Nordel

GRID DISTURBANCE AND FAULT STATISTICS

2006

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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 2006. 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 power systems.

Nordel's Guidelines for the Classification of Grid Disturbances [1] were prepared during the years 1999-2000. These guidelines have been used since 2000. When the guidelines were introduced, the statistics were expanded to contain various charts that exclusively include the period 2000-2006. Therefore there are tables in this report that include data only for the period 2000-2006. In those cases where data for the previous 10 years was available, the period 1997 – 2006 has been used.

The statistics can be found in Nordel's webpage www.nordel.org. The guidelines and Nordel disturbance statistics were in the "Scandinavian" language until 2005. In 2007 the guidelines were translated into English and the report of 2006 was the first statistic to be written in English.

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 differences in interpretation between different countries and companies. These differences may have a small scale effect on the statistics 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 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 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 in www.cigre.org.

In Chapter 2 the statistics are summarized, covering the consequences of disturbances in the form of energy not supplied and covering the total number of disturbances in the Nordic power system

In Chapter 3 disturbances are discussed. The focus is on the analysis and allocation of causes to disturbances. The division of disturbances during the year 2006 for each country is presented; for example, 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 contact persons with their addresses are 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

Actual 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	60	110	95	132	100	132	98	130	100
110 - 150	**132**	132	40	-	-	-	-	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 actual voltages, in accordance with Table 1.1.
The percentage of the grid is estimated according to the length of lines in kilometres included in the statistics material.

1.4. Scope and limitations of the statistics

Table 1.2 presents the coverage of the statistics in each country.

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 %	94 %	100 %	99 %	99 %

Finland: The data includes approximately 94 % of Finnish 110 kV lines and stations and approximately 65 % of 110/20 kV transformers. Compared to earlier years, a larger part of the Finnish network is included in this year’s statistics. In the year 2005, 88% of the 110 kV lines were included.

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

Sweden: The network statistics cover data from six different grid owners and the representation of their statistics is not fully consistent.

2. SUMMARY

In 2006 energy not supplied (ENS) due to faults in the Nordic main grid was quite low. ENS was 3.65 GWh, which is about the same magnitude as 3.55 GWh in 2005 and clearly lower than 5.33 GWh in 2004. The ten year annual average energy not supplied during the 1997-2006 period in the Nordel area is 9.23. The corresponding average value for each country is presented in brackets in the following paragraphs. The number in brackets for disturbances that caused the energy not supplied is an average value from the period 2002-2006.

In Denmark the energy not supplied for year 2006 was 34 (989) MWh. The number of grid disturbances was 104 (77) and 7 (4) of them caused ENS. 65 % of ENS is from disturbances in March 2006, the causes of which are not known. This ENS is classified as system disturbance in Table 4.4 and as other in Table 4.2 and Figure 4.5. An ice storm hit Denmark in January. The ice settled on overhead lines in the transmission and distribution systems. The result was galloping lines.

For Finland the energy not supplied in 2006 was 302 (180) MWh. The number of grid disturbances was 250 (309) and 70 (51) of them caused energy not to be supplied. 51 (39) % of ENS occurred due to technical equipment failures. Most of the disturbances were caused by lightning and occurred during the summer months. The percentage of unknown disturbances rose to 45 % in 2006 (from 36 % in 2005).

For Iceland the energy not supplied for 2006 was 913 (426) MWh. The total number of faults was 61 (56), of which 38 (26) led to ENS. About half of the ENS was due to a single fault on a radial line that was out of order for 3 days. Approximately 65% of the faults were due to ice and wind.

For Norway the energy not supplied in 2006 was 1094 (3663) MWh. The number of grid disturbances was 382 (369). The winter storms in January-December gave 50% of the total ENS for 2006. The second biggest contributor to ENS over the year was technical equipment, with 30%.

In Sweden the energy not supplied in 2006 was 1303 (3969) MWh. The total number of disturbances was 475 (713) and 103 (149) of those caused ENS. The winter storms were not as severe as in year 2005 and the amount of ENS was very low.

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 development over the ten year period 1997-2006. 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. Disturbances and Energy Not Supplied (ENS)

The number of disturbances during the year 2006 in the Nordic main grid was 1248, which is somewhat lower than average. The number of grid disturbances cannot be used directly for comparative purposes between countries, because of big differences between external conditions in the Nordel counries' transmission networks.

3.1.1. Number of disturbances according to year during the period 1997-2006

The table below presents the sum of disturbances during the year 2006 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 1997-2006.

Table 3.1. Number of grid disturbances in 2006

Year 2006	**Denmark**	**Finland**	**Iceland**	**Norway**	**Sweden**
Number of disturbances	104	250	37	382	475

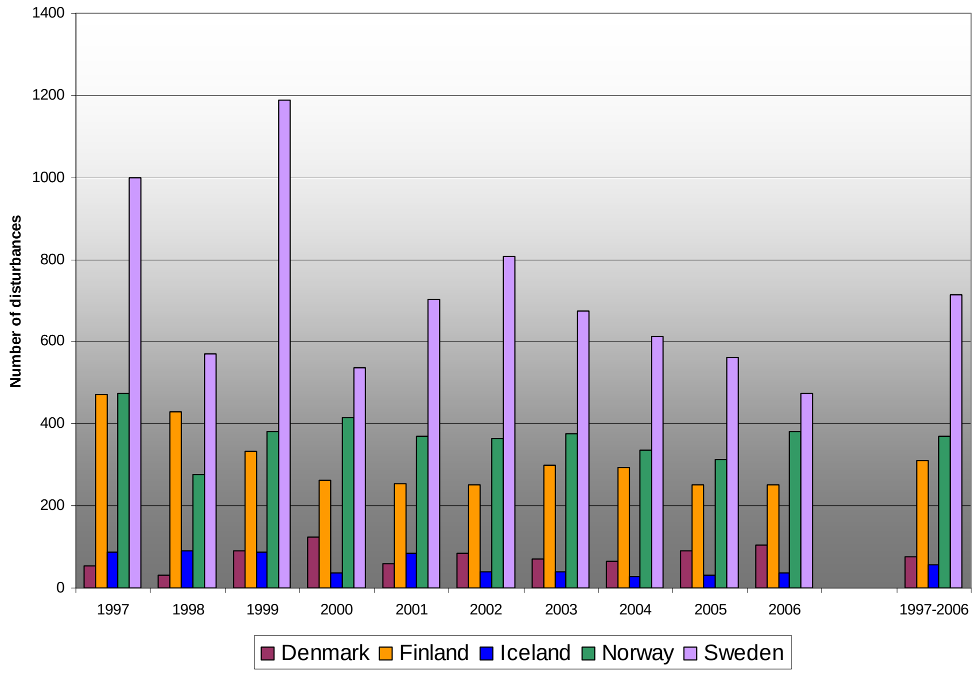

Figure 3.1. Number of grid disturbances in each Nordel country 1997-2006

3.1.2. Distribution of grid disturbances in 2006

The following figure presents the percentage distribution of grid disturbances according to month in 2006. The numbers in the table are a sum of all the disturbances in the 100-400 kV networks.

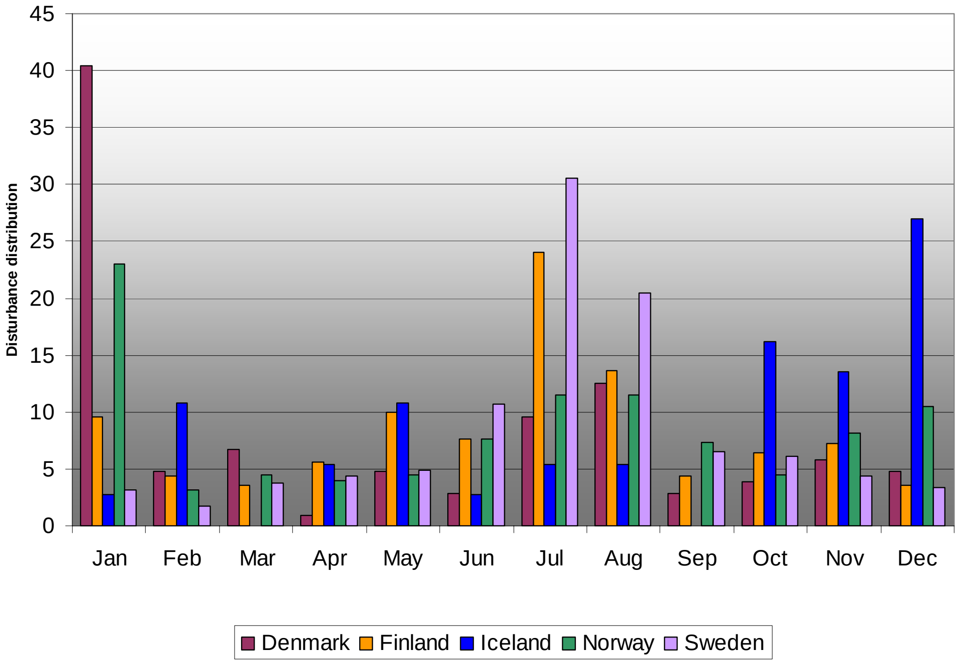

Figure 3.2. Percentage division of grid disturbances according to month for each country in 2006

For all countries except Iceland the number of disturbances is usually greatest during the summer period. This is caused by lightning during summer. The high number of disturbances in Denmark during January was caused by galloping lines due to an ice storm. Table 3.2 presents the numerical values behind Figure 3.2.

Table 3.2. Percentage distribution of grid disturbances per month for each country in 2006

Country	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Denmark	40	5	7	1	5	3	10	13	3	4	6	5
Finland	10	4	4	6	10	8	24	14	4	6	7	4
Iceland	3	11	0	5	11	3	5	5	0	16	14	27
Norway	23	3	4	4	4	8	12	12	7	4	8	10
Sweden	3	2	4	4	5	11	31	20	7	6	4	3
Nordel	14	3	4	4	6	8	21	15	6	6	6	6

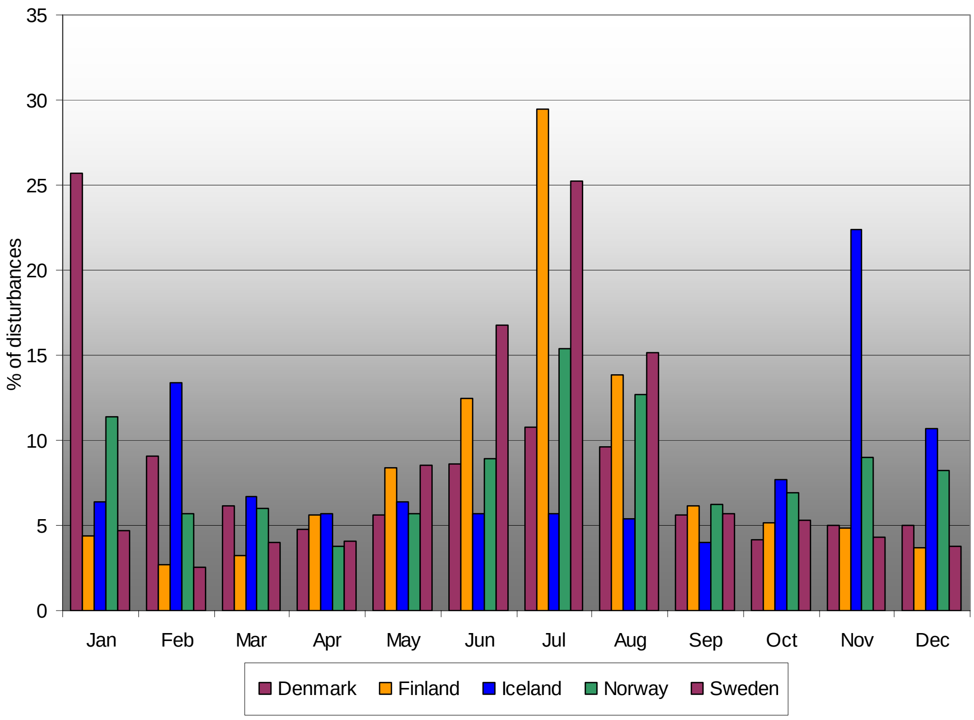

Figure 3.3. Percentage distribution of grid disturbances during the period 2000 – 2006

Table 3.3. Percentage division of grid disturbances during the years 2000 – 2006

Country	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Denmark	26	9	6	5	6	9	11	10	6	4	5	5
Finland	4	3	3	6	8	12	29	14	6	5	5	4
Iceland	6	13	7	6	6	6	6	5	4	8	22	11
Norway	11	6	6	4	6	9	15	13	6	7	9	8
Sweden	5	3	4	4	9	17	25	15	6	5	4	4
Nordel	8	4	5	4	8	13	22	14	6	6	6	5

3.2. Grid 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 (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 causes of grid disturbances and energy not supplied in each country is presented in Table 3.5.

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 of disturbances		Percentage distribution of ENS[1]	
		2006	2000-2006	2006	2000-2006
Lightning	Denmark	12	17	17	0
	Finland	26	38	2	9
	Iceland	5	2	1	1
	Norway	22	23	10	6
	Sweden	46	45	47	12
Other natural causes	Denmark	37	31	0	0
	Finland	7	4	2	13
	Iceland	24	42	65	54
	Norway	15	18	50	29
	Sweden	5	4	5	6
External influences	Denmark	10	14	0	0
	Finland	3	2	2	4
	Iceland	3	1	0	0
	Norway	1	1	0	2
	Sweden	3	3	7	1
Operation and maintenance	Denmark	28	15	17	4
	Finland	8	5	28	25
	Iceland	11	10	3	14
	Norway	19	14	7	12
	Sweden	6	7	18	10
Technical equipment	Denmark	2	11	0	12
	Finland	6	4	51	29
	Iceland	30	21	25	24
	Norway	30	23	27	36
	Sweden	11	16	7	51
Other	Denmark	3	5	65	84
	Finland	4	9	10	16
	Iceland	22	17	0	2
	Norway	16	16	6	14
	Sweden	12	9	9	17
Unknown	Denmark	10	8	0	0
	Finland[2]	45	37	4	5
	Iceland	5	6	5	4
	Norway	4	5	0	1
	Sweden	17	16	8	3

[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 lightning and other natural phenomena as their cause, but this is only speculation.

In Figure 3.4 disturbances for all voltage levels are identified in terms of the initial fault.

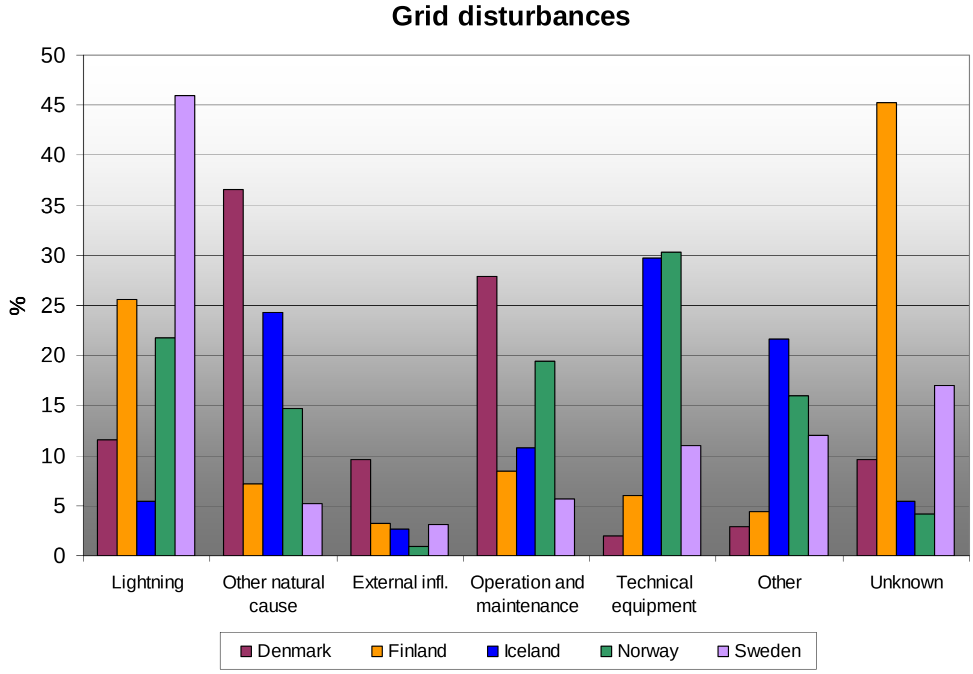

Figure 3.4. Grid disturbances divided according to cause in 2006

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

4. ENERGY NOT SUPPLIED (ENS)

This chapter presents an overview of energy not supplied in the Nordel countries. It should be noted 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. The definition of energy not supplied is:
The estimated energy which would have been supplied to end users if no interruption and no transmission restrictions had occurred [1, 2].

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	Energy not supplied MWh	ENS divided into different voltage levels (%) 2000-2006			
	2006	132 kV	220 kV	>400 kV	Other[2)]
Denmark	34.4	4.7	0.0	95.3[1)]	0.0
Finland	301.6	95.1	2.6	0.0	2.3
Iceland	913.2	50.4	49.6	0.0	0.0
Norway	1093.7	40.0	34.6	3.3	22.0
Sweden	1302.8	44.9	4.4	38.3[1)]	12.5
Nordel	3645.6	38	16	33	13

[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 the connections to foreign countries, auxiliary equipment and lower voltage level networks, etc.

In Figures 4.1 and 4.2 (next page), energy not supplied is summarized according to the different voltage levels for the year 2006 and for the period 1997-2006, respectively. Voltage level refers to the initiating fault of the respective disturbance.

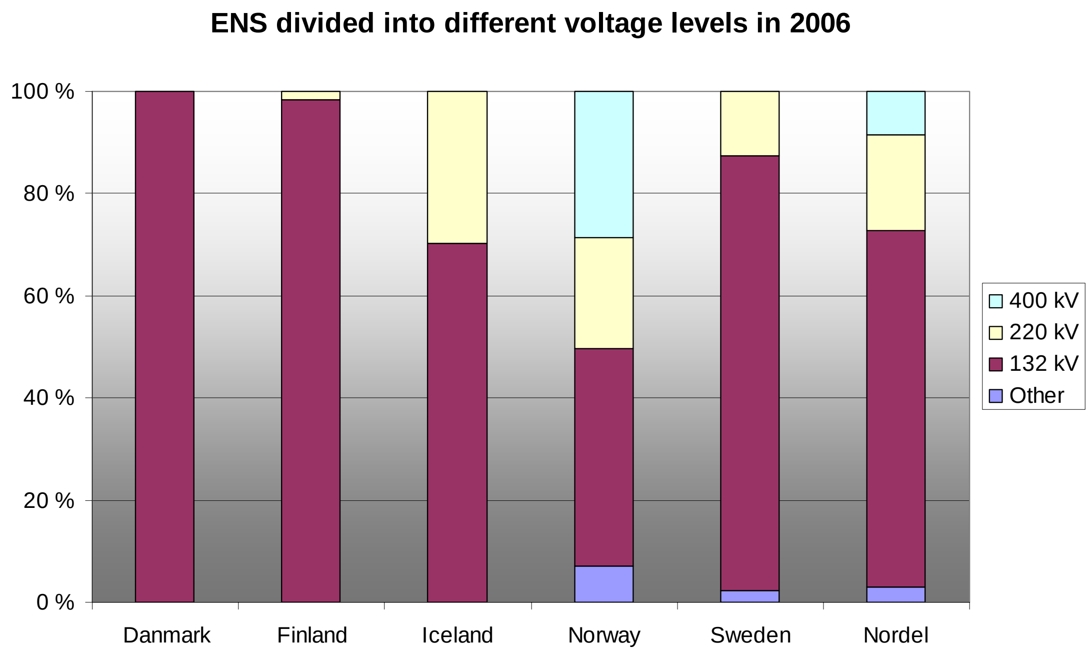

Figure 4.1. Energy Not Supplied (ENS) in terms of the voltage level of the initiating fault in 2006

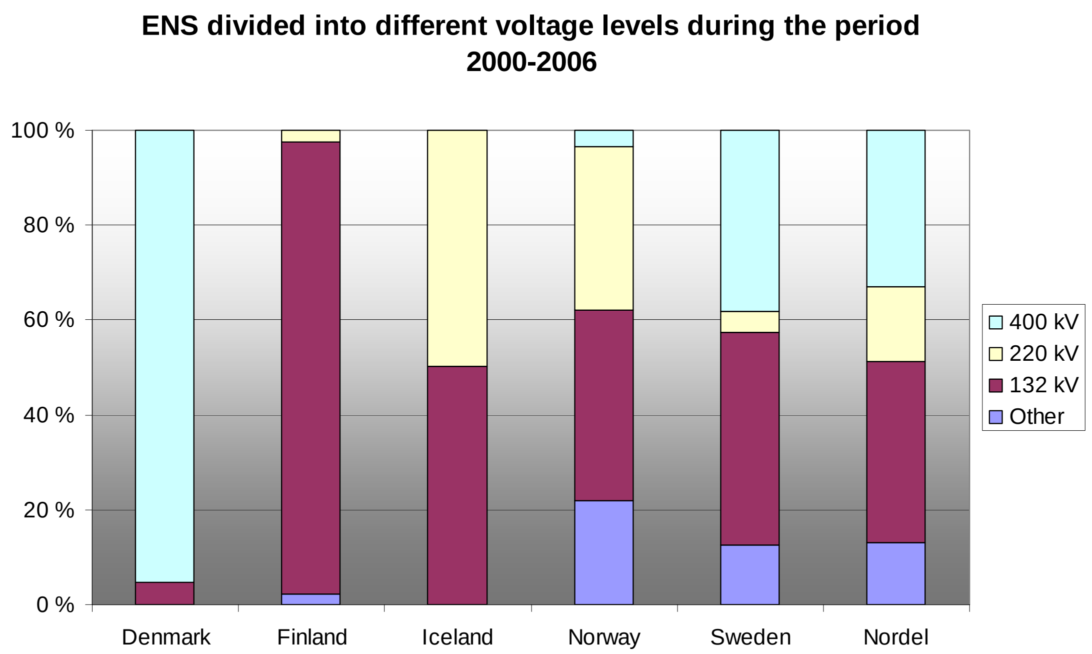

Figure 4.2. Energy Not Supplied (ENS) in terms of the voltage level of the initiating fault during the period 2000-2006

The large amount of energy not supplied at 400 kV 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.

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	ENS	ENS / Consumption		Division of ENS by installation for the period 1997-2006 (%)			
	GWh 2006	MWh 2006	Ppm 2006	Ppm 1997-2006	Overhead line	Cable	Stations	Other
Denmark	35750	34.39	0.96	28.40	11.7	0.0	6.9	81.4
Finland	81824	301.58	3.69	2.66	25.2	0.0	53.7	21.1
Iceland	9925	913.18	92.01	57.37	56.2	0.0	39.2	4.6
Norway	121167	1093.66	9.03	30.98	33.6	0.8	47.8	17.9
Sweden	145667	1302.82	8.94	31.19	19.8	8.1	62.3	9.8
Total	394333	3645.63	9.25	25.96	26.2	3.8	49.4	20.7

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

Figure 4.3 presents the development of energy not supplied during the period 1997-2006. It should be noted 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.

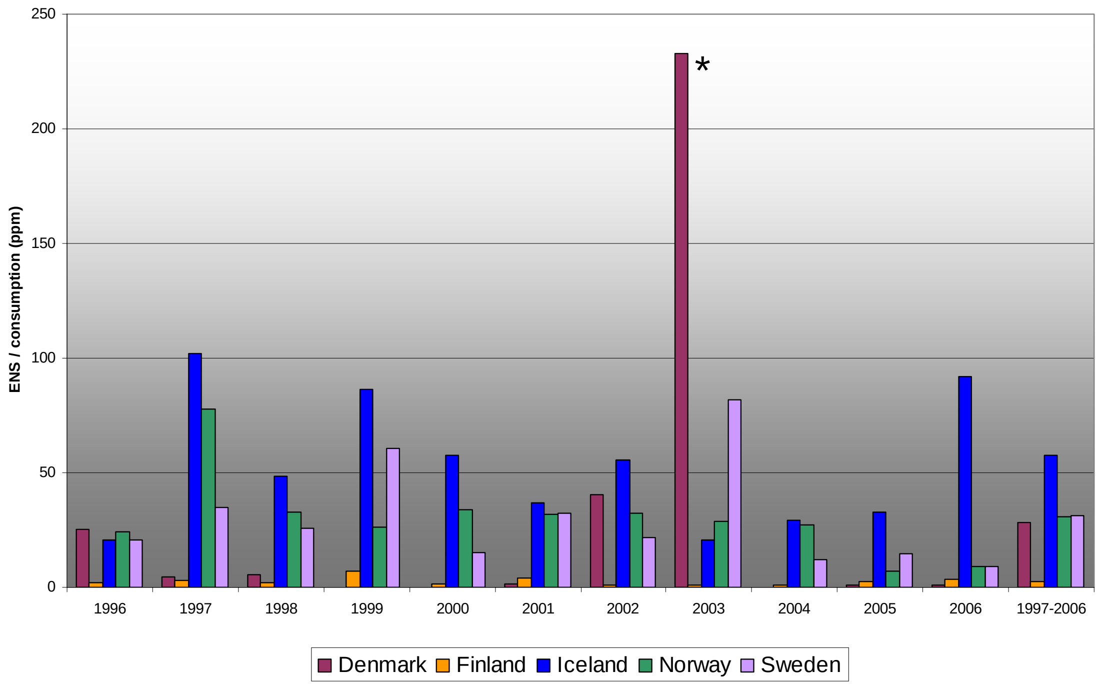

Figure 4.3. Energy Not Supplied (ENS) / consumption (ppm)

* The large amount of energy not supplied in Denmark is a consequence of the big disturbance in Southern Sweden on the 23rd of September in 2003 that caused the whole of Zealand to lose its power.

4.1.1. Energy not supplied according to month in 2006

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

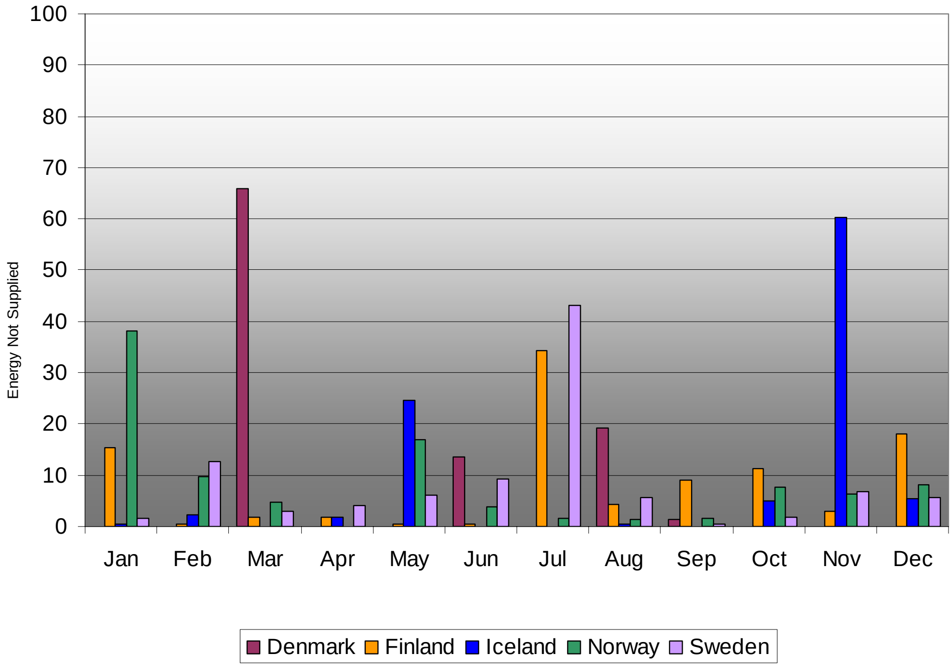

Figure 4.4. Energy Not Supplied according to month in 2006

The high value for Iceland in November is caused by a single radial line that had a standing ground-fault that could not be repaired for three days because of bad weather. 65 % of Danish energy not supplied is from system disturbances with unknown cause that occurred in March.

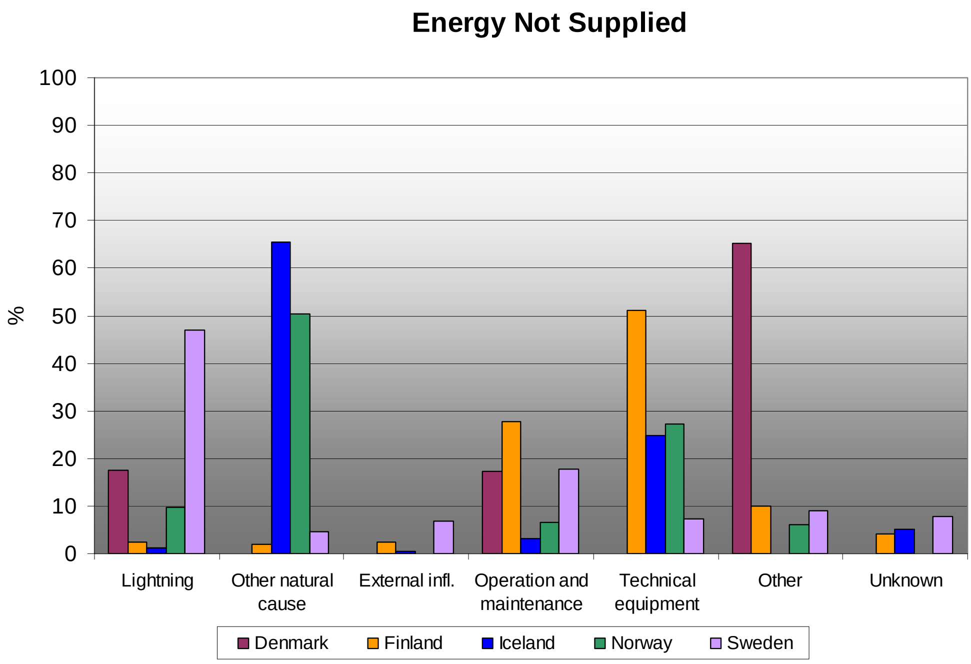

Figure 4.5. Grouping of Energy Not Supplied in 2006 by cause

The high value of Iceland in the category ”Other natural cause” is caused by the fact that almost all faults in Iceland are due to storm and ice, which is categorized as other natural cause. 65 % of the Danish energy not supplied is from system disturbances (classified as “Other”) with unknown causes in March.

Table 4.3. Energy Not Supplied in year 2006 and the annual average for the period 2000-2006

	Denmark		**Finland**		**Iceland**		**Norway**		**Sweden**		**Nordel**	
ENS	2006	2000-2006	2006	2000-2006	2006	2000-2006	2006	2000-2006	2006	2000-2006	2006	2000-2006
MWh	34	1382	302	193	913	347	1094	2414	1303	3743	3646	8079

Table 4.4. Percentage distribution of Energy Not Supplied in terms of component

Fault location	Denmark		Finland		Iceland		Norway		Sweden		Nordel	
	2006	2000-2006	2006	2000-2006	2006	2000-2006	2006	2000-2006	2006	2000-2006	2006	2000-2006
Overhead line	17.4	1.4	50.5	38.9	66.9	54.5	43.3	28.0	51.4	17.3	52.5	19.9
Cable	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	11.1	0.0	5.3
Sum of Line faults	17.4	1.5	50.5	38.9	66.9	54.5	43.3	28.6	51.4	28.4	52.5	25.2
Power transformer	13.6	0.6	10.2	2.3	0.0	0.6	1.6	0.7	8.8	10.6	4.6	5.3
Instrument transformer	0.0	0.0	0.0	4.4	0.0	0.1	4.3	3.9	3.8	2.5	2.7	2.5
Circuit breaker	0.0	3.4	10.4	4.5	0.0	11.6	0.4	1.3	5.4	1.8	2.9	2.4
Disconnector	0.6	0.0	0.8	0.8	0.0	0.0	0.0	4.9	5.7	40.5	2.1	20.2
Surge arrester and spark gap	0.0	0.0	0.6	3.3	0.0	0.0	17.2	2.7	0.0	0.2	5.2	1.0
Busbar	0.0	0.1	15.4	4.5	0.0	7.3	0.0	1.8	0.1	1.7	1.3	1.7
Control equipment	3.1	11.4	1.9	21.0	27.1	23.4	23.2	29.1	13.0	4.4	18.6	14.2
Common ancillary equipment	0.0	0.0	0.0	1.4	0.0	0.0	0.0	0.1	0.2	0.0	0.1	0.1
Other substation faults	0.0	0.0	5.4	1.3	0.0	0.0	2.8	1.7	2.8	2.2	2.3	1.6
Sum of Substation faults	17.3	15.5	44.7	43.5	27.1	43.0	49.6	46.2	39.9	63.9	39.8	49.0
Shunt capacitor	0.0	0.0	0.0	0.4	0.6	0.2	0.0	0.1	0.0	1.2	0.2	0.6
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	0.1	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 Compensation	0.0	0.0	0.0	0.4	0.6	0.2	0.0	0.1	0.0	1.2	0.2	0.6
System fault	65.3	82.9	0.0	0.0	5.4	2.3	2.6	8.2	1.4	0.5	3.2	17.0
Faults in adjoining statistical area	0.0	0.1	4.8	10.4	0.0	0.0	4.5	17.0	7.3	5.2	4.4	7.7
Unknown	0.0	0.0	0.0	6.8	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.5
Sum of other faults	65.3	83.0	4.8	17.2	5.4	2.3	7.1	25.1	8.7	6.4	7.6	25.2

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. It is not possible to present very detailed information in the Nordel statistics. Readers who need more detailed data should use the national statistics.

Definition of a component fault:
The inability of a component to perform its required function [3, 4].

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. As a new addition compared to the 2005 statistics the fault trend curves of some components have been added. The trend curves show the variation in fault frequencies of consecutive 5-year periods. These curves are not divided into different voltage levels.

5.1. Overview of all faults

Table 5.1 presents the number of faults and disturbances during 2006.

Table 5.1. Number of faults and grid disturbances in 2006

Year 2006	**Denmark**	**Finland**	**Iceland**	**Norway**	**Sweden**
Number of faults	122	280	42	485	484
Number of disturbances	104	250	37	382	475
Fault / disturbance –ratio in 2006	1.17	1.12	1.14	1.27	1.02
The average fault / disturbance –ratio during 2000-2006	1.16	1.16	1.21	1.34	1.15

5.1.1. Overview of faults divided according to country and 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 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 transformers.

Table 5.2. Faults in different countries in terms of voltage level

Voltage(ENS)	Country	Size of the grid		Number of faults		ENS * (MWh)	
		Number of transformers	Length of lines in km	2006	2000-2006 (annual average)	2006	2000-2006 annual average
400 kV	Denmark	23	1228	8	12.4	0.0	470.1
	Finland	49	4175	12	22.1	0.0	0.0
	Iceland	0	0	0	-	0.0	-
	Norway	63	2708	93	62.4	312.6	82.0
	Sweden	28	10649	103	130.9	0.1	1499.2
220 kV	Denmark	2	105	0	0.9	0.0	0.0
	Finland	23	2401	16	25.9	5.1	4.1
	Iceland	27	749	15	14.9	272.2	207.0
	Norway	274	6165	113	121.9	239.0	1034.2
	Sweden	120	4331.637	61	68.1	163.9	172.4
132 kV	Denmark	241	3640	112	82.6	34.4	64.5
	Finland	591	14031	247	218.3	296.5	153.5
	Iceland	41	1292.1	27	34.6	640.9	208.2
	Norway	722	10677	205	190.0	464.3	1299.0
	Sweden	694	15450	297	413.1	1108.8	1759.0

*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. It should be noted 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 Energy Not Supplied according to component

Fault location	Denmark 2006	Denmark 2000-2006	Finland 2006	Finland 2000-2006	Iceland 2006	Iceland 2000-2006	Norway 2006	Norway 2000-2006	Sweden 2006	Sweden 2000-2006	Nordel 2006	Nordel 2000-2006
Overhead line	56.6	60.5	76.4	72.4	38.1	42.7	45.6	38.5	62.9	57.5	58.3	54.3
Cable	0.8	2.1	0.0	0.0	0.0	0.0	0.2	0.7	0.0	0.2	0.1	0.4
Sum of all line faults	57.4	62.7	76.4	72.4	38.1	42.7	45.8	39.2	62.9	57.8	58.5	54.7
Power transformer	4.1	4.0	2.5	0.7	0.0	1.9	1.2	1.8	6.0	5.2	3.3	3.2
Instrument transformer	1.6	0.6	0.4	0.4	0.0	0.5	1.4	1.9	1.0	0.8	1.1	1.0
Circuit breaker	5.7	5.7	1.1	1.4	2.4	8.1	1.9	3.4	5.2	3.9	3.2	3.5
Disconnector	3.3	1.7	1.1	0.6	0.0	0.0	0.2	1.3	1.0	0.6	0.9	0.9
Surge arresters and spark gap	0.0	0.6	0.4	0.2	0.0	0.5	0.8	0.9	0.0	0.2	0.4	0.4
Busbar	0.0	0.4	0.7	0.4	0.0	0.8	1.0	1.2	0.8	1.0	0.8	0.9
Control equipment	13.9	12.4	11.4	11.7	31.0	25.9	27.2	32.2	6.8	12.8	16.1	18.7
Common ancillary equipment	0.0	0.4	0.0	0.3	0.0	0.0	1.6	0.8	0.6	1.0	0.8	0.8
Other substation faults	3.3	2.7	2.9	0.7	0.0	8.6	2.1	2.0	1.0	0.9	1.9	1.5
Sum of all substation faults	32.0	28.6	20.4	16.4	33.3	46.5	37.5	45.5	22.5	26.3	28.4	31.0
Shunt capacitor	0.8	0.1	1.4	1.2	2.4	0.5	0.8	1.3	0.2	0.7	0.8	0.9
Series capacitor	0.0	0.0	0.4	0.1	0.0	0.3	0.0	0.0	1.2	1.1	0.5	0.5
Reactor	2.5	1.7	0.0	0.6	0.0	0.0	0.8	0.5	1.0	0.9	0.8	0.7
SVC and statcom	0.0	0.0	0.0	0.0	0.0	0.0	1.9	1.1	1.9	1.0	1.3	0.7
Synchronous compensator	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.9	0.2	0.3	0.4	0.4
Sum of all compensation	3.3	1.9	1.8	1.9	2.4	0.8	4.3	3.8	4.5	4.0	3.7	3.3
System fault	5.7	3.1	0.0	0.0	26.2	9.2	0.6	2.2	6.0	3.7	3.5	2.7
Faults in adjoining statistical area	1.6	3.6	1.4	4.8	0.0	0.0	11.8	9.3	4.1	4.7	5.9	5.8
Unknown	0.0	0.1	0.0	4.5	0.0	0.8	0.0	0.0	0.0	3.6	0.0	2.4
Sum of all other faults	7.4	6.9	1.4	9.3	26.2	10.0	12.4	11.5	10.1	11.9	9.4	11.0

5.2. Faults in overhead lines

Overhead lines constitute a very large part of the Nordel transmission grid. Therefore, the table below shows the division of faults in 2006 as well as the ten year period 1997-2006. Faults divided by cause during the ten year period are also given. Along with the tables, the annual division of faults during the period 1997-2006 is presented graphically for all voltage levels. Figure 5.4 presents 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. Overhead lines 400 kV

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

Country	Line km 2006	Number of faults 2006	Number of faults per 100 km		Faults divided by cause during the period 1997-2006 (%)								
			2006	1997-2006	Lightning	Other natural causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown	1-phase faults	Permanent faults
Denmark	1228	1	0.08	0.38	17.8	62.2	4.4	6.8	6.6	2.2	0.0	51	7
Finland	4175	2	0.05	0.29	82.1	6.8	0.8	1.7	0.9	3.4	4.2	56	7
Norway	2683	58	2.16	1.27	23.7	71.0	0.3	0.0	2.0	1.4	1.6	73	8
Sweden	10645	29	0.27	0.40	55.1	20.3	2.0	1.8	2.8	0.9	17.0	81	9
Nordel	18731	90	0.48	0.49	46.1	37.9	1.4	1.4	2.5	1.5	9.2	73	8

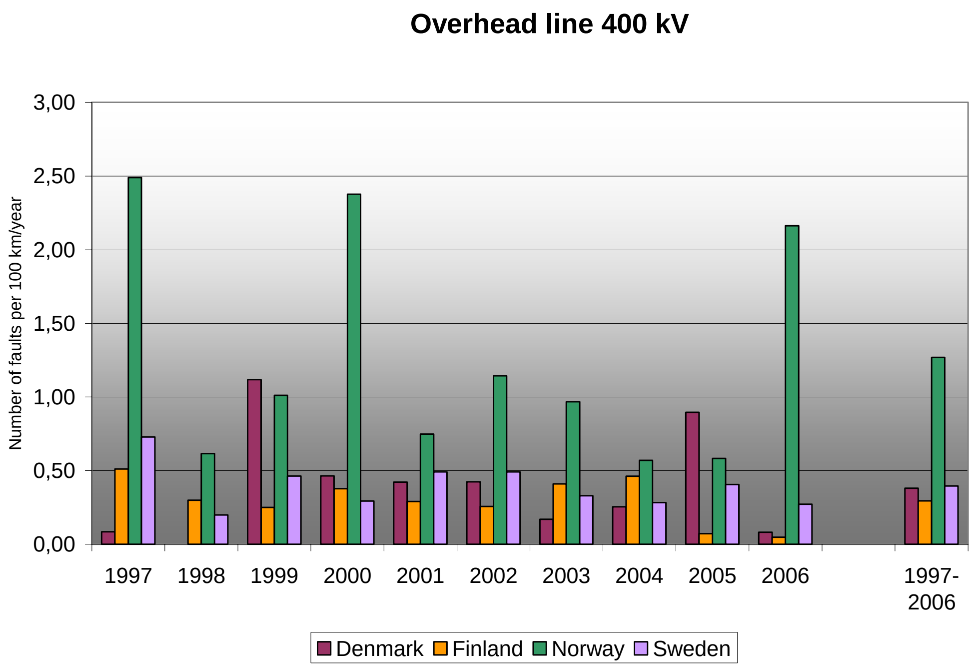

Figure 5.1. Annual division of faults during the period 1997-2006

5.2.2. Overhead lines 220 kV

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

Country	Line km	Number of faults	Number of faults per 100 km		Faults divided by cause during the period 1997-2006 (%)								
	2006	2006	2006	1997-2006	Lightning	Other natural causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown	1-phase faults	Permanent faults
Denmark	105	0	0.00	0.67	57.1	14.3	14.3	0.0	0.0	0.0	14.3	86	0
Finland	2401	11	0.46	0.84	51.2	3.9	2.5	0.5	0.5	1.0	40.5	66	3
Iceland	749	1	0.13	0.43	37.0	51.9	0.0	0.0	11.1	0.0	0.0	67	15
Norway	5715	33	0.58	0.77	56.6	31.2	1.1	0.2	2.9	2.5	5.7	64	10
Sweden	4117	40	0.97	0.94	74.7	4.6	3.2	3.7	2.1	0.5	11.2	56	8
Nordel	13087	85	0.65	0.82	62.0	16.4	2.2	1.6	2.4	1.4	14.2	61	8

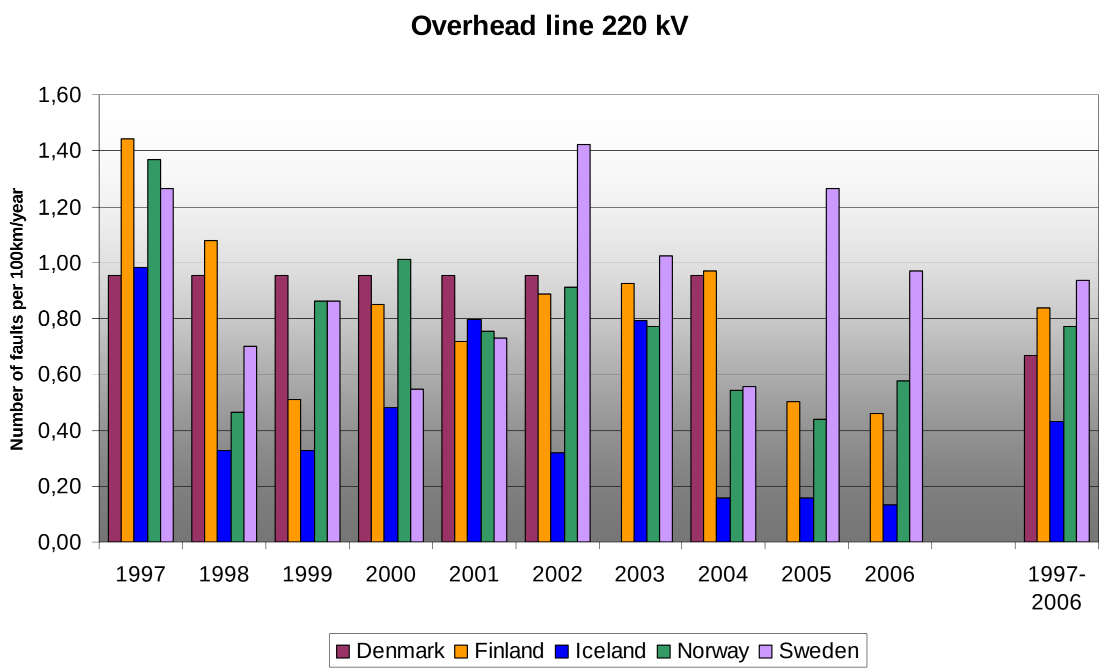

Figure 5.2. Annual division of faults during the period 1997-2006

5.2.3. Overhead lines 132 kV

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

Country	Line km 2006	Num-ber of faults 2006	Number of faults per 100 km		Faults divided by cause during the period 1997-2006 (%)								
			2006	1997-2006	Light-ning	Other natural causes	Ex-ternal influ-ences	Ope-ration and mainte-nance	Tech-nical equip-ment	Oth-er	Un-known	1-pha-se faults	Perma-nent faults
Denmark	3640	68	1.87	1.13	24.4	44.7	17.6	2.9	1.5	3.6	5.3	48	5
Finland	13916	201	1.44	2.09	48.1	5.7	1.7	0.7	0.3	0.8	42.7	73	2
Iceland	1247	15	1.20	1.50	2.2	86.7	2.9	1.1	6.5	0.0	0.5	47	13
Norway	10475	130	1.24	1.18	57.5	28.7	2.9	0.8	5.8	3.7	0.6	21	15
Sweden	15236	236	1.55	2.69	65.7	4.9	2.6	1.7	1.9	1.7	21.6	41	5
Nordel	44514	650	1.46	1.91	55.0	13.7	3.4	1.3	2.2	1.9	22.6	48	6

* The Norwegian grid partly includes a resonant earthed system, which has an effect on the low number of single phase earth faults in Norway.

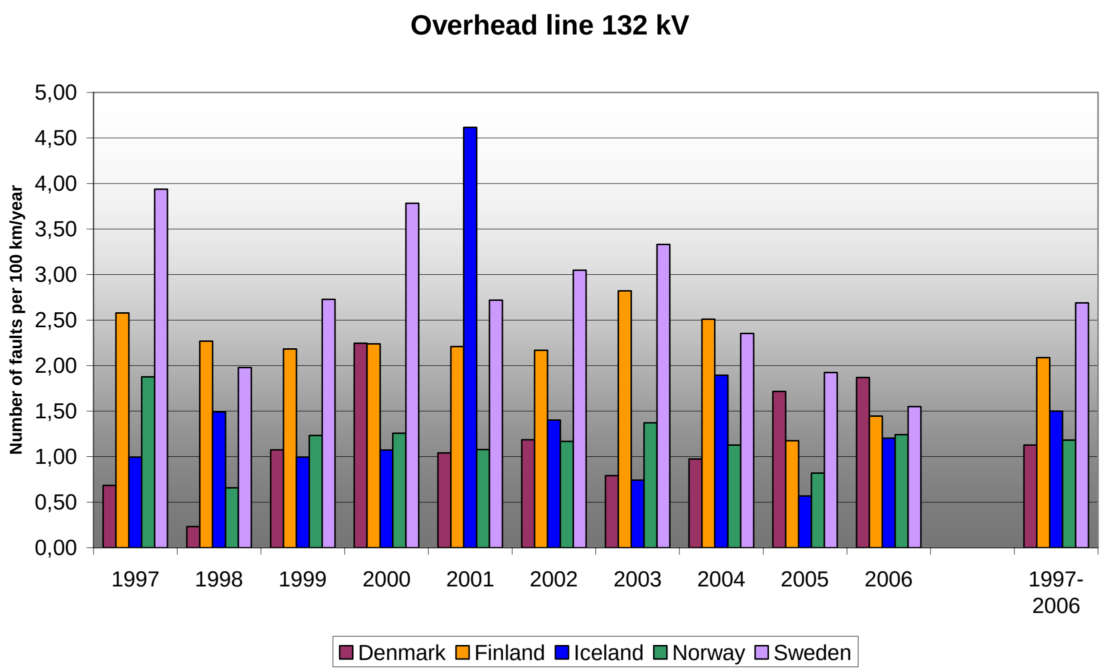

Figure 5.3. Annual division of faults during the period 1997-2006

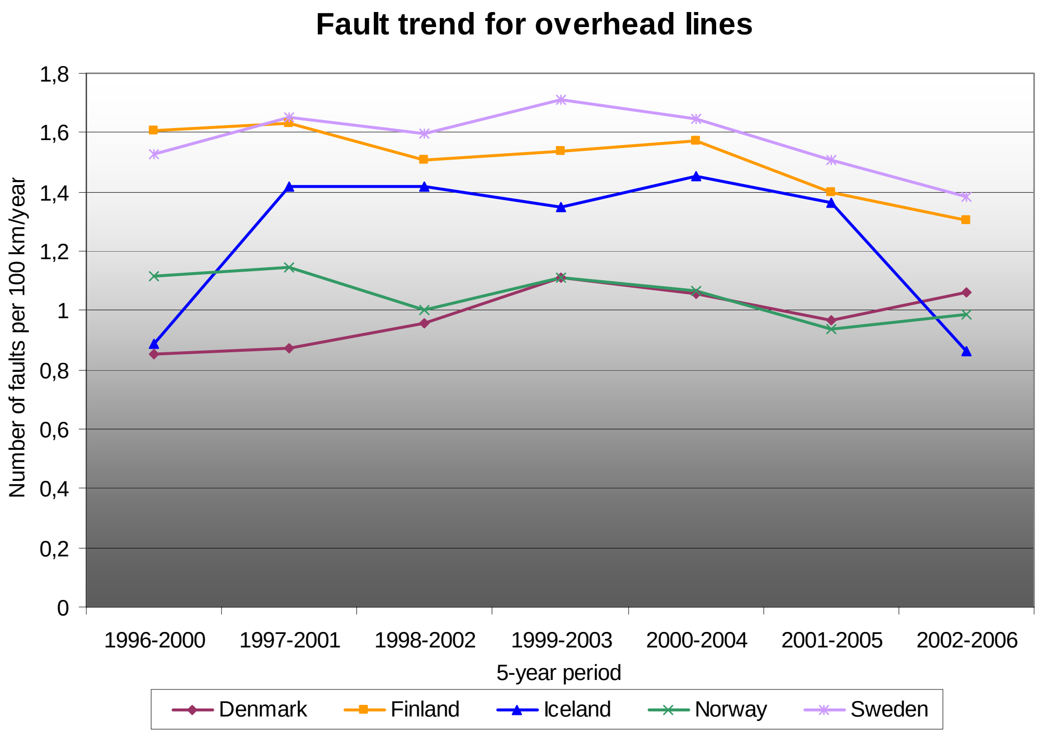

Figure 5.4. Fault trend for overhead lines at all voltage levels

Figure 5.4 presents faults divided by line length at all 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 below present faults in cables at each respective voltage level, with fault division for year 2006 and for the period 1997-2006. In addition the division of faults according to cause is given for the ten year period. The annual division of faults during the period 1997-2006 is presented graphically for 132 kV cables. Figure 5.6 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. For more detailed information, use of the relevant national statistics is recommended.

5.3.1. Cables 400 kV

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

Country	Line km	Number of faults	Number of faults per 100 km		Faults divided by cause during the period 1997-2006 (%)						
	2006	2006	2006	1997-2006	Lightning	Other natural cause	External influence	Operation and maintenance	Technical equipment	Other	Unknown
Denmark	174	0	0.00	0.58	0.0	0.0	0.0	16.7	50.0	16.7	16.7
Norway	25	0	0.00	0.38	0.0	0.0	0.0	0.0	100.0	0.0	0.0
Sweden	4	0	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nordel	203	0	0.00	0.52	0.0	0.0	0.0	14.3	57.1	14.3	14.3

5.3.2. Cables 220 kV

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

Country	Line km	Number of faults	Number of faults per 100 km		Faults divided by cause during the period 1997-2006 (%)						
	2006	2006	2006	1997-2006	Lightning	Other natural cause	External influence	Operation and maintenance	Technical equipment	Other	Unknown
Norway	450	0	0.00	0.14	0.0	33.3	0.0	33.3	33.3	0.0	0.0
Sweden	215	0	0.00	0.33	0.0	0.0	0.0	0.0	100.0	0.0	0.0
Nordel	667	0	0.00	0.18	0.0	20.0	0.0	20.0	60.0	0.0	0.0

5.3.3. Cables 132 kV

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

Country	Line km 2006	Number of faults 2006	Number of faults per 100 km		Faults divided by cause during the period 1997-2006 (%)						
			2006	1997-2006	Lightning	Other natural cause	External influence	Operation and maintenance	Technical equipment	Other	Unknown
Denmark	500	1	0.20	0.30	7.7	0.0	46.2	15.4	23.1	7.7	0.0
Finland	115	0	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Iceland	45	0	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Norway	202	1	0.50	1.69	0.0	3.2	12.9	3.2	67.7	9.7	3.2
Sweden	213	0	0.00	0.59	0.0	0.0	25.0	8.3	25.0	33.3	8.3
Nordel	1075	2	0.19	0.63	1.8	1.8	16.1	7.1	48.2	14.3	3.6

*Cables in Norway include resonant earthed cables.

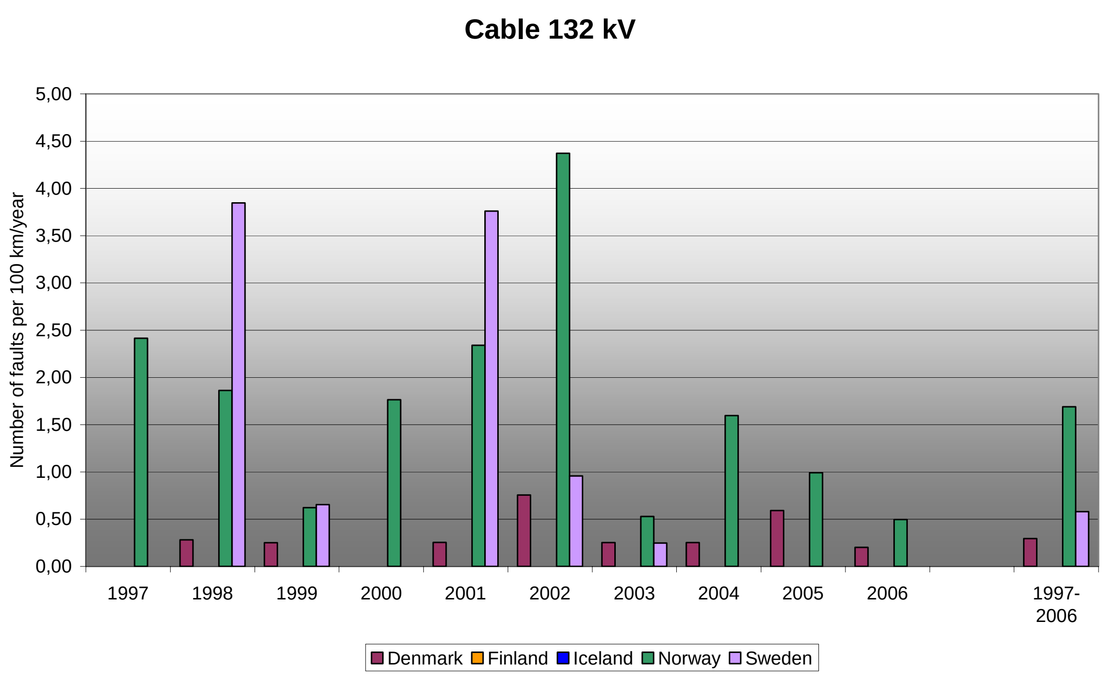

Figure 5.5. Annual division of faults during the period 1997-2006

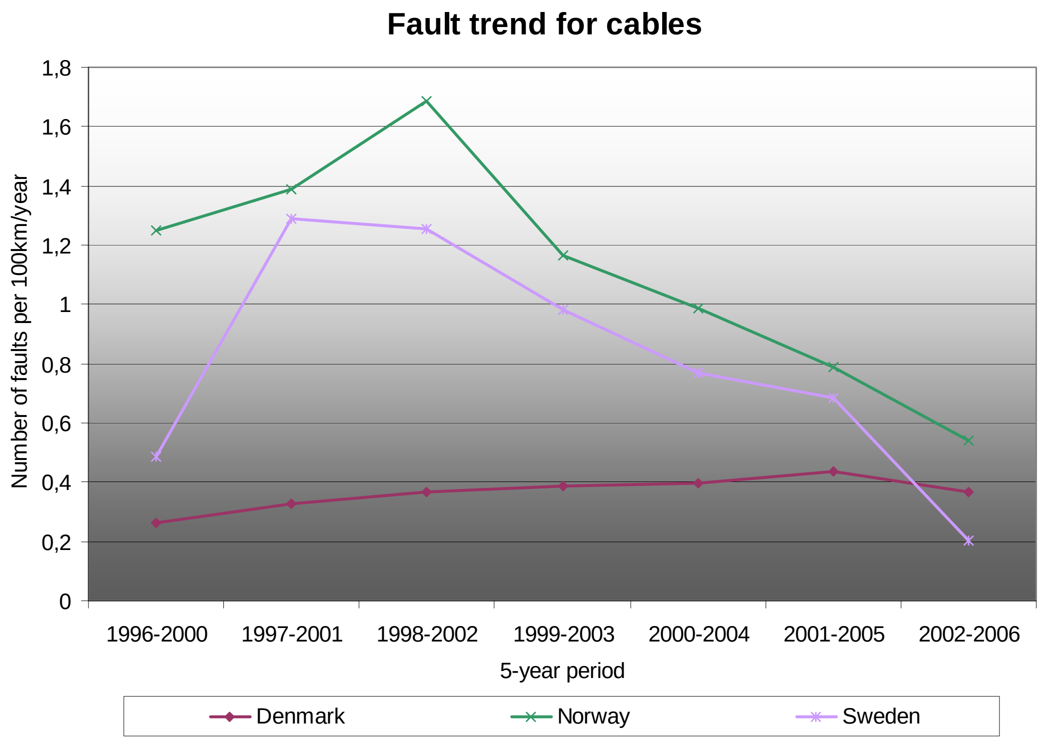

Figure 5.6. Fault trend for cables at all voltage level

Figure 5.6 presents the fault trend only for Denmark, Norway and Sweden due to the low number of cables in Finland and Iceland.

5.4. Faults in power transformers

The tables below present the faults division for the year 2006 and for the period 1997-2006 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 1997-2006 is presented graphically for all voltage levels. Figure 5.10 presents the trend of faults for power transformers, which also allows the trend of faults to be estimated in the future. For more detailed information one should use the national statistics.

5.4.1. Power transformers 400 kV

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

Country	Number of devices 2006	Number of faults 2006	Number of faults per 100 devices		Faults divided by cause during the period 1997-2006 (%)						
			2006	1997-2006	Lightning	Other natural cause	External influence	Operation and maintenance	Technical equipment	Other	Unknown
Denmark	23	0	0.00	3.18	14.3	14.3	0.0	14.3	14.3	0.0	42.9
Finland	49	2	4.08	1.86	0.0	25.0	0.0	12.5	37.5	12.5	12.5
Norway	63	0	0.00	0.98	16.7	0.0	0.0	0.0	66.7	16.7	0.0
Sweden	28	1	3.57	1.65	11.0	5.6	0.0	27.7	33.4	22.3	0.0
Nordel	163	3	1.84	1.61	10.5	10.5	0.0	18.4	36.9	15.8	7.9

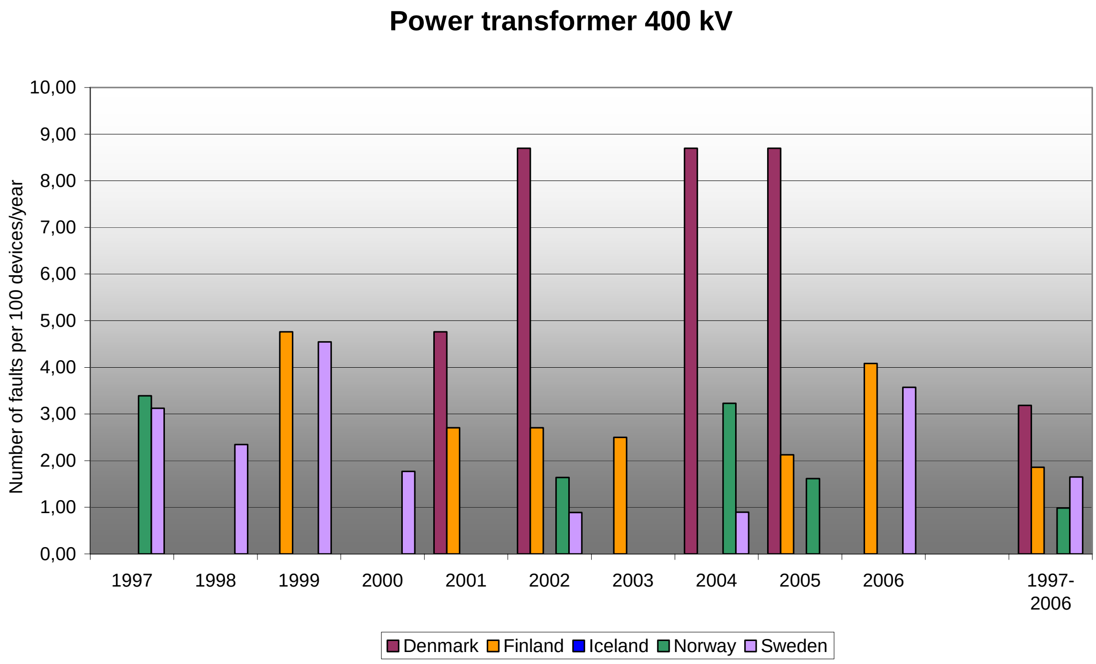

Figure 5.7. Annual division of faults during the period 1997-2006

The high number of faults in Denmark is caused by a transformer that inflicted three out of the seven faults registered during the period 2001-2005.

5.4.2. Power transformers 220 kV

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

Country	Number of devices 2006	Number of faults 2006	Number of faults per 100 devices		Faults divided by cause during the period 1997-2006 (%)						
			2006	1997-2006	Lightning	Other natural 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	23	0	0.00	1.95	20.0	0.0	0.0	0.0	20.0	0.0	60.0
Iceland	27	0	0.00	2.97	0.0	0.0	0.0	28.6	57.1	14.3	0.0
Norway	274	4	1.46	1.65	4.5	0.0	2.3	29.5	50.0	11.4	2.3
Sweden	120	3	2.50	3.19	27.3	4.5	2.3	22.7	20.4	20.5	2.3
Nordel	446	7	1.57	2.19	15.0	2.0	2.0	25.0	36.0	15.0	5.0

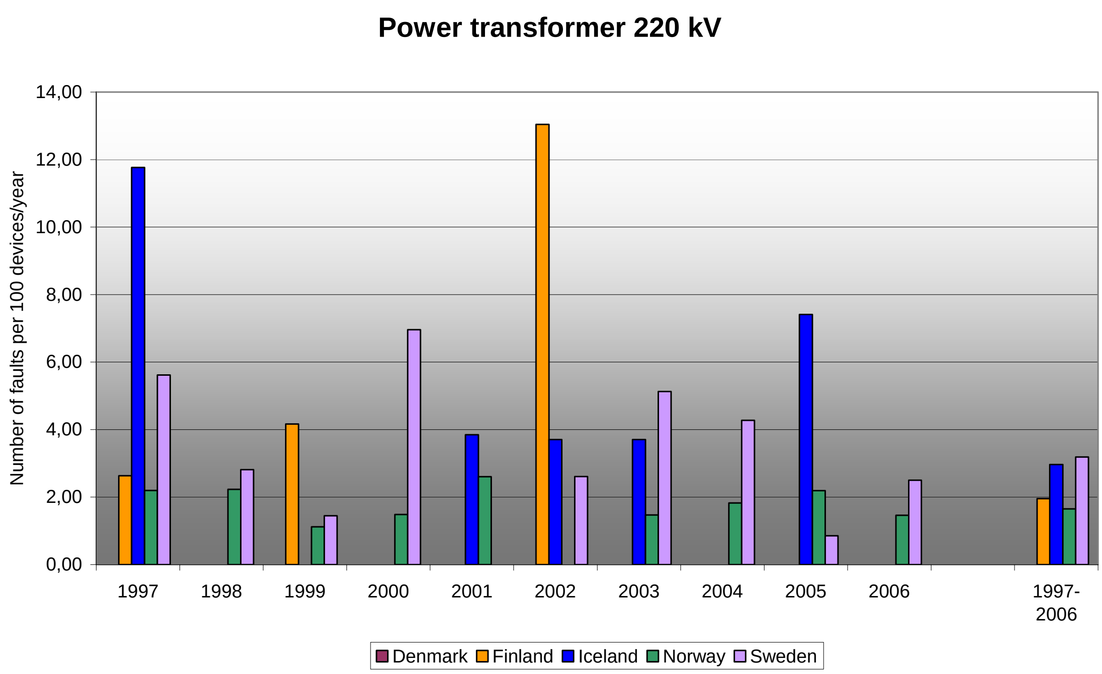

Figure 5.8. Annual division of faults during the period 1997-2006

5.4.3. Power transformers 132 kV

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

Country	Number of devices 2006	Number of faults 2006	Number of faults per 100 devices		Faults divided by cause during the period 1997-2006 (%)						
			2006	1997-2006	Lightning	Other natural cause	External influence	Operation and maintenance	Technical equipment	Other	Unknown
Denmark	241	5	2.07	0.92	4.2	8.3	4.2	33.3	25.0	4.2	20.8
Finland	591	5	0.85	0.41	0.0	0.0	0.0	20.0	40.0	0.0	40.0
Iceland	41	0	0.00	0.51	0.0	0.0	0.0	0.0	50.0	0.0	50.0
Norway	722	2	0.28	0.59	4.7	4.7	2.4	28.7	45.1	11.9	2.4
Sweden	694	25	3.60	5.14	17.9	4.5	3.0	14.5	29.7	17.1	13.4
Nordel	2289	37	1.62	2.06	14.9	4.7	2.9	17.6	31.5	15.2	13.2

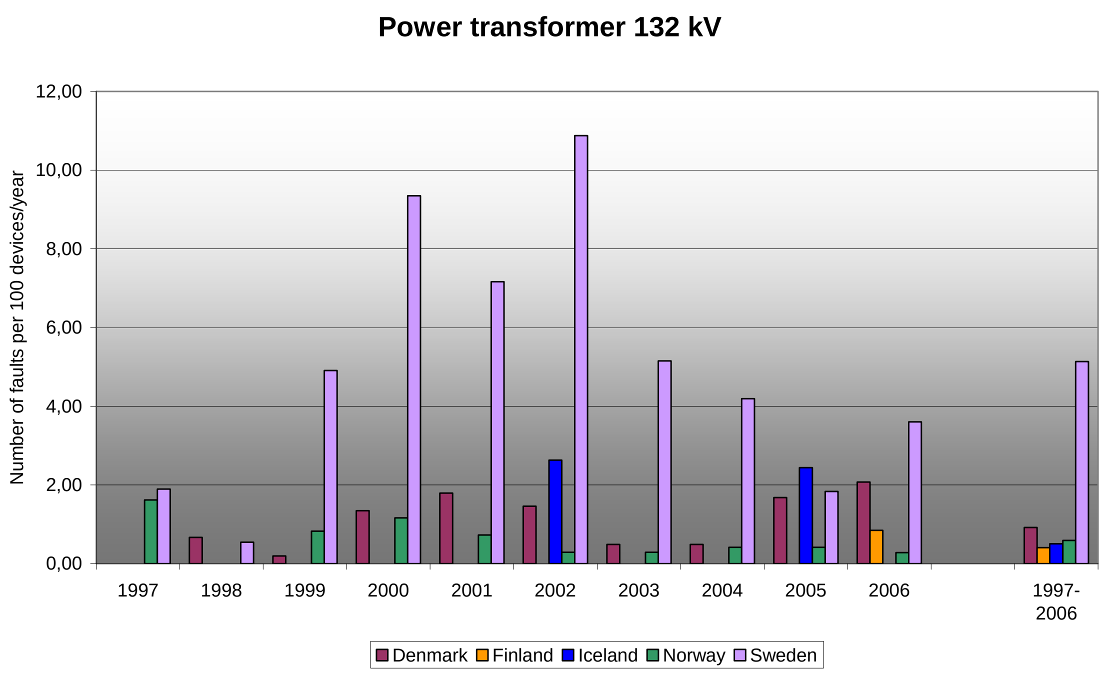

Figure 5.9. Annual division of faults during the period 1997-2006

The high number of faults shown for Sweden during the period 1999 - 2004 was caused by misinterpretation of the Nordic guidelines [1]. In fact, some faults didn't actually concern power transformers.

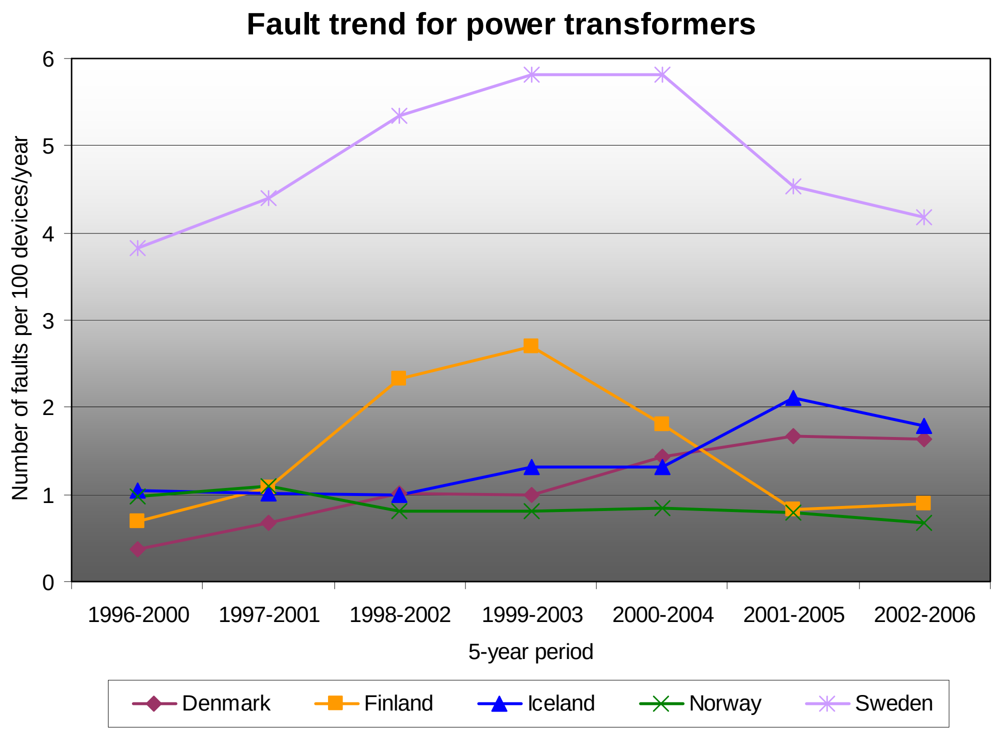

Figure 5.10. Fault trend for power transformers at all voltage levels

The number of Finnish 110/20 kV transformers included in the statistics has increased considerably during the years 2005 and 2006.

5.5. Faults in instrument transformers

The tables below present the faults in instrument transformers for the year 2006 and for the period 1997-2006 at each respective voltage level. In addition, the division of faults according to cause during the ten year period is presented. Figure 5.11 presents 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. For more detailed information the use of national statistics is recommended.

5.5.1. Instrument transformers 400 kV

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

Country	Number of devices 2006	Number of faults 2006	Number of faults per 100 devices		Faults divided by cause during the period 1997-2006 (%)						
			2006	1997-2006	Lightning	Other natural cause	External influence	Operation and maintenance	Technical equipment	Other	Unknown
Denmark	533	0	0.00	0.10	0.0	66.7	0.0	0.0	33.3	0.0	0.0
Finland	359	0	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Norway	933	0	0.00	0.18	0.0	8.3	0.0	8.3	41.7	33.3	8.3
Sweden	935	1	0.11	0.09	8.3	0.0	0.0	16.7	75.0	0.0	0.0
Nordel	2760	1	0.04	0.10	3.7	11.1	0.0	11.1	55.6	14.8	3.7

5.5.2. Instrument transformers 220 kV

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

Country	Number of devices 2006	Number of faults 2006	Number of faults per 100 devices		Faults divided by cause during the period 1997-2006 (%)						
			2006	1997-2006	Lightning	Other natural 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	144	0	0.00	0.04	0.0	0.0	0.0	0.0	100.0	0.0	0.0
Iceland	385	0	0.00	0.06	0.0	0.0	0.0	0.0	100.0	0.0	0.0
Norway	2808	2	0.07	0.10	0.0	7.4	0.0	3.7	55.6	25.9	7.4
Sweden	905	1	0.11	0.06	0.0	0.0	0.0	12.5	87.5	0.0	0.0
Nordel	4254	3	0.07	0.08	0.0	5.3	0.0	5.3	65.8	18.4	5.3

5.5.3. Instrument transformers 132 kV

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

Country	Number of devices 2006	Number of faults 2006	Number of faults per 100 devices 2006	Number of faults per 100 devices 1997-2006	Faults divided by cause during the period 1997-2006 (%) Lightning	Other natural cause	External influence	Operation and maintenance	Technical equipment	Other	Unknown
Denmark	4300	2	0.05	0.03	12.8	12.5	24.9	12.5	12.5	12.4	12.5
Finland	1400	1	0.07	0.06	22.2	0.0	11.1	11.1	44.4	11.1	0.0
Iceland	530	0	0.00	0.02	0.0	0.0	0.0	0.0	100.0	0.0	0.0
Norway	7765	5	0.06	0.06	12.0	0.0	0.0	10.0	44.0	26.0	8.0
Sweden	6550	3	0.05	0.08	19.1	2.1	0.0	2.1	57.4	14.9	4.3
Nordel	20545	11	0.05	0.06	15.9	1.8	0.9	7.1	48.7	19.5	6.2

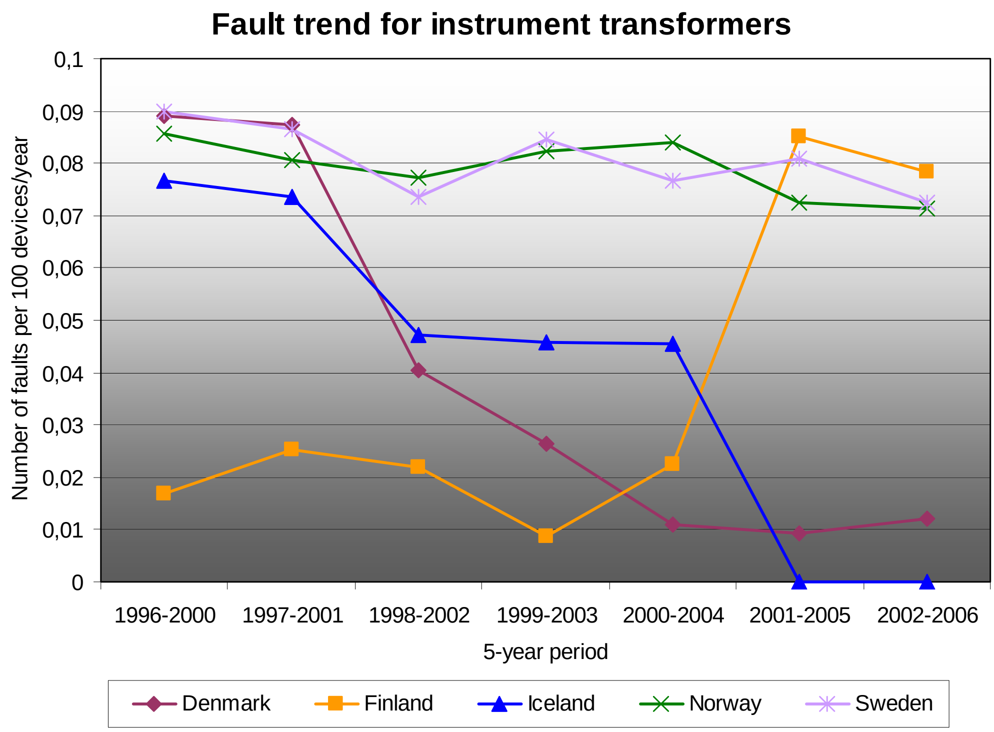

Figure 5.11. Fault trend for instrument transformers at all voltage levels

5.6. Faults in circuit breakers

The tables below present circuit breaker faults for the year 2006 and for the period 1997-2006 at each respective voltage level. The division of faults according to cause during the ten year period is also presented. Figure 5.12 presents the trend of faults for circuit breakers. More detailed information is available in the national statistics.

It should be noted that a significant part of the faults are caused by shunt reactor circuit breakers, which usually operate very often compared to other circuit breakers.

5.6.1. Circuit breakers 400 kV

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

Country	Number of devices 2006	Number of faults 2006	Number of faults per 100 devices		Faults divided by cause during the period 1997-2006 (%)						
			2006	1997-2006	Lightning	Other natural cause	External influence	Operation and maintenance	Technical equipment	Other	Unknown
Denmark	144	1	0.69	0.68	0.0	12.5	12.5	12.5	50.0	12.5	0.0
Finland	213	1	0.47	0.18	0.0	0.0	33.3	33.3	33.3	0.0	0.0
Norway	259	2	0.77	1.16	0.0	0.0	0.0	28.5	60.8	3.6	7.1
Sweden	410	8	1.95	1.83	0.0	2.7	0.0	1.3	77.4	14.6	4.0
Nordel	1031	12	1.16	1.22	0.0	2.6	1.8	9.6	70.2	11.4	4.4

Disturbances caused by erroneous circuit breaker operations are registered as faults in circuit breakers, with operation and maintenance as their cause.

5.6.2. Circuit breakers 220 kV

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

Country	Number of devices 2006	Number of faults 2006	Number of faults per 100 devices		Faults divided by cause during the period 1997-2006 (%)						
			2006	1997-2006	Lightning	Other natural 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	92	1	1.09	0.42	0.0	0.0	0.0	0.0	75.0	25.0	0.0
Iceland	68	1	1.47	4.22	0.0	8.0	0.0	12.0	68.0	0.0	12.0
Norway	721	6	0.83	1.24	1.2	1.1	0.0	28.2	59.0	8.2	2.4
Sweden	391	0	0.00	1.02	0.0	0.0	0.0	13.5	81.2	5.3	0.0
Nordel	1274	8	0.63	1.25	0.7	1.3	0.0	21.3	66.8	6.6	3.3

Disturbances caused by erroneous circuit breaker operations are registered as faults in circuit breakers, with operation and maintenance as their cause.

5.6.3. Circuit breakers 132 kV

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

Country	Number of devices 2006	Number of faults 2006	Number of faults per 100 devices		Faults divided by cause during the period 1997-2006 (%)						
			2006	1997-2006	Lightning	Other natural cause	External influence	Operation and maintenance	Technical equipment	Other	Unknown
Denmark	803	6	0.75	0.51	0.0	9.0	2.4	36.4	41.0	11.3	0.0
Finland	1605	1	0.06	0.29	29.2	8.3	0.0	8.3	45.8	4.2	4.2
Iceland	122	0	0.00	0.79	0.0	0.0	0.0	22.2	66.7	0.0	11.1
Norway	2122	1	0.05	0.44	0.0	0.0	0.0	54.7	40.6	2.3	2.3
Sweden	1647	17	1.03	1.11	20.9	2.0	2.0	16.3	47.7	3.9	7.2
Nordel	6299	25	0.40	0.61	12.4	2.8	1.0	29.2	45.4	4.4	4.8

Disturbances caused by erroneous circuit breaker operations are registered as faults in circuit breakers, with operation and maintenance as their cause.

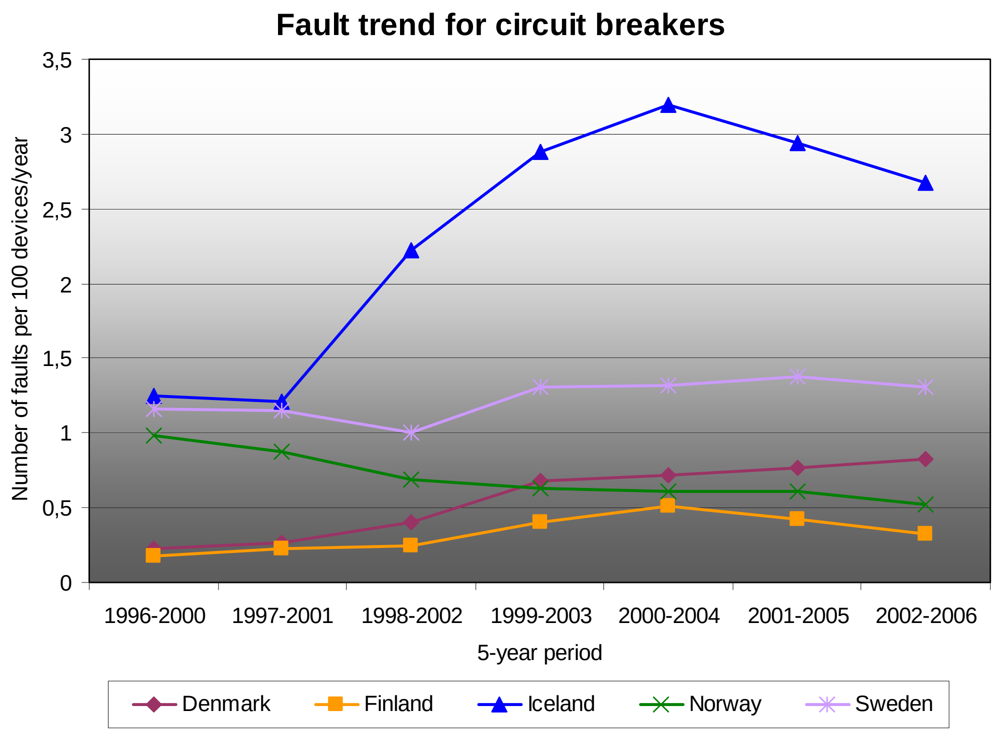

Figure 5.12. Fault trend for circuit breakers at all voltage levels

5.7. Faults in control equipment

The tables below present faults in control equipment at each respective voltage level for the year 2006 and for the period 1997-2006. In addition, the division of faults according to cause during the ten year period is presented. More detailed information is available in the national statistics.

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. The Nordic guidelines of these statistics [1] can be used to obtain more detailed definitions.

5.7.1. Control equipment 400 kV

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

Country	Number of devices 2006	Number of faults 2006	Number of faults per 100 devices		Faults divided by cause during the period 1997-2006 (%)						
			2006	1997-2006	Lightning	Other natural cause	External influence	Operation and maintenance	Technical equipment	Other	Unknown
Denmark	131	1	0.76	2.26	4.2	0.0	4.2	25.0	29.2	20.8	16.7
Finland	213	6	2.82	7.78	0.0	0.0	0.0	27.9	30.2	32.6	9.3
Norway	259	24	9.27	13.38	0.0	1.6	0.3	30.8	40.4	13.9	13.0
Sweden	381	23	6.04	11.88	0.4	0.6	0.3	12.9	78.4	5.7	1.7
Nordel	984	54	5.49	10.36	0.3	0.9	0.1	21.5	57.6	12.6	7.1

5.7.2. Control equipment 220 kV

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

Country	Number of devices 2006	Number of faults 2006	Number of faults per 100 devices		Faults divided by cause during the period 1997-2006 (%)						
			2006	1997-2006	Lightning	Other natural 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	92	4	4.35	5.29	0.0	0.0	0.0	38.0	50.0	6.0	6.0
Iceland	68	7	10.29	13.18	3.8	10.3	2.6	34.7	44.8	3.8	0.0
Norway	721	54	7.49	10.09	0.5	1.0	0.4	31.7	42.9	9.1	14.3
Sweden	386	6	1.55	4.28	0.0	0.0	1.8	33.3	52.4	9.5	3.0
Nordel	1269	71	5.59	8.01	0.7	1.5	0.8	32.5	45.0	8.6	10.8

5.7.3. Control equipment 132 kV

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

Country	Number of devices 2006	Number of faults 2006	Number of faults per 100 devices 2006	Number of faults per 100 devices 1997-2006	Lightning	Other natural cause	External influence	Operation and maintenance	Technical equipment	Other	Unknown
					Faults divided by cause during the period 1997-2006 (%)						
Denmark	803	16	1.99	0.82	6.3	0.0	3.1	42.9	19.1	22.2	6.3
Finland	1605	22	1.37	2.38	3.0	0.0	1.0	32.6	28.7	19.1	15.6
Iceland	120	6	5.00	4.59	0.0	3.8	1.9	38.5	53.8	0.0	1.9
Norway	2058	54	2.62	3.44	1.1	1.5	0.4	32.5	35.4	11.1	18.1
Sweden	1577	4	0.25	1.20	6.4	0.0	0.0	44.5	26.0	11.6	11.6
Nordel	6163	102	1.66	2.27	2.4	6.0	0.7	35.1	32.8	12.6	15.3

5.8. Faults in compensation devices

In the year 2000 the Nordic 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 2006	Number of faults 2006	Number of faults per 100 devices 2006	Number of faults per 100 devices 2000-2006	Lightning	Other natural cause	External influence	Operation and maintenance	Technical equipment	Other	Unknown
					Faults divided by cause during the period 1997-2006 (%)						
Denmark	36	3	8.33	5.26	0.0	0.0	0.0	8.0	67.0	0.0	25
Finland	56	0	0.00	3.08	0.0	0.0	0.0	0.0	66.7	25.0	8.3
Norway	36	4	11.11	7.83	0.0	0.0	0.0	23.5	64.7	5.9	5.9
Sweden	49	5	10.20	14.66	0.0	33.3	4.4	6.7	37.8	11.1	6.7
Nordel	177	12	6.78	7.53	0.0	17.4	2.3	9.3	51.2	10.5	9.3

Table 5.23. Division of faults according to cause for series capacitors

Country	Number of devices 2006	Number of faults 2006	Number of faults per 100 devices 2006	Number of faults per 100 devices 2000-2006	Lightning	Other natural cause	External influence	Operation and maintenance	Technical equipment	Other	Unknown
					Faults divided by cause during the period 1997-2006 (%)						
Finland	7	1	14.29	6.82	0.0	0.0	0.0	0.0	66.7	0.0	33.3
Iceland	1	0	0.00	14.29	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	6	50.00	64.29	1.9	0.0	0.0	3.7	37.0	40.7	16.7
Nordel	23	7	30.43	37.66	1.7	0.0	0.0	3.4	39.7	37.9	17.2

Table 5.24. Division of faults according to cause for shunt capacitors

Country	Number of devices 2006	Number of faults 2006	Number of faults per 100 devices 2006	Number of faults per 100 devices 2000-2006	Lightning	Other natural cause	External influence	Operation and maintenance	Technical equipment	Other	Unknown
					Faults divided by cause during the period 1997-2006 (%)						
Denmark	14	1	7.14	0.91	0.0	0.0	100.0	0.0	0.0	0.0	0.0
Finland	26	4	15.38	13.11	0.0	29.2	45.8	0.0	4.2	16.7	4.2
Iceland	9	1	11.11	3.23	0.0	0.0	0.0	0.0	100.0	0.0	0.0
Norway	194	4	2.06	3.32	0.0	0.0	2.3	4.5	47.7	45.5	0.0
Sweden	72	1	1.39	9.60	8.3	2.8	11.1	11.1	30.6	0.0	36.1
Nordel	315	11	3.49	4.87	3.0	1.0	17.0	6.0	35.0	24.0	14.0

Table 5.25. Division of faults according to cause for SVC-devices

Country	Number of devices 2006	Number of faults 2006	Number of faults per 100 devices 2006	Number of faults per 100 devices 2000-2006	Lightning	Other natural cause	External influence	Operation and maintenance	Technical equipment	Other	Unknown
					Faults divided by cause during the period 1997-2006 (%)						
Norway	15	9	60.00	39.78	0.0	5.4	0.0	5.4	62.2	13.5	13.5
Sweden	4	9	225.00	60.00	0.0	8.3	6.3	16.7	58.3	2.1	8.3
Nordel	20	18	90.00	46.55	0.0	2.5	3.7	12.3	63.0	7.4	11.1

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 (Guidelines [1] Chapter 5.3) was introduced in the Nordel statistics in 2000. This chapter covers statistics only for the year 2006. The Danish outage data was available only from the western parts of the country, as has been the case during the previous years.

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. Outages in power system units

The following tables present outages in different power system units. Outages in Sweden concern the 220 kV and 400 kV voltage levels.

Table 6.1. Grouping of overhead lines according to number of outages in 2006

Line		Number of outages						
	Number of lines	Number of lines with no outages	1	2	3	4	5	>5
Denmark	168	142	21	4	0	1	0	0
Finland	288	167	75	26	12	5	3	0
Iceland	53	40	6	4	2	0	0	1
Norway	641	456	109	48	13	4	1	10
Sweden	178	128	30	10	4	4	1	1

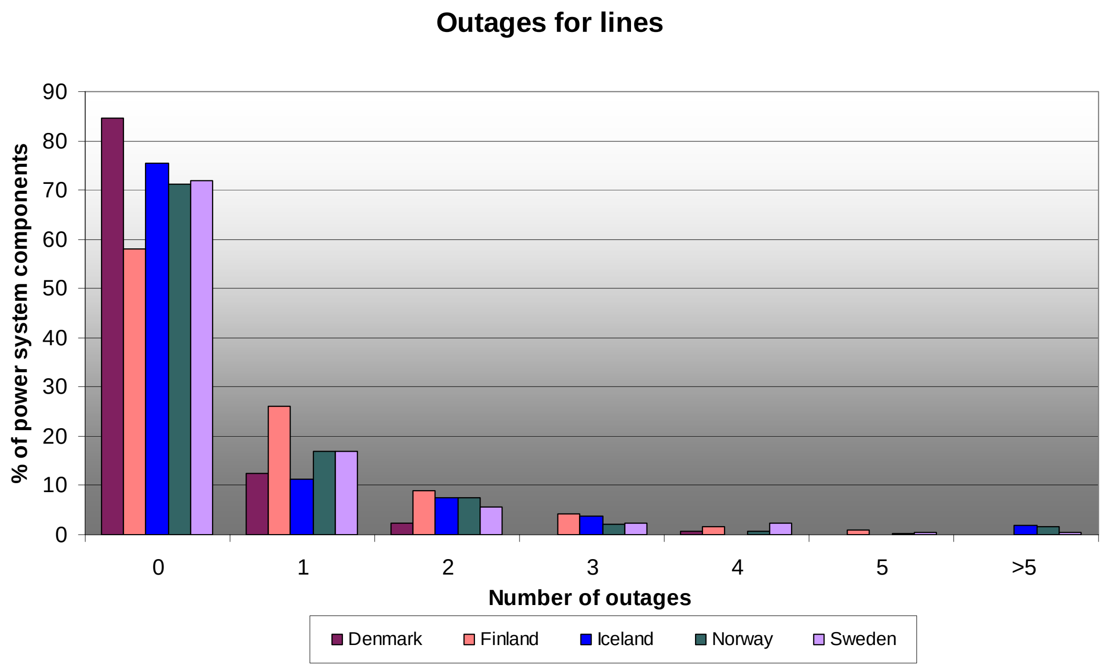

Figure 6.1. Grouping of overhead lines according to number of outages in 2006

Table 6.2. Grouping of transformers according to number of outages in 2006

Transformer		**Number of outages**						
	Num-ber	**No outages**	**1**	**2**	**3**	**4**	**5**	**>5**
Denmark	139	132	6	0	0	1	0	0
Finland	663	656	6	1	0	0	0	0
Iceland	68	67	1	0	0	0	0	0
Norway	800	696	70	22	6	4	0	2
Sweden*	842	813	29	0	0	0	0	0

*All three voltage levels are included in the Swedish transformer data, unlike the other tables in this chapter.

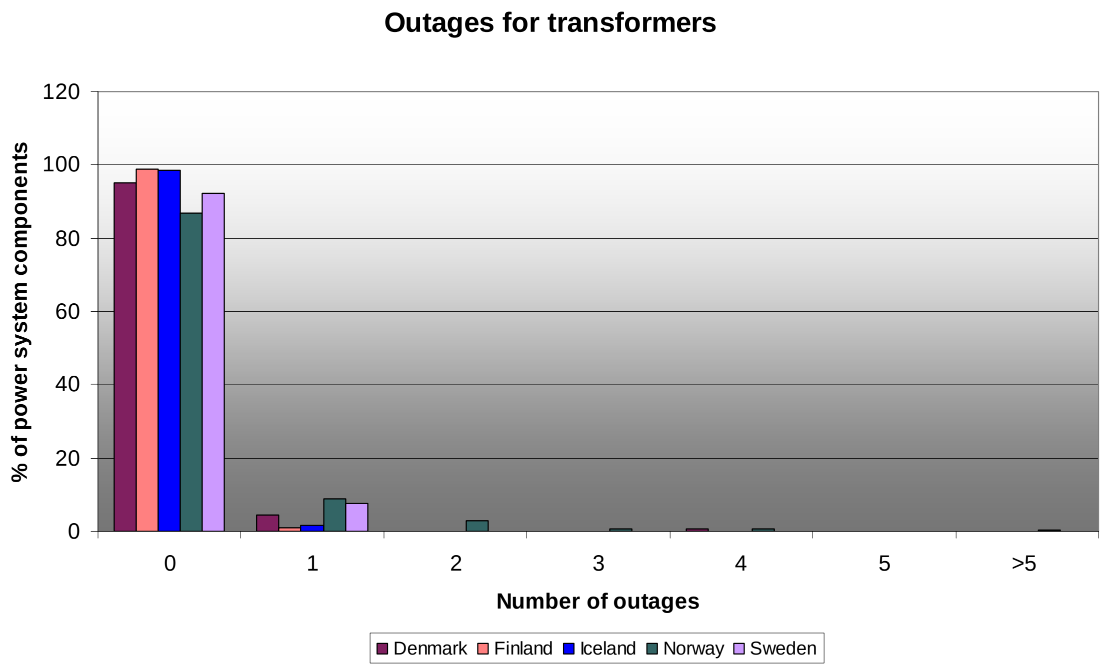

Figure 6.2. Grouping of transformers according to number of outages in 2006

Table 6.3. Grouping of busbars according to number of outages in 2006

Busbar		**Number of outages**						
	Number	**No outages**	**1**	**2**	**3**	**4**	**5**	**>5**
Denmark	162	160	2	0	0	0	0	0
Finland	473	471	2	0	0	0	0	0
Iceland*	45	44	1	0	0	0	0	0
Norway	519	507	11	1	0	0	0	0
Sweden	250	246	3	0	1	0	0	0

*The number of busbars in Iceland has reduced compared to the year 2005 due to the new definition of busbars in this country.

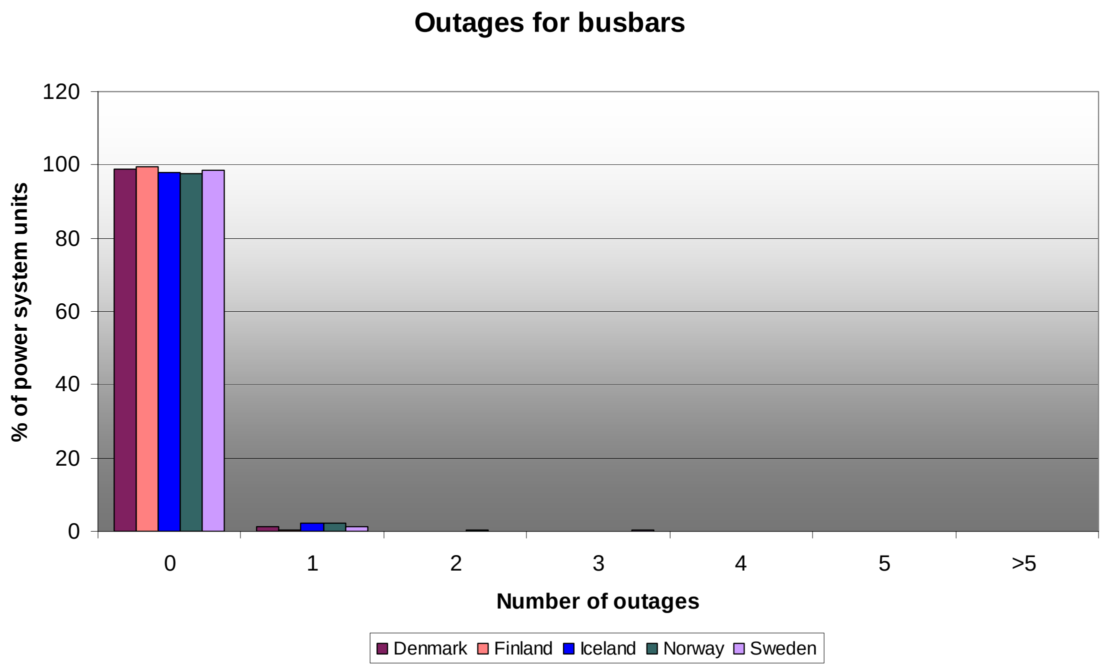

Figure 6.3. Grouping of busbars according to number of outages in 2006

Table 6.4. Grouping of reactors according to number of outages in 2006

Reactor		Number of outages						
	Number	**No outages**	**1**	**2**	**3**	**4**	**5**	**>5**
Denmark	27	27	0	0	0	0	0	0
Finland	56	56	0	0	0	0	0	0
Norway	0	0	0	0	0	0	0	0
Sweden	26	24	0	0	0	0	0	2

Table 6.5. Grouping of shunt capacitors according to number of outages in 2006

Shunt capacitors		Number of outages						
	Number	**No outages**	**1**	**2**	**3**	**4**	**5**	**>5**
Denmark	14	10	3	1	0	0	0	0
Finland	26	22	4	0	0	0	0	0
Iceland	9	7	0	0	0	1	1	0
Norway	164	150	6	1	2	2	0	3
Sweden	4	4	0	0	0	0	0	0

6.2. 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. Outage duration of lines in 2006

Line	**Outage duration, minutes Number of components in each category**								
	No outages	**<3**	**3-10**	**10-30**	**30-60**	**60-120**	**120-240**	**240-480**	**>480**
Denmark	142	1	8	2	1	3	3	1	7
Finland	167	96	5	6	3	1	4	0	6
Iceland	40	0	3	3	2	3	0	0	2
Norway	456	32	44	34	37	11	7	2	18
Sweden	128	24	7	4	0	2	3	1	9

Note that the concept of “line” in power system units can consist of both overhead lines and cables.

Table 6.7. Outage duration of transformers in 2006

Transformer	**Outage duration, minutes Number of components in each category**								
	No outages	**<3**	**3-10**	**10-30**	**30-60**	**60-120**	**120-240**	**240-480**	**>480**
Denmark	132	1	3	1	1				1
Finland	656	0	0	1	2	1	2	0	1
Iceland	67	0	0	0	0	1	0	0	0
Norway	696	15	23	35	5	7	8	7	4
Sweden*	813	-	-	-	-	29	-	-	-

*A detailed time distribution is not available from the Swedish data. All three voltage levels are included in the Swedish transformer data, unlike the other tables in this chapter.

Table 6.8 Outage duration of busbars in 2006

Busbar	**Outage duration, minutes Number of components in each category**								
	No outages	**<3**	**3-10**	**10-30**	**30-60**	**60-120**	**120-240**	**240-480**	**>480**
Denmark	160	0	0	0	0	2	0	0	0
Finland	471	0	1	0	0	0	0	1	0
Iceland	44	0	1	0	0	0	0	0	0
Norway	507	3	3	2	0	1	1	0	2
Sweden	246	1	1	1	0	0	1	0	0

Table 6.9. Outage duration of reactors in 2006

Reactor	Outage duration, minutes Number of components in each category								
	No outages	<3	3-10	10-30	30-60	60-120	120-240	240-480	>480
Denmark	25	0	0	0	0	0	0	0	0
Finland	56	0	0	0	0	0	0	0	0
Iceland	0	0	0	0	0	0	0	0	0
Norway	24	0	1	0	0	0	0	0	1
Sweden	37	2	0	0	1	1	2	0	4

Table 6.10. Outage duration of shunt capacitors in 2006

Shunt capacitor	Outage duration, minutes Number of components in each category								
	No outages	<3	3-10	10-30	30-60	60-120	120-240	240-480	>480
Denmark	10	0	0	0	0	1	0	0	3
Finland	22	0	0	0	0	2	2	0	0
Iceland	7	0	0	0	0	0	1	0	1
Norway	150	2	2	0	1	4	2	1	2
Sweden	4	0	0	0	0	0	0	0	0

6.3. 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.

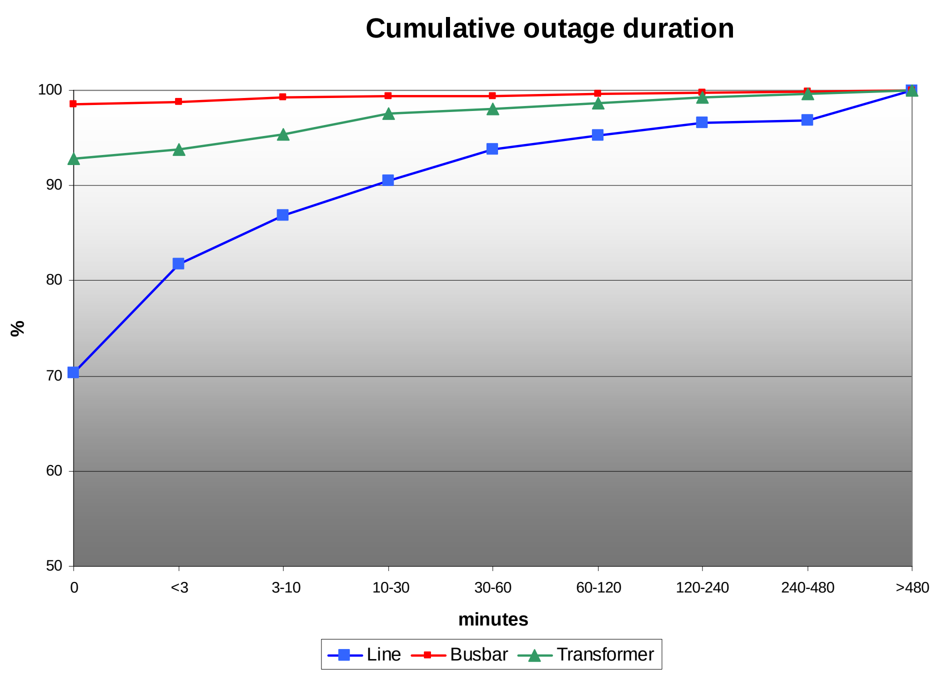

Figure 6.4. Cumulative duration of outages in selected power systems units

Figure 6.4 shows that about 70 % of lines, 93 % of transformers and 99 % of busbars had no outages in 2006. The situation was similar in 2005, but earlier years had somewhat lower values of availability.

7. REFERENCES

[1]: Nordel's Guidelines for the Classification of Grid Disturbances 2007 http://www.nordel.org/

[2]: Energibedriftenes Landsforening, Norges Vassdrags- og energidirektorat, Statnett og Sintef Energiforskning - Definisjoner knyttet til feil og avbrudd i det elektriske kraftsystemet - Versjon 2, 2001. Retrieved on 5th July at http://195.18.187.211/Resources/Filer/Dokumenter/PDF/definisjoner.pdf

[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.

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

	Tel:	Fax:
Denmark:		
Sebastian Dollerup Energinet.dk Fjordvej 1-11 DK-7000 Fredericia E-mail: sdo@energinet.dk	+45 7010 2244	+45 7624 5180
Finland:		
Hannu Hätönen FINGRID OYJ P.O. Box 530 Arkadiankatu 23 B FIN-00101 Helsinki E-mail: hannu.hatonen@fingrid.fi	+358 30 395 5155	+358 30 395 5199
Iceland:		
Vignir Örn Sigþórsson Landsnet Krókhals 5C IS-110 Reykjavik E-mail:vignir@landsnet.is	+354 563 9378	+354 563 9449
Norway:		
Jørn Schaug-Pettersen STATNETT SF Postboks 5192, Maj NO-0302 Oslo E-mail: jsp@statnett.no	+47 22 52 74 47	+47 22 52 70 01

	Tel:	Fax:
Sweden:		
Sture Holmström Svenska Kraftnät Box 526 SE-162 15 Vällingby E-mail: sture.holmstrom@svk.se	+46 8 7397513	+46 8 7397599
Johan Lilliecrona Svenska Kraftnät Box 526 SE-162 15 Vällingby E-mail: johan.lilliecrona@svk.se	+46 8 7397953	+46 8 7397599
Production of the report:		
Liisa Haarla and Janne Seppänen Helsinki University of Technology, Power Systems and High Voltage Engineering P.O. BOX 3000 FI-02015 TKK, Finland E-mail: liisa.haarla@tkk.fi or janne.seppanen@tkk.fi	+358 9 4515428	+358 9 451 5012

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.

These people can provide more detailed information about these statistics:

	Tel:	Fax:
For Denmark:		
Peter Hansen	+45 35 300 779	+45 35 300 771
DEFU		
Rosenørns Allé 9		
DK-1970 Frederiksberg C		
E-mail: pha@defu.dk		
For Finland:		
Elina Lehtomäki	+358 9 5305 2502	+358 9 5305 2900
Energiateollisuus ry		
Fredrikinkatu 51-53 B		
P.O. Box 100		
FIN-00101 Helsinki		
E-mail: elina.lehtomaki@energia.fi		
For Iceland:		
Sigurdur Ágústsson	+354 588 4430	+354 588 4431
Samorka		
Sudurlandsbraut 48		
108 Reykjavík		
E-mail: sa@samorka.is		
For Norway:		
EBL Kompetanse	+47 23 20 57 00	+47 23 20 57 49
Sørkedalsveien 10 B		
Postboks 7123 Majorstua		
N-0307 Oslo		
E-mail: post@ebl-kompetanse.no		
Internet:www.ebl.no		

	Tel:	Fax:
For Sweden:		
Matz Tapper Svensk Energi SE-101 53 Stockholm	+46 8 677 27 26	+46 8 677 25 48