Nordel

GRID DISTURBANCE AND FAULT STATISTICS

2007

TABLE OF CONTENTS

Page

1. INTRODUCTION

This report is an overview of the Danish, Finnish, Icelandic, Norwegian and Swedish transmission grid disturbance statistics for the year 2007. 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 2000-2007. Therefore there are tables in this report that include data only for the period 2000-2007. In those cases where data for the previous 10 years was available, the period 1998 – 2007 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. The structure of these statistics is similar to the 2006 statistics.

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

Despite common guidelines, there are 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 (ENS) and covering the total number of disturbances in the Nordic power system. As a new addition to this report each Transmission System Operator has presented the two most important issues from the year 2007.

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 2007 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

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	60	110	100	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 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%	90%	100%	99%	100%

Denmark: The network statistics cover data from eight different grid owners. Energinet.dk collects data from five grid owners for this report.

Finland: The data includes approximately 90% of Finnish 110 kV lines and stations and approximately 70% of 110/20 kV transformers. Compared to earlier years, a larger number of Finnish transformers are included in this year's statistics.

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

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

2. SUMMARY

In 2007 the energy not supplied (ENS) due to faults in the Nordic main grid was quite low. ENS was 4.70 GWh, which is somewhat higher than 3.65 GWh in 2006, but still lower than average. The ten year annual average of energy not supplied during the 1998-2007 period in the Nordel area was 8.41 GWh. The corresponding average value for each country is presented in brackets in the following paragraphs. The number in brackets for the disturbances that caused the energy not supplied is an average value from the period 2002-2007. In addition, the two most important issues in 2007 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 2007 was 26 MWh (10 year average 976 MWh). The number of grid disturbances was 77 (10 year average 80). In 2007, 3 of those 77 caused ENS. On average 4 disturbances per year caused ENS during 2002-2007. 57% of ENS was caused by a single disturbance in April. An ice storm hit Denmark in February.

The high value of ENS for Denmark in April was caused by an undesired connection of an earth connector between a circuit breaker and current transformers in a power plant after maintenance work on the 16th of April. This caused a busbar trip and a drop of the frequency to 47.9 Hz in 150ms. Three power plants (AMV, HCV, SMV) were disconnected from the grid due to this incident. The above also explains the high value of ENS due to operation and maintenance.

The high number of disturbances in February was caused by galloping lines due to an ice storm that occurred on the 24th of February. The ice settled on overhead lines in the transmission systems, and lasted from 06:30 to 13:00.

2.2. Summary for Finland

For Finland the energy not supplied in 2007 was 220 MWh (10 year average 188 MWh). The number of grid disturbances was 247 (10 year average 287) and 56 of them caused ENS. On average 52 disturbances per year caused ENS in 2002-2007. In 2007, 27% of ENS occurred due to operation and maintenance. Most of the disturbances were caused by lightning and occurred during the summer months. The percentage of unknown disturbances rose to 52% in 2007 from 45% in 2006.

In Finland during 2007 there were a higher than average number of disturbances related to operation and maintenance. Two of them caused nuclear power plant to trip from the network and one of them caused a power cut for 160 000 people that lasted as long as 14 minutes.

75% of ENS was caused by 5 disturbances. The highest number of ENS in a single disturbance was caused by tree cutting by a local land owner. This occurrence also explains the high value (22%) of ENS due to external influence.

2.3. Summary for Iceland

For Iceland the energy not supplied in 2007 was 2366 MWh (10 year average 608 MWh). The total number of disturbances was 42 (10 year average 52), of which 38 led to ENS. On average there have been 28 disturbances per year that caused ENS in 2002-2007. One big disturbance caused nearly 50% of ENS for the year 2007. 40% of ENS was due to bad weather in November and December.

47% of the ENS was due to a single fault caused by maintenance work on a single busbar in the 220 kV system feeding two power intensive industry plants. Bad weather conditions in November and December caused an unusual number of disturbances on the 132 kV network ring around the island, leading to an unusual amount of ENS.

A big change in the Icelandic network was a new power intensive industry and a large hydro power station connected to two 220 kV lines feeding an aluminium plant and the 132 kV ring.

2.4. Summary for Norway

For Norway the energy not supplied for 2007 was 652 MWh (10 year average 2830 MWh). The number of grid disturbances was 265 (10 year average 348). The two biggest contributors to ENS in 2007 were faults during maintenance and faults on technical equipment. They caused more than 2/3 of the total ENS.

The margin for secure grid operation in 2007 has been smaller than earlier. High grid utilization, high maintenance activity and grid investments/reinvestments in combination with old unknown construction faults resulted in several outages and ENS. 2007 was a difficult year for dispatch, planning and maintenance personnel.

A high number of technical equipment faults has been a trend in recent years. These faults have resulted in about 15-30% of total yearly ENS. A high focus on standardized solutions for relay and control equipment is essential to be able to turn the trend towards an acceptable level. The trend on transformer faults is also increasing.

2.5. Summary for Sweden

In Sweden the energy not supplied in 2007 was 1438 MWh (10 year average 3805 MWh). The total number of disturbances was 435 (10 year average 657) and 58 of those caused ENS. On average there have been 134 disturbances per year that have caused ENS in 2002-2007. The amount of ENS was low and the number of faults due to lightning was smaller than during any other year since 1998.

The number of transformer faults at the 132 kV level is significantly higher compared to the other countries. The reason could be age distribution or different maintenance strategies. This may be an interesting topic to investigate further.

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 1998-2007. 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 2007 in the Nordic main grid was 1066, which is clearly lower than the 10 year average of 1422. 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 1998-2007

The table below presents the sum of disturbances during the year 2007 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 1998-2007.

Table 3.1. Number of grid disturbances in 2007

Year 2007	**Denmark**	**Finland**	**Iceland**	**Norway**	**Sweden**
Number of disturbances	77	247	42	265	435

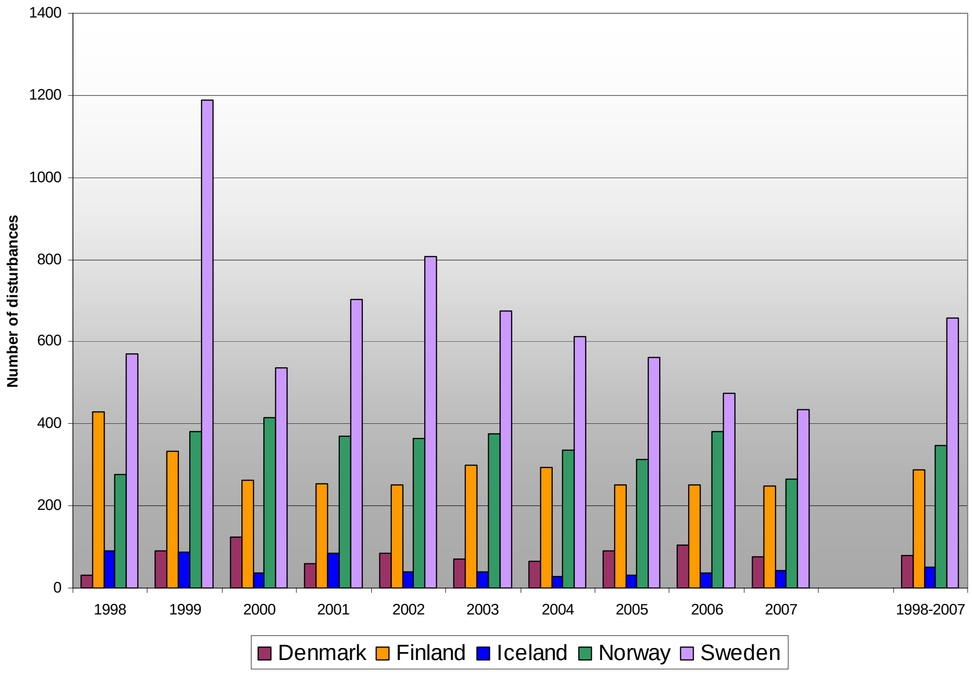

Figure 3.1. Number of grid disturbances in each Nordel country during the period 1998-2007

3.1.2. Distribution of grid disturbances in 2007

The following figure presents the percentage distribution of grid disturbances according to month in 2007. The numbers in the table are a sum of all the disturbances in the 100-400 kV networks.

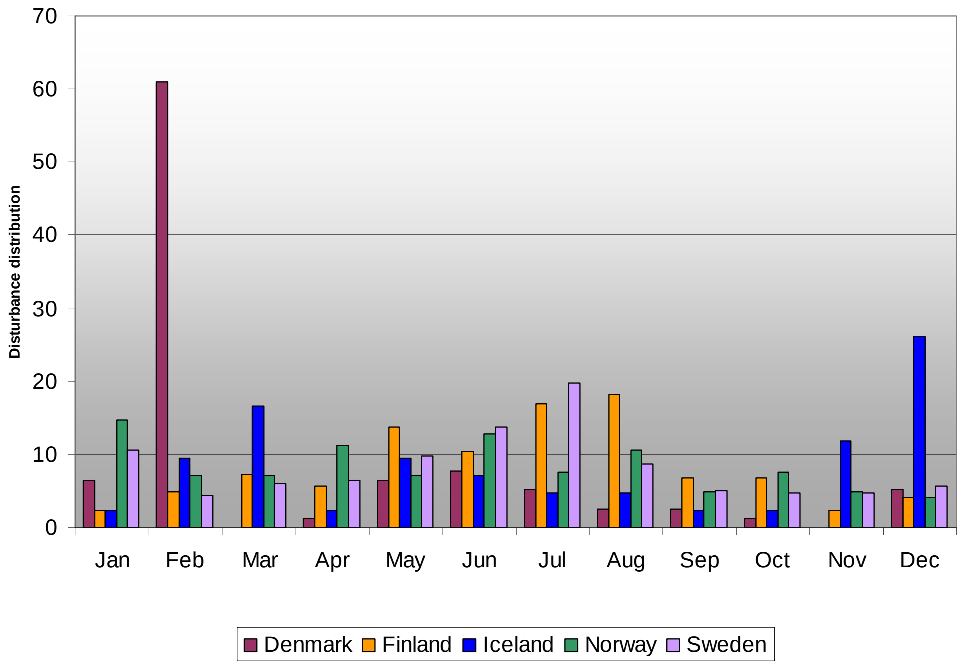

Figure 3.2. Percentage division of grid disturbances according to month for each country in 2007

The high number of disturbances in Denmark during February was caused by galloping lines due to an ice storm. Almost 30% of the disturbances in the Icelandic grid occurred in December. This was due to very bad weather. 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 2007

Country	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Denmark	6	61	0	1	6	8	5	3	3	1	0	5
Finland	2	5	7	6	14	11	17	18	7	7	2	4
Iceland	2	10	17	2	10	7	5	5	2	2	12	26
Norway	15	7	7	11	7	13	8	11	5	8	5	4
Sweden	11	4	6	6	10	14	20	9	5	5	5	6
Nordel	9	9	7	7	10	12	14	11	5	6	4	6

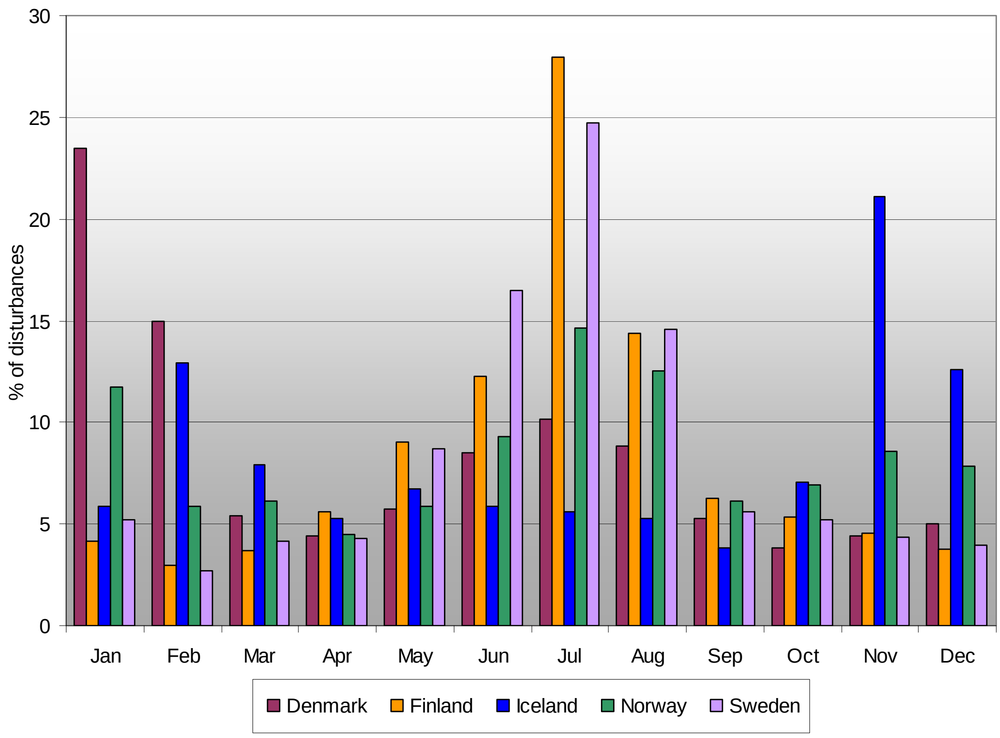

Figure 3.3. Percentage distribution of grid disturbances during the period 2000 – 2007

For all countries except Iceland the number of disturbances is usually greatest during the summer period. This is caused by lightning during summer.

Table 3.3. Percentage division of grid disturbances during the years 2000 – 2007

Country	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Denmark	23	15	5	4	6	9	10	9	5	4	4	5
Finland	4	3	4	6	9	12	28	14	6	5	5	4
Iceland	6	13	8	5	7	6	6	5	4	7	21	13
Norway	12	6	6	5	6	9	15	13	6	7	9	8
Sweden	5	3	4	4	9	16	25	15	6	5	4	4
Nordel	8	5	5	5	8	13	21	13	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 the causes of grid disturbances and energy not supplied in each country is presented in Table 3.4.

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

Table 3.4. Grouping of grid disturbances and Energy Not Supplied (ENS) by cause

Cause	Country	**Percentage of disturbances**		**Percentage distribution of ENS**[1)]	
		2007	2000-2007	2007	2000-2007
Lightning	Denmark	10	17	0	0
	Finland	21	36	14	10
	Iceland	2	2	0	1
	Norway	10	22	5	6
	Sweden	27	43	2	11
Other natural causes	Denmark	57	34	0	0
	Finland	2	4	17	13
	Iceland	29	40	18	38
	Norway	15	18	4	28
	Sweden	9	4	7	6
External influences	Denmark	5	13	0	0
	Finland	4	3	22	7
	Iceland	2	1	0	0
	Norway	1	2	0	2
	Sweden	2	3	5	2
Operation and maintenance	Denmark	5	14	57	4
	Finland	14	6	27	25
	Iceland	14	11	45	28
	Norway	19	15	69	14
	Sweden	9	7	57	13
Technical equipment	Denmark	8	10	0	12
	Finland	6	4	14	27
	Iceland	33	23	20	22
	Norway	30	23	18	36
	Sweden	15	16	19	49
Other	Denmark	4	5	0	84
	Finland	1	8	0	13
	Iceland	17	17	16	8
	Norway	16	15	3	13
	Sweden	9	9	5	17
Unknown	Denmark	10	8	43	0
	Finland[2)]	52	39	6	5
	Iceland	2	6	0	2
	Norway	4	5	1	1
	Sweden	29	17	5	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 other natural phenomena or external influence 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.

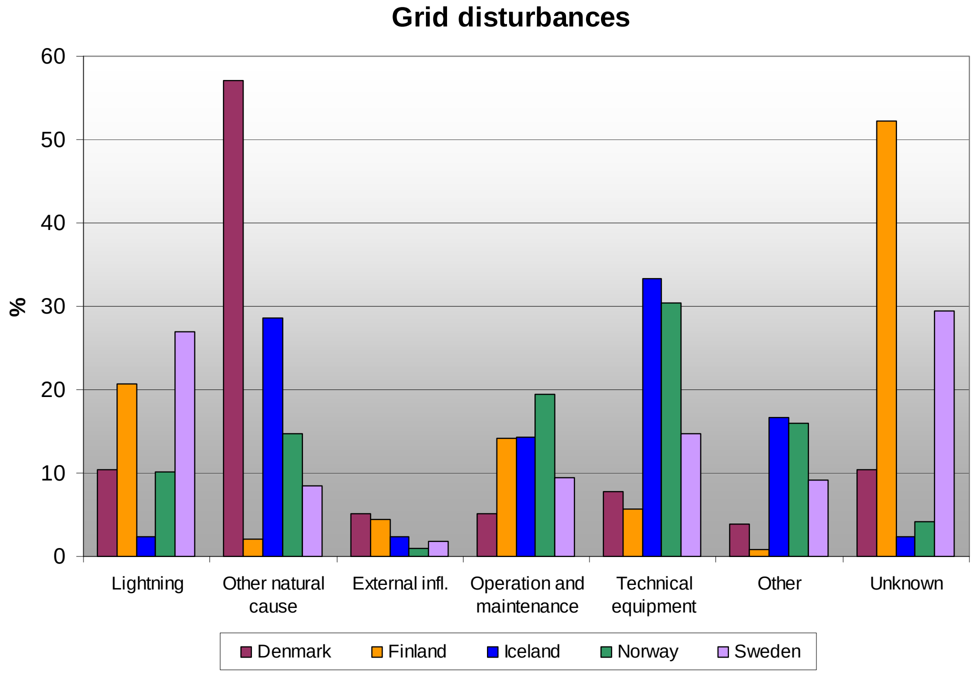

Figure 3.4. Grid disturbances divided according to cause in 2007

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 (%) 2000-2007			
	2007	132 kV	220 kV	>400 kV	Other[2)]
Denmark	26.3	5.0	0.0	95.0[1)]	0.0
Finland	219.6	95.9	2.2	0.0	1.9
Iceland	2365.8	39.1	60.9	0.0	0.0
Norway	652.2	40.4	34.6	3.7	21.3
Sweden	1438.3	46.5	5.3	36.3[1)]	11.8
Nordel	4702.2	39.0	18.2	30.8	12.0

[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, system faults, auxiliary equipment and lower voltage level networks, etc.

In Figures 4.1 and 4.2, energy not supplied is summarized according to the different voltage levels for the year 2007 and for the period 1998-2007, respectively. Voltage level refers to the initiating fault of the respective disturbance.

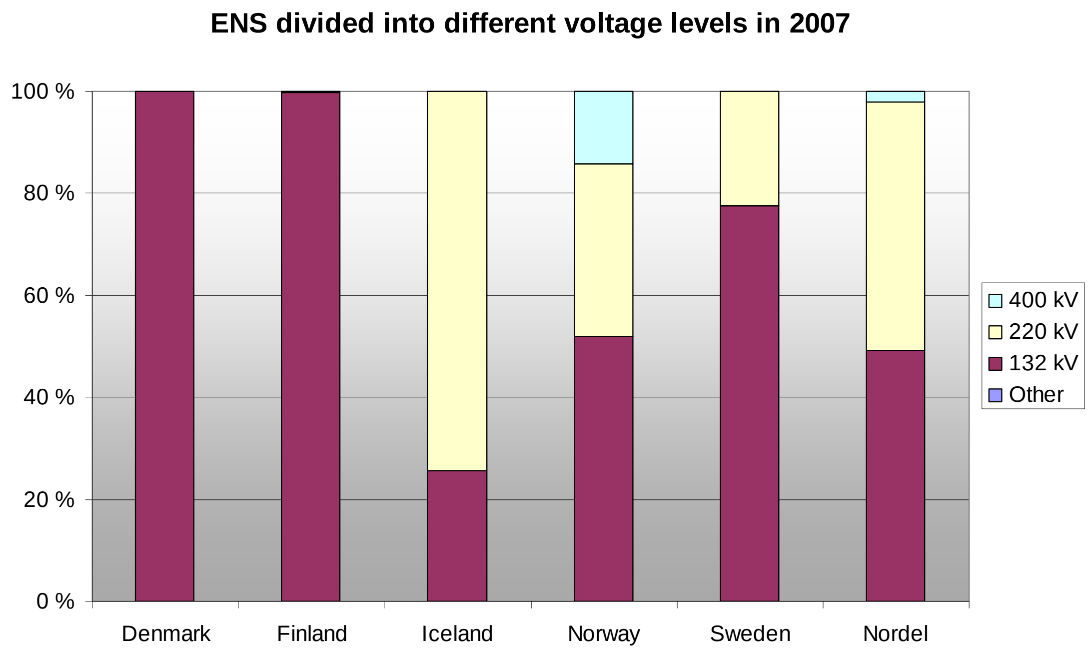

Figure 4.1. Energy Not Supplied (ENS) in terms of the voltage level of the initiating fault in 2007

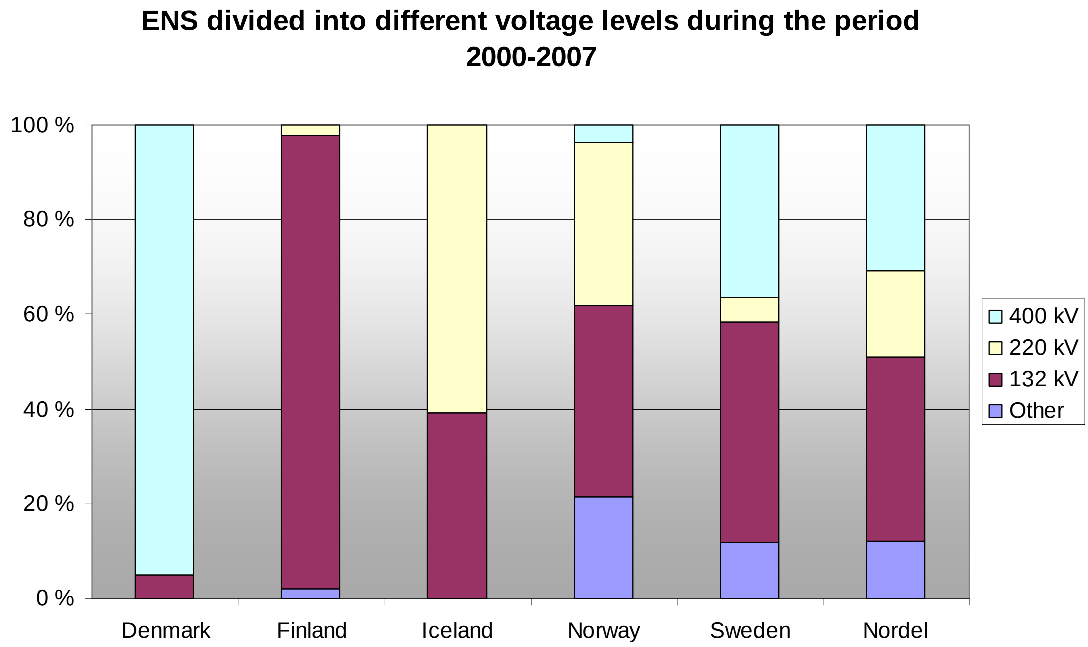

Figure 4.2. Energy Not Supplied (ENS) in terms of the voltage level of the initiating fault during the period 2000-2007

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 GWh 2007	ENS MWh 2007	ENS / Consumption Ppm 2007	Ppm 1998-2007	Division of ENS by installation for the period 1998-2007 (%) Overhead line	Cable	Stations	Other
Denmark	34109	26.3	0.8	28.1	11.6	0.0	6.0	82.4
Finland	90300	219.6	2.4	2.6	29.3	0.0	51.5	19.2
Iceland	11976	2365.8	197.5	75.2	40.2	0.0	48.1	11.7
Norway	124773	652.2	5.2	23.7	31.5	0.7	45.6	22.3
Sweden	146300	1438.3	9.8	28.6	17.2	8.6	64.4	9.8
Total	407458	4702.2	11.5	22.9	23.3	4.1	49.8	22.8

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 1998-2007. 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.

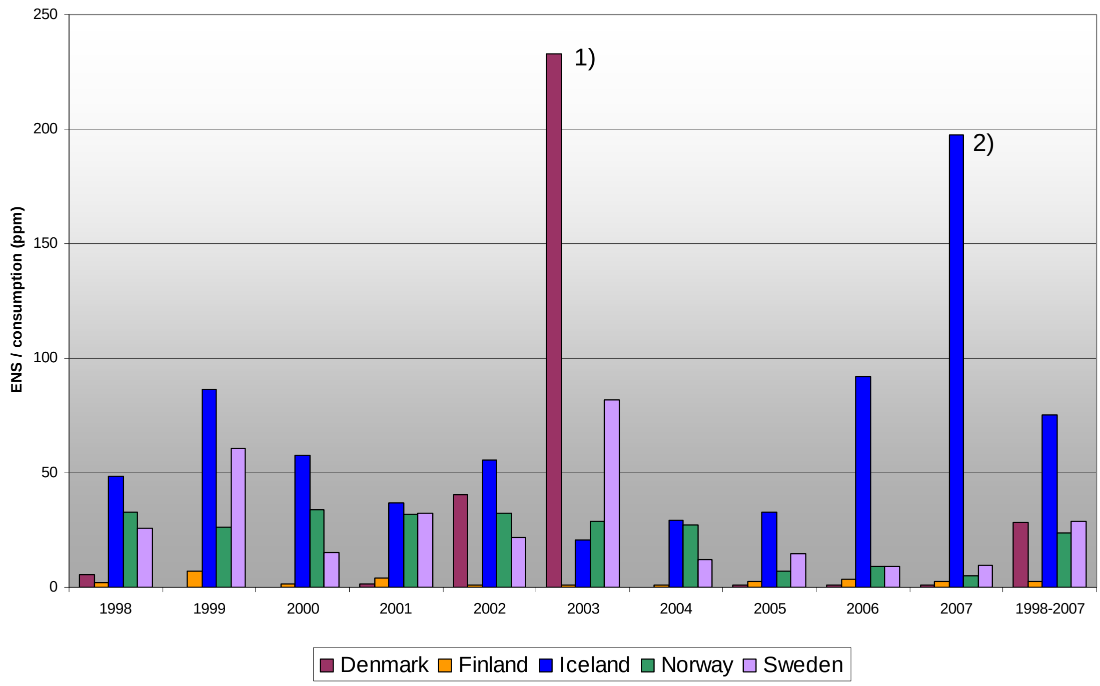

Figure 4.3. Energy Not Supplied (ENS) / consumption (ppm)

[1)] 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.

[2)] An unusual number of disturbances, which had an influence on the power intensive industry, caused the high value of energy not supplied during 2007 in Iceland.

4.1.1. Energy not supplied according to month in 2007

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

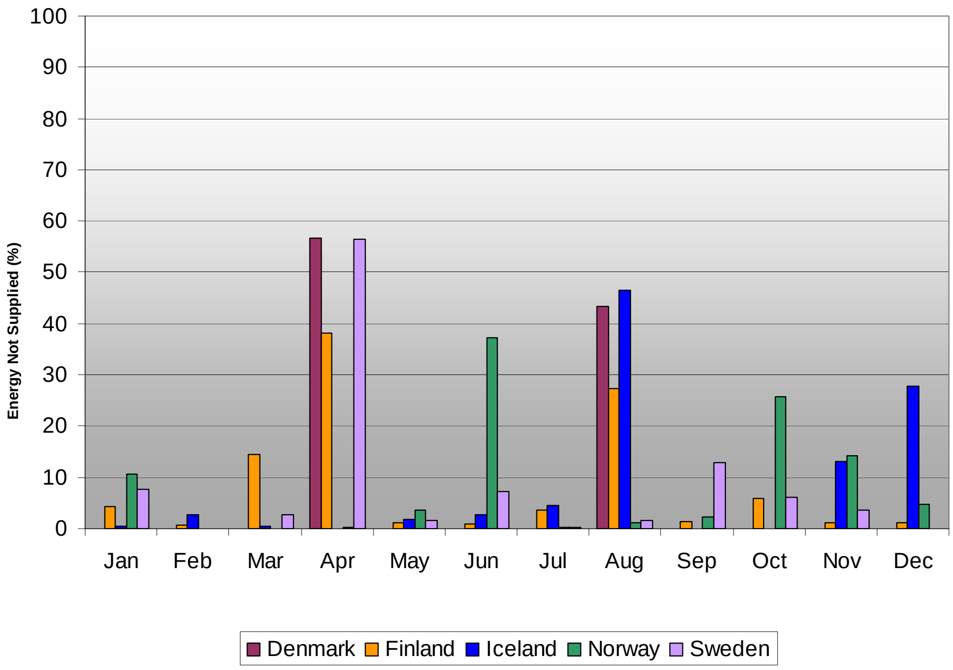

Figure 4.4. Energy Not Supplied according to month in 2007

The high value of ENS for Denmark in April was caused by an undesired connection of an earth connector between a circuit breaker and current transformers in a power plant after maintenance work. Three power plants were disconnected from the grid due to this incident. The high values of ENS in Sweden during April were caused by strong winds. For Iceland, the biggest value in August was caused by a single incident but the high value in December was caused by several incidents due to bad weather.

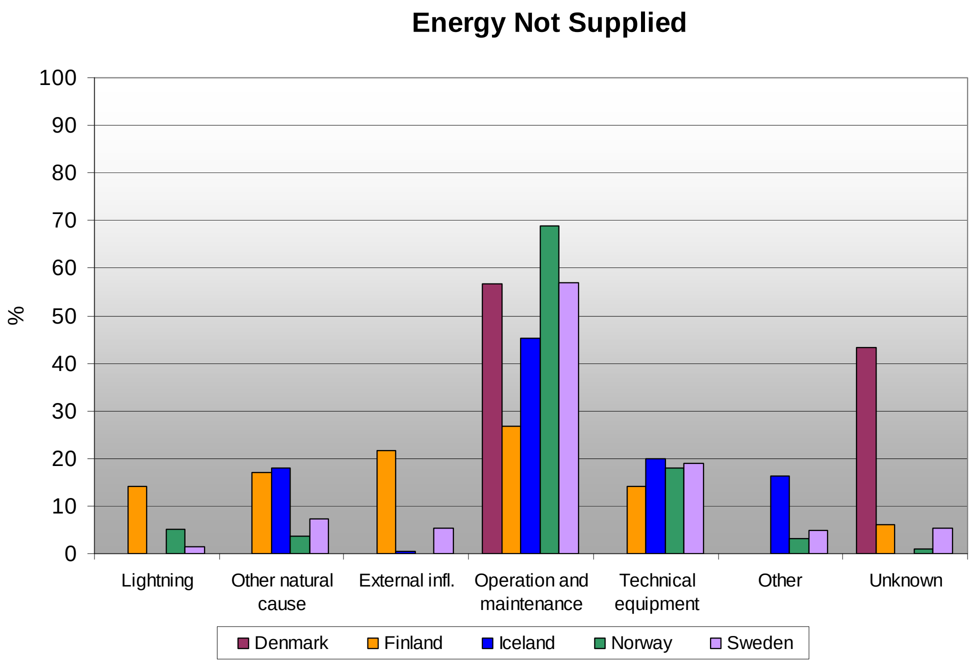

Figure 4.5. Grouping of Energy Not Supplied in 2007 by cause

In Norway, high grid utilization, high maintenance activity and grid investments/reinvestments in combination with old unknown construction faults resulted in several outages and ENS. This can been seen as the large amount of ENS under operation and maintenance. The high value of ENS for Denmark in operation and maintenance was caused by an undesired connection of an earth connector between a circuit breaker and current transformers in a power plant after maintenance work. For Sweden, a storm in April caused many disturbances and long interruptions (5 hours) for industrial customers. The ENS caused by this storm was classified as operation and maintenance, because the severity of the storm damage was probably due to poor maintenance.

Table 4.3. Energy Not Supplied in year 2007 and the annual average for the period 2000-2007

	Denmark		**Finland**		**Iceland**		**Norway**		**Sweden**		**Nordel**	
ENS	2007	2000-2007	2007	2000-2007	2007	2000-2007	2007	2000-2007	2007	2000-2007	2007	2000-2007
MWh	26	1212	220	197	2366	599	652	2194	1438	3455	4702	7657

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

Fault location	Denmark 2007	Denmark 2000-2007	Finland 2007	Finland 2000-2007	Iceland 2007	Iceland 2000-2007	Norway 2007	Norway 2000-2007	Sweden 2007	Sweden 2000-2007	Nordel 2007	Nordel 2000-2007
Overhead line	0.0	1.4	75.1	44.0	20.9	37.9	47.2	28.7	12.1	17.1	24.2	20.2
Cable	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	5.5	10.8	1.7	5.0
Sum of Line faults	0.0	1.5	75.1	44.0	20.9	37.9	47.2	29.3	17.5	27.9	25.9	25.3
Power transformer	0.0	0.6	0.3	2.0	0.0	0.3	2.7	0.7	16.7	10.9	5.5	5.3
Instrument transformer	0.0	0.0	1.4	4.0	0.0	0.0	3.3	3.9	0.4	2.4	0.7	2.3
Circuit breaker	0.0	3.4	3.7	4.4	0.0	5.9	0.0	1.2	0.0	1.7	0.2	2.2
Disconnector	56.6	0.2	0.0	0.7	41.0	20.2	0.0	4.7	54.6	41.2	37.6	21.6
Surge arrester and spark gap	0.0	0.0	0.0	2.9	0.0	0.0	0.0	2.6	0.1	0.2	0.0	0.9
Busbar	43.4	0.2	0.0	3.9	0.0	3.7	0.0	1.8	2.3	1.7	0.9	1.7
Control equipment	0.0	11.4	19.4	20.8	8.9	16.3	39.1	29.5	1.6	4.3	11.3	14.0
Common ancillary equipment	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1
Other substation faults	0.0	0.0	0.0	1.1	0.0	0.0	7.1	1.9	0.7	2.2	1.2	1.6
Sum of Substation faults	100	15.8	24.9	40.9	49.9	46.4	52.2	46.4	76.4	64.6	57.4	49.6
Shunt capacitor	0.0	0.0	0.0	0.3	7.2	3.7	0.6	0.1	2.0	1.2	4.3	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	0.1	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	7.2	3.7	0.6	0.1	2.0	1.3	4.3	0.9
System fault	0.0	82.7	0.0	0.0	22.0	12.0	0.0	7.8	0.0	0.5	11.1	16.5
Faults in adjoining statistical area	0.0	0.1	0.0	8.9	0.0	0.0	0.0	16.3	4.1	5.1	1.3	7.2
Unknown	0.0	0.0	0.0	5.8	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.4
Sum of other faults	0.0	82.8	0.0	14.8	22.0	12.0	0.0	24.2	4.1	6.3	12.3	24.2

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].

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

5.1. Overview of all faults

Table 5.1 presents the number of faults and disturbances during 2007.

Table 5.1. Number of faults and grid disturbances in 2007

Year 2007	**Denmark**[1)]	**Finland**	**Iceland**	**Norway**	**Sweden**[2)]
Number of faults	89	268	54	327	446
Number of disturbances	77	247	42	265	435
Fault / disturbance –ratio in 2007	1.16	1.09	1.29	1.23	1.03
The average fault / disturbance –ratio during 2000-2007	1.16	1.15	1.22	1.33	1.14

[1)]Denmark: The network statistics cover data from eigth different grid owners and the representation of their statistics is not consistent.
[2)]Sweden: The fault statistics cover data from six different grid owners and the representation of their statistics is not consistent.

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 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)]**	2007	2000-2007 (annual average)	2007	2000-2007 (annual average)
400 kV	Denmark	23	1537	4	11.4	0.0	411.4
	Finland	49	4420.2	20	21.9	0.0	0.0
	Iceland	0	0	0	0	0	0
	Norway	63	2708	46	60.4	92.3	83.3
	Sweden	59	10653	105	127.6	0.0	1311.8
220 kV	Denmark	2	105	0	0.8	0.0	0.0
	Finland	23	2401	23	25.5	0.6	3.7
	Iceland	27	749	22	15.8	1758.3	400.9
	Norway	274	6165	64	114.6	221.1	932.5
	Sweden	106	4331.6	52	66.1	321.1	191.0
132 kV	Denmark	237	4248	83	82.6	26.3	59.7
	Finland	751	14106	222	218.8	219.0	161.7
	Iceland	41	1292.1	32	34.3	607.5	258.1
	Norway	722	10677	217	193.4	338.7	1179.0
	Sweden	717	15634	273	395.6	1117.2	1678.7

[1)]Length of lines is the sum of the length of cables and overhead lines.
[2)] Calculation of energy not supplied (ENS) varies between countries.

Table 5.3 shows the number of faults classified according to the component groups used in the Nordel statistics for each respective country. 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 faults according to component

Fault location	Denmark		Finland		Iceland		Norway		Sweden		Nordel	
	2007	2000-2007	2007	2000-2007	2007	2000-2007	2007	2000-2007	2007	2000-2007	2007	2000-2007
Overhead line	69.7	61.5	75.7	72.7	31.5	41.3	26.9	37.5	55.6	57.4	52.2	54.1
Cable	2.2	2.2	0.0	0.0	1.9	0.2	0.0	0.6	1.8	0.4	0.9	0.5
Sum of all line faults	71.9	63.7	75.7	72.7	33.3	41.5	26.9	38.1	57.4	57.7	53.1	54.5
Power transformer	2.2	3.8	1.1	0.7	11.1	3.1	0.9	1.7	9.0	5.5	4.6	3.3
Instrument transformer	0.0	0.5	0.4	0.4	0.0	0.5	1.2	1.8	1.1	0.8	0.8	1.0
Circuit breaker	3.4	5.5	3.0	1.6	3.7	7.5	4.0	3.4	3.4	3.8	3.5	3.5
Disconnector	1.1	1.6	0.7	0.6	1.9	0.2	1.2	1.3	1.6	0.7	1.3	0.9
Surge arresters and spark gap	0.0	0.5	0.0	0.2	0.0	0.5	3.4	1.1	0.9	0.3	1.3	0.5
Busbar	1.1	0.5	0.4	0.4	0.0	0.7	1.5	1.3	1.1	1.0	1.0	0.9
Control equipment	14.6	12.7	11.6	11.7	18.5	25.0	25.1	31.6	8.3	12.4	14.6	18.4
Common ancillary equipment	0.0	0.4	0.0	0.3	0.0	0.0	3.1	1.0	0.0	0.9	0.8	0.8
Other substation faults	0.0	2.4	4.5	1.1	0.0	7.5	29.1	4.3	3.8	1.1	10.5	2.4
Sum of all substation faults	22.5	27.9	21.6	17.0	35.2	45.0	69.4	47.6	29.1	26.6	38.3	31.7
Shunt capacitor	0.0	0.1	0.4	1.1	3.7	0.9	2.1	1.4	0.9	0.7	1.2	0.9
Series capacitor	0.0	0.0	1.5	0.3	0.0	0.2	0.0	0.0	2.5	1.2	1.3	0.6
Reactor	2.2	1.8	0.0	0.5	0.0	0.0	0.6	0.5	1.8	1.0	1.0	0.8
SVC and statcom	1.1	0.1	0.0	0.0	0.0	0.0	0.6	1.0	1.6	1.0	0.8	0.7
Synchronous compensator	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.9	0.2	0.3	0.2	0.4
Sum of all compensation	3.4	2.0	1.9	1.9	3.7	1.2	3.7	3.8	7.0	4.2	4.5	3.4
System fault	0.0	2.8	0.0	0.0	27.8	11.6	0.0	2.0	3.4	3.6	2.5	2.7
Faults in adjoining statistical area	2.2	3.4	0.7	4.3	0.0	0.0	0.0	8.5	3.1	4.5	1.5	5.4
Unknown	0.0	0.1	0.0	4.0	0.0	0.7	0.0	0.0	0.0	3.3	0.0	2.2
Sum of all other faults	2.2	6.3	0.7	8.3	27.8	12.3	0.0	10.5	6.5	11.5	4.1	10.3

5.2. Faults in overhead lines

Overhead lines constitute a very large part of the Nordel transmission grid. Therefore, the tables below show the division of faults in 2007 as well as the ten year period 1998-2007. Faults divided by cause during the ten year period are also given. Along with the tables, the annual division of faults during the period 1998-2007 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 2007	Number of faults 2007	Number of faults per 100 km		Faults divided by cause during the period 1998-2007 (%)								
			2007	1998-2007	Lightning	Other natural causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown	1-phase faults	Permanent faults
Denmark	1228	2	0.16	0.39	17.4	63.0	6.5	4.4	6.4	2.2	0.0	50	7
Finland	4420	5	0.11	0.25	77.5	7.8	0.9	2.9	1.0	3.9	5.8	54	4
Norway	2683	16	0.60	1.08	23.2	70.7	0.4	0.0	2.7	1.2	1.9	70	6
Sweden	10645	28	0.26	0.35	48.4	26.0	1.6	0.8	3.2	1.1	18.9	83	10
Nordel	18976	51	0.27	0.43	42.0	40.7	1.4	1.0	2.9	1.5	10.4	73	8

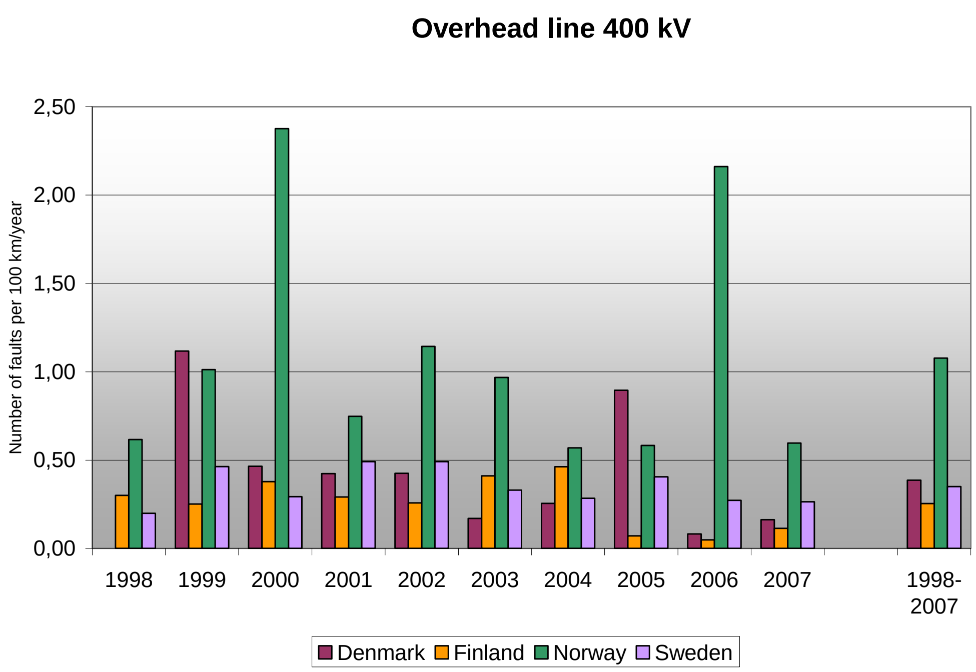

Figure 5.1. Annual division of faults during the period 1998-2007

5.2.2. Overhead lines 220 kV

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

Country	Line km 2007	Number of faults 2007	Number of faults per 100 km 2007	Number of faults per 100 km 1998-2007	Faults divided by cause during the period 1998-2007 (%) Lightning	Other natural causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown	1-phase faults	Permanent faults
Denmark	105	0	0.00	0.57	50.0	16.7	16.7	0.0	0.0	0.0	16.7	83	0
Finland	2401	17	0.71	0.76	46.4	3.3	3.3	0.5	0.6	1.1	44.8	67	3
Iceland	749	5	0.67	0.42	40.7	44.4	0.0	0.0	14.8	0.0	0.0	59	22
Norway	5715	16	0.28	0.66	56.4	31.3	1.0	0.3	2.6	2.1	6.6	62	13
Sweden	4117	23	0.56	0.86	71.6	5.1	2.9	4.3	2.4	0.5	13.3	55	9
Nordel	13087	61	0.47	0.73	59.9	16.2	2.3	1.9	2.5	1.2	16.2	60	10

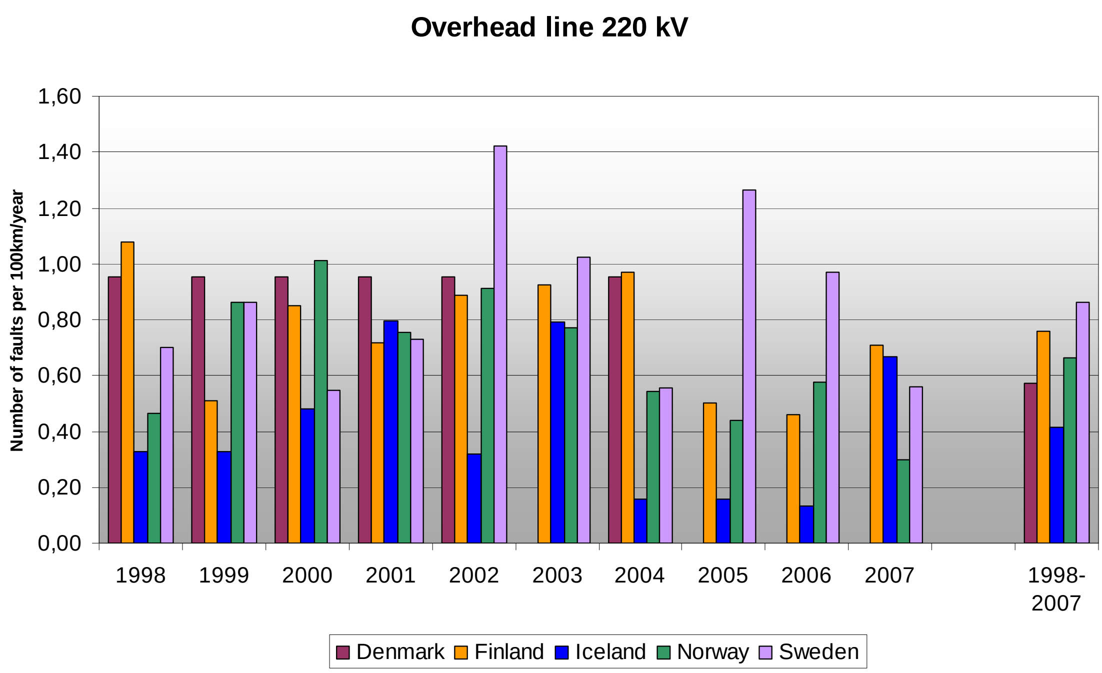

Figure 5.2. Annual division of faults during the period 1998-2007

5.2.3. Overhead lines 132 kV

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

Country	Line km 2007	Num-ber of faults 2007	Number of faults per 100 km		Faults divided by cause during the period 1998-2007 (%)								
			2007	1998-2007	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	60	1.65	1.23	21.7	48.9	16.7	2.4	1.2	3.2	6.0	47	5
Finland	13991	181	1.29	1.92	44.2	3.9	2.1	1.3	0.5	0.9	47.1	75	2
Iceland	1247	12	0.96	1.49	2.2	86.1	3.4	1.1	6.6	0.0	0.5	47	14
Norway*	10475	56	0.53	1.05	57.2	27.7	3.4	0.6	6.1	4.1	0.9	26*	17
Sweden	15418	197	1.28	2.42	63.2	4.4	2.8	1.9	1.9	1.9	24.0	42	5
Nordel	44771	506	1.13	1.77	52.1	13.4	3.7	1.5	2.2	2.0	25.0	50	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.

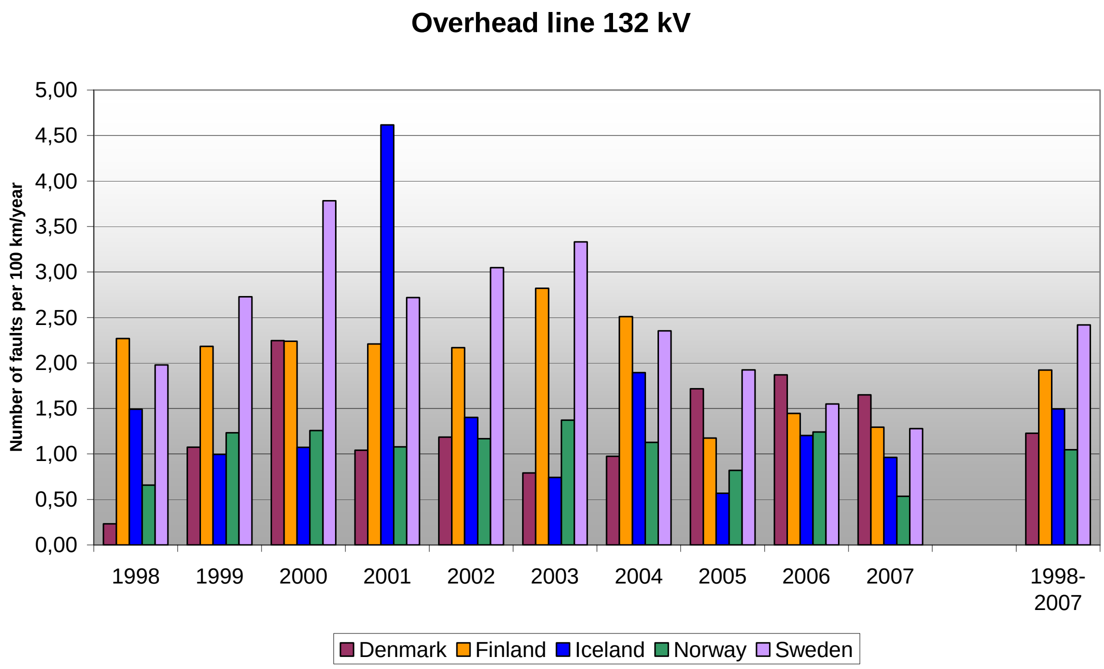

Figure 5.3. Annual division of faults during the period 1998-2007

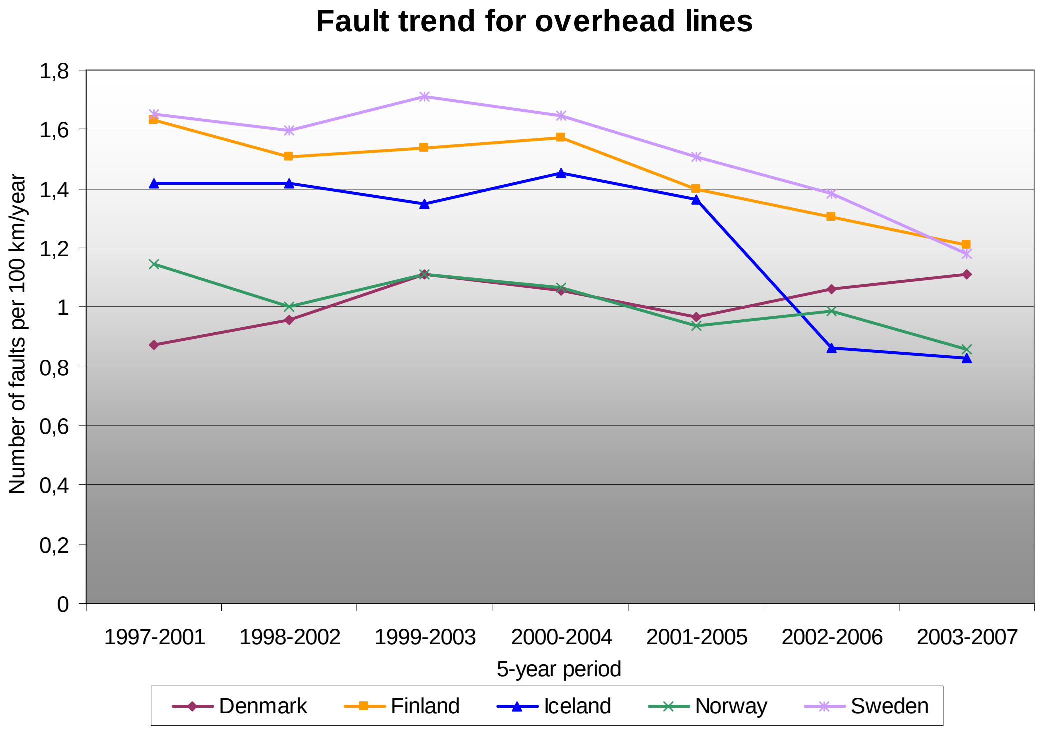

Figure 5.4. Fault trend for overhead lines at all voltage levels

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 2007 and for the period 1998-2007. In addition the division of faults according to cause is given for the ten year period. The annual division of faults during the period 1998-2007 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 2007	Number of faults 2007	Number of faults per 100 km 2007	Number of faults per 100 km 1998-2007	Lightning	Other natural cause	External influence	Operation and maintenance	Technical equipment	Other	Unknown
					Faults divided by cause during the period 1998-2007 (%)						
Denmark	174	0	0.00	0.34	0.0	0.0	0.0	25.0	25.0	25.0	25.0
Norway	25	0	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sweden	8	0	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nordel	207	0	0.00	0.27	0.0	0.0	0.0	25.0	25.0	25.0	25.0

5.3.2. Cables 220 kV

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

Country	Line km 2007	Number of faults 2007	Number of faults per 100 km 2007	Number of faults per 100 km 1998-2007	Lightning	Other natural cause	External influence	Operation and maintenance	Technical equipment	Other	Unknown
					Faults divided by cause during the period 1998-2007 (%)						
Norway	450	0	0.00	0.12	0.0	33.3	0.0	33.3	33.3	0.0	0.0
Sweden*	215	7	3.25	1.13	0.0	0.0	0.0	11.1	77.8	0.0	11.1
Nordel	665	7	1.05	0.36	0.0	8.3	0.0	16.7	66.7	0.0	8.3

*Most of the Swedish faulted 220 kV cables were taken into operation in the beginning of 1990’s.

5.3.3. Cables 132 kV

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

Country	Line km 2007	Number of faults 2007	Number of faults per 100 km 2007	Number of faults per 100 km 1998-2007	Faults divided by cause during the period 1998-2007 (%): Lightning	Other natural cause	External influence	Operation and maintenance	Technical equipment	Other	Unknown
Denmark	608	2	0.33	0.32	6.7	0.0	40.0	20.0	20.0	13.3	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	1	2.22	0.30	0.0	0.0	0.0	0.0	100.0	0.0	0.0
Norway*	202	0	0.00	1.42	0.0	3.8	15.3	3.8	61.5	11.5	3.8
Sweden	216	1	0.46	0.58	0.0	0.0	23.1	7.7	23.1	30.8	15.4
Nordel	1186	4	0.34	0.58	1.8	1.8	16.4	9.1	41.8	16.4	5.5

*Cables in Norway include resonant earthed cables.

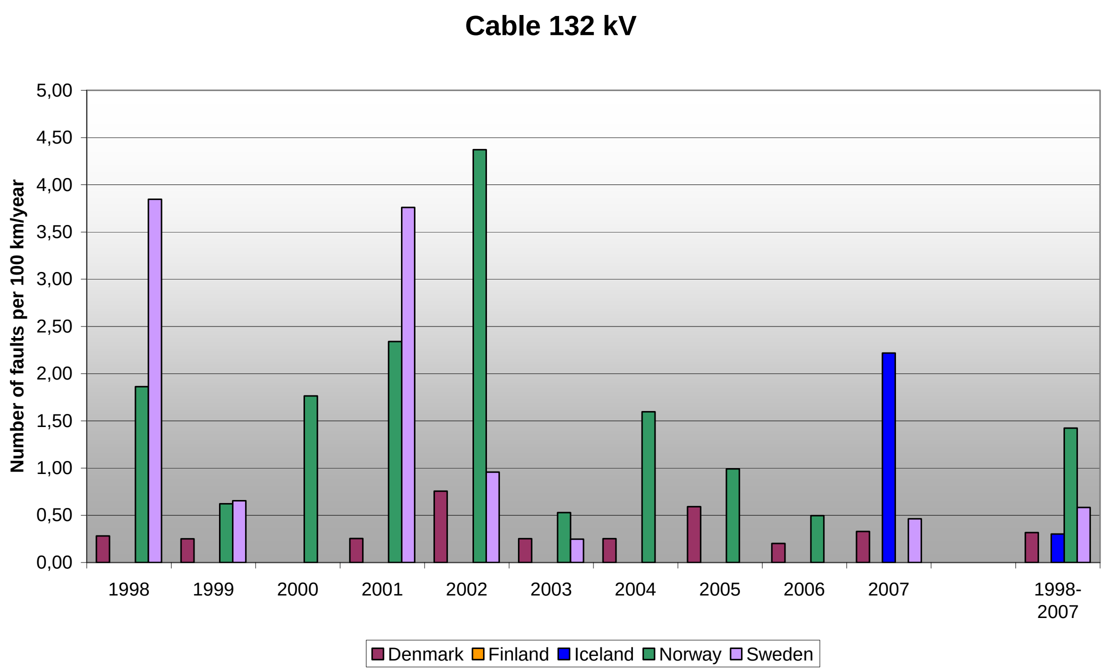

Figure 5.5. Annual division of faults during the period 1998-2007

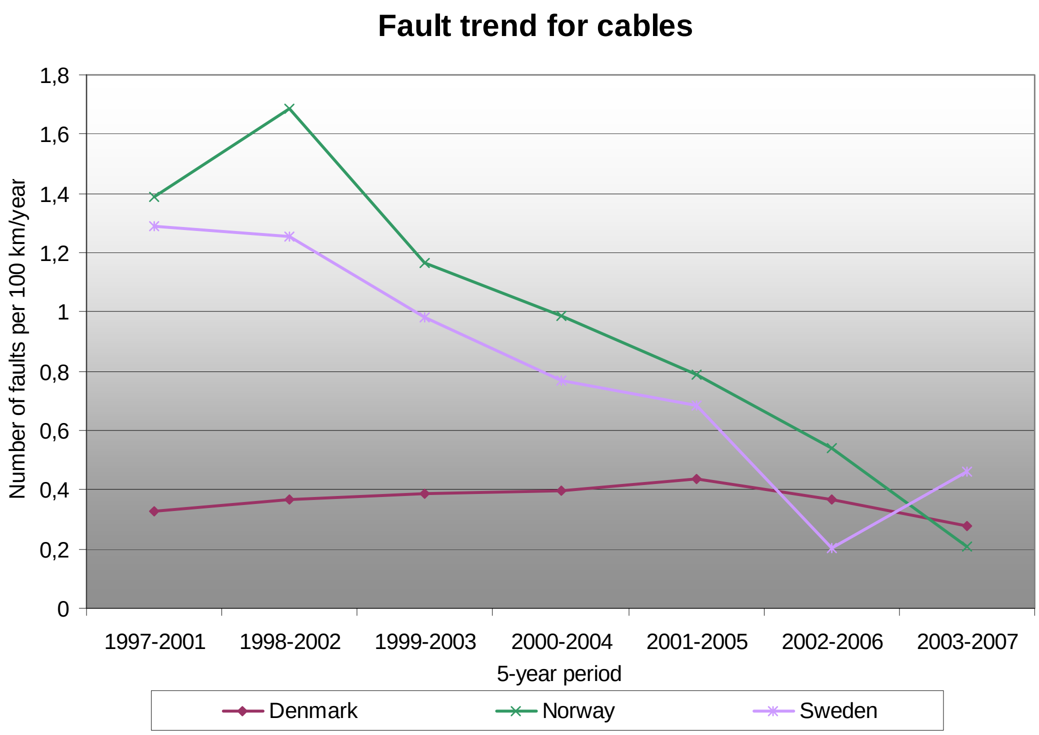

Figure 5.6. Fault trend for cables at all voltage level

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 2007 and for the period 1998-2007 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 1998-2007 is presented graphically for all voltage levels. Figure 5.10 presents 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. 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 2007	Number of faults 2007	Number of faults per 100 devices		Faults divided by cause during the period 1998-2007 (%)						
			2007	1998-2007	Lightning	Other natural cause	External influence	Operation and maintenance	Technical equipment	Other	Unknown
Denmark	23	0	0.00	3.14	14.3	14.3	0.0	14.3	14.3	0.0	42.9
Finland	49	1	2.04	2.10	0.0	22.2	0.0	11.1	44.4	11.1	11.1
Norway	63	0	0.00	0.65	0.0	0.0	0.0	0.0	100	0.0	0.0
Sweden	59	2	3.39	1.57	12.4	0.0	0.0	31.2	37.6	18.9	0.0
Nordel	194	3	1.55	1.53	8.5	8.6	0.0	20.0	42.9	11.5	8.6

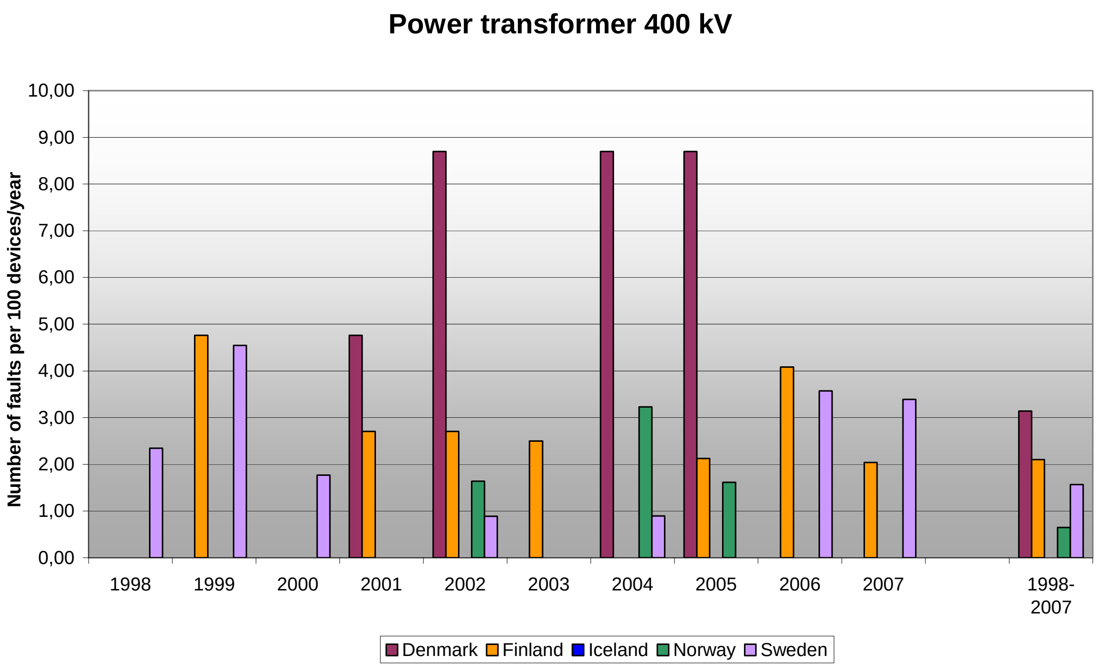

Figure 5.7. Annual division of faults during the period 1998-2007

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 2007	Number of faults 2007	Number of faults per 100 devices 2007	Number of faults per 100 devices 1998-2007	Faults divided by cause during the period 1998-2007 (%) 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	1.66	0.0	0.0	0.0	0.0	25.0	0.0	75.0
Iceland	27	2	7.41	2.85	0.0	0.0	0.0	14.3	71.4	0.0	14.3
Norway	274	0	0.00	1.44	5.1	0.0	2.6	30.8	48.7	10.3	2.6
Sweden	106	6	5.66	3.06	27.5	5.0	7.5	20.0	25.0	7.6	7.5
Nordel	432	8	1.85	1.99	14.4	2.2	4.4	23.3	38.9	7.8	8.9

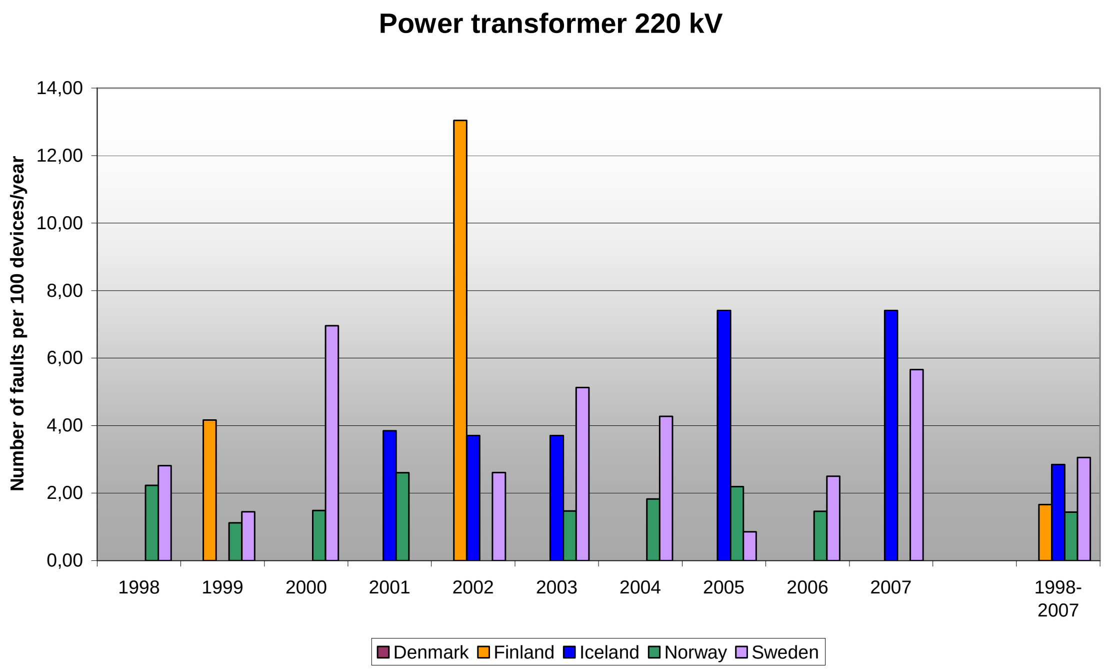

Figure 5.8. Annual division of faults during the period 1998-2007

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 2007	Number of faults 2007	Number of faults per 100 devices		Faults divided by cause during the period 1998-2007 (%)						
			2007	1998-2007	Lightning	Other natural cause	External influence	Operation and maintenance	Technical equipment	Other	Unknown
Denmark	237	2	0.84	1.00	3.8	7.7	3.8	30.8	26.9	3.8	23.1
Finland	751	2	0.27	0.37	0.0	14.3	14.3	14.3	28.6	0.0	28.6
Iceland	41	2	4.88	1.01	0.0	0.0	0.0	50.0	25.0	0.0	25.0
Norway	722	3	0.42	0.48	2.9	2.9	2.9	23.6	52.8	11.8	2.9
Sweden	717	32	4.46	5.26	17.7	4.1	3.1	16.7	26.8	15.7	16.0
Nordel	2468	41	1.66	2.07	14.8	4.4	3.3	18.7	29.2	14.0	15.6

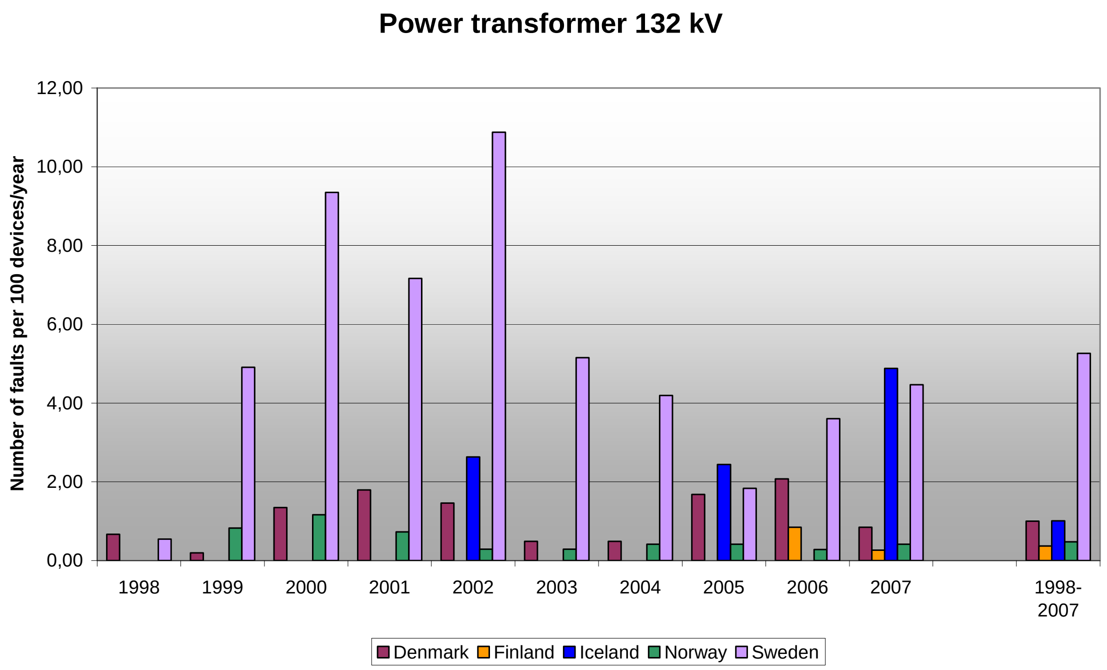

Figure 5.9. Annual division of faults during the period 1998-2007

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.

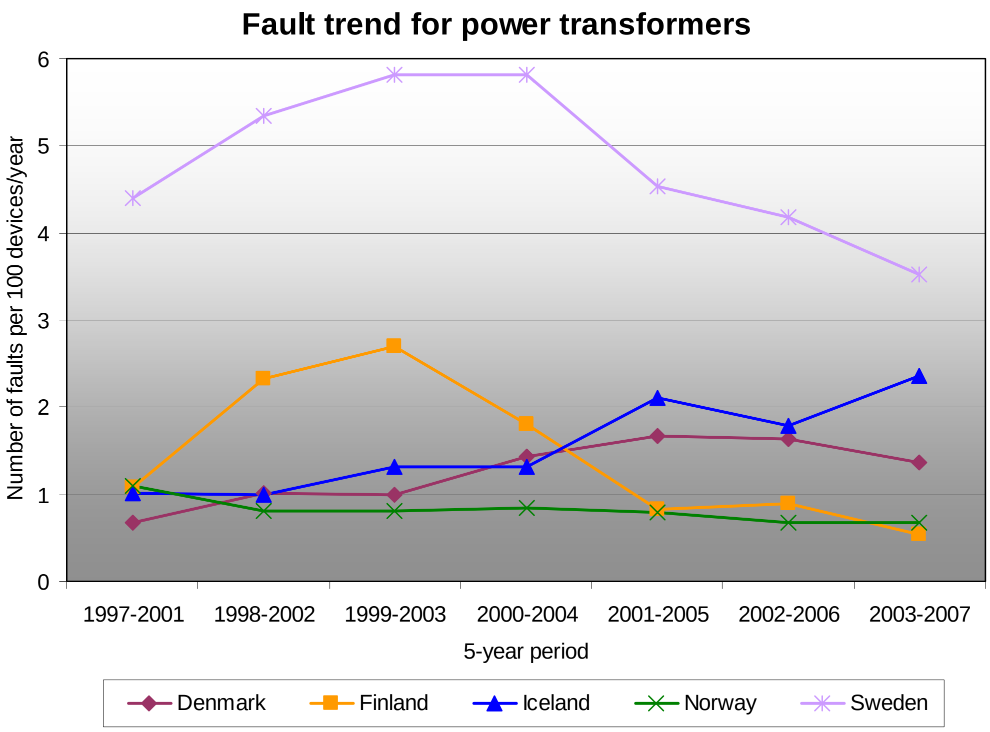

Figure 5.10. Fault trend for power transformers at all voltage levels

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

5.5. Faults in instrument transformers

The tables below present the faults in instrument transformers for the year 2007 and for the period 1998-2007 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 2007	Number of faults 2007	Number of faults per 100 devices		Faults divided by cause during the period 1998-2007 (%)						
			2007	1998-2007	Lightning	Other natural cause	External influence	Operation and maintenance	Technical equipment	Other	Unknown
Denmark	533	0	0.00	0.06	0.0	100.0	0.0	0.0	0.0	0.0	0.0
Finland	373	0	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Norway	933	0	0.00	0.14	0.0	10.0	0.0	10.0	30.0	40.0	10.0
Sweden	885	2	0.23	0.11	7.7	0.0	0.0	15.4	69.2	0.0	7.7
Nordel	2724	2	0.07	0.09	4.0	12.0	0.0	12.0	48.0	16.0	8.0

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 2007	Number of faults 2007	Number of faults per 100 devices		Faults divided by cause during the period 1998-2007 (%)						
			2007	1998-2007	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	145	0	0.00	0.04	0.0	0.0	0.0	0.0	100.0	0.0	0.0
Iceland	385	0	0.00	0.03	0.0	0.0	0.0	0.0	100.0	0.0	0.0
Norway	2808	0	0.00	0.09	0.0	8.3	0.0	4.2	54.2	25.0	8.3
Sweden	982	1	0.10	0.06	0.0	0.0	0.0	12.5	87.5	0.0	0.0
Nordel	4332	1	0.02	0.07	0.0	5.9	0.0	5.9	64.7	17.6	5.9

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 2007	Number of faults 2007	Number of faults per 100 devices 2007	Number of faults per 100 devices 1998-2007	Faults divided by cause during the period 1998-2007 (%) Lightning	Other natural cause	External influence	Operation and maintenance	Technical equipment	Other	Unknown
Denmark	4312	0	0.00	0.02	0.0	20.0	20.0	20.0	20.0	0.0	20.0
Finland	1514	1	0.07	0.05	28.6	0.0	14.3	0.0	42.9	14.3	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	4	0.05	0.06	10.2	0.0	0.0	12.2	44.9	22.4	10.2
Sweden	6673	2	0.03	0.07	22.0	2.4	0.0	4.9	53.7	12.2	4.9
Nordel	20794	7	0.03	0.05	15.8	2.0	1.0	7.9	48.5	16.8	7.9

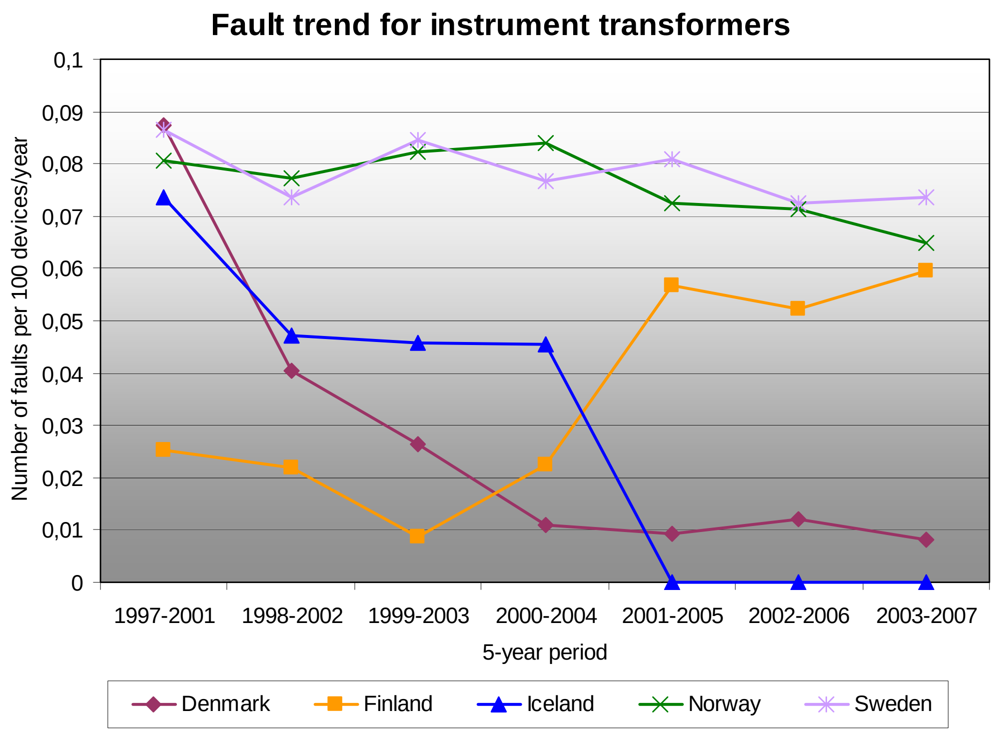

Figure 5.11. Fault trend for instrument transformers at all voltage levels

5.6. Faults in circuit breakers

The tables below present circuit breaker faults for the year 2007 and for the period 1998-2007 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. Disturbances caused by erroneous circuit breaker operations are registered as faults in circuit breakers, with operation and maintenance as their cause.

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 2007	Number of faults 2007	Number of faults per 100 devices		Faults divided by cause during the period 1998-2007 (%)						
			2007	1998-2007	Lightning	Other natural cause	External influence	Operation and maintenance	Technical equipment	Other	Unknown
Denmark	149	0	0.00	0.65	0.0	12.5	12.5	12.5	50.0	12.5	0.0
Finland	213	3	1.41	0.34	0.0	0.0	16.7	16.7	66.7	0.0	0.0
Norway	259	3	1.16	1.03	0.0	0.0	0.0	28.0	56.0	8.0	8.0
Sweden	429	10	2.33	1.91	0.0	2.5	0.0	2.5	79.7	11.4	3.8
Nordel	1050	16	1.52	1.24	0.0	2.5	1.7	9.3	72.0	10.2	4.2

For Sweden, the breaker failures at the 400 kV level all occurred in breakers used to switch the reactors. This may be 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. Circuit breakers 220 kV

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

Country	Number of devices 2007	Number of faults 2007	Number of faults per 100 devices		Faults divided by cause during the period 1998-2007 (%)						
			2007	1998-2007	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	95	0	0.00	0.43	0.0	0.0	0.0	0.0	75.0	25.0	0.0
Iceland	68	1	1.47	4.21	0.0	7.7	0.0	11.5	69.2	0.0	11.5
Norway	721	4	0.55	1.01	1.4	0.0	0.0	32.8	58.6	4.3	2.9
Sweden	394	3	0.76	0.69	4.0	0.0	0.0	20.0	72.0	0.0	4.0
Nordel	1280	8	0.63	1.03	1.6	0.8	0.0	25.0	64.5	3.2	4.8

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 2007	Number of faults 2007	Number of faults per 100 devices		Faults divided by cause during the period 1998-2007 (%)						
			2007	1998-2007	Lightning	Other natural cause	External influence	Operation and maintenance	Technical equipment	Other	Unknown
Denmark	807	3	0.37	0.55	0.0	8.4	2.2	34.0	44.8	10.6	0.0
Finland	1946	5	0.26	0.29	25.0	7.1	0.0	21.4	39.3	3.6	3.6
Iceland	122	1	0.82	0.78	0.0	0.0	0.0	22.2	66.7	0.0	11.1
Norway	2122	6	0.28	0.39	0.0	0.0	0.0	53.2	40.3	2.6	3.9
Sweden	1697	2	0.12	1.02	22.1	2.1	2.1	15.9	46.2	4.2	7.6
Nordel	6694	17	0.25	0.57	12.8	2.9	1.0	28.9	44.6	4.6	5.2

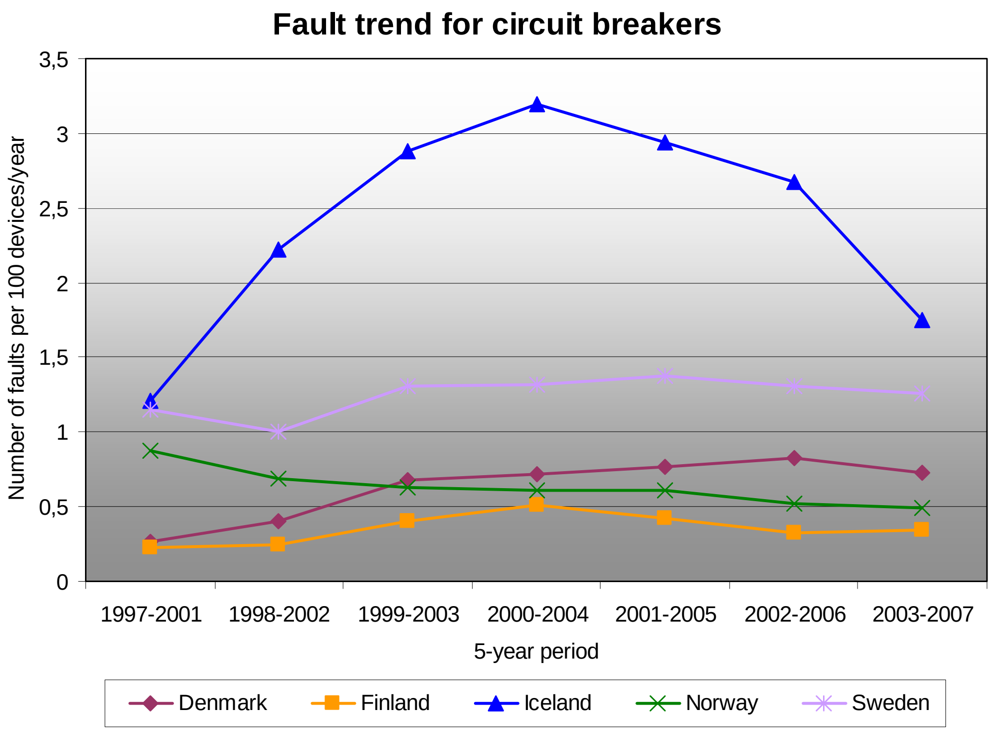

Figure 5.12. Fault trend for circuit breakers at all voltage levels

5.7. Faults in control equipment

The tables below present faults in control equipment at each respective voltage level for the year 2007 and for the period 1998-2007. 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 2007	Number of faults 2007	Number of faults per 100 devices		Faults divided by cause during the period 1998-2007 (%)						
			2007	1998-2007	Lightning	Other natural cause	External influence	Operation and maintenance	Technical equipment	Other	Unknown
Denmark	149	0	0.00	2.16	4.2	0.0	4.2	25.0	29.2	20.8	16.7
Finland	213	7	3.29	7.47	0.0	0.0	0.0	30.2	27.9	32.6	9.3
Norway	259	10	3.86	11.87	0.0	0.7	0.3	31.9	39.1	13.1	14.9
Sweden	429	31	7.23	12.18	0.4	0.6	0.3	12.6	79.1	5.1	1.9
Nordel	1050	48	4.57	9.98	0.3	0.5	0.1	21.5	58.2	11.9	7.4

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 2007	Number of faults 2007	Number of faults per 100 devices		Faults divided by cause during the period 1998-2007 (%)						
			2007	1998-2007	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	95	5	5.26	5.69	0.0	0.0	0.0	41.5	47.2	5.7	5.7
Iceland	68	2	2.94	11.83	4.1	11.0	0.0	34.3	46.6	4.1	0.0
Norway	721	13	1.80	9.08	0.5	0.8	0.5	32.2	41.3	8.7	16.1
Sweden	394	5	1.27	4.12	0.0	0.0	1.8	33.7	52.1	9.2	3.1
Nordel	1280	25	1.95	7.37	0.7	1.4	0.7	33.2	44.0	8.3	11.9

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 2007	Number of faults 2007	Number of faults per 100 devices 2007	Number of faults per 100 devices 1998-2007	Faults divided by cause during the period 1998-2007 (%) Lightning	Other natural cause	External influence	Operation and maintenance	Technical equipment	Other	Unknown
Denmark	807	13	1.61	0.95	5.5	6.8	2.7	42.5	17.8	16.4	8.2
Finland	1946	19	0.98	2.10	3.0	0.0	1.0	35.3	27.4	16.9	16.4
Iceland	120	8	6.67	4.62	0.0	3.8	1.9	37.7	54.7	0.0	1.9
Norway	2058	59	2.87	3.20	0.7	1.7	0.4	32.2	33.5	10.5	20.9
Sweden	1697	1	0.06	1.07	7.1	0.0	0.0	44.2	25.0	10.9	12.8
Nordel	6628	100	1.51	2.12	2.3	9.0	0.7	35.4	31.2	11.6	17.2

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 2007	Number of faults 2007	Number of faults per 100 devices 2007	Number of faults per 100 devices 2000-2007	Faults divided by cause during the period 2000-2007 (%) Lightning	Other natural cause	External influence	Operation and maintenance	Technical equipment	Other	Unknown
Denmark	36	2	5.56	5.30	0.0	0.0	0.0	21.4	57.1	0.0	21.4
Finland	44	0	0.00	2.76	0.0	0.0	0.0	0.0	66.7	25.0	8.3
Norway	36	2	5.56	7.51	0.0	0.0	0.0	31.6	57.9	5.3	5.3
Sweden	66	8	12.12	14.21	0.0	32.1	5.7	5.7	39.6	11.3	5.7
Nordel	182	12	6.59	7.40	0.0	17.3	3.1	12.2	49.0	10.2	8.2

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

Country	Number of devices 2007	Number of faults 2007	Number of faults per 100 devices 2007	2000-2007	Faults divided by cause during the period 2000-2007 (%) Lightning	Other natural cause	External influence	Operation and maintenance	Technical equipment	Other	Unknown
Finland	7	4	57.14	13.73	0.0	0.0	0.0	14.3	42.9	0.0	42.9
Iceland	1	0	0.00	12.50	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	11	91.67	67.71	1.5	0.0	0.0	3.1	32.3	44.6	18.5
Nordel	23	15	65.22	41.24	1.4	0.0	0.0	4.1	34.2	39.7	20.5

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

Country	Number of devices 2007	Number of faults 2007	Number of faults per 100 devices 2007	2000-2007	Faults divided by cause during the period 2000-2007 (%) Lightning	Other natural cause	External influence	Operation and maintenance	Technical equipment	Other	Unknown
Denmark	14	1	7.14	1.61	0.0	0.0	100.0	0.0	0.0	0.0	0.0
Finland	27	1	3.70	11.90	0.0	28.0	48.0	0.0	4.0	16.0	4.0
Iceland	9	2	22.22	5.63	0.0	0.0	0.0	0.0	100.0	0.0	0.0
Norway	194	7	3.61	3.36	0.0	0.0	2.0	11.8	45.1	39.2	2.0
Sweden	77	4	5.19	8.85	7.5	2.5	10.0	10.0	37.5	0.0	32.5
Nordel	321	15	4.67	4.84	2.6	0.9	16.5	8.7	37.4	20.9	13.0

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

Country	Number of devices 2007	Number of faults 2007	Number of faults per 100 devices 2007	2000-2007	Faults divided by cause during the period 2000-2007 (%) Lightning	Other natural cause	External influence	Operation and maintenance	Technical equipment	Other	Unknown
Norway	15	2	13.33	36.11	0.0	5.1	0.0	10.3	59.0	12.8	12.8
Sweden	3	7	233.33	66.27	0.0	7.3	5.5	16.4	61.8	1.8	7.3
Nordel	18	9	50.00	47.12	0.0	2.2	3.3	14.4	63.3	6.7	10.0

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 2007.

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 Danish outage data was available only from the western parts of the country, as has been the case during the previous years. The Swedish outage data for 2007 includes approximately 30% of the power system units operating at 132 kV and 100% of the units from the 220 kV and 400 kV voltage levels. Earlier the Swedish data did not include outages from the 132 kV voltage level and therefore the number of the different power system units has increased compared to previous years.

6.2. Outages in power system units

The following tables present outages in different power system units.

Table 6.1. Grouping of overhead lines according to number of outages in 2007

Line		Number of outages						
	Number of lines	Number of lines with no outages	1	2	3	4	5	>5
Denmark	179	159	10	8	2	0	0	0
Finland	321	211	63	25	10	6	4	2
Iceland	57	31	12	5	3	1	2	3
Norway	641	569	46	4	9	6	3	4
Sweden	389	279	74	20	9	5	1	1

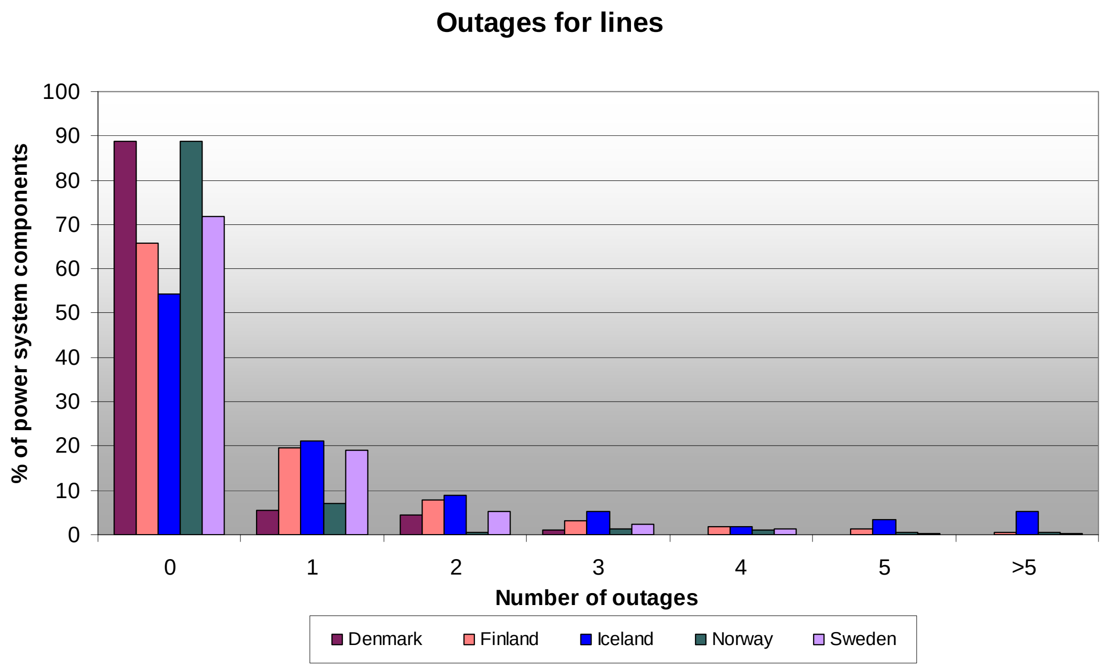

Figure 6.1. Grouping of overhead lines according to number of outages in 2007

Table 6.2. Grouping of transformers according to number of outages in 2007

Transformer		Number of outages						
	Number	**No outages**	**1**	**2**	**3**	**4**	**5**	**>5**
Denmark	149	148	1	0	0	0	0	0
Finland	823	822	1	0	0	0	0	0
Iceland	93	87	4	0	0	0	1	1
Norway	800	778	3	4	4	2	6	3
Sweden	279	260	12	6	0	0	0	1

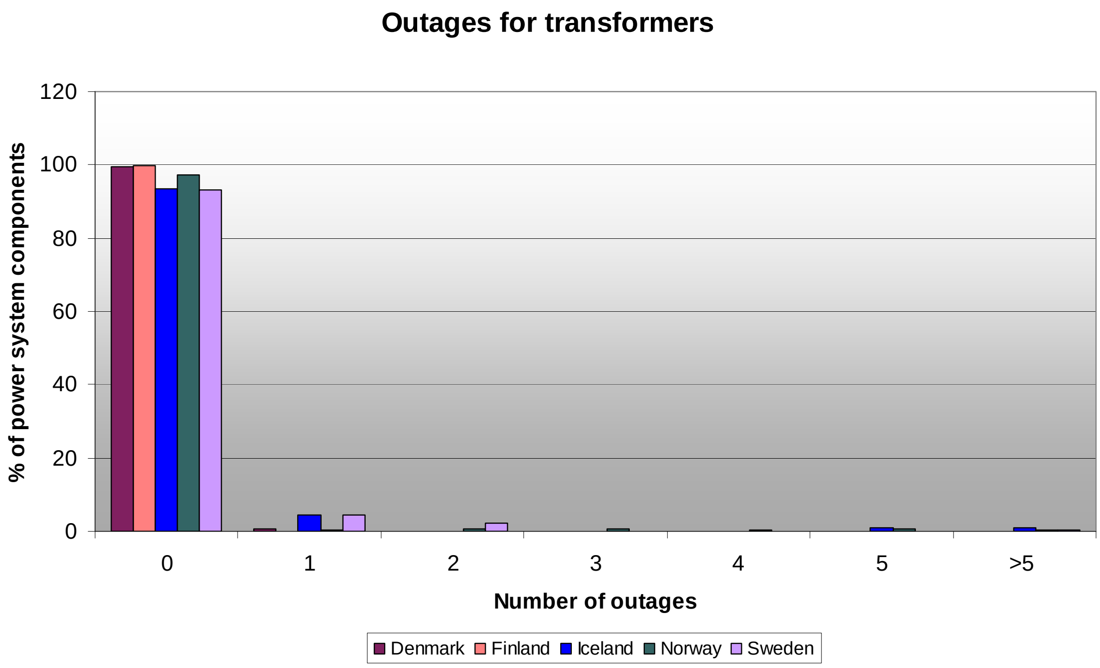

Figure 6.2. Grouping of transformers according to number of outages in 2007

Table 6.3. Grouping of busbars according to number of outages in 2007

Busbar		**Number of outages**						
	Number	**No outages**	**1**	**2**	**3**	**4**	**5**	**>5**
Denmark	172	172	0	0	0	0	0	0
Finland	688	688	0	0	0	0	0	0
Iceland	53	49	3	1	0	0	0	0
Norway	519	504	3	1	6	2	0	3
Sweden	475	470	4	0	1	0	0	0

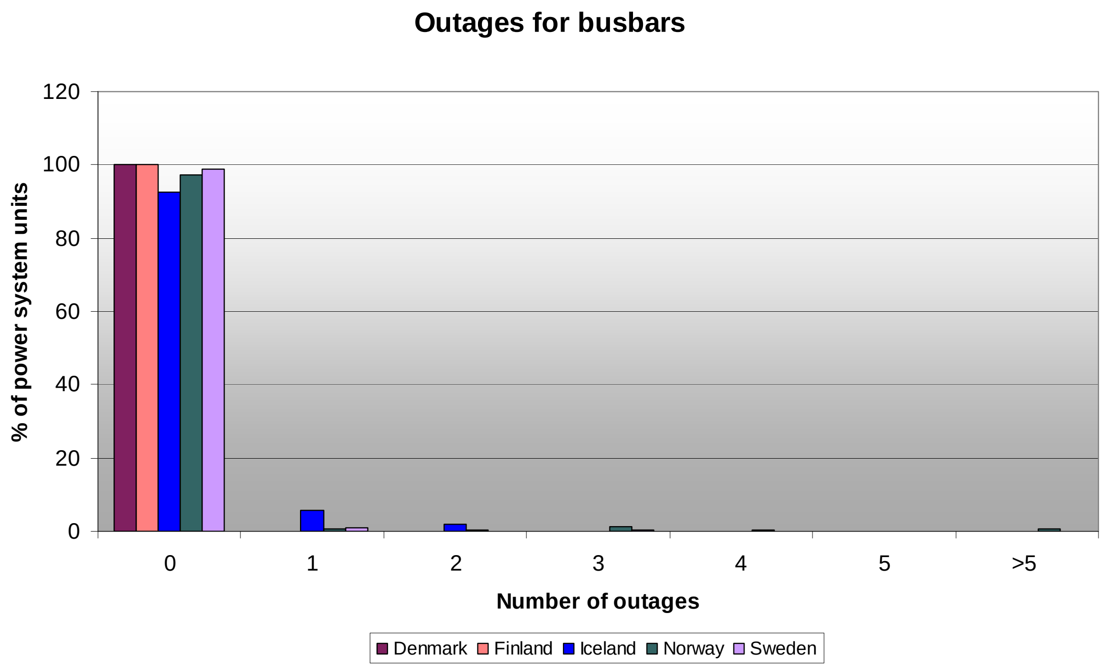

Figure 6.3. Grouping of busbars according to number of outages in 2007

Table 6.4. Grouping of reactors according to number of outages in 2007

Reactor		Number of outages						
	Number	No outages	1	2	3	4	5	>5
Denmark	13	13	0	0	0	0	0	0
Finland	44	44	0	0	0	0	0	0
Norway	26	24	2	0	0	0	0	0
Sweden	47	37	8	0	0	2	0	0

Table 6.5. Grouping of shunt capacitors according to number of outages in 2007

Shunt capacitors		Number of outages						
	Number	No outages	1	2	3	4	5	>5
Denmark	13	13	0	0	0	0	0	0
Finland	27	26	1	0	0	0	0	0
Iceland	9	7	1	1	0	0	0	0
Norway	164	158	3	0	1	0	2	0
Sweden	10	9	0	0	0	1	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. Outage duration of lines in 2007

Line		**Outage duration, minutes Number of components in each category**								
	Number	**No outages**	**<3**	**3-10**	**10-30**	**30-60**	**60-120**	**120-240**	**240-480**	**>480**
Denmark	179	159	11	0	4	1	0	0	0	4
Finland	321	211	84	4	10	4	3	2	0	3
Iceland	57	31	1	3	7	5	1	1	2	6
Norway	641	569	23	24	8	2	1	7	2	5
Sweden	389	279	58	15	12	0	3	5	3	14

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 2007

Transformer		**Outage duration, minutes Number of components in each category**								
	Number	**No outages**	**<3**	**3-10**	**10-30**	**30-60**	**60-120**	**120-240**	**240-480**	**>480**
Denmark	149	148	0	1	0	0	0	0	0	0
Finland	823	822	0	0	0	0	0	1	0	0
Iceland	93	87	1	1	0	1	0	0	0	3
Norway	800	778	4	6	2	3	1	3	2	1
Sweden*	279	260	0	3	0	1	10	0	2	3

*A detailed time distribution is not available from the Swedish data.

Table 6.8 Outage duration of busbars in 2007

Busbar		**Outage duration, minutes Number of components in each category**								
	Number	**No outages**	**<3**	**3-10**	**10-30**	**30-60**	**60-120**	**120-240**	**240-480**	**>480**
Denmark	172	172	0	0	0	0	0	0	0	0
Finland	688	688	0	0	0	0	0	0	0	0
Iceland	53	49	0	0	4	0	0	0	0	0
Norway	519	504	3	3	2	3	1	1	0	2
Sweden	475	470	2	1	0	1	0	1	0	0

Table 6.9. Outage duration of reactors in 2007

Reactor		Outage duration, minutes Number of components in each category								
	Number	No outages	<3	3-10	10-30	30-60	60-120	120-240	240-480	>480
Denmark	13	13	0	0	0	0	0	0	0	0
Finland	44	44	0	0	0	0	0	0	0	0
Norway	26	24	0	1	0	0	0	0	0	1
Sweden	47	37	2	0	0	1	1	2	0	4

Table 6.10. Outage duration of shunt capacitors in 2007

Shunt capacitor		Outage duration, minutes Number of components in each category								
	Number	No outages	<3	3-10	10-30	30-60	60-120	120-240	240-480	>480
Denmark	13	13	0	0	0	0	0	0	0	0
Finland	27	26	0	0	0	0	0	0	0	1
Iceland	9	7	0	0	0	0	0	0	0	2
Norway	164	158	1	3	0	1	0	1	0	0
Sweden	10	9	0	0	0	0	0	0	0	1

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.

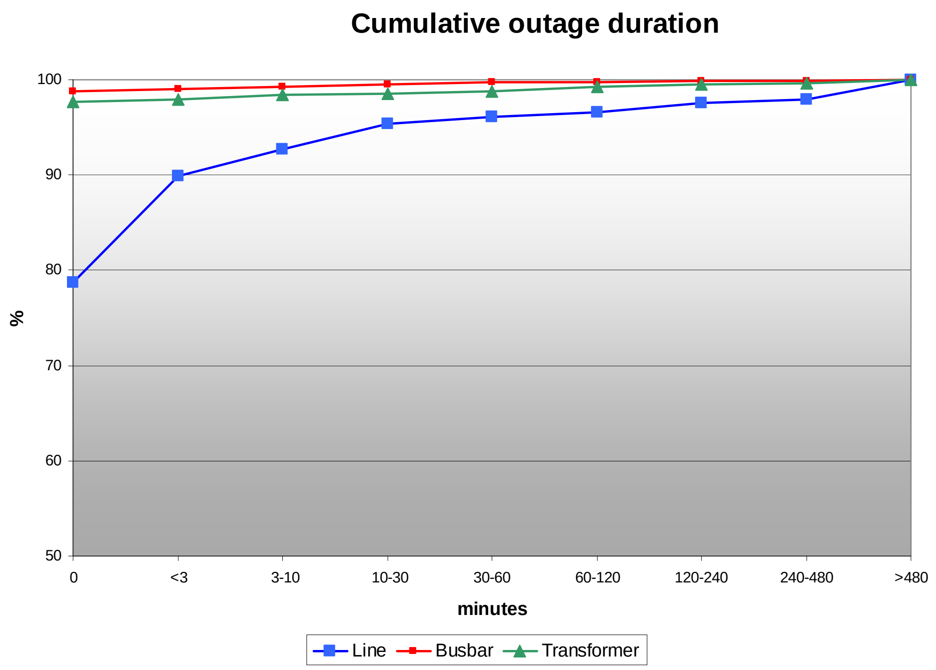

Figure 6.4. Cumulative duration of outages in selected power systems units

Figure 6.4 shows that about 79% of lines, 98% of transformers and 99% of busbars had no outages in 2007. The situation was somewhat similar in 2006 and 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]: The Energy Concern's National League, The Norwegian Water Supply and Energy Department, Statnett and Sintef Energy Research – Definitions in relation to faults and outages in the electrical power system - Version 2, 2001 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

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Appendix 3: Contact persons for the distribution network statistics

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

These people can provide more detailed information about these statistics:

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