entsoe

Regional Group Nordic

GRID DISTURBANCE AND FAULT STATISTICS

2009

Table of contents

1 Introduction

This report is an overview of the Danish, Finnish, Icelandic, Norwegian and Swedish transmission grid disturbance statistics for the year 2009. Although Iceland does not belong to the ENTSO-E Regional Group Nordic, it is included in this report. Also the disturbance data of the whole Denmark is included in this report although only the grid of eastern Denmark belongs to the synchronous Nordic grid. The report is made according to ENTSO-E Nordic 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.

ENTSO-E Nordic Guidelines for the Classification of Grid Disturbances [1] were prepared by Nordel[1] during the years 1999–2000 and have been used since 2000. Therefore, most charts include data for the ten-year period 2000–2009. In those cases where older data has been available, even longer periods have been used.

The statistics can be found at ENTSO-E website www.entsoe.eu. The guidelines and 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.

Although this summary originates from the Nordic co-operation that has aimed to use the combined experience from the five countries regarding the design and operation of their respective power systems, other ENTSO-E countries are encouraged to participate in the statistics as well. 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 being 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.

[1] Nordel was the predecessor of ENTSO-E Regional Group Nordic until 2009.

The total number of HVDC disturbances is too low to make relevant statistics for the Nordic countries. For the time being, the report does not include HVDC fault statistics either. However, there is parallel reporting to CIGRE that makes a worldwide HVDC statistics every second year. 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 most important issues of the year 2009.

In Chapter 3 disturbances are discussed. The focus is on the analysis and allocation of the causes of disturbances. The division of disturbances during the year 2009 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 ENTSO-E Nordic disturbance statistics. The relevant contact information is given in Appendix 2.

1.2 Guidelines of the statistics

The scope and definitions of ENTSO-E Nordic disturbance statistics are presented in more detail in ENTSO-E Nordic Guidelines for the Classification of Grid Disturbances [1].

1.3 Voltage levels in the ENTSO-E Nordic network

The Nordic main grid is in Figure 1 [5]. 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 ENTSO-E Nordic network

Nominal voltage level kV	Statis-tical voltage U (kV)	Denmark		Finland		Iceland		Norway		Sweden	
		U_N kV	P %	U_N kV	P %	U_N kV	P %	U_N kV	P %	U_N kV	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	64	110	100	132	100	132	98	130	100
110–150	**132**	132	36	-	-	-	-	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%	99%	100%	100%	99%

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 99% of Finnish 110 kV lines and approximately 90% 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 2009, the energy not supplied (ENS) due to faults in the Nordic main grid was quite high. ENS was 6.24 GWh, which is more than during any other year since 2003. The ten-year annual average of energy not supplied during the 2000–2009 period in the ENTSO-E Nordic area was 7.72 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 2009. The corresponding annual averages are from the periods 2000–2009 and 2002–2009, respectively. In addition, the most important issues in 2009 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 2009 was 12.7 MWh (10-year average 959 MWh). The number of grid disturbances was 52 (10-year average 77). In 2009, four of those 52 disturbances caused ENS. Approximately 100 000 customers were interrupted during these four grid disturbances. On average four disturbances per year caused ENS during 2002–2009.

On the 4th of March, a 150 kV power transformer tripped due to icing on a pressure switch. This fault resulted in 0.7 MWh ENS.

On the 28th of May, a 150 kV power transformer tripped due to high pressure. Further investigation showed a blocked drain on a tap changer. This fault resulted in 11.5 MWh ENS (power flow from 60 kV to 150 kV grid due to a large amount of wind power).

2.2 Summary for Finland

For Finland, the energy not supplied in 2009 was 509 MWh (10-year average 200 MWh). The number of grid disturbances was 386 (10-year average 282) and 77 of them caused ENS. On average 55 disturbances per year caused ENS in 2002–2009. In 2009, 30% of ENS occurred due to operation and maintenance and 30% of ENS occurred due to external influences. Most of the disturbances were caused by lightning and occurred during the summer months.

The percentage of unknown disturbances went down to 48% in 2009 from 58% in 2008. Almost all of the unknown disturbances occurred in 110 kV lines.

72% of ENS was caused by only five disturbances. The highest amount of ENS (115 MWh) in a single disturbance was caused by a passenger hoist collision to power lines, which also resulted in one person being injured.

2.3 Summary for Iceland

For Iceland, the energy not supplied in 2009 was 562 MWh (10-year average 756 MWh). The total number of disturbances was 17 (10-year average 40), of which 9 led to ENS. On average there have been 25 disturbances per year that caused ENS in 2002–2009.

In Iceland, over 75% of ENS occurred in January. Two of the disturbances in January were relatively significant. On the 23rd of January, a suspension lock on the 132 kV radial line MJ1 broke, causing a conductor to fall to the earth. That same day the transmission line GE1 (serial in front of MJ1) tripped owing to icing during the outage of the MJ1 line. Energy not supplied as a result of these disturbances totalled 416 MWh.

In October, a widespread disturbance occurred in the eastern Iceland. The disturbance was caused by icing and lasted for a relatively long period, but resulted in rather low ENS.

2.4 Summary for Norway

For Norway, the energy not supplied for 2009 was 1156 MWh (10-year average 2358 MWh). The number of grid disturbances was 237 (10-year average 331), which is less than during any other year since 1999. Of these 237 disturbances 80 led to ENS. On average, there have been 100 disturbances per year that caused ENS in 2002–2009.

In 2009, the two biggest contributors to ENS were faults on technical equipment and faults with unknown cause. They caused together 2/3 of the total ENS.

2.5 Summary for Sweden

In Sweden, the energy not supplied in 2009 was 4001 MWh (10-year average 3451 MWh). The total number of disturbances was 555 (10-year average 585) and 146 of those caused ENS. On average there have been 133 disturbances per year that have caused ENS in 2002–2009.

The amount of ENS consists of many disturbances; no single significant incidents occurred.

3 Disturbances

This chapter includes an overview of disturbances in the ENTSO-E Nordic 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 the number of disturbances over the ten-year period 2000–2009. 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 2000–2009

The number of disturbances during the year 2009 in the Nordic main grid was 1247, which is slightly lower than the 10-year average of 1315. 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 ENTSO-E Nordic countries.

Table 3.1 presents the sum of disturbances during the year 2009 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 2000–2009.

Table 3.1 Number of grid disturbances in 2009

Year 2009	**Denmark**	**Finland**	**Iceland**	**Norway**	**Sweden**
Number of disturbances	52	386	17	237	555

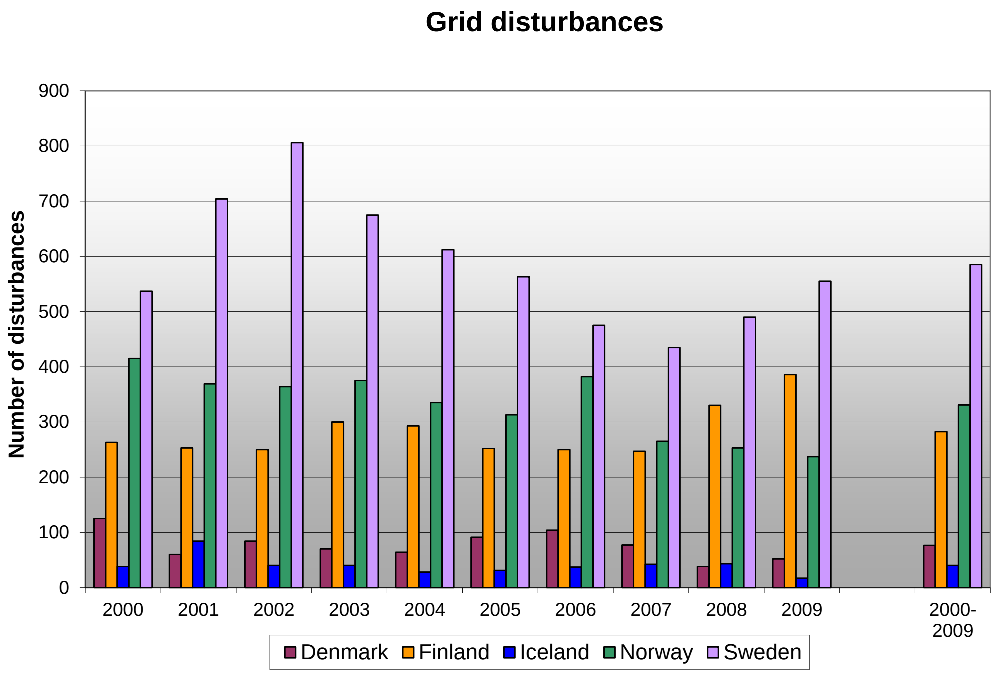

Figure 3.1 Number of grid disturbances in each Nordic country during the period 2000–2009.

3.2 Disturbances divided according to month

Figure 3.2 presents the percentage distribution of grid disturbances according to month in different countries in the year 2009. Figure 3.3 shows the ten-year average distribution of disturbances during the period 2000–2009.

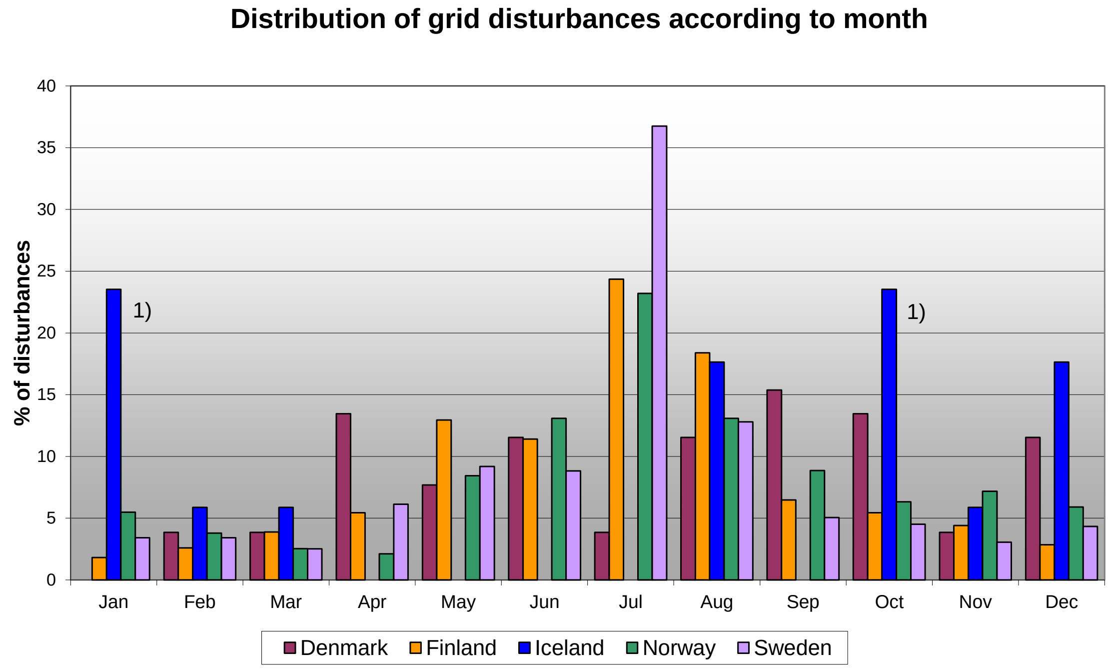

Figure 3.2 Percentage distribution of grid disturbances according to month in each country in 2009.

[1)] For Iceland, the high percentage of disturbances in January and October was caused by bad weather.

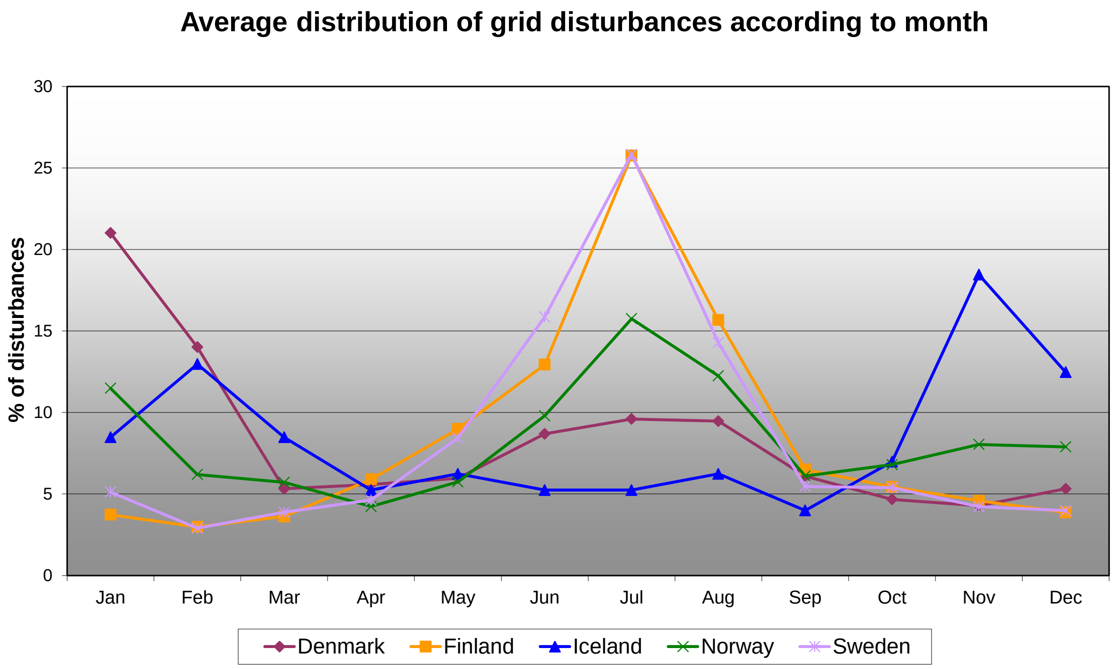

Figure 3.3 Average percentage distribution of grid disturbances according to month for the period 2000–2009.

Table 3.2 and Table 3.3 present the numerical values behind Figure 3.2 and Figure 3.3. 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 2009

Country	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Denmark	0	4	4	13	8	12	4	12	15	13	4	12
Finland	2	3	4	5	13	11	24	18	6	5	4	3
Iceland	24	6	6	0	0	0	0	18	0	24	6	18
Norway	5	4	3	2	8	13	23	13	9	6	7	6
Sweden	3	3	3	6	9	9	37	13	5	5	3	4
Nordic	3	3	3	5	10	10	28	15	7	6	4	5

Table 3.3 Percentage division of grid disturbances during the years 2000–2009

Country	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Denmark	21	14	5	6	6	9	10	9	6	5	4	5
Finland	4	3	4	6	9	13	26	16	7	5	5	4
Iceland	8	13	8	5	6	5	5	6	4	7	18	12
Norway	11	6	6	4	6	10	16	12	6	7	8	8
Sweden	5	3	4	5	8	16	26	14	5	5	4	4
Nordic	7	5	5	5	8	13	22	14	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]. ENTSO-E Nordic'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 ENTSO-E Nordic's statistics has its own more detailed way of gathering data according to fault cause. ENTSO-E Nordic's guidelines [1] describe how each fault cause relates to ENTSO-E Nordic'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)]	
		2009	2000–2009	2009	2000–2009
Lightning	Denmark	17	17	0	0
	Finland	27	33	8	9
	Iceland	6	2	11	1
	Norway	34	24	11	6
	Sweden	38	42	6	11
Other environmental causes	Denmark	13	31	6	0
	Finland	1	3	0	9
	Iceland	65	41	89	54
	Norway	13	18	10	26
	Sweden	3	4	2	5
External influences	Denmark	23	14	0	0
	Finland	4	3	30	14
	Iceland	6	1	0	0
	Norway	2	2	0	1
	Sweden	3	3	1	2
Operation and maintenance	Denmark	12	13	94	4
	Finland	10	6	14	23
	Iceland	0	10	0	20
	Norway	5	14	11	17
	Sweden	8	7	2	11
Technical equipment	Denmark	15	11	0	11
	Finland	5	4	31	26
	Iceland	18	23	0	17
	Norway	15	22	31	34
	Sweden	14	16	7	43
Other	Denmark	4	5	0	84
	Finland	6	7	10	13
	Iceland	6	17	0	6
	Norway	14	15	9	12
	Sweden	6	9	48	20
Unknown	Denmark	15	9	0	0
	Finland[2)]	48	42	6	7
	Iceland	0	5	0	2
	Norway	16	6	27	2
	Sweden	27	19	33	8

[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 3.4, disturbances for all voltage levels are identified in terms of the initial fault.

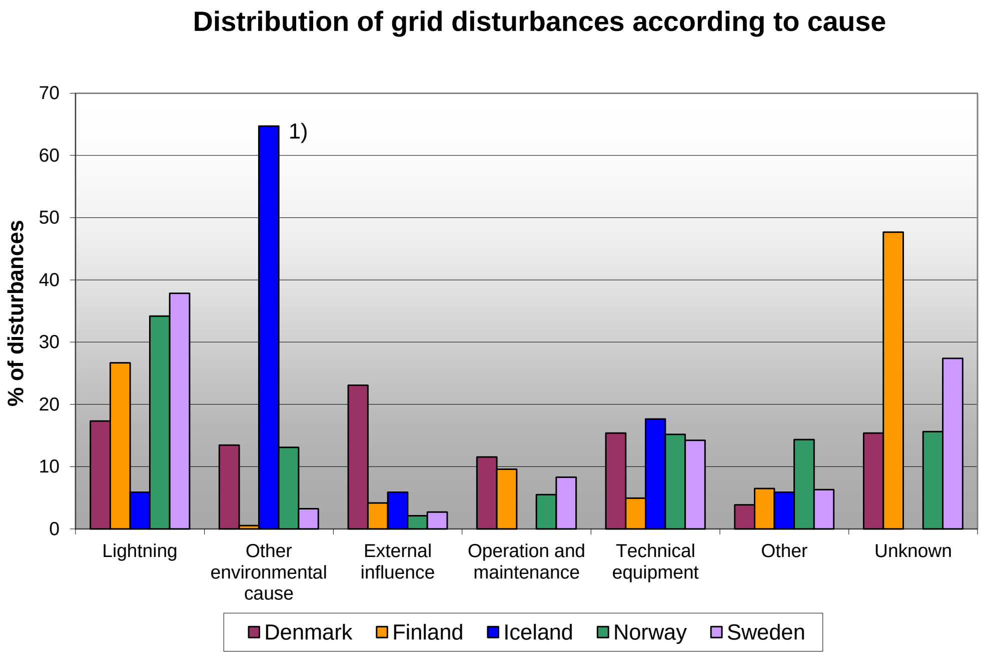

Figure 3.4 Percentage distribution of grid disturbances according to cause in 2009.

1) For Iceland, the high percentage of disturbances in the category *other environmental cause* results mainly from bad weather in January and October.

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 ENTSO-E Nordic 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 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 2009**	**ENS divided into different voltage levels during the period 2000–2009 (%)**			
		132 kV	**220 kV**	**400 kV**	**Other[2)]**
Denmark	12,7[3)]	5,2	0,0	94,8	0,0
Finland	508,9	94,3	4,1	0,3	1,3
Iceland	562,5	42,6	57,4	0,0	0,0
Norway	1156,0	41,4	32,7	6,8	19,2
Sweden	4001,1	51,6	8,0	30,4	9,9
Nordic	6241,2	43,0	19,3	27,4	10,3

[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.

[3)] The further explanation for the low ENS in Denmark compared with other countries can be found in Appendix 1, where the different calculation methods of ENS are discussed.

In Figure 4.1 and Figure 4.2, energy not supplied is summarised according to the different voltage levels for the year 2009 and for the period 2000–2009, respectively. Voltage level refers to the initiating fault of the respective disturbance.

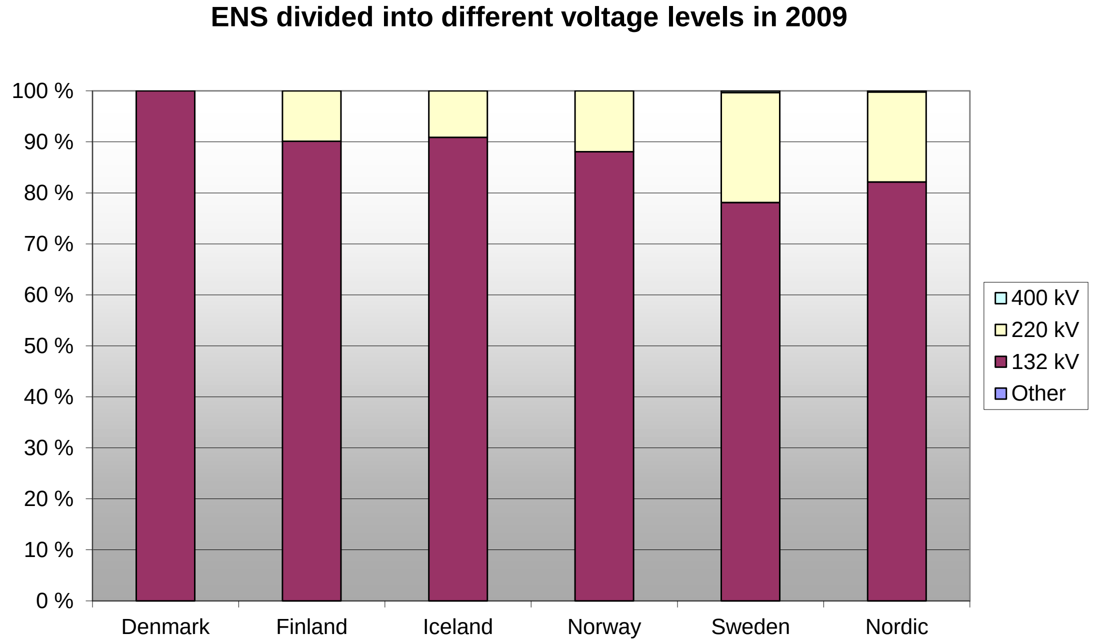

Figure 4.1 Energy not supplied (ENS) in terms of the voltage level of the initiating fault in 2009.

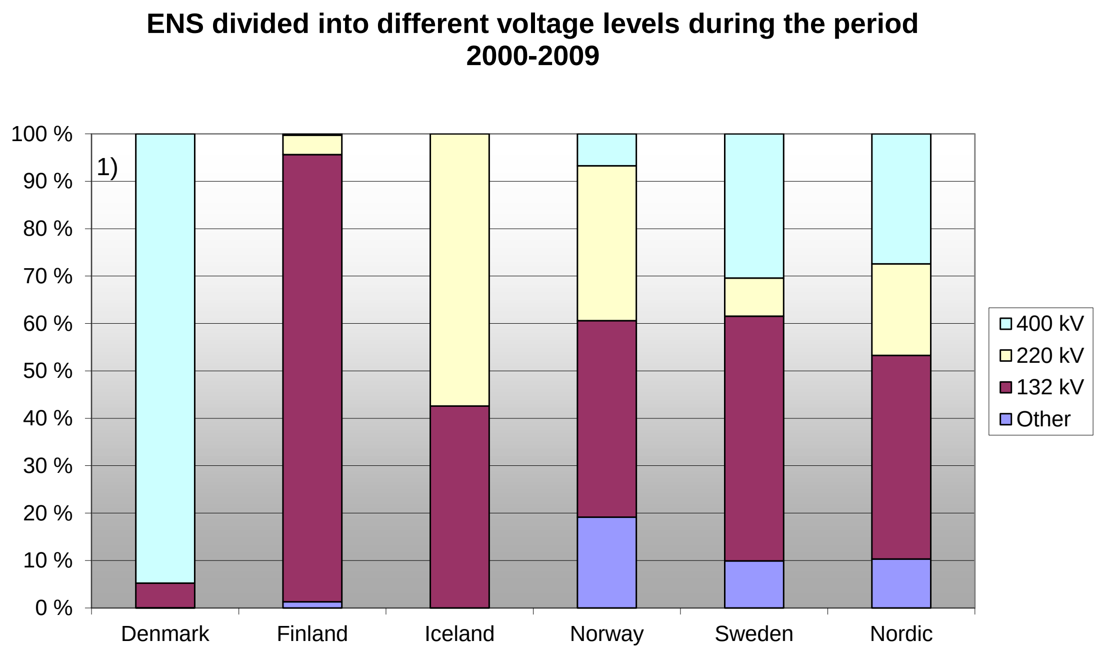

Figure 4.2 Energy not supplied (ENS) in terms of the voltage level of the initiating fault during the period 2000–2009.

[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 its division according to installation.

Table 4.2 Energy not supplied (ENS) according to installation

Country	Total con-sumption	ENS	ENS / consumption		ENS divided according to installation during the period 2000–2009 (%)			
	GWh 2009	MWh 2009	Ppm 2009	Ppm 2000–2009	Overhead line	Cable	Sta-tions	Other
Denmark	32166	12,7	0,4	27,8	11,7	0,0	4,6	83,6
Finland	80800	508,9	6,3	2,6	44,1	0,0	43,5	12,4
Iceland	16835	562,5	33,4	71,9	40,0	1,1	44,1	14,8
Norway	166203	1156,0	7,0	18,7	34,7	0,5	41,8	23,0
Sweden	138400	4001,1	28,9	23,6	15,8	9,1	65,7	9,4
Nordic	434404	6241,2	14,4	19,6	24,2	4,3	48,1	23,4

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 2000–2009. 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.

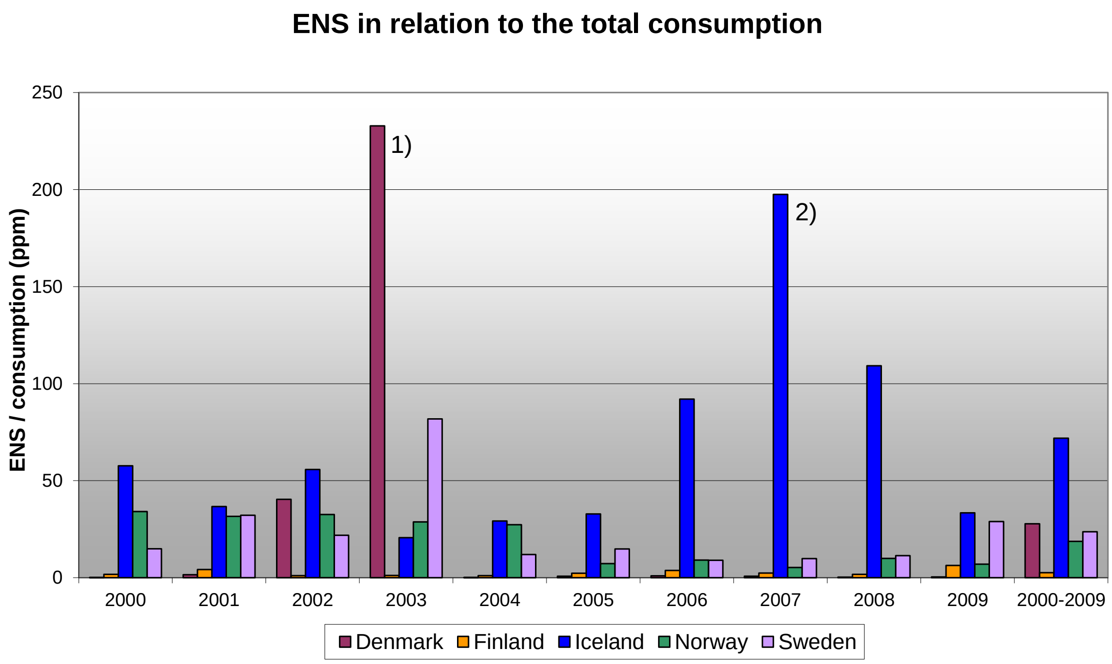

Figure 4.3 Energy not supplied (ENS) / consumption (ppm).

[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 in Iceland during 2007.

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.

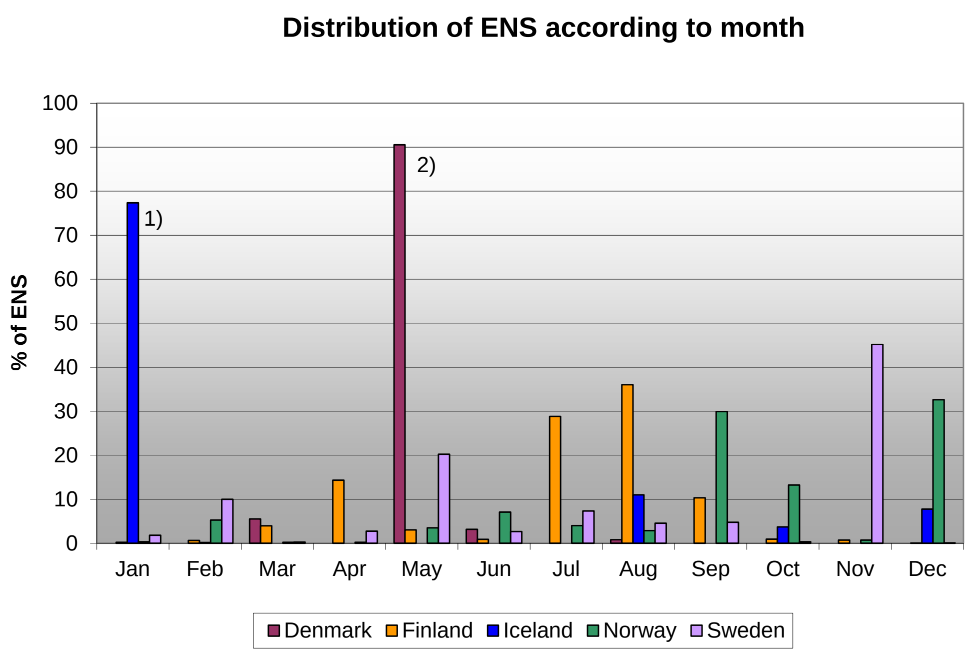

Figure 4.4 Percentage distribution of energy not supplied (ENS) according to month in 2009.

[1] In Iceland, the high value of ENS in January was mainly caused by two relatively significant disturbances on the 23rd of January.
[2] In Denmark, only four disturbances led to ENS in 2009.

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.

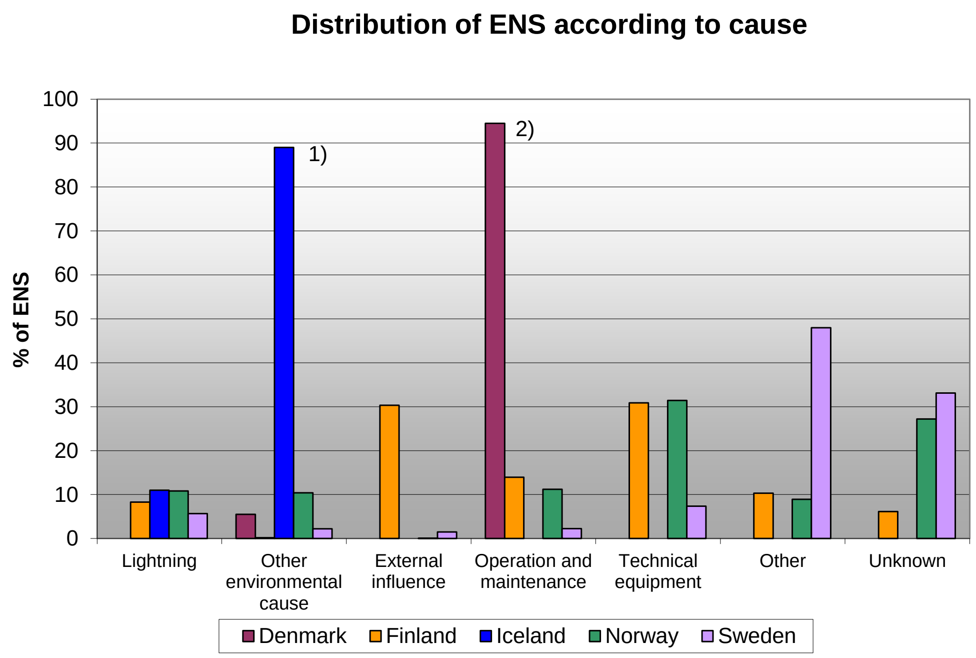

Figure 4.5 Percentage distribution of energy not supplied (ENS) according to the cause of the primary fault in 2009.

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

2) The major ENS contribution in Denmark was caused by a blocked drain.

4.5 Energy not supplied (ENS) divided according to component

Table 4.3 shows the amount of energy not supplied in 2009 and the annual average for the period 2001–2009. Table 4.4 shows the distribution of energy not supplied according to component.

Table 4.3 Energy not supplied (ENS) in 2009 and the annual average for the period 2001–2009

	Denmark		**Finland**		**Iceland**		**Norway**		**Sweden**		**Nordic**	
Time period	2009	2001–2009	2009	2001–2009	2009	2001–2009	2009	2001–2009	2009	2001–2009	2009	2001–2009
ENS (MWh)	13	1066	509	208	562	791	1156	2151	4001	3588	6241	7804

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

Fault location	Denmark		Finland		Iceland		Norway		Sweden		Nordic	
	2009	2001–2009	2009	2001–2009	2009	2001–2009	2009	2001–2009	2009	2001–2009	2009	2001–2009
Overhead line	0,0	0,4	73,1	47,2	90,9	40,7	42,2	31,6	2,8	14,4	23,8	20,8
Cable	0,0	0,0	0,0	0,0	0,0	1,2	0,0	0,5	0,5	9,7	0,3	4,7
Sum of line faults	**0,0**	**0,4**	**73,1**	**47,2**	**90,9**	**41,9**	**42,2**	**32,1**	**3,4**	**24,1**	**24,1**	**25,5**
Power transformer	96,9	0,7	1,2	2,0	0,0	0,2	0,4	0,7	4,8	10,4	3,4	5,1
Instrument transformer	0,0	0,0	0,0	4,9	0,0	0,0	1,6	3,9	1,0	2,5	0,9	2,4
Circuit breaker	0,0	3,5	0,0	3,6	0,0	3,9	6,8	1,7	0,0	1,6	1,3	2,2
Disconnector	0,0	0,2	11,9	3,9	0,0	13,6	0,2	4,7	0,1	35,7	1,0	19,2
Surge arrester and spark gap	0,0	0,0	0,0	3,1	0,0	0,0	3,9	2,6	0,5	0,2	1,0	0,9
Busbar	0,0	0,2	0,0	3,6	0,0	8,6	1,9	1,7	0,2	1,5	0,5	2,1
Control equipment	3,1	11,4	13,7	22,7	9,1	12,1	38,6	28,7	2,1	4,0	10,4	13,1
Common ancillary equipment	0,0	0,0	0,0	1,0	0,0	0,0	0,0	0,1	0,0	0,0	0,0	0,1
Other substation faults	0,0	0,0	0,1	1,0	0,0	0,0	4,3	2,1	87,5	13,8	56,9	6,9
Sum of substation faults	**100,0**	**16,0**	**26,9**	**45,7**	**9,1**	**38,4**	**57,8**	**46,2**	**96,1**	**69,7**	**75,6**	**52,1**
Shunt capacitor	0,0	0,0	0,0	0,0	0,0	3,9	0,0	0,0	0,0	1,0	0,0	0,9
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**	**0,0**	**3,9**	**0,0**	**0,0**	**0,0**	**1,0**	**0,0**	**0,9**
System fault	0,0	83,6	0,0	0,0	0,0	15,8	0,0	7,1	0,5	0,7	0,3	15,3
Faults in adjoining statistical area	0,0	0,0	0,0	7,1	0,0	0,0	0,0	14,6	0,0	4,5	0,0	6,3
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**	**83,7**	**0,0**	**7,1**	**0,0**	**15,8**	**0,0**	**21,7**	**0,5**	**5,2**	**0,3**	**21,6**

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 ENTSO-E Nordic statistics is given. More detailed statistics relating to each specific component group are then presented. Ten-year average values have been calculated for most components. For overhead lines, even a longer period has been used due to their long lifetime. In the calculation of 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 the 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 2009. 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 2009

	Denmark	**Finland**	**Iceland**	**Norway**	**Sweden**
Number of faults in 2009	53	408	24	275	557
Number of disturbances in 2009	52	386	17	237	555
Fault/disturbance ratio in 2009	1,02	1,06	1,41	1,16	1,00
The average fault/disturbance ratio during 2000–2009	1,16	1,13	1,26	1,31	1,12

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]**	2009	2000–2009 (annual average)	2009	2000–2009 (annual average)
400 kV	Denmark	23	1537	8	10,2	0,0	329,1
	Finland	43	4570	27	21,9	0,0	0,5
	Iceland	0	0	-	-	-	-
	Norway	64	2708	44	57,1	0,0	148,1
	Sweden	63	10728	79	119,6	13,1	1050,8
220 kV	Denmark	2	105	0	0,6	0,0	0,0
	Finland	24	2402	22	23,9	50,3	8,2
	Iceland	32	868	7	16,1	51,2	438,3
	Norway	271	6165	87	109,4	137,8	783,4
	Sweden	101	4261	71	66,1	862,2	277,5
132 kV	Denmark	238	4401	43	74,8	12,7	50,0
	Finland	920	16877	349	240,6	458,6	189,4
	Iceland	59	1343	17	32,7	511,3	324,9
	Norway	724	10677	144	186,2	1018,2	1064,3
	Sweden	737	15064	389	387,0	3125,8	1780,5

[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 ENTSO-E Nordic 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 ENTSO-E Nordic statistics' voltage range (typically from networks with voltages lower than 100 kV) but that nevertheless have an influence on the ENTSO-E Nordic statistic area are included in the statistics.

Table 5.3 Percentage division of faults according to component

Fault location	Denmark		Finland		Iceland		Norway		Sweden		Nordic	
	2009	2000–2009	2009	2000–2009	2009	2000–2009	2009	2000–2009	2009	2000–2009	2009	2000–2009
Overhead line	60,4	60,9	74,3	73,9	54,2	39,6	43,3	39,1	38,4	55,0	51,7	54,1
Cable	9,4	2,7	0,0	0,0	0,0	0,6	1,1	0,8	0,7	0,5	0,9	0,6
Sum of line faults	**69,8**	**63,6**	**74,3**	**73,9**	**54,2**	**40,2**	**44,4**	**39,9**	**39,1**	**55,5**	**52,6**	**54,7**
Power transformer	7,5	3,8	2,2	0,9	4,2	3,1	3,6	1,8	7,5	5,7	5,0	3,4
Instrument transformer	1,9	0,7	0,2	0,4	0,0	0,4	1,5	1,8	1,1	0,9	0,9	1,0
Circuit breaker	7,5	5,7	0,5	1,3	0,0	6,3	2,5	3,3	1,3	3,6	1,5	3,2
Disconnector	0,0	1,5	0,7	0,6	0,0	0,2	2,5	1,5	0,9	0,7	1,1	0,9
Surge arresters and spark gap	1,9	0,6	0,2	0,2	0,0	0,4	0,7	1,1	0,9	0,3	0,7	0,5
Busbar	0,0	0,5	0,0	0,4	0,0	0,8	2,2	1,2	0,5	1,0	0,7	0,9
Control equipment[1)]	5,7	13,1	14,7	12,1	20,8	26,2	18,2	30,2	3,4	11,3	10,4	17,4
Common ancillary equipment	0,0	0,3	0,0	0,2	0,0	0,0	1,1	1,0	0,4	0,8	0,4	0,7
Other substation faults	0,0	2,3	2,5	1,2	4,2	7,8	20,0	5,5	36,4	5,5	20,4	4,5
Sum of substation faults	**24,5**	**28,4**	**21,1**	**17,4**	**29,2**	**45,1**	**52,4**	**47,5**	**52,4**	**29,7**	**41,2**	**32,7**
Shunt capacitor	0,0	0,1	0,0	0,8	8,3	1,9	0,0	1,2	0,2	0,7	0,2	0,9
Series capacitor	0,0	0,0	2,0	0,6	0,0	0,2	0,0	0,0	0,5	1,1	0,8	0,6
Reactor	1,9	1,7	0,0	0,4	0,0	0,0	0,0	0,5	1,6	1,0	0,8	0,7
SVC and statcom	0,0	0,1	0,0	0,0	0,0	0,0	3,3	1,2	1,8	1,1	1,4	0,8
Synchronous compensator	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,8	0,5	0,4	0,2	0,4
Sum of compensation faults	**1,9**	**1,9**	**2,0**	**1,8**	**8,3**	**2,1**	**3,3**	**3,6**	**4,7**	**4,3**	**3,5**	**3,4**
System fault	0,0	2,5	0,2	0,1	8,3	12,0	0,0	1,7	1,6	3,4	0,9	2,5
Faults in adjoining statistical area	3,8	3,5	2,5	3,9	0,0	0,0	0,0	7,4	2,2	4,3	1,8	4,9
Unknown	0,0	0,1	0,0	3,0	0,0	0,6	0,0	0,0	0,0	2,8	0,0	1,8
Sum of other faults	**3,8**	**6,1**	**2,7**	**7,0**	**8,3**	**12,6**	**0,0**	**9,1**	**3,8**	**10,5**	**2,7**	**9,2**

[1)] The category *control equipment* includes also protection.

5.2 Faults in overhead lines

Overhead lines constitute a very large part of the Nordic transmission grid. Therefore, the tables in this section show the division of faults in 2009 as well as the average values for the period 1996–2009. Faults divided by cause during the period 1996–2009 are also given. Along with the tables, the annual division of faults during the period 2000–2009 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 2009	Number of faults 2009	Number of faults per 100 km		Faults divided by cause during the period 1996–2009 (%)								
			2009	1996–2009	Lightning	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown	1-phase faults	Permanent faults
Denmark	1228	4	0,33	0,35	19,0	58,6	8,6	5,2	5,2	1,7	1,7	50,0	5,2
Finland	4570	6	0,13	0,25	78,5	5,6	1,4	3,5	2,8	2,8	5,6	58,3	8,3
Norway	2683	16	0,60	1,08	24,8	67,3	0,3	0,3	1,9	2,2	3,3	65,1	7,9
Sweden	10720	28	0,26	0,35	54,1	19,4	1,7	2,5	2,5	1,1	18,8	81,8	8,3
Nordic	19201	54	0,28	0,43	45,6	35,7	1,6	2,0	2,5	1,7	10,9	71,4	8,0

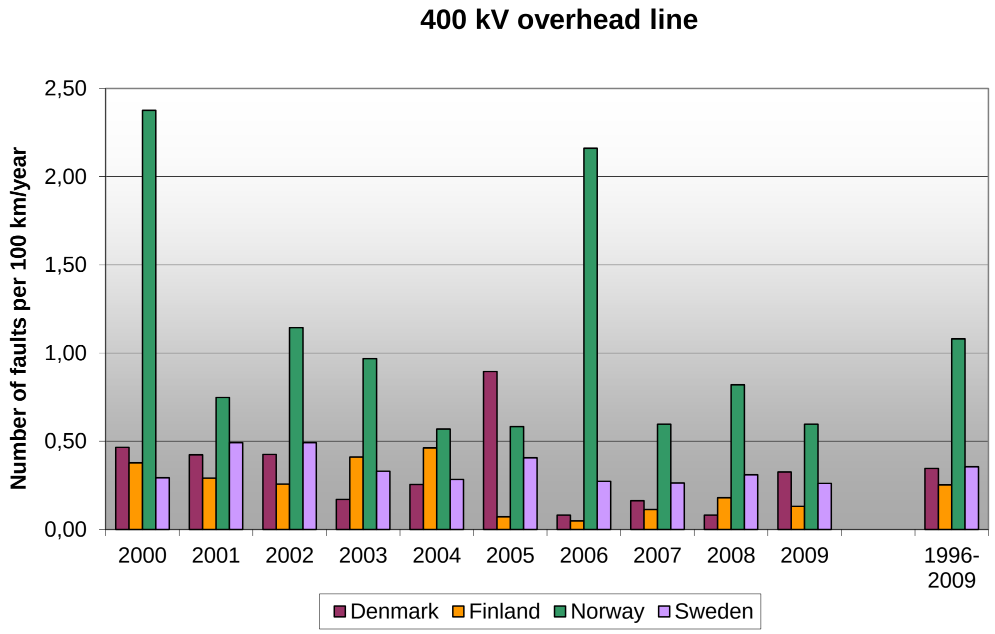

Figure 5.1 Annual division of faults during the period 2000–2009.

5.2.2 220 kV overhead lines

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

Country	Line km 2009	Number of faults 2009	Number of faults per 100 km 2009	Number of faults per 100 km 1996–2009	Faults divided by cause during the period 1996–2009 (%) 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	57,1	14,3	14,3	0,0	0,0	0,0	14,3	85,7	0,0
Finland	2402	11	0,46	0,78	47,2	3,0	2,2	0,4	0,4	0,7	46,1	71,2	2,6
Iceland	867	0	0,00	0,40	29,7	51,4	0,0	0,0	18,9	0,0	0,0	56,8	24,3
Norway	5715	35	0,61	0,71	55,6	32,1	1,1	0,4	2,3	2,8	5,8	58,4	12,5
Sweden	4042	36	0,89	0,88	71,5	4,3	3,7	3,9	2,8	0,4	13,5	56,2	7,9
Nordic	13131	82	0,62	0,76	59,4	16,5	2,3	1,7	2,5	1,4	16,2	60,1	9,1

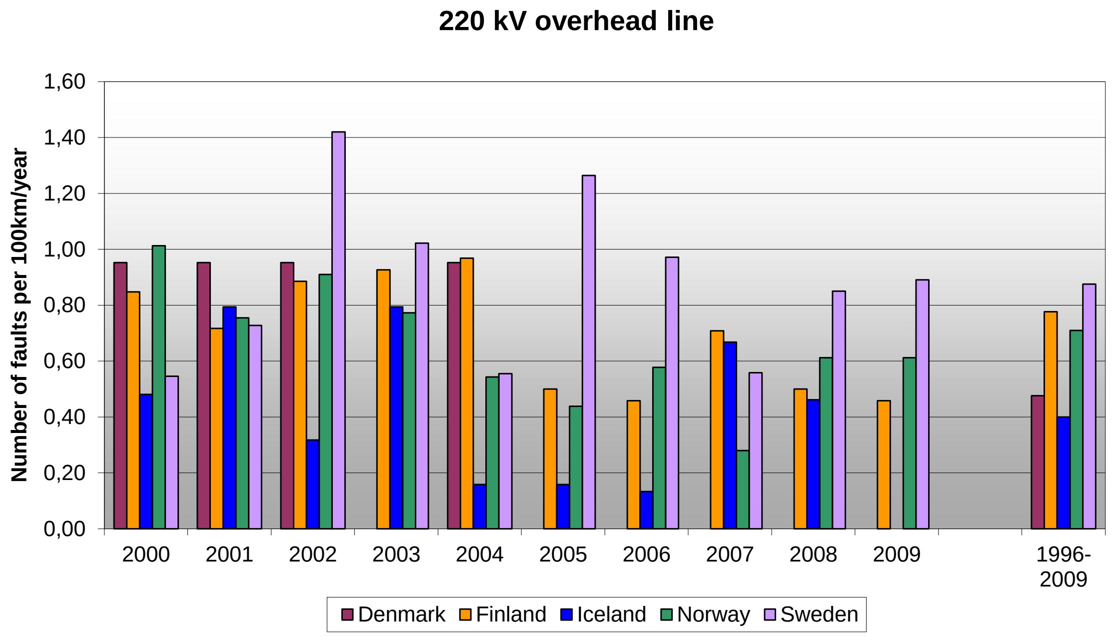

Figure 5.2 Annual division of faults during the period 2000–2009.

5.2.3 132 kV overhead lines

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

Country	Line km 2009	Number of faults 2009	Number of faults per 100 km 2009	Number of faults per 100 km 1996–2009	Faults divided by cause during the period 1996–2009 (%) Lightning	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown	1-phase faults	Permanent faults
Denmark	3669	28	0,76	1,09	23,7	45,9	17,1	2,2	1,3	2,7	7,1	47,3	5,1
Finland	16688	286	1,71	1,92	41,8	6,2	1,7	1,2	0,4	0,8	48,0	76,2	2,8
Iceland	1272	13	1,02	1,36	3,0	86,3	3,4	0,9	6,0	0,0	0,4	42,9	12,4
Norway	10475	68	0,65	1,07	55,9	29,2	2,9	1,0	6,3	3,5	1,4	21,6	16,7
Sweden	14858	150	1,01	2,24	63,7	5,1	2,6	1,9	2,4	1,8	22,5	40,7	5,3
Nordic	46962	545	1,16	1,70	51,3	14,1	3,3	1,5	2,4	1,7	25,7	49,5	6,5

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

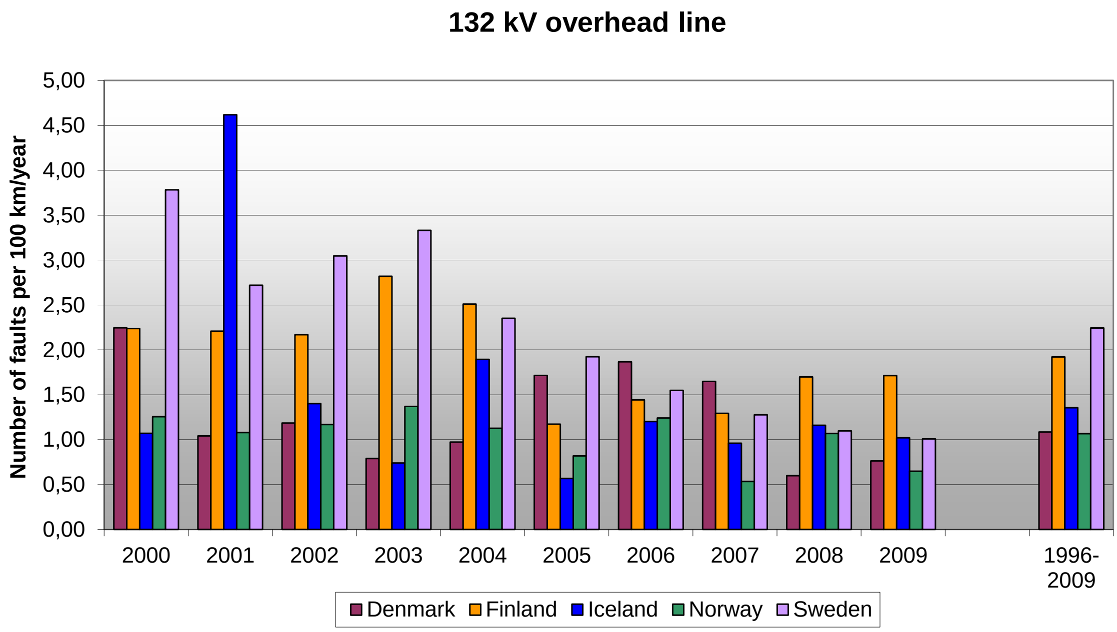

Figure 5.3 Annual division of faults during the period 2000–2009.

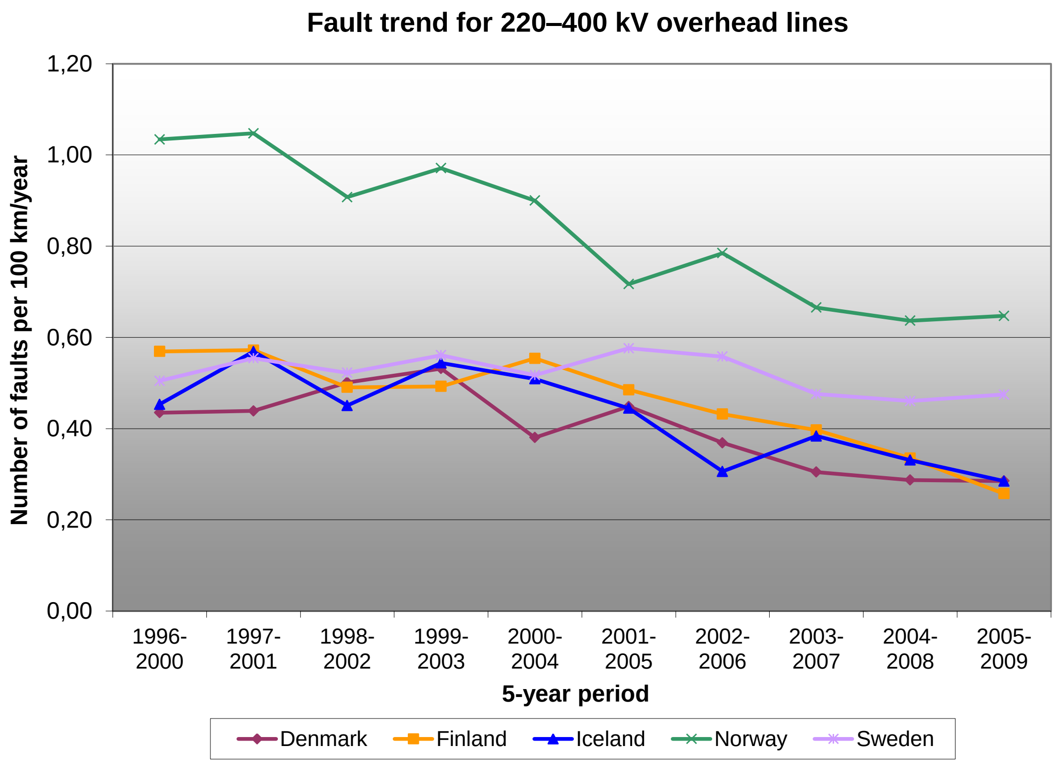

Figure 5.4 Fault trend for overhead lines at voltage level 220–400 kV.

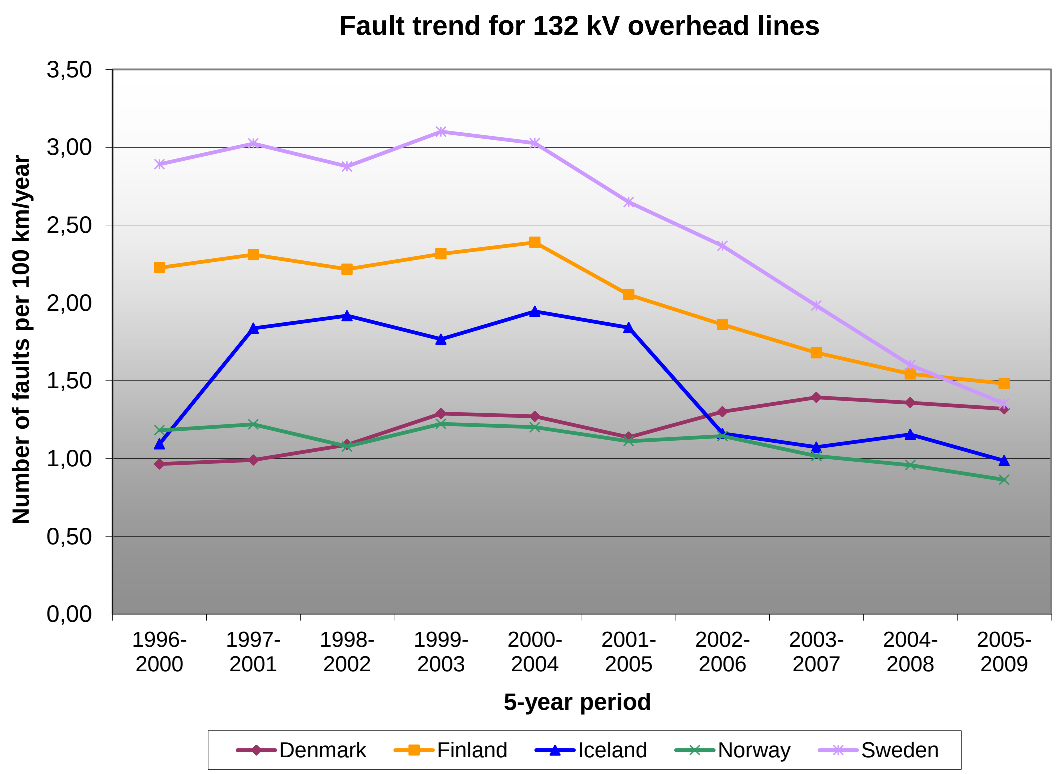

Figure 5.5 Fault trend for overhead lines at voltage level 132 kV.

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 2009 and for the period 2000–2009. 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 2000–2009 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 2009	Number of faults 2009	Number of faults per 100 km		Faults divided by cause during the period 2000–2009 (%)						
			2009	2000–2009	Lightning	Other environmental cause	External influence	Operation and maintenance	Technical equipment	Other	Unknown
Denmark	309	0	0,00	0,24	0,0	0,0	0,0	25,0	25,0	25,0	25,0
Norway	25	2	8,00	1,62	0,0	0,0	0,0	0,0	50,0	25,0	25,0
Sweden	8	0	0,00	0,00	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Nordic	342	2	0,58	0,41	0,0	0,0	0,0	12,5	37,5	25,0	25,0

5.3.2 220 kV cables

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

Country	Line km 2009	Number of faults 2009	Number of faults per 100 km		Faults divided by cause during the period 2000–2009 (%)						
			2009	2000–2009	Lightning	Other environmental cause	External influence	Operation and maintenance	Technical equipment	Other	Unknown
Norway	450	1	0,22	0,09	0,0	33,3	0,0	33,3	0,0	0,0	33,3
Sweden	219	0	0,00	0,75	0,0	0,0	0,0	11,1	77,8	0,0	11,1
Nordic	669	1	0,15	0,26	0,0	8,3	0,0	16,7	58,3	0,0	16,7

5.3.3 132 kV cables

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

Country	Line km 2009	Number of faults 2009	Number of faults per 100 km 2009	Number of faults per 100 km 2000–2009	Faults divided by cause during the period 2000–2009 (%) Lightning	Other environmental cause	External influence	Operation and maintenance	Technical equipment	Other	Unknown
Denmark	732	5	0,68	0,38	0,0	0,0	26,3	15,8	42,1	10,5	5,3
Finland	189	0	0,00	0,00	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Iceland	71	0	0,00	0,75	0,0	0,0	0,0	0,0	100,0	0,0	0,0
Norway[1)]	202	0	0,00	1,36	0,0	0,0	11,5	19,2	53,8	11,5	3,8
Sweden	206	4	1,94	0,97	0,0	0,0	20,8	12,5	33,3	16,7	16,7
Nordic	1399	9	0,64	0,69	0,0	0,0	18,1	15,3	45,8	12,5	8,3

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

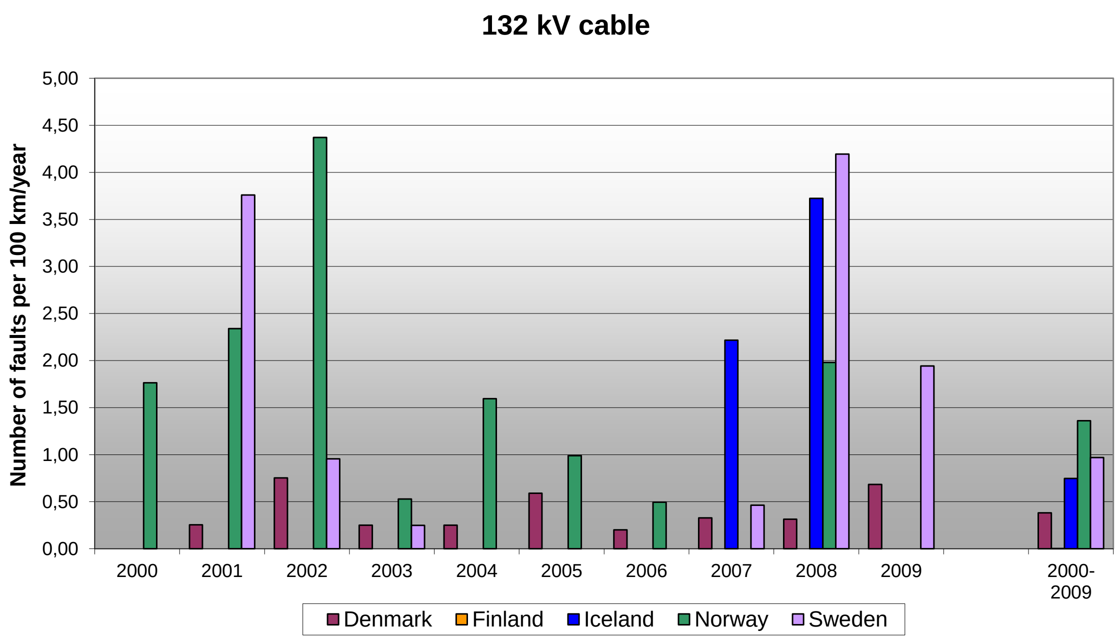

Figure 5.6 Annual division of faults during the period 2000–2009.

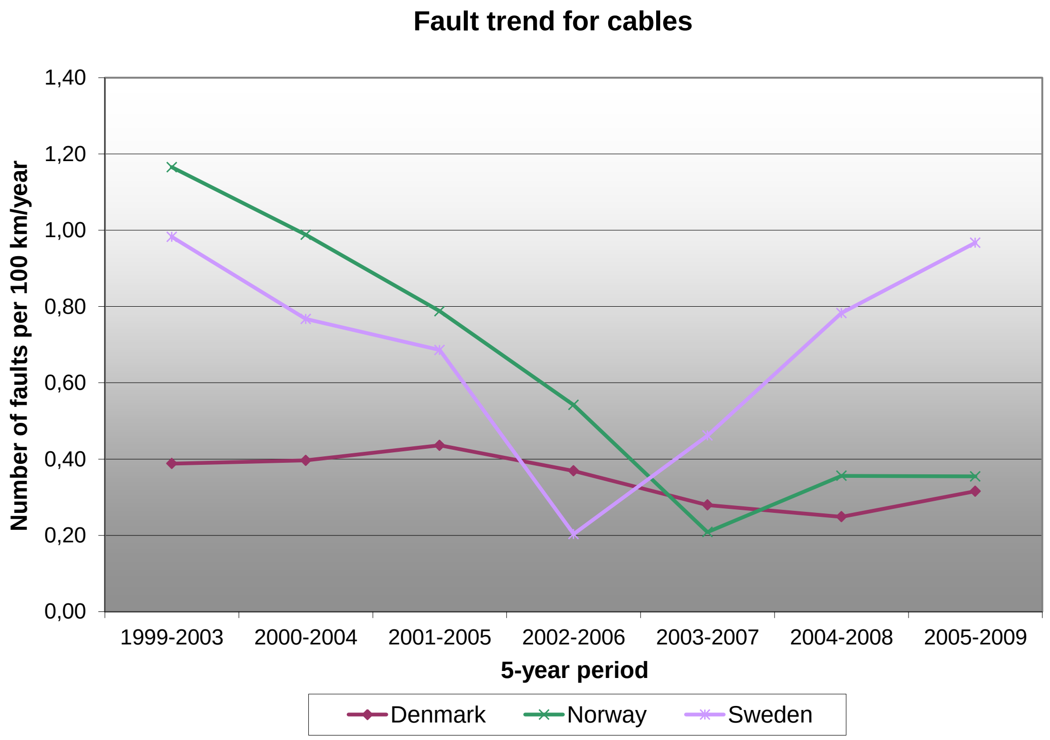

Figure 5.7 Fault trend for cables at all voltage level.

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 division of faults for the year 2009 and for the period 2000–2009 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 2000–2009 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 2009	Number of faults 2009	Number of faults per 100 devices 2009	Number of faults per 100 devices 2000–2009	Faults divided by cause during the period 2000–2009 (%) Lightning	Other environmental cause	External influence	Operation and maintenance	Technical equipment	Other	Unknown
Denmark	23	1	4,35	3,56	12,5	12,5	0,0	12,5	12,5	0,0	50,0
Finland	43	2	4,65	2,05	0,0	22,2	0,0	22,2	33,3	11,1	11,1
Norway	64	2	3,13	1,13	0,0	0,0	0,0	14,3	57,1	0,0	28,6
Sweden	63	2	3,17	1,13	0,0	0,0	0,0	60,0	20,0	20,0	0,0
Nordic	193	7	3,63	1,56	2,9	8,8	0,0	29,4	29,4	8,8	20,6

[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.

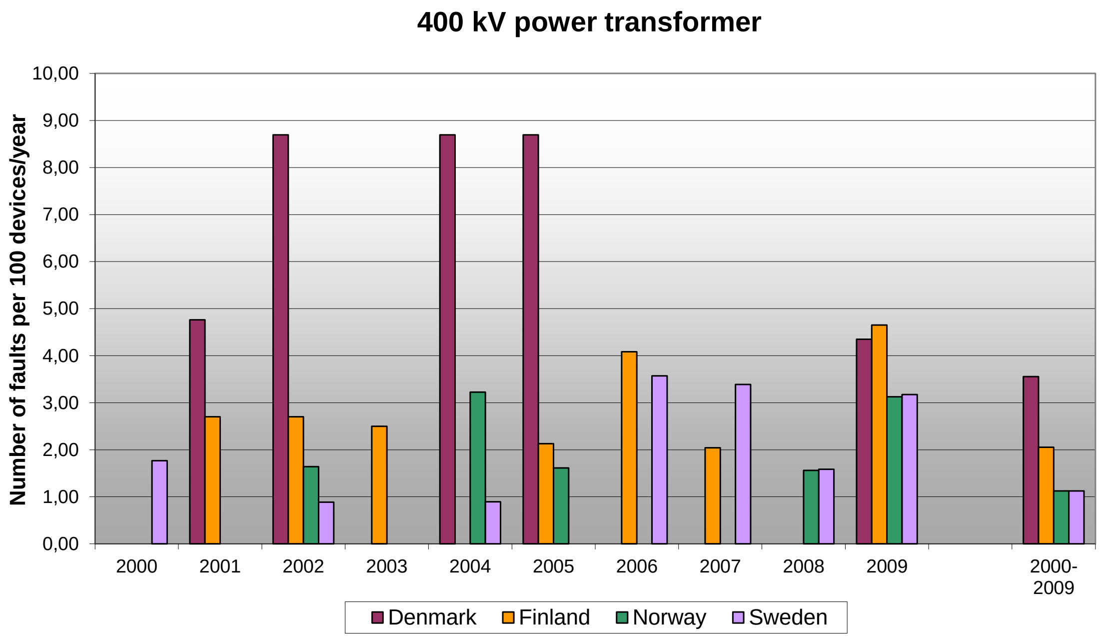

Figure 5.8 Annual division of faults during the period 2000–2009.

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 2009	Number of faults 2009	Number of faults per 100 devices 2009	Number of faults per 100 devices 2000–2009	Faults divided by cause during the period 2000–2009 (%) 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	1,31	0,0	0,0	0,0	0,0	0,0	0,0	100,0
Iceland	32	1	3,13	3,82	0,0	0,0	0,0	10,0	80,0	0,0	10,0
Norway	271	3	1,11	1,29	5,7	2,9	2,9	25,7	42,9	17,1	2,9
Sweden	101	6	5,94	3,46	33,3	5,1	10,3	20,5	17,9	2,6	10,3
Nordic	430	10	2,33	2,00	17,2	3,4	5,7	20,7	34,5	8,0	10,3

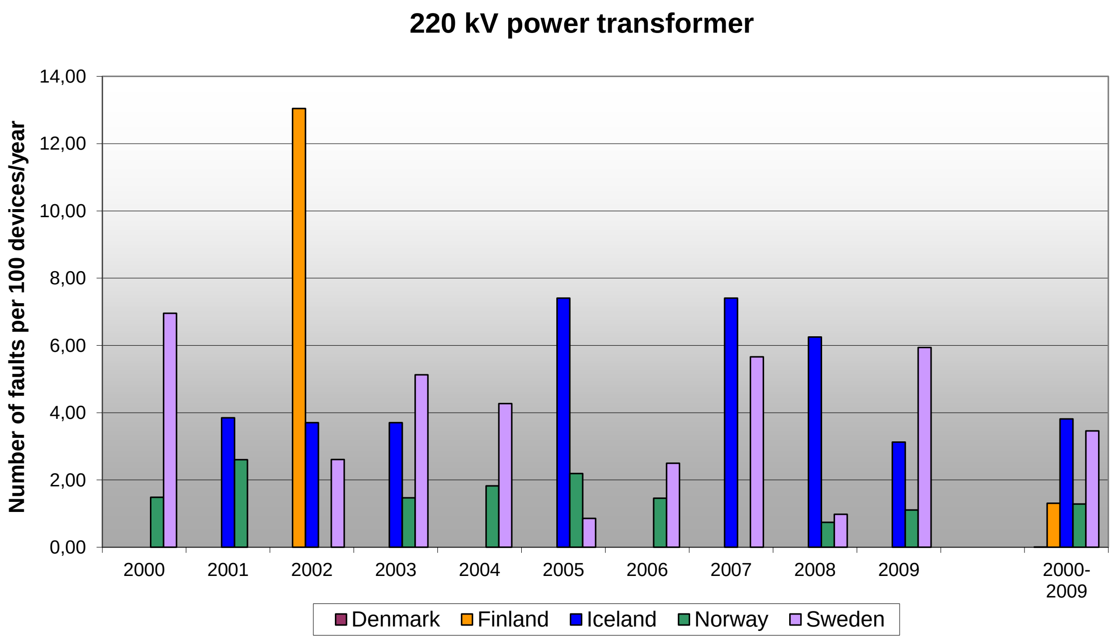

Figure 5.9 Annual division of faults during the period 2000–2009.

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 2009	Number of faults 2009	Number of faults per 100 devices 2009	Number of faults per 100 devices 2000–2009	Faults divided by cause during the period 2000–2009 (%): Lightning	Other environmental cause	External influence	Operation and maintenance	Technical equipment	Other	Unknown
Denmark	238	3	1,26	1,15	3,8	7,7	3,8	34,6	23,1	3,8	23,1
Finland	920	7	0,76	0,47	0,0	5,9	23,5	11,8	23,5	0,0	35,3
Iceland	59	0	0,00	0,93	0,0	0,0	0,0	50,0	25,0	0,0	25,0
Norway	724	5	0,69	0,51	2,8	11,1	5,6	19,4	38,9	16,7	5,6
Sweden[1)]	737	34	4,61	5,23	18,4	2,8	3,4	16,9	27,5	12,2	18,7
Nordic	2678	49	1,83	2,07	15,1	4,0	4,5	18,4	28,0	11,4	18,6

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

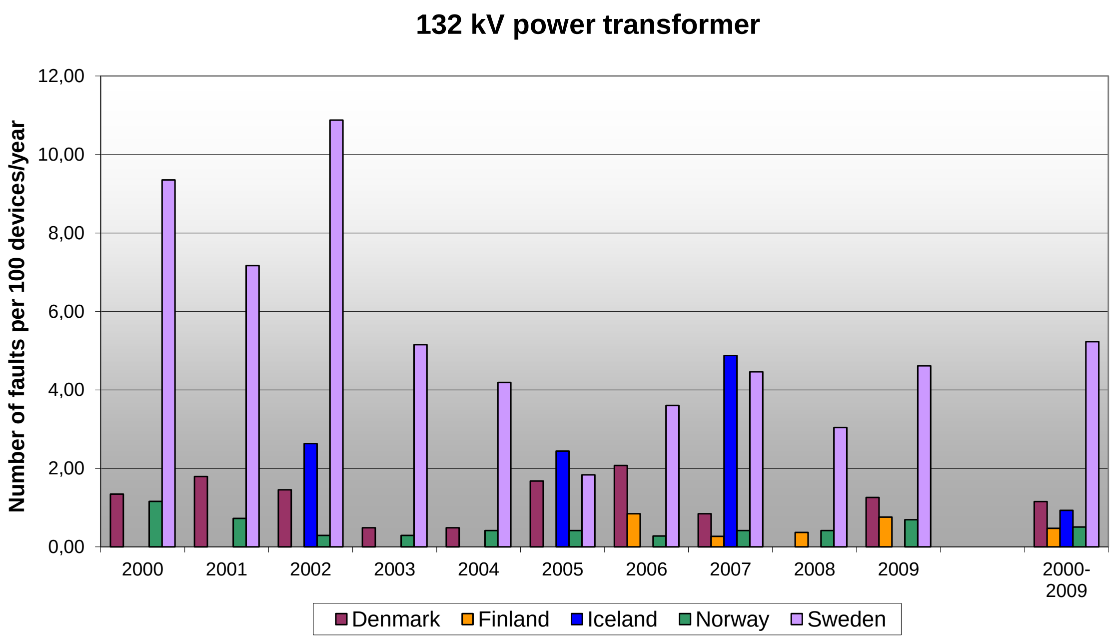

Figure 5.10 Annual division of faults during the period 2000–2009.

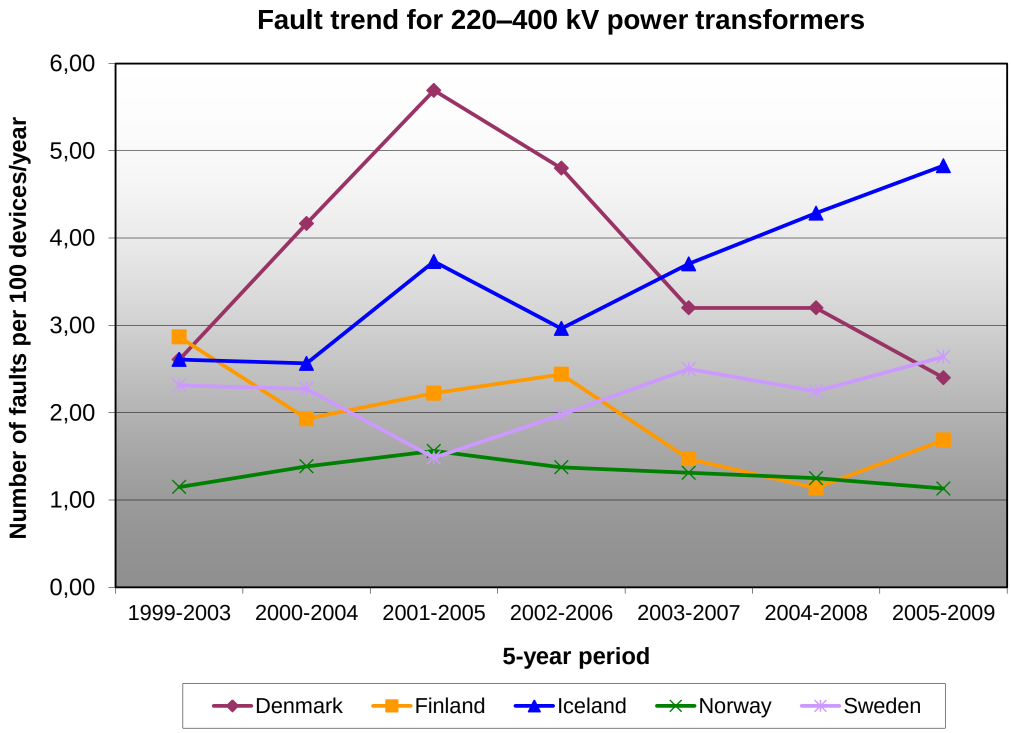

Figure 5.11 Fault trend for power transformers at voltage level 220–400 kV.

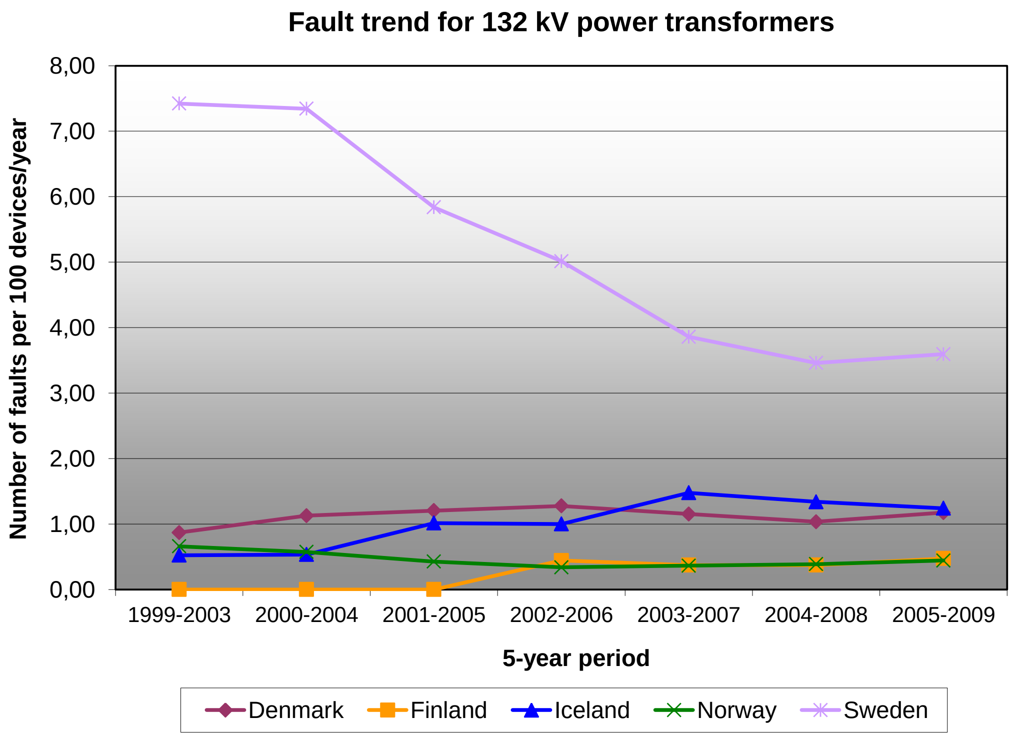

Figure 5.12 Fault trend for power transformers at voltage level 132 kV.

5.5 Faults in instrument transformers

The tables in this section present the faults in instrument transformers for the year 2009 and for the period 2000–2009 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 2009	Number of faults 2009	Number of faults per 100 devices		Faults divided by cause during the period 2000–2009 (%)						
			2009	2000–2009	Lightning	Other environmental cause	External influence	Operation and maintenance	Technical equipment	Other	Unknown
Denmark	533	0	0,00	0,00	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Finland	407	0	0,00	0,00	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Norway	930	0	0,00	0,12	0,0	10,0	0,0	10,0	30,0	40,0	10,0
Sweden	982	0	0,00	0,11	8,3	0,0	0,0	16,7	66,7	0,0	8,3
Nordic	2852	0	0,00	0,08	4,5	4,5	0,0	13,6	50,0	18,2	9,1

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 2009	Number of faults 2009	Number of faults per 100 devices		Faults divided by cause during the period 2000–2009 (%)						
			2009	2000–2009	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	158	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	1	0,04	0,08	9,1	9,1	0,0	0,0	63,6	9,1	9,1
Sweden	1095	1	0,09	0,08	0,0	0,0	0,0	10,0	90,0	0,0	0,0
Nordic	4514	2	0,04	0,07	6,1	6,1	0,0	3,0	72,7	6,1	6,1

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 2009	Number of faults 2009	Number of faults per 100 devices 2009	Number of faults per 100 devices 2000–2009	Faults divided by cause during the period 2000–2009 (%) Lightning	Other environmental cause	External influence	Operation and maintenance	Technical equipment	Other	Unknown
Denmark	4592	1	0,02	0,02	0,0	16,7	0,0	16,7	50,0	0,0	16,7
Finland	1783	1	0,06	0,07	20,0	0,0	10,0	0,0	60,0	10,0	0,0
Iceland	634	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	13,0	0,0	0,0	8,7	47,8	15,2	15,2
Sweden	4945	5	0,10	0,06	20,0	0,0	0,0	8,6	60,0	2,9	8,6
Nordic	19722	10	0,05	0,05	15,3	1,0	1,0	8,2	54,1	9,2	11,2

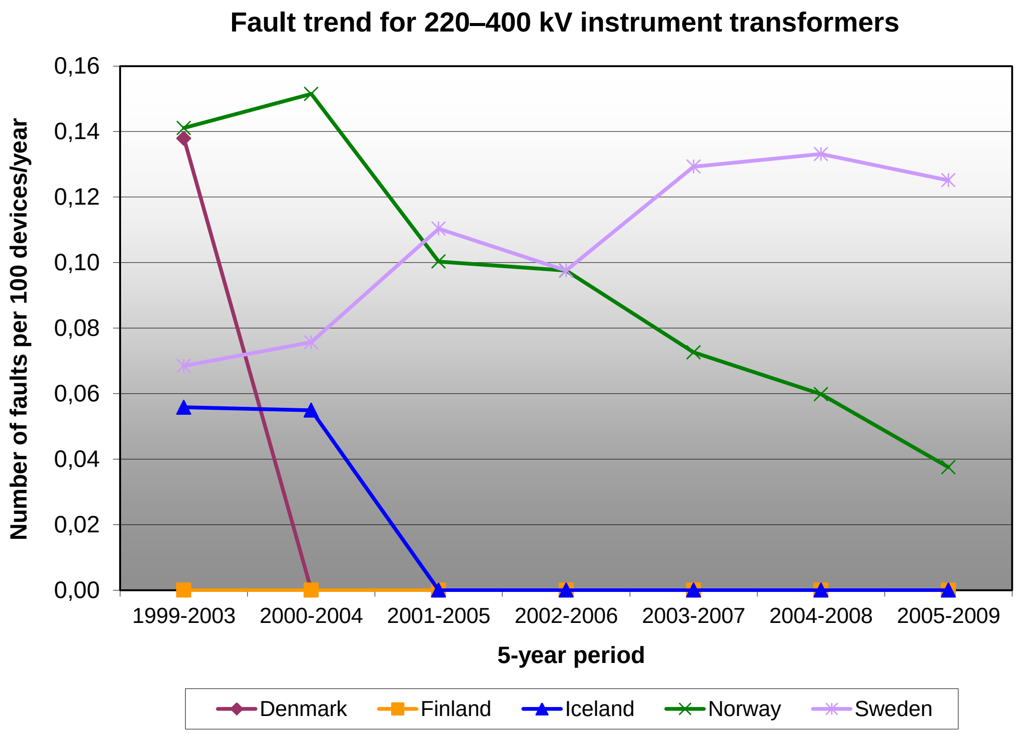

Figure 5.13 Fault trend for instrument transformers at voltage level 220–400 kV.

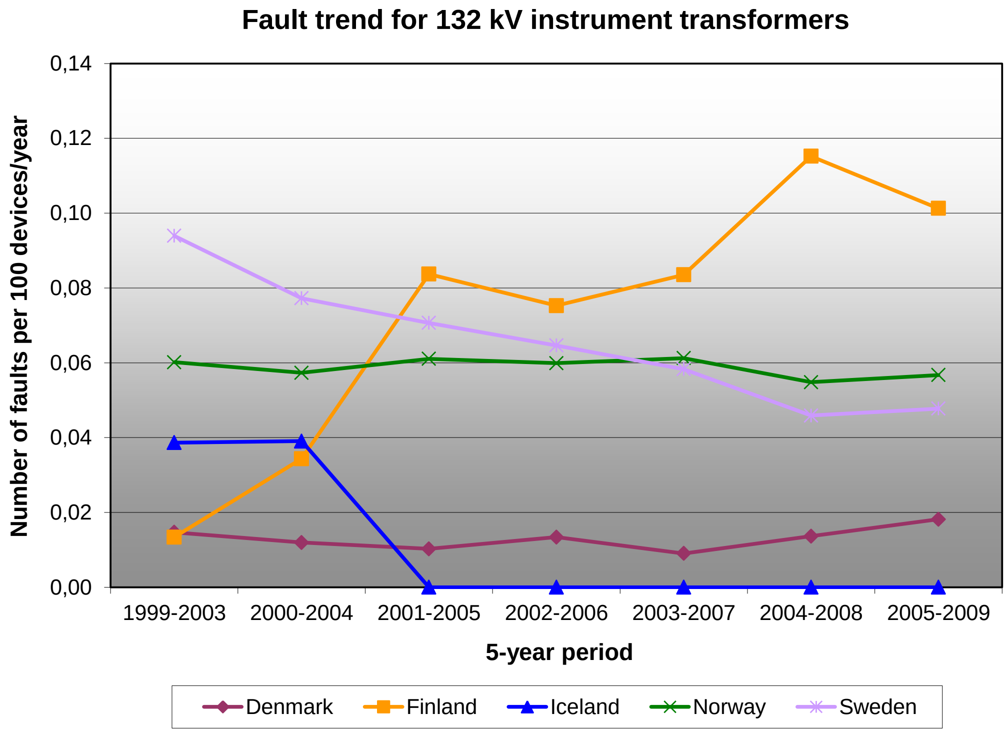

Figure 5.14 Fault trend for instrument transformers at voltage level 132 kV.

5.6 Faults in circuit breakers

The tables in this section present circuit breaker faults for the year 2009 and for the period 2000–2009 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 with 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 2009	Number of faults 2009	Number of faults per 100 devices 2009	Number of faults per 100 devices 2000–2009	Faults divided by cause during the period 2000–2009 (%) Lightning	Other environmental cause	External influence	Operation and maintenance	Technical equipment	Other	Unknown
Denmark	149	1	0,67	0,77	0,0	10,0	10,0	20,0	50,0	10,0	0,0
Finland	235	0	0,00	0,31	0,0	0,0	16,7	16,7	66,7	0,0	0,0
Norway	262	3	1,15	1,01	0,0	0,0	0,0	28,0	56,0	4,0	12,0
Sweden[1)]	453	5	1,10	2,00	0,0	2,4	0,0	3,6	75,9	12,0	6,0
Nordic	1099	9	0,82	1,26	0,0	2,4	1,6	10,5	69,4	9,7	6,5

[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 2009	Number of faults 2009	Number of faults per 100 devices 2009	Number of faults per 100 devices 2000–2009	Faults divided by cause during the period 2000–2009 (%) 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	103	2	1,94	0,64	0,0	0,0	0,0	0,0	83,3	16,7	0,0
Iceland	79	0	0,00	3,75	0,0	8,0	0,0	8,0	72,0	0,0	12,0
Norway	724	3	0,41	0,73	0,0	0,0	0,0	35,3	54,9	2,0	7,8
Sweden	412	2	0,49	0,50	5,0	0,0	0,0	20,0	70,0	0,0	5,0
Nordic	1320	7	0,53	0,81	1,0	2,0	0,0	23,5	63,7	2,0	7,8

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 2009	Number of faults 2009	Number of faults per 100 devices 2009	Number of faults per 100 devices 2000–2009	Faults divided by cause during the period 2000–2009 (%) Lightning	Other environmental cause	External influence	Operation and maintenance	Technical equipment	Other	Unknown
Denmark	821	3	0,37	0,55	0,0	2,3	0,0	36,4	54,5	6,8	0,0
Finland	2436	0	0,00	0,20	25,9	7,4	0,0	22,2	37,0	3,7	3,7
Iceland	142	0	0,00	0,66	0,0	0,0	0,0	12,5	75,0	0,0	12,5
Norway	2119	1	0,05	0,32	3,1	0,0	0,0	52,3	38,5	1,5	4,6
Sweden	1929	0	0,00	0,84	24,6	2,3	2,3	18,5	41,5	2,3	8,5
Nordic	7447	4	0,05	0,47	15,0	2,2	1,1	29,6	43,4	2,9	5,8

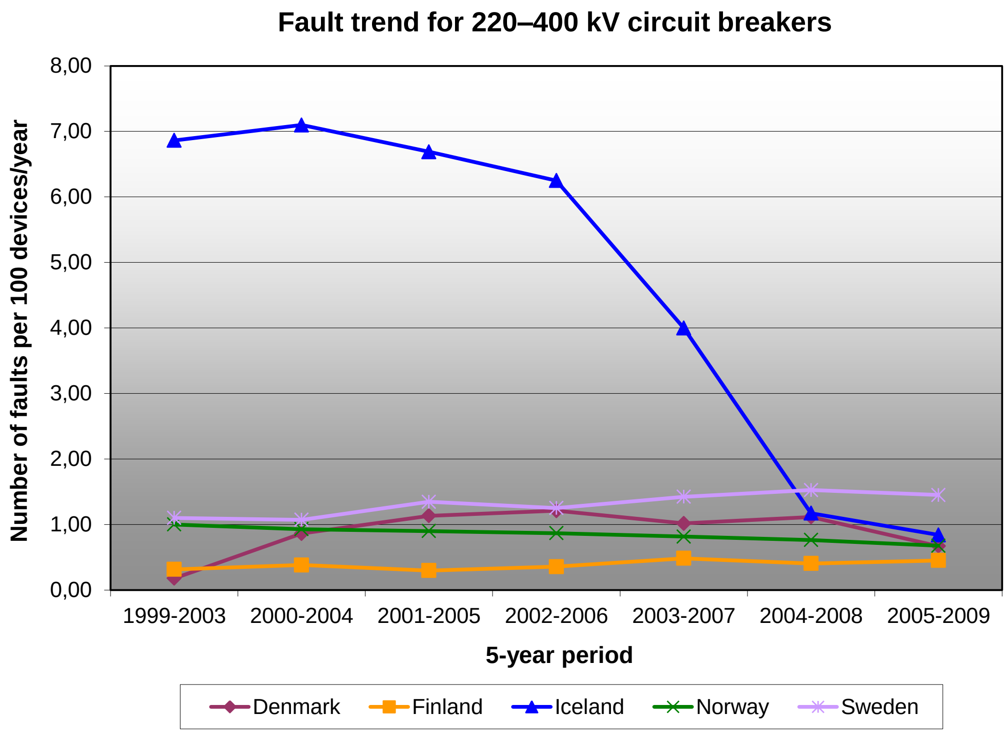

Figure 5.15 Fault trend for circuit breakers at voltage level 220–400 kV.

[1)] The explanation for the remarkable improvement on the fault trend of Iceland is that most of the disturbances on circuit breakers up to 2003 in the 220 kV network were in one substation. These breakers caused problems due to gas leaks and were repaired in 2003. In addition to this, two new substations were installed with total of 18 circuit breakers (from 56 breakers to 74 breakers total).

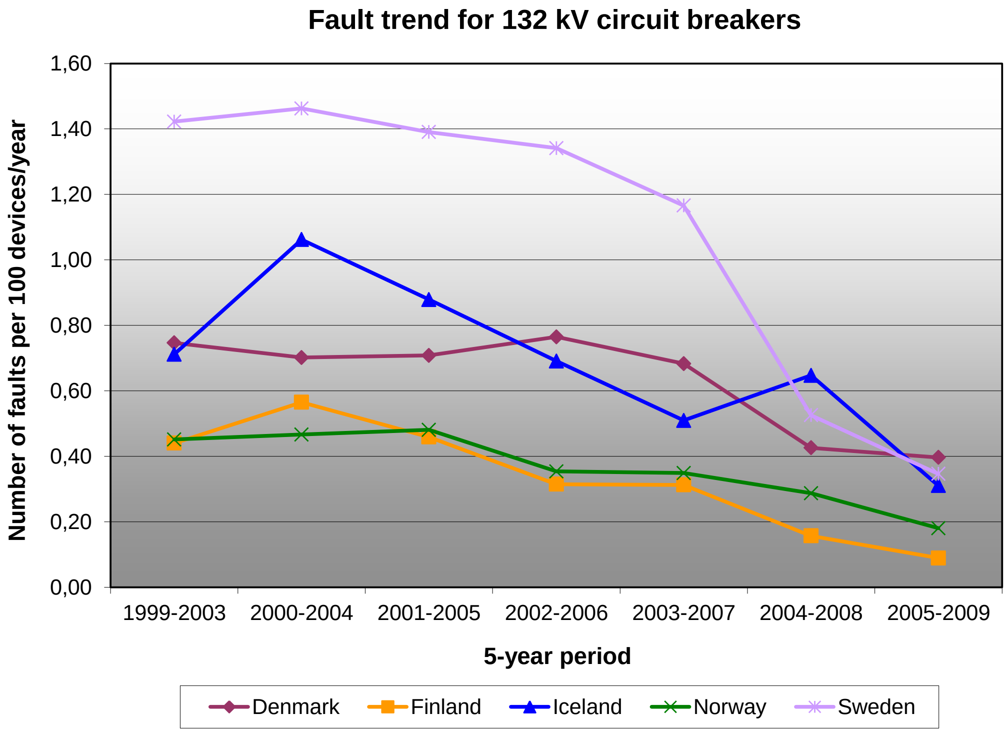

Figure 5.16 Fault trend for circuit breakers at voltage level 132 kV.

5.7 Faults in control equipment

The tables in this section present faults in control equipment at each respective voltage level for the year 2009 and for the period 2000–2009. 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. ENTSO-E Nordic'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 2009	Number of faults 2009	Number of faults per 100 devices 2009	Number of faults per 100 devices 2000–2009	Faults divided by cause during the period 2000–2009 (%) Lightning	Other environmental cause	External influence	Operation and maintenance	Technical equipment	Other	Unknown
Denmark	131	0	0,00	1,71	5,0	0,0	0,0	30,0	35,0	10,0	20,0
Finland	235	14	5,96	5,69	0,0	0,0	0,0	34,9	9,2	39,4	16,5
Norway	261	8	3,07	9,26	0,0	0,9	0,4	28,7	46,1	3,5	20,4
Sweden	454	12	2,64	10,52	0,5	0,7	0,0	13,2	80,6	2,8	2,1
Nordic	1081	34	3,15	8,15	0,4	0,6	0,1	21,2	59,3	8,3	10,0

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 2009	Number of faults 2009	Number of faults per 100 devices 2009	Number of faults per 100 devices 2000–2009	Faults divided by cause during the period 2000–2009 (%) 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	103	9	8,74	5,83	0,0	0,0	0,0	41,8	47,3	5,5	5,5
Iceland	79	3	3,80	11,84	3,8	10,1	0,0	34,2	46,8	5,1	0,0
Norway	721	18	2,50	7,44	0,8	0,8	0,8	32,6	42,1	2,7	20,3
Sweden	406	1	0,25	3,78	0,0	0,0	2,0	31,8	53,6	8,6	4,0
Nordic	1311	31	2,36	6,38	0,9	1,5	0,9	33,2	45,1	4,2	14,3

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 2009	Number of faults 2009	Number of faults per 100 devices 2009	Number of faults per 100 devices 2000–2009	Faults divided by cause during the period 2000–2009 (%) Lightning	Other environmental cause	External influence	Operation and maintenance	Technical equipment	Other	Unknown
Denmark	814	3	0,37	1,08	5,2	6,5	2,6	41,6	24,7	11,7	7,8
Finland	2436	37	1,52	1,77	2,6	0,0	2,6	39,1	26,0	11,1	18,7
Iceland	140	2	1,43	4,58	0,0	3,6	1,8	29,1	63,6	0,0	1,8
Norway	2064	24	1,16	2,78	0,5	2,1	0,4	32,0	34,0	4,5	26,5
Sweden	1816	6	0,33	0,92	8,8	0,0	0,0	45,3	25,5	5,8	14,6
Nordic	7270	72	0,99	1,88	2,4	1,8	1,0	35,8	32,0	6,4	20,6

5.8 Faults in compensation devices

In 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 2009	Number of faults 2009	Number of faults per 100 devices 2009	Number of faults per 100 devices 2000–2009	Faults divided by cause during the period 2000–2009 (%) Lightning	Other environmental cause	External influence	Operation and maintenance	Technical equipment	Other	Unknown
Denmark	17	1	5,88	5,03	0,0	0,0	0,0	26,7	53,3	0,0	20,0
Finland[1)]	67	0	0,00	2,13	0,0	0,0	0,0	0,0	66,7	25,0	8,3
Norway	36	0	0,00	6,15	0,0	5,0	0,0	30,0	55,0	5,0	5,0
Sweden	78	9	11,54	13,12	0,0	31,8	4,5	9,1	39,4	9,1	6,1
Nordic	198	10	5,05	6,69	0,0	19,5	2,7	14,2	46,9	8,8	8,0

[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 2009	Number of faults 2009	Number of faults per 100 devices 2009	Number of faults per 100 devices 2000–2009	Faults divided by cause during the period 2000–2009 (%) Lightning	Other environmental cause	External influence	Operation and maintenance	Technical equipment	Other	Unknown
Finland	9	8	88,89	26,87	0,0	0,0	11,1	5,6	33,3	0,0	50,0
Iceland	1	0	0,00	10,00	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	59,17	1,4	0,0	0,0	2,8	32,4	40,8	22,5
Nordic	25	11	44,00	40,00	1,1	0,0	2,2	3,3	33,3	32,2	27,8

Table 5.24 Division of faults according to cause for shunt capacitors

Country	Number of devices 2009	Number of faults 2009	Number of faults per 100 devices 2009	Number of faults per 100 devices 2000–2009	Faults divided by cause during the period 2000–2009 (%) Lightning	Other environmental cause	External influence	Operation and maintenance	Technical equipment	Other	Unknown
Denmark	15	0	0,00	1,30	0,0	0,0	100,0	0,0	0,0	0,0	0,0
Finland	56	0	0,00	7,81	0,0	28,0	48,0	0,0	4,0	16,0	4,0
Iceland	10	2	20,00	10,99	0,0	20,0	0,0	0,0	80,0	0,0	0,0
Norway	194	0	0,00	2,68	0,0	0,0	2,0	11,8	45,1	39,2	2,0
Sweden	324	1	0,31	4,61	6,7	4,4	11,1	8,9	37,8	0,0	31,1
Nordic	599	3	0,50	3,86	2,3	8,3	15,0	7,5	36,8	18,0	12,0

Table 5.25 Division of faults according to cause for SVC devices

Country	Number of devices 2009	Number of faults 2009	Number of faults per 100 devices 2009	Number of faults per 100 devices 2000–2009	Faults divided by cause during the period 2000–2009 (%) Lightning	Other environmental cause	External influence	Operation and maintenance	Technical equipment	Other	Unknown
Norway	15	9	60,00	36,96	0,0	3,9	0,0	7,8	52,9	19,6	15,7
Sweden	3	10	333,33	79,78	0,0	7,0	4,2	15,5	63,4	1,4	8,5
Nordic	18	19	105,56	53,04	0,0	5,7	2,5	12,3	59,0	9,0	11,5

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]. For the most part, this chapter covers statistics only for the year 2009. A ten-year trend line for the reliability of some power system components is presented at the end of the chapter.

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 2009 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 with the 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 the number of outages in 2009

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	316	289	23	4	0	0	0	0
Finland	319	149	99	41	13	8	2	7
Iceland	57	49	4	2	0	1	0	1
Norway	641	492	121	23	2	1	1	1
Sweden	370	264	60	27	18	0	1	0

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

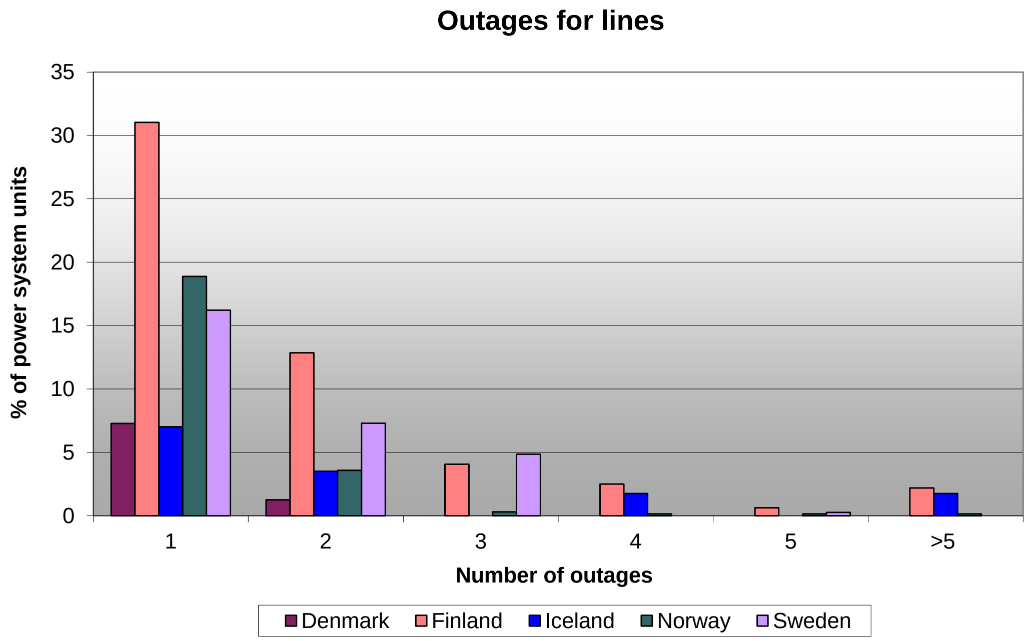

Figure 6.1 Grouping of lines according to number of outages in 2009.

Table 6.2 Grouping of transformers according to the number of outages in 2009

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	263	255	8	0	0	0	0	0
Finland	987	978	8	1	0	0	0	0
Iceland	92	90	0	0	2	0	0	0
Norway	800	790	7	3	0	0	0	0
Sweden	309	287	19	0	3	0	0	0

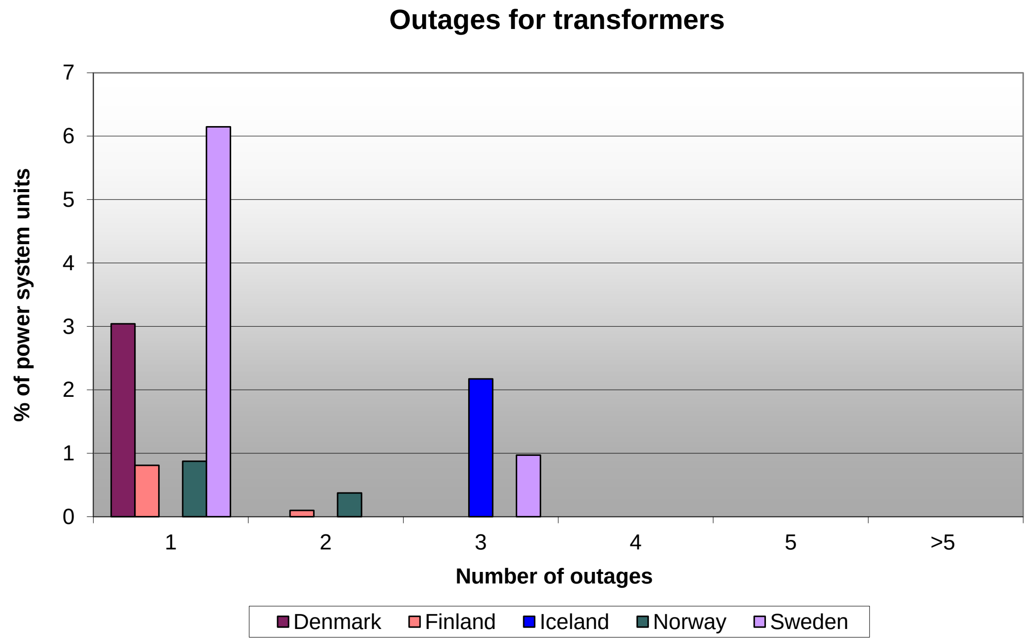

Figure 6.2 Grouping of transformers according to number of outages in 2009.

Table 6.3 Grouping of busbars according to the number of outages in 2009

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	149	147	2	0	0	0	0	0
Finland	774	774	0	0	0	0	0	0
Iceland	53	53	0	0	0	0	0	0
Norway	435	429	3	2	1	0	0	0
Sweden	228	223	5	0	0	0	0	0

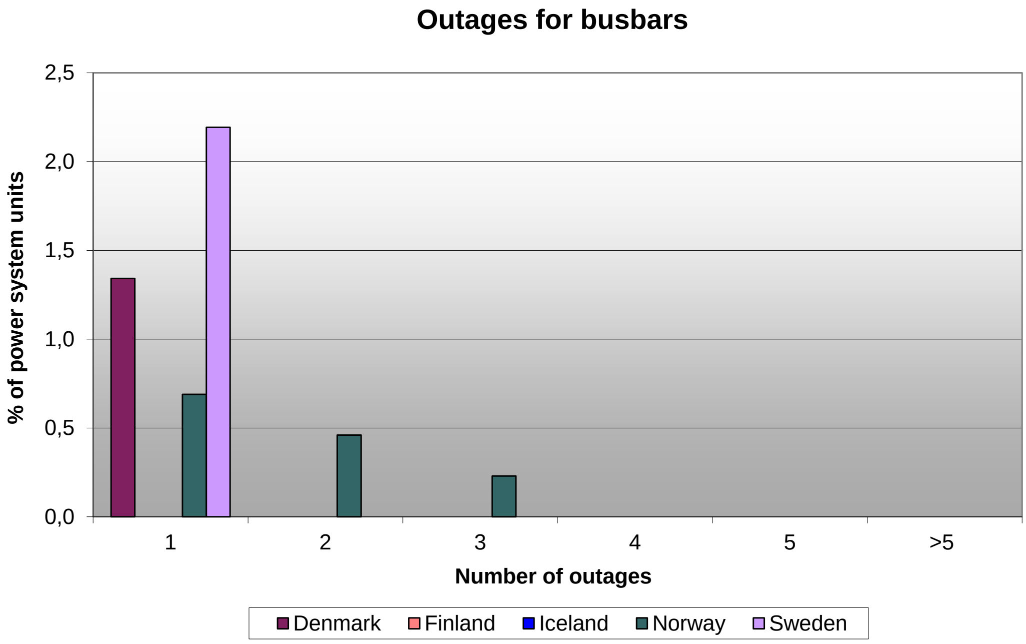

Figure 6.3 Grouping of busbars according to number of outages in 2009.

Table 6.4 Grouping of reactors according to the number of outages in 2009

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	67	67	0	0	0	0	0	0
Norway	36	36	0	0	0	0	0	0
Sweden	35	24	8	1	2	0	0	0

Table 6.5 Grouping of shunt capacitors according to the number of outages in 2009

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	56	56	0	0	0	0	0	0
Iceland	10	9	0	0	1	0	0	0
Norway	164	164	0	0	0	0	0	0
Sweden	42	41	1	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 2009

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	316	289	7	2	0	4	1	3	1	9
Finland	319	149	128	14	9	6	2	3	3	5
Iceland	57	49	1	0	2	0	0	1	0	4
Norway	641	492	128	5	5	3	3	2	2	1
Sweden	370	264	91	2	4	1	4	0	1	3

[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 2009

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	263	255	2	3	0	1	0	0	0	2
Finland	987	978	2	2	2	1	0	1	0	1
Iceland	92	90	0	0	0	0	1	0	0	1
Norway	800	790	5	2	2	0	1	0	0	0
Sweden	309	287	3	5	5	6	1	0	1	1

Table 6.8 Number of busbars with different outage durations in 2009

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	149	147	0	0	0	2	0	0	0	0
Finland	774	774	0	0	0	0	0	0	0	0
Iceland	53	53	0	0	0	0	0	0	0	0
Norway	435	429	4	0	0	0	2	0	0	0
Sweden	228	223	1	0	1	0	2	1	0	0

Table 6.9 Number of reactors with different outage durations in 2009

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	67	67	0	0	0	0	0	0	0	0
Norway	36	36	0	0	0	0	0	0	0	0
Sweden	35	24	0	0	3	0	1	2	0	5

Table 6.10 Number of shunt capacitors with different outage durations in 2009

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	56	56	0	0	0	0	0	0	0	0
Iceland	10	9	0	0	0	0	0	0	0	1
Norway	164	164	0	0	0	0	0	0	0	0
Sweden	42	41	0	0	0	1	0	0	0	0

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.

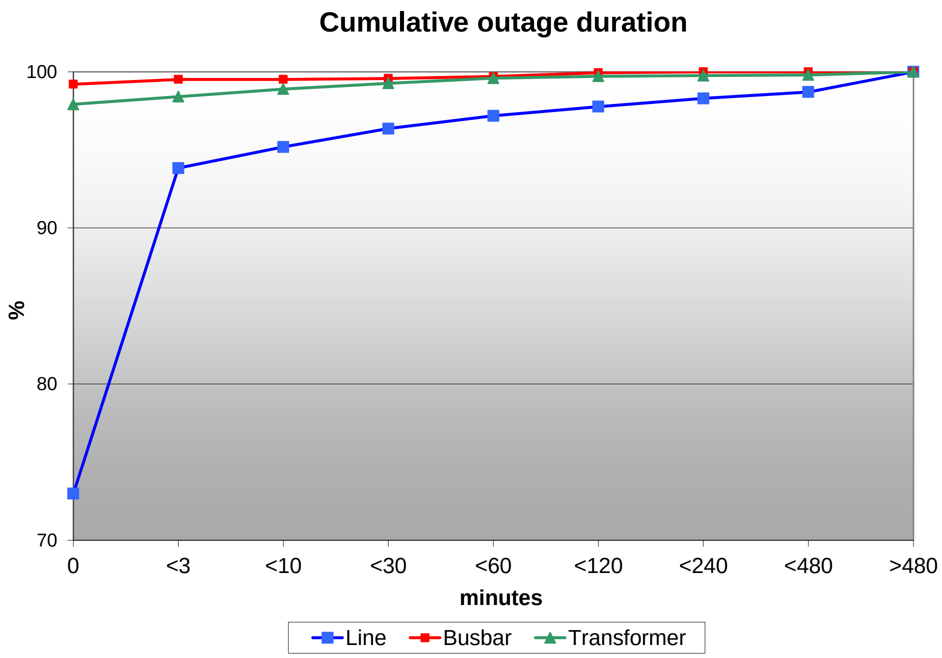

Figure 6.4 Cumulative duration of outages in selected power systems units.

Figure 6.4 shows that about 73% of lines, 98% of transformers and over 99% of busbars had no outages in 2009.

6.5 Reliability trend for some power system units

Figure 6.5 presents a reliability trend for lines, busbars, and transformers during the period 2000–2009.

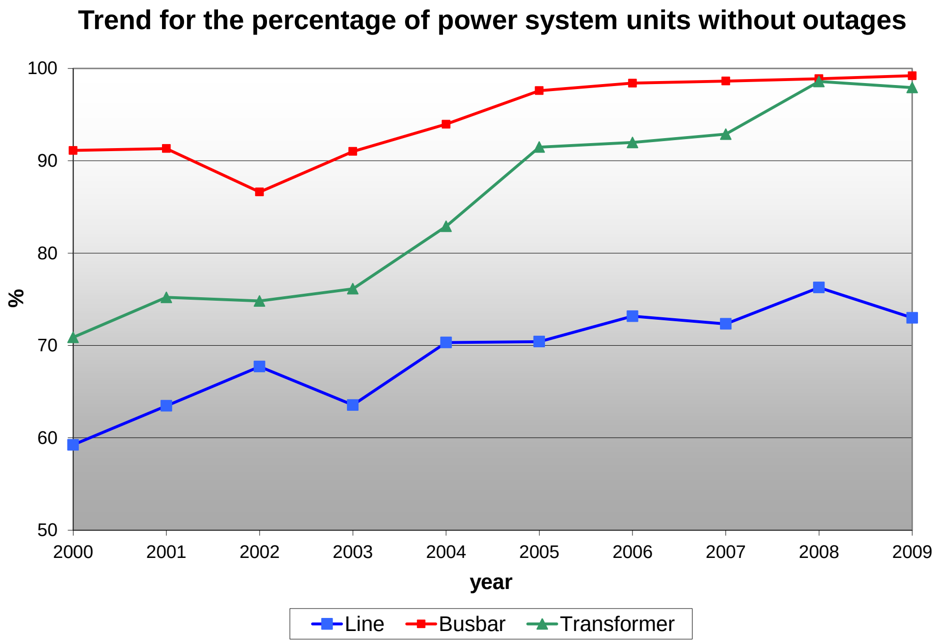

Figure 6.5 The yearly percentage of the power system units that had no outages during the period 2000–2009.

One should note that all five countries are included in Figure 6.4 and Figure 6.5.

7 References

[1]: ENTSO-E Nordic Guidelines for the Classification of Grid Disturbances 2009 http://www.entsoe.eu/index.php?id=63

[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)

[5]: The ENTSO-E interconnected system grid map

https://www.entsoe.eu/index.php?id=77

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 as the transformer load just before the grid disturbance or interruption multiplied by the outage duration. Transformer load covers load/consumption and generation at lower/medium voltage.

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 ENTSO-E Nordic statistics, ENS that was caused by the generation 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 the Nordic countries

Denmark: Peter Diemer
Energinet.dk
Tonne Kjærsvej 65, DK-7000 Fredericia
Tel. +45 76 22 46 37, Fax +45 76 24 51 80
E-mail: pdi@energinet.dk

Finland: Ville Viita
Fingrid Oyj
Arkadiankatu 23 B, P.O. Box 530, FI-00101 Helsinki
Tel. +358 30 395 4229, Fax +358 30 395 5199
E-mail: ville.viita@fingrid.fi

Iceland: Ragnar Stefansson
Landsnet
Gylfaflöt 9, IS-112 Reykjavik
Tel. +354 863 7181, Fax +354 563 9379
E-mail: ragnars@landsnet.is

Norway: Jørn Schaug-Pettersen
Statnett SF
Postboks 5192 Majorstuen, NO-0302 Oslo
Tel. +47 22 52 74 47, Fax +47 22 52 70 01
E-mail: jsp@statnett.no

Sweden: Sture Holmström
Svenska Kraftnät
Sturegatan 1, P.O. Box 1200, SE-172 24 Sundbyberg
Tel. +46 8 475 81 00, Fax +46 8 475 89 60
E-mail: sture.holmstrom@svk.se

Production of the report:
Liisa Haarla, Ilkka Luukkonen and Niina Helistö
Aalto University School of Science and Technology
Department of Electrical Engineering
P.O. BOX 3000, FI-02015 TKK, Finland
Tel. +358 9 451 5428, Fax +358 9 451 5012
E-mail: liisa.haarla@aalto.fi or ilkka.luukkonen@tkk.fi

Appendix 3: Contact persons for the distribution network statistics

ENTSO-E Regional Group Nordic 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 Nordic countries which are listed below:

Denmark:

Peter Hansen
Danish Energy Association R&D
Rosenørns Allé 9, DK-1970 Frederiksberg
Tel. +45 300 400, Fax +45 300 401
E-mail: pha@danskenergi.dk

Finland:

Elina Lehtomäki
Energiateollisuus ry
Fredrikinkatu 51–53 B, P.O. Box 100, FI-00101 Helsinki
Tel. +358 50 522 3402, Fax +358 9 5305 2900
E-mail: elina.lehtomaki@energia.fi

Iceland:

Sigurdur Ágústsson
Samorka
Sudurlandsbraut 48, IS-108 Reykjavík
Tel. +354 588 4430, Fax +354 588 4431
E-mail: sa@samorka.is

Norway:

Jørn Schaug-Pettersen
Statnett SF
Postboks 5192 Majorstuen, NO-0302 Oslo
Tel. +47 22 52 74 47, Fax +47 22 52 70 01
E-mail: jsp@statnett.no

Sweden:

Matz Tapper
Svensk Energi
SE-101 53 Stockholm
Tel. +46 8 677 27 26, Fax +46 8 677 25 06
E-mail: matz.tapper@svenskenergi.se