	0.7	1.4	0.7	32.7	43.8	8.2	12.5

5.7.3 132 kV control equipment

Table 5.21 Division of faults according to cause for 132 kV control equipment

Country	Number of devices 2008	Number of faults 2008	Number of faults per 100 devices 2008	Number of faults per 100 devices 1999–2008	Faults divided by cause during the period 1999–2008 (%) Lightning	Other environmental cause	External influence	Operation and maintenance	Technical equipment	Other	Unknown
Denmark	812	12	1.48	1.10	4.9	6.2	2.4	40.8	24.7	13.5	7.4
Finland	2535	36	1.42	1.98	2.6	0.0	1.3	39.2	26.5	14.5	15.9
Iceland	140	12	8.57	4.86	0.0	3.5	1.8	29.8	63.2	0.0	1.8
Norway	2064	32	1.55	3.08	0.9	1.8	0.5	31.9	32.5	9.6	22.9
Sweden	1846	1	0.05	1.01	7.3	0.0	0.0	43.0	25.8	10.6	13.2
Nordel	7397	93	1.26	2.06	2.3	1.6	0.8	35.4	31.4	10.5	18.0

5.8 Faults in compensation devices

In the year 2000, Nordel's guidelines for compensation equipment changed. Therefore, the following four categories are used: reactors, series capacitors, shunt capacitors and SVC devices.

Table 5.22 Division of faults according to cause for reactors

Country	Number of devices 2008	Number of faults 2008	Number of faults per 100 devices 2008	Number of faults per 100 devices 2000–2008	Faults divided by cause during the period 2000–2008 (%) Lightning	Other environmental cause	External influence	Operation and maintenance	Technical equipment	Other	Unknown
Denmark	17	0	0.00	4.98	0.0	0.0	0.0	21.4	57.1	0.0	21.4
Finland[1)]	62	0	0.00	2.42	0.0	0.0	0.0	0.0	66.7	25.0	8.3
Norway	36	1	2.78	6.92	0.0	5.0	0.0	30.0	55.0	5.0	5.0
Sweden	52	4	7.69	13.41	0.0	33.3	5.3	5.3	38.6	10.5	7.0
Nordel	167	5	2.99	6.91	0.0	19.4	2.9	11.7	47.6	9.7	8.7

[1)] In Finland, reactors which compensate the reactive power of 400 kV lines are connected to the 20 kV tertiary winding of the 400/110/20 kV power transformers.

Table 5.23 Division of faults according to cause for series capacitors

Country	Number of devices 2008	Number of faults 2008	Number of faults per 100 devices 2008	Number of faults per 100 devices 2000–2008	Faults divided by cause during the period 2000–2008 (%) Lightning	Other environmental cause	External influence	Operation and maintenance	Technical equipment	Other	Unknown
Finland	7	3	42.86	17.24	0.0	0.0	0.0	10.0	30.0	0.0	60.0
Iceland	1	0	0.00	11.11	0.0	0.0	0.0	0.0	100.0	0.0	0.0
Norway	3	0	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sweden	12	3	25.00	62.96	1.5	0.0	0.0	2.9	32.4	42.6	20.6
Nordel	23	6	26.09	39.50	1.3	0.0	0.0	3.8	32.9	36.7	25.3

Table 5.24 Division of faults according to cause for shunt capacitors

Country	Number of devices 2008	Number of faults 2008	Number of faults per 100 devices 2008	Number of faults per 100 devices 2000–2008	Faults divided by cause during the period 2000–2008 (%) Lightning	Other environmental cause	External influence	Operation and maintenance	Technical equipment	Other	Unknown
Denmark	15	0	0.00	1.44	0.0	0.0	100.0	0.0	0.0	0.0	0.0
Finland	54	0	0.00	9.47	0.0	28.0	48.0	0.0	4.0	16.0	4.0
Iceland	10	4	40.00	9.88	0.0	12.5	0.0	0.0	87.5	0.0	0.0
Norway	194	0	0.00	2.98	0.0	0.0	2.0	11.8	45.1	39.2	2.0
Sweden	200	4	2.00	6.75	6.8	4.5	11.4	9.1	38.6	0.0	29.5
Nordel	473	8	1.69	4.56	2.3	7.7	15.4	7.7	36.9	18.5	11.5

Table 5.25 Division of faults according to cause for SVC devices

Country	Number of devices	Number of faults	Number of faults per 100 devices		Faults divided by cause during the period 2000–2008 (%)						
	2008	2008	2008	2000–2008	Lightning	Other environmental cause	External influence	Operation and maintenance	Technical equipment	Other	Unknown
Norway	15	3	20.00	34.15	0.0	4.8	0.0	9.5	57.1	16.7	11.9
Sweden	3	6	200.00	70.93	0.0	6.6	4.9	18.0	60.7	1.6	8.2
Nordel	18	9	50.00	49.05	0.0	5.8	2.9	14.6	59.2	7.8	9.7

SVC devices are often subjects to temporary faults. A typical fault is an error in the computer of the control system that leads to the tripping of the circuit breaker of the SVC device. After the computer is restarted, the SVC device works normally. This explains the high number of faults in SVC devices.

6 Outages

The presentation of outages in power system units was introduced in the Nordel statistics in 2000. More information is in the guidelines [1, Section 5.3]. This chapter covers statistics only for the year 2008.

Definition of a power system unit:
A group of components which are delimited by one or more circuit breakers [2].

Definition of an outage state:
The component or unit is not in the in-service state; that is, it is partially or fully isolated from the system [4].

6.1 Coverage of the outage statistics

The Swedish outage data for 2008 includes approximately 30% of the power system units operating at 132 kV and 100% of the units at the 220 kV and 400 kV voltage levels. Before the year 2007, the Swedish data did not include outages from the 132 kV voltage level, and therefore the number of the different power system units is higher compared to year 2006 and before.

6.2 Outages in power system units

The tables and figures in this section present outages in different power system units.

Table 6.1 Grouping of lines according to number of outages in 2008

Line [1)]		Number of system units grouped by number of outages						
Country	**Number of system units**	**No outages**	**1 outage**	**2 outages**	**3 outages**	**4 outages**	**5 outages**	**>5 outages**
Denmark	309	289	18	2	0	0	0	0
Finland	321	168	91	27	19	9	5	2
Iceland	57	37	12	3	1	1	1	2
Norway	641	544	58	24	10	4	1	0
Sweden	392	274	86	16	9	4	3	0

[1)] Note that the concept of *line* in power system units can consist of both overhead lines and cables.

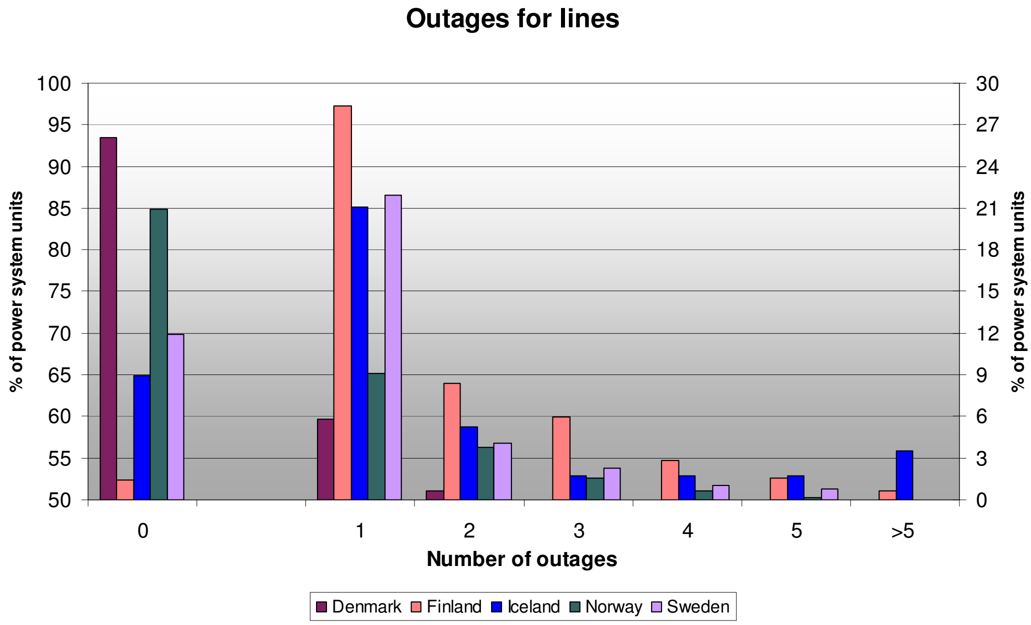

Figure 6.1 Grouping of lines according to number of outages in 2008. The leftmost clustered column is scaled on the left y-axis, whereas the other six clustered columns are scaled on the right y-axis.

Table 6.2 Grouping of transformers according to number of outages in 2008

Transformer		Number of system units grouped by number of outages						
Country	**Number of system units**	**No outages**	**1 outage**	**2 outages**	**3 outages**	**4 outages**	**5 outages**	**>5 outages**
Denmark	257	249	7	1	0	0	0	0
Finland	889	888	0	0	1	0	0	0
Iceland	92	87	1	1	0	0	3	0
Norway	800	797	1	1	1	0	0	0
Sweden	279	263	15	0	0	0	0	1

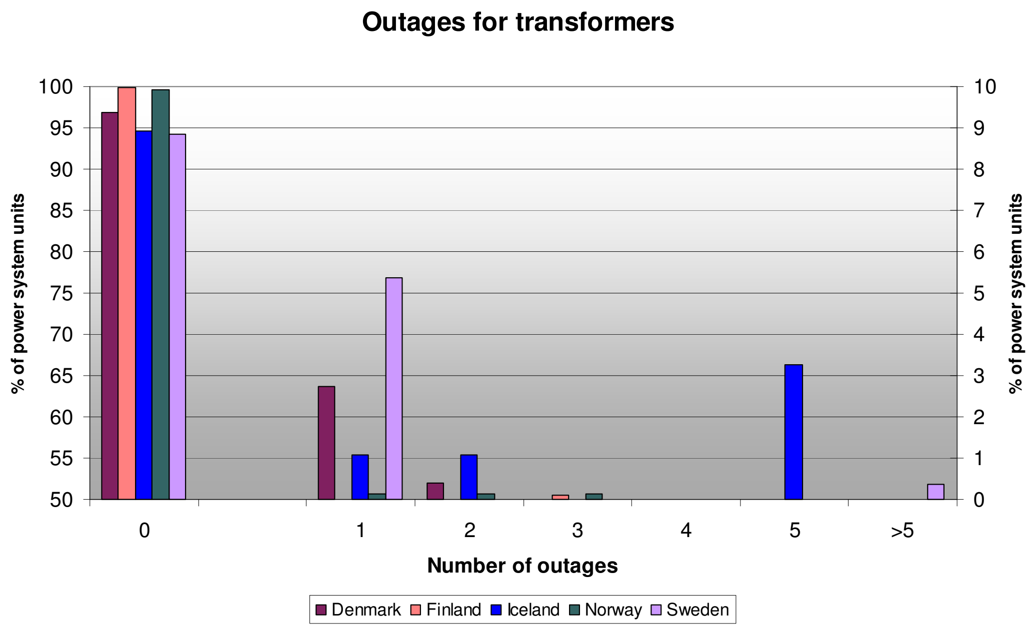

Figure 6.2 Grouping of transformers according to number of outages in 2008. The leftmost clustered column is scaled on the left y-axis, whereas the other six clustered columns are scaled on the right y-axis.

Table 6.3 Grouping of busbars according to number of outages in 2008

Busbar		Number of system units grouped by number of outages						
Country	**Number of system units**	**No outages**	**1 outage**	**2 outages**	**3 outages**	**4 outages**	**5 outages**	**>5 outages**
Denmark	138	130	7	1	0	0	0	0
Finland	864	862	2	0	0	0	0	0
Iceland	53	47	2	4	0	0	0	0
Norway	435	434	1	0	0	0	0	0
Sweden	474	469	2	2	0	1	0	0

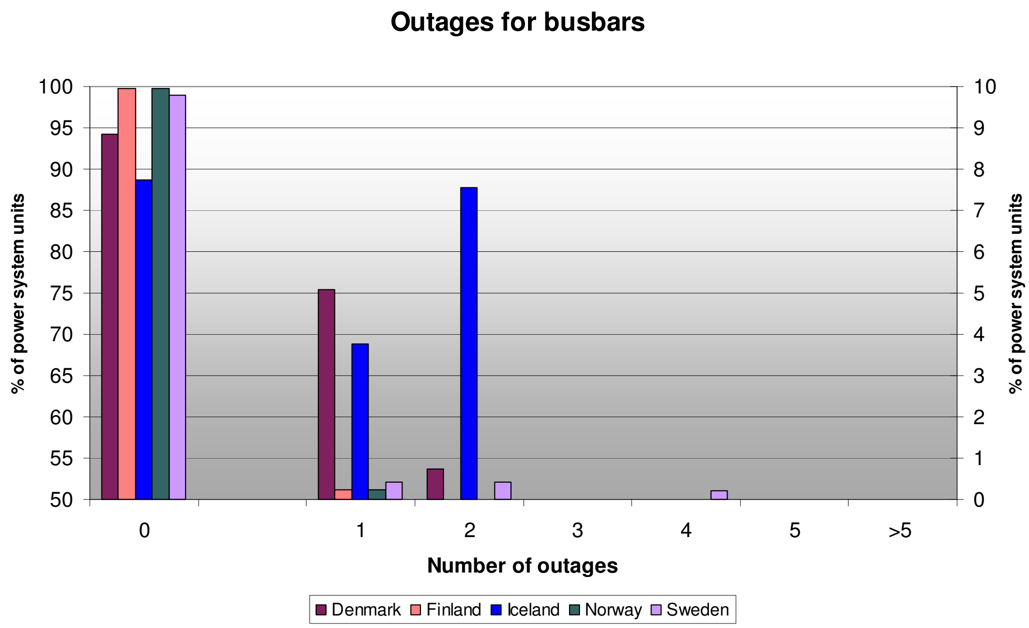

Figure 6.3 Grouping of busbars according to number of outages in 2008. The leftmost clustered column is scaled on the left y-axis, whereas the other six clustered columns are scaled on the right y-axis.

Table 6.4 Grouping of reactors according to number of outages in 2008

Reactor		Number of system units grouped by number of outages						
Country	**Number of system units**	**No outages**	**1 outage**	**2 outages**	**3 outages**	**4 outages**	**5 outages**	**>5 outages**
Denmark	17	17	0	0	0	0	0	0
Finland	62	62	0	0	0	0	0	0
Norway	36	35	1	0	0	0	0	0
Sweden	47	37	7	1	2	0	0	0

Table 6.5 Grouping of shunt capacitors according to number of outages in 2008

Shunt capacitor		Number of system units grouped by number of outages						
Country	**Number of system units**	**No outages**	**1 outage**	**2 outages**	**3 outages**	**4 outages**	**5 outages**	**>5 outages**
Denmark	15	15	0	0	0	0	0	0
Finland	54	54	0	0	0	0	0	0
Iceland	9	7	0	0	0	0	1	1
Norway	164	164	0	0	0	0	0	0
Sweden	9	7	2	0	0	0	0	0

6.3 Duration of outages in different power system units

Outage duration is registered from the start of the outage to the time when the system is ready to be taken into operation. If the connection is postponed intentionally, the intentional waiting time is not included in the duration of the outage.

Table 6.6 Number of lines with different outage durations in 2008

Line [1)]		Number of system units grouped by total outage duration time								
Country	**Number**	**No outages**	**<3 minutes**	**3–10 minutes**	**10–30 minutes**	**30–60 minutes**	**60–120 minutes**	**120–240 minutes**	**240–480 minutes**	**>480 minutes**
Denmark	309	289	7	0	4	1	3	1	1	3
Finland	321	168	127	7	9	3	3	1	0	3
Iceland	57	37	0	3	7	2	1	0	3	4
Norway	641	544	18	20	9	4	6	12	19	9
Sweden	392	274	66	15	12	7	7	2	2	7

[1)] Note that the concept of *line* in power system units can consist of both overhead lines and cables.

Table 6.7 Number of transformers with different outage durations in 2008

Transformer		Number of system units grouped by total outage duration time								
Country	**Number**	**No outages**	**<3 minutes**	**3–10 minutes**	**10–30 minutes**	**30–60 minutes**	**60–120 minutes**	**120–240 minutes**	**240–480 minutes**	**>480 minutes**
Denmark	257	249	3	0	1	3	0	0	0	1
Finland	889	888	0	0	0	0	0	0	0	1
Iceland	92	87	0	1	0	0	3	1	0	0
Norway	800	797	1	0	1	0	0	0	0	1
Sweden	279	263	5	1	3	1	0	1	0	5

Table 6.8 Number of busbars with different outage durations in 2008

Busbar		Number of system units grouped by total outage duration time								
Country	**Number**	**No outages**	**<3 minutes**	**3–10 minutes**	**10–30 minutes**	**30–60 minutes**	**60–120 minutes**	**120–240 minutes**	**240–480 minutes**	**>480 minutes**
Denmark	138	130	3	1	1	2	0	0	0	1
Finland	864	862	0	0	0	1	1	0	0	0
Iceland	53	47	0	0	1	4	0	0	0	1
Norway	435	434	1	0	0	0	0	0	0	0
Sweden	474	469	0	0	0	1	2	1	1	0

Table 6.9 Number of reactors with different outage durations in 2008

Reactor		Number of system units grouped by total outage duration time								
Country	**Number**	**No outages**	**<3 minutes**	**3–10 minutes**	**10–30 minutes**	**30–60 minutes**	**60–120 minutes**	**120–240 minutes**	**240–480 minutes**	**>480 minutes**
Denmark	17	17	0	0	0	0	0	0	0	0
Finland	62	62	0	0	0	0	0	0	0	0
Norway	36	35	0	0	0	0	0	0	0	1
Sweden	47	37	2	0	0	0	2	0	1	5

Table 6.10 Number of shunt capacitors with different outage durations in 2008

Shunt capacitor		Number of system units grouped by total outage duration time								
Country	**Number**	**No outages**	**<3 minutes**	**3–10 minutes**	**10–30 minutes**	**30–60 minutes**	**60–120 minutes**	**120–240 minutes**	**240–480 minutes**	**>480 minutes**
Denmark	15	15	0	0	0	0	0	0	0	0
Finland	54	54	0	0	0	0	0	0	0	0
Iceland	9	7	0	0	0	0	0	0	1	1
Norway	164	164	0	0	0	0	0	0	0	0
Sweden	9	7	0	0	0	0	0	0	0	2

6.4 Cumulative duration of outages in some power system units

Figure 6.4 presents the cumulative duration of outages in the following power system units: lines, busbars and transformers.

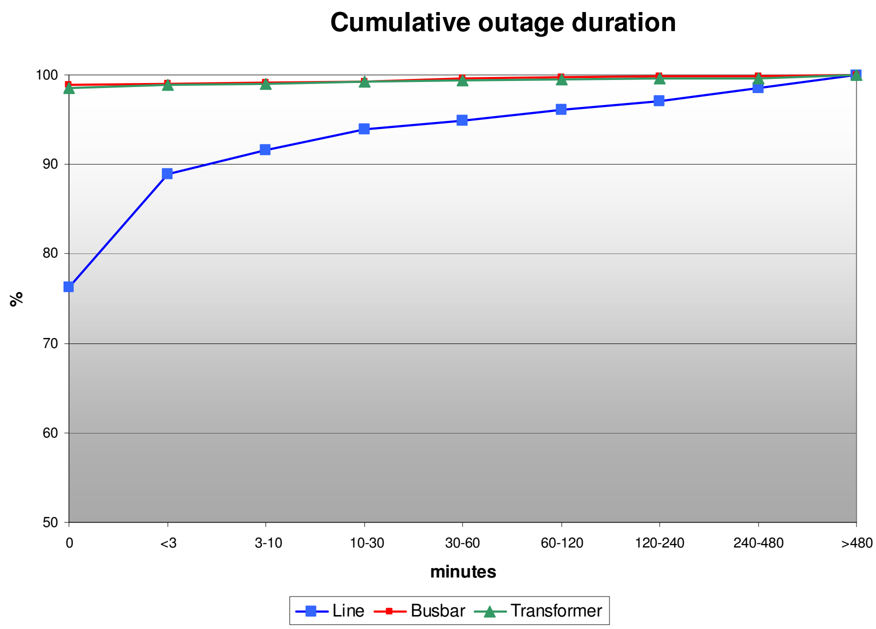

Figure 6.4 Cumulative duration of outages in selected power systems units.

Figure 6.4 shows that about 76% of lines, 99% of transformers and 99% of busbars had no outages in 2008. The situation was somewhat similar in 2007, 2006 and 2005, but earlier years had somewhat lower values of availability.

7 References

[1]: Nordel's Guidelines for the Classification of Grid Disturbances 2009 http://www.nordel.org/

[2]: The Energy Concern's National League, The Norwegian Water Supply and Energy Department, Statnett and Sintef Energy Research. Definisjoner knyttet til feil og avbrudd i det elektriske kraftsystemet – Versjon 2 (In English: Definitions in relation to faults and outages in the electrical power system – Version 2), 2001
http://www.energy.sintef.no/Prosjekt/KILE/

[3]: IEC 50(191-05-01): International Electrotechnical Vocabulary, Dependability and quality of service

[4]: IEEE Standard Terms for Reporting and Analyzing Outage Occurrence and Outage States of Electrical Transmission Facilities (IEEE Std 859-1987)

Appendix 1: The calculation of energy not supplied

The calculation of energy not supplied (ENS) is performed in various ways in different countries.

In Denmark, the ENS of the transmission grid is calculated by using the cut-off power detected at the moment when the outage starts and the outage duration. It is impossible to determine if some end users get their electricity supply restored before this occurs in the transmission grid. The cut-off power includes consumption as well as production of electricity. The amount of ENS (to end users) may in fact be higher caused by the fact that electricity production in the distribution network (e.g., from wind turbines or CHP) is ignored.

In Finland, the ENS in the transmission grid is counted for those faults that caused outage at the point of supply. The point of supply means the high voltage side of the transformer. ENS is calculated individually for all points of supply and is linked to the fault that caused the outage. ENS is counted by multiplying the outage duration and the power before the fault. Outage duration is the time that the point of supply is dead or the time until the delivery of power to the customer can be arranged via another grid connection.

In Iceland, ENS is computed according to the delivery from the transmission grid. ENS is calculated at the points of supply in the 220 kV or 132 kV systems. ENS is linked to the fault that caused the outage. In the data of the Nordel statistics, ENS that was caused by the production or distribution systems has been left out. In the distribution systems, the outages in the transmission and distribution systems that affect the end user and the ENS are also registered. Common rules for registration of faults and ENS in all grids are used in Iceland.

In Norway, ENS is referred to the end user. ENS is calculated at the point of supply that is located on the low voltage side of the distribution transformer (1 kV) or in some other location where the end user is directly connected. All ENS is linked to the fault that caused the outage. ENS is calculated according to a standardized method that has been established by the authority.

In Sweden, the ENS of the transmission grid is calculated by using the outage duration and the cut-off power that was detected at the instant when the outage occurred. Because the cut-off effect is often not registered, some companies use the rated power of the point of supply multiplied by the outage duration.

Appendix 2: Contact persons in Nordel countries

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Appendix 3: Contact persons for the distribution network statistics

Nordel provides no statistics for distribution networks (voltage <100 kV). However, there are more or less developed national statistics for these voltage levels.

More detailed information about these statistics can be obtained from the representatives of the Nordel countries which are listed below:

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