entsoe

European Network of
Transmission System Operators
for Electricity

NORDIC GRID DISTURBANCE AND FAULT STATISTICS 2010

31.08.2011

REGIONAL GROUP NORDIC

ENTSO-E AISBL • Avenue Cortenbergh 100 • 1000 Brussels • Belgium • Tel +32 2 741 09 50 • Fax +32 2 741 09 51 • info@entsoe.eu • www.entsoe.eu

1 INTRODUCTION

This report is an overview of the Danish, Finnish, Icelandic, Norwegian and Swedish transmission grid disturbance statistics for the year 2010. Although Iceland does not belong to the ENTSO-E Regional Group Nordic, it is included in this report. In addition, the disturbance data of the whole Denmark is included in this report, although only the grid of eastern Denmark belongs to the synchronous Nordic grid. Transmission System Operators providing the statistical data are *Energinet.dk* in Denmark, *Fingrid Oyj* in Finland, *Landsnet* in Iceland, *Statnett SF* in Norway and *Svenska Kraftnät* in Sweden.

The report is made according to Nordic guidelines for disturbance statistics [1] and includes the faults causing disturbances in the 100–400 kV grids. The guidelines for the Classification of Grid Disturbances [1] were prepared by Nordel[1] during the years 1999–2000 and have been used since 2000. Most charts include data for the ten-year period 2001–2010. In some cases where older data has been available, even longer periods have been used.

The statistics can be found at ENTSO-E website, www.entsoe.eu. The guidelines and disturbance statistics were in the "Scandinavian" language until 2005. In 2007, however, the guidelines were translated into English and the report of the statistical year 2006 was the first set of statistics written in English. The structure of these statistics is similar to the 2006 statistics.

Although this summary originates from the Nordic co-operation that has aimed to use the combined experience from the five countries regarding the design and operation of their respective power systems, other ENTSO-E countries are encouraged to participate in the statistics as well. The material in the statistics covers the main systems and associated network devices with the 100 kV voltage level as the minimum. Control equipment and installations for reactive compensation are also included in the statistics.

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

Chapter 2 summarises the statistics, covering the consequences of disturbances in the form of energy not supplied (ENS) and covering the total number of disturbances in the Nordic power system. In addition, each Transmission System Operator has presented the most important issues of the year 2010.

[1] Nordel was the co-operation organization of the Nordic Transmission System Operators until 2009.

ENTSO-E AISBL • Avenue Cortenbergh 100 • 1000 Brussels • Belgium • Tel +32 2 741 09 50 • Fax +32 2 741 09 51 • info@entsoe.eu • www.entsoe.eu

Chapter 3 discusses the disturbances and focuses on the analysis and allocation of the causes of disturbances. The division of disturbances during the year 2010 for each country is presented; for example, the consequences of the disturbances in the form of energy not supplied.

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

Chapter 5 discusses the faults in different components. 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.

Chapter 7 presents a summary of HVDC disturbances and maintenances for the year 2010, outages and limitations as well as energy not transferred (ENT) resulted from them. This section is included in the report for the first time.

There are no common Nordic disturbance statistics for voltage levels lower than 100 kV. However, 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 contact person can provide additional information concerning ENTSO-E Nordic disturbance statistics. The relevant contact information is given in Appendix 2.

1.2 GUIDELINES OF THE STATISTICS

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

1.3 VOLTAGE LEVELS IN THE ENTSO-E NORDIC NETWORK

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

FIGURE 1.1 THE NORDIC MAIN GRID [2]

TABLE 1.1 VOLTAGE LEVELS IN THE ENTSO-E NORDIC NETWORK

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

U – statistical (designated) voltage, U_N – nominal voltage
P – percentage of the grid at the respective nominal voltage level for each statistical voltage.

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

1.4 SCOPE AND LIMITATIONS OF THE STATISTICS

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

TABLE 1.2 PERCENTAGE OF NATIONAL NETWORKS INCLUDED IN THE STATISTICS

Voltage level	Denmark	Finland	Iceland	Norway	Sweden
400 kV	100%	100%	-	100%	100%
220 kV	100%	100%	100%	100%	100%
132 kV	100%	96%	100%	100%	100%

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

Finland: The data includes approximately 96% of Finnish 110 kV lines and approximately 90% of 110/20 kV transformers.

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

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

ENTSO-E AISBL • Avenue Cortenbergh 100 • 1000 Brussels • Belgium • Tel +32 2 741 09 50 • Fax +32 2 741 09 51 • info@entsoe.eu • www.entsoe.eu

2 SUMMARY

In 2010, the energy not supplied (ENS) due to faults in the Nordic main grid was relatively low. ENS totalled 4.51 GWh, which is clearly below the ten-year annual average. The annual average of ENS was 7.48 GWh in the ENTSO-E Nordic region during the period 2001–2010. The corresponding average value for each country is presented in brackets in the following paragraphs. The following paragraphs also present the number of disturbances for each country as well as the number of disturbances that caused energy not supplied in 2010. The corresponding annual averages are calculated for the periods 2001–2010 and 2002–2010, respectively. In addition, the summaries present the most important issues in 2010 defined by each Transmission System Operator.

2.1 SUMMARY FOR DENMARK

In Denmark, the energy not supplied for the year 2010 was 14.7 MWh (ten-year average 961 MWh). The number of grid disturbances was 47 (ten-year average 69). In 2010, six of those 47 disturbances caused ENS. On average, four disturbances per year caused ENS during 2002–2010.

In Denmark, two grid disturbances lead to approximately 90% of ENS in 2010. Approximately 45 000 customers were interrupted by these two disturbances.

On January 29, high pressure in a tap changer on a 150/60 kV transformer caused 30 000 customers being interrupted and ENS of 6.2 MWh. Furthermore, on October 31 a poorly adjusted relay protection unit caused a 150 kV transformer to trip when transformer load was increased, which lead to ENS of 6 MWh. Approximately 15 000 customers were interrupted, and some of the customers were interrupted more than once.

2.2 SUMMARY FOR FINLAND

For Finland, the energy not supplied in 2010 was 757 MWh (ten-year average 263 MWh). The number of grid disturbances was 487 (ten-year average 305) and 100 of them caused ENS. On average, 60 disturbances per year caused ENS in 2002–2010. In 2010, 57% of ENS occurred due to other environmental causes and 13% 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 stayed at the same level as in the previous year 2009, 46% in 2010 and 48% in 2009. Almost all of the unknown disturbances occurred in 110 kV lines.

73% of ENS was caused by only five disturbances. The highest amount of ENS (411 MWh) in a single disturbance was caused by ‘other environmental causes’ in September; wind crashed one tower in Northern Finland, and a line went down for six days.

ENTSO-E AISBL • Avenue Cortenbergh 100 • 1000 Brussels • Belgium • Tel +32 2 741 09 50 • Fax +32 2 741 09 51 • info@entsoe.eu • www.entsoe.eu

2.3 SUMMARY FOR ICELAND

For Iceland, the energy not supplied in 2010 was 264 MWh (ten-year average 738 MWh). The total number of disturbances was 26 (ten-year average 39), and 10 of them caused ENS. On average, 24 disturbances per year caused ENS in 2002–2010.

About 75% of the ENS in Iceland occurred on May 7, 2010 in two disturbances. In one disturbance, problems in a large energy intensive unit caused power oscillations to the transmission system and some loads were disconnected. In the second disturbance, a large part of the 132 kV system in western, northern and eastern Iceland was disconnected due to a fault in the transformer control system.

2.4 SUMMARY FOR NORWAY

In Norway, the energy not supplied for 2010 was 904 MWh, the lowest value since the statistics have been done (ten-year average 2026 MWh). The number of grid disturbances was 158 (ten-year average 305), which is less than during any other year since 1999. Of these 158 disturbances 60 led to ENS. On average, 93 disturbances per year caused ENS in 2002–2010.

2.5 SUMMARY FOR SWEDEN

In Sweden, the energy not supplied in 2010 was 2576 MWh (ten-year average 3490 MWh). The total number of disturbances was 581 (ten-year average 590) and 144 of those caused ENS. On average, 134 disturbances per year caused ENS in 2002–2010.

The amount of ENS consists of many disturbances. One disturbance caused by a lightning stroke that tripped the HVDC link to the island of Gotland. The restart of the link was delayed and ENS totalled 456 MWh during two and a half hours.

3 DISTURBANCES

This chapter includes an overview of disturbances in the Nordic countries. It also presents the connection between disturbances, energy not supplied, fault causes and division during the year, together with the development of the number of disturbances over the ten-year period 2001–2010. 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, 3].

3.1 ANNUAL NUMBER OF DISTURBANCES DURING THE PERIOD 2001–2010

The number of disturbances during the year 2010 in the Nordic main grid was 1298, which is slightly below the ten-year average of 1307. The number of grid disturbances cannot directly be used for comparative purposes between countries because of the large differences between external conditions in the transmission networks of the Nordic countries.

Table 3.1 presents the sum of disturbances during the year 2010 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 2001–2010.

TABLE 3.1 NUMBER OF GRID DISTURBANCES IN 2010

Year 2010	Denmark	Finland	Iceland	Norway	Sweden
Number of disturbances	47	487	26	158	581

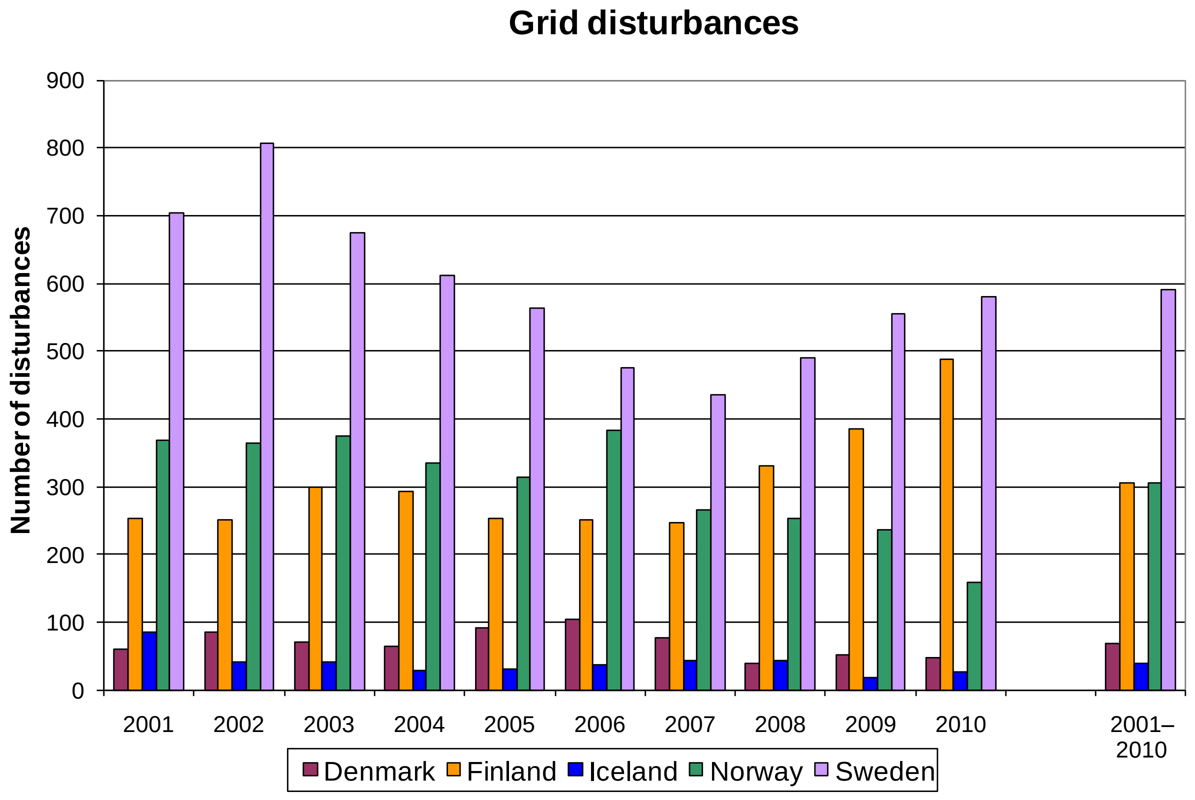

FIGURE 3.1 NUMBER OF GRID DISTURBANCES IN EACH NORDIC COUNTRY DURING THE PERIOD 2001–2010.

3.2 DISTURBANCES DIVIDED ACCORDING TO MONTH

Figure 3.2 presents the percentage distribution of grid disturbances according to month in different countries in the year 2010. In addition, Figure 3.3 shows the ten-year average distribution of disturbances during the period 2001–2010.

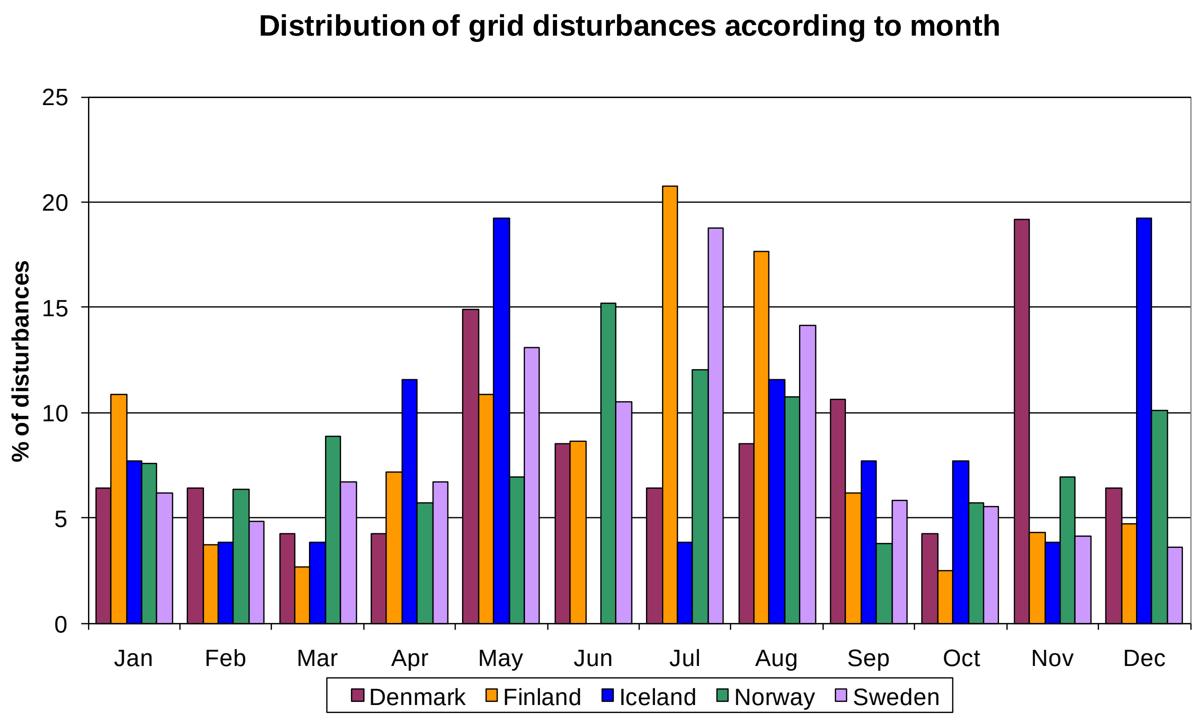

FIGURE 3.2 PERCENTAGE DISTRIBUTION OF GRID DISTURBANCES ACCORDING TO MONTH IN EACH COUNTRY IN 2010.

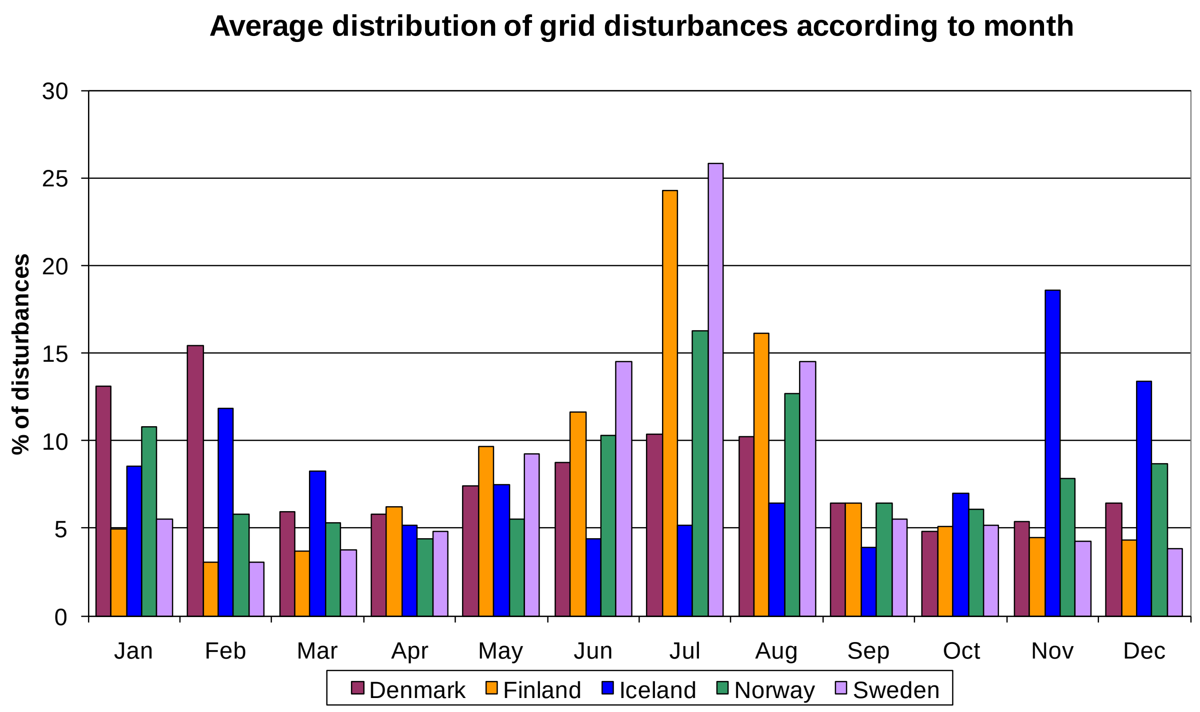

FIGURE 3.3 AVERAGE PERCENTAGE DISTRIBUTION OF GRID DISTURBANCES ACCORDING TO MONTH FOR THE PERIOD 2001–2010.

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

TABLE 3.2 PERCENTAGE DISTRIBUTION OF GRID DISTURBANCES PER MONTH FOR EACH COUNTRY IN 2010

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

TABLE 3.3 PERCENTAGE DIVISION OF GRID DISTURBANCES DURING THE YEARS 2001–2010

Country	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Denmark	13	15	6	6	7	9	10	10	6	5	5	6
Finland	5	3	4	6	10	12	24	16	6	5	4	4
Iceland	9	12	8	5	7	4	5	6	4	7	19	13
Norway	11	6	5	4	6	10	16	13	6	6	8	9
Sweden	6	3	4	5	9	14	26	15	6	5	4	4
Nordic	7	5	4	5	8	12	22	14	6	5	6	5

3.3 DISTURBANCES DIVIDED ACCORDING TO CAUSE

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

Each country that participates in the ENTSO-E Nordic statistics has its own detailed way of gathering data according to fault cause. The guidelines [1] describe the relations between the detailed fault causes and the common Nordic cause allocation.

ENTSO-E AISBL • Avenue Cortenbergh 100 • 1000 Brussels • Belgium • Tel +32 2 741 09 50 • Fax +32 2 741 09 51 • info@entsoe.eu • www.entsoe.eu

TABLE 3.4 GROUPING OF GRID DISTURBANCES AND ENERGY NOT SUPPLIED (ENS) BY CAUSE

Cause	Country	Percentage distribution of disturbances		Percentage distribution of ENS[1)]	
		2010	2001–2010	2010	2001–2010
Lightning	Denmark	6	17	2	0
	Finland	25	31	1	6
	Iceland	0	3	0	1
	Norway	16	23	1	6
	Sweden	29	40	40	12
Other environmental causes	Denmark	13	24	1	0
	Finland	11	5	57	22
	Iceland	27	40	0	55
	Norway	23	17	11	24
	Sweden	6	4	4	5
External influences	Denmark	19	15	0	0
	Finland	1	3	9	12
	Iceland	0	2	0	0
	Norway	3	2	5	2
	Sweden	3	3	23	4
Operation and maintenance	Denmark	15	15	41	4
	Finland	7	7	13	21
	Iceland	8	7	10	20
	Norway	11	14	20	17
	Sweden	10	7	6	11
Technical equipment	Denmark	26	13	6	11
	Finland	3	4	6	22
	Iceland	15	23	61	16
	Norway	18	23	26	34
	Sweden	10	15	1	42
Other	Denmark	11	6	8	84
	Finland	6	8	5	11
	Iceland	50	21	29	7
	Norway	23	15	9	13
	Sweden	19	10	4	18
Unknown	Denmark	11	10	42	0
	Finland[2)]	46	44	8	6
	Iceland	0	5	0	1
	Norway	6	6	28	3
	Sweden	24	20	21	9

1) Calculation of energy not supplied varies between different countries and is presented in Appendix 1.
2) Most of the Finnish unknown disturbances probably have other natural phenomenon or external influence as their cause.

Figure 3.4 identifies disturbances for all voltage levels in terms of the initial fault, and Figure 3.5 presents the respective ten-year average values.

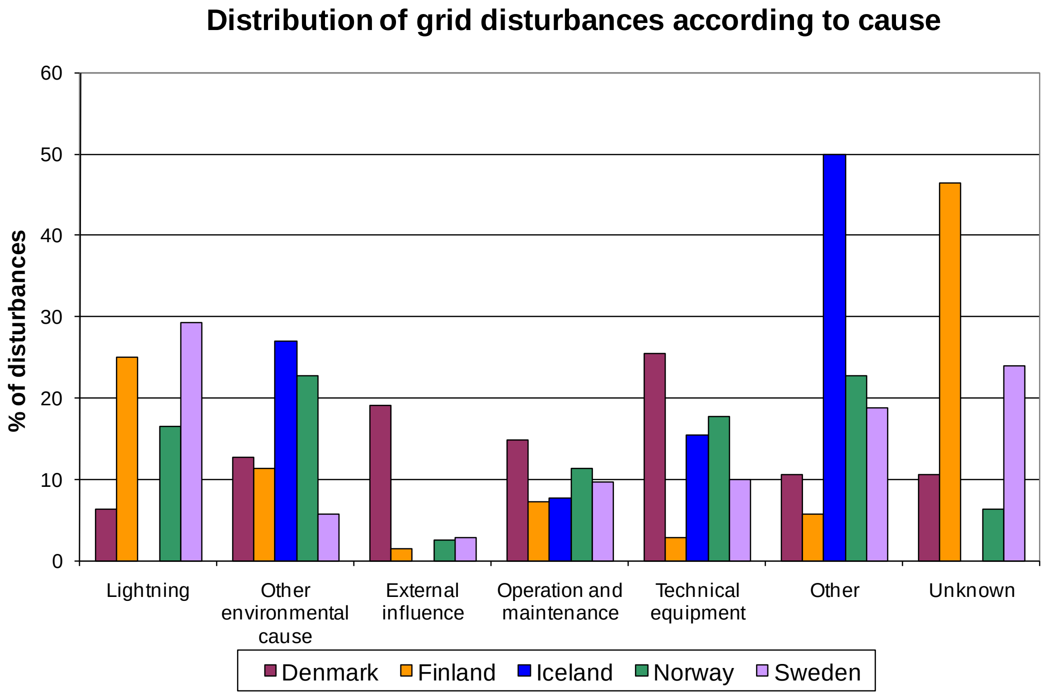

FIGURE 3.4 PERCENTAGE DISTRIBUTION OF GRID DISTURBANCES ACCORDING TO CAUSE IN 2010.

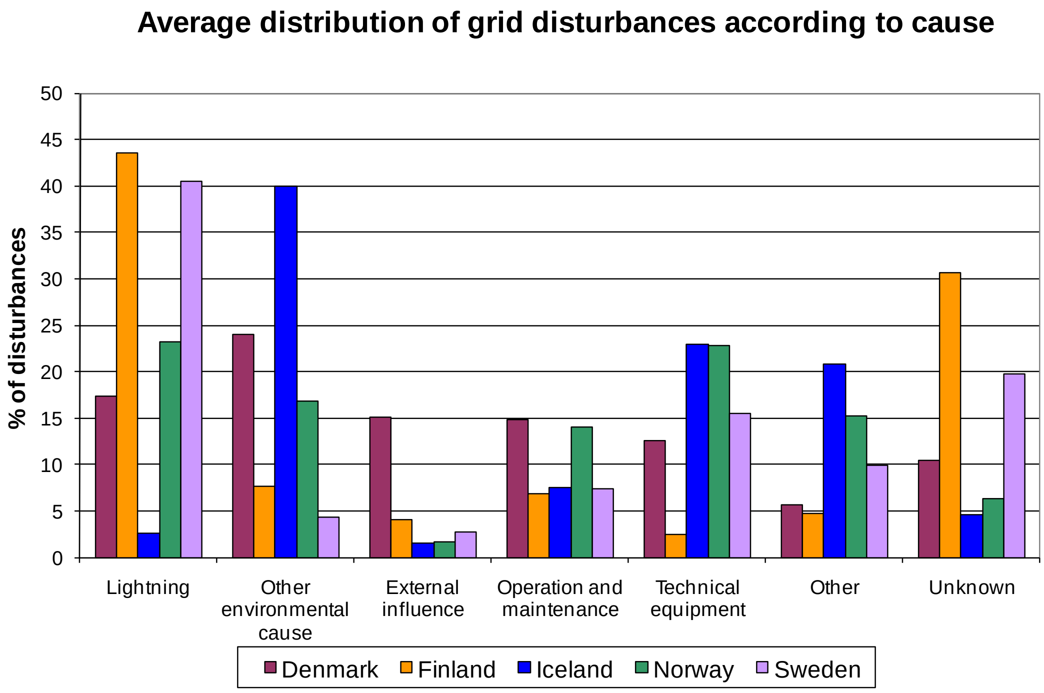

FIGURE 3.5 AVERAGE PERCENTAGE DISTRIBUTION OF GRID DISTURBANCES ACCORDING TO CAUSE DURING THE PERIOD 2001–2010.

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

4 ENERGY NOT SUPPLIED (ENS)

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

Definition of energy not supplied:

The estimated energy which would have been supplied to end users if no interruption and no transmission restrictions had occurred [1, 3].

4.1 ENERGY NOT SUPPLIED (ENS) DIVIDED ACCORDING TO VOLTAGE LEVEL

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

TABLE 4.1 ENERGY NOT SUPPLIED (ENS) ACCORDING TO THE VOLTAGE LEVEL OF THE INITIATING FAULT

Country	ENS MWh 2010	Annual average of ENS MWh 2001–2010	ENS divided into different voltage levels during the period 2001–2010 (%)			
			132 kV	220 kV	400 kV	Other[1)]
Denmark	14.7[2)]	960.5	5.3	0.0	94.6[3)]	0.0
Finland	757.0	262.7	95.3	3.5	0.2	1.0
Iceland	263.8	737.8	42.8	57.2	0.0	0.0
Norway	903.5	2026.3	38.4	32.2	8.3	21.2
Sweden	2575.9	3489.3	50.5	9.6	30.1[3)]	9.8
Nordic	4515.0	7476.6	42.2	19.0	28.5	10.3

1) The category other contains energy not supplied from system faults, auxiliary equipment, lower voltage level networks and the connections to foreign countries, etc.
2) The further explanation for the low ENS in Denmark compared with other countries can be found in Appendix 1, which discusses the different calculation methods of ENS.
3) 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.

ENTSO-E AISBL • Avenue Cortenbergh 100 • 1000 Brussels • Belgium • Tel +32 2 741 09 50 • Fax +32 2 741 09 51 • info@entsoe.eu • www.entsoe.eu

Figure 4.1 and Figure 4.2 summarise the energy not supplied according to the different voltage levels for the year 2010 and for the period 2001–2010, respectively. Voltage level refers to the initiating fault of the respective disturbance.

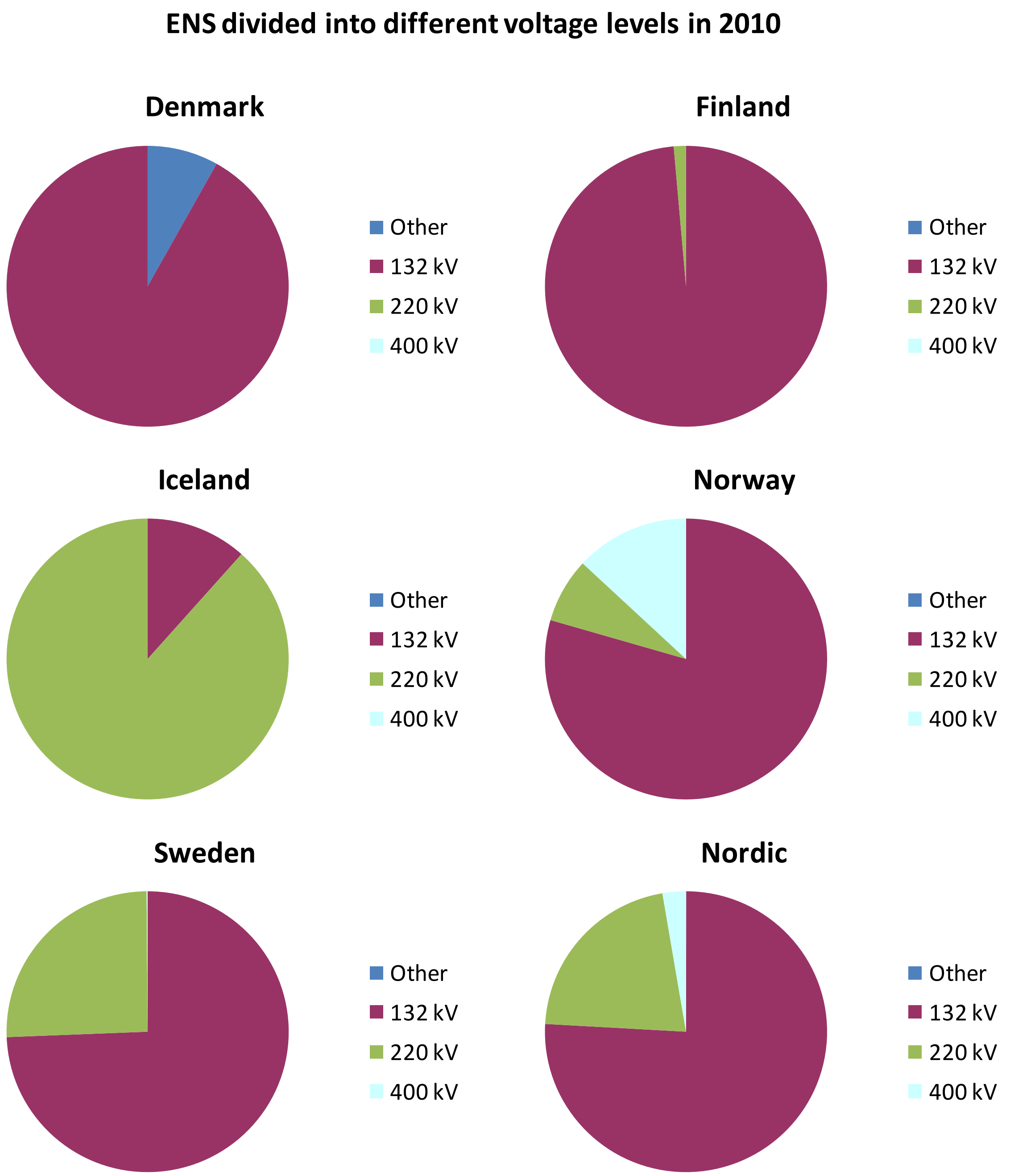

FIGURE 4.1 ENERGY NOT SUPPLIED (ENS) IN TERMS OF THE VOLTAGE LEVEL OF THE INITIATING FAULT IN 2010.

ENTSO-E AISBL • Avenue Cortenbergh 100 • 1000 Brussels • Belgium • Tel +32 2 741 09 50 • Fax +32 2 741 09 51 • info@entsoe.eu • www.entsoe.eu

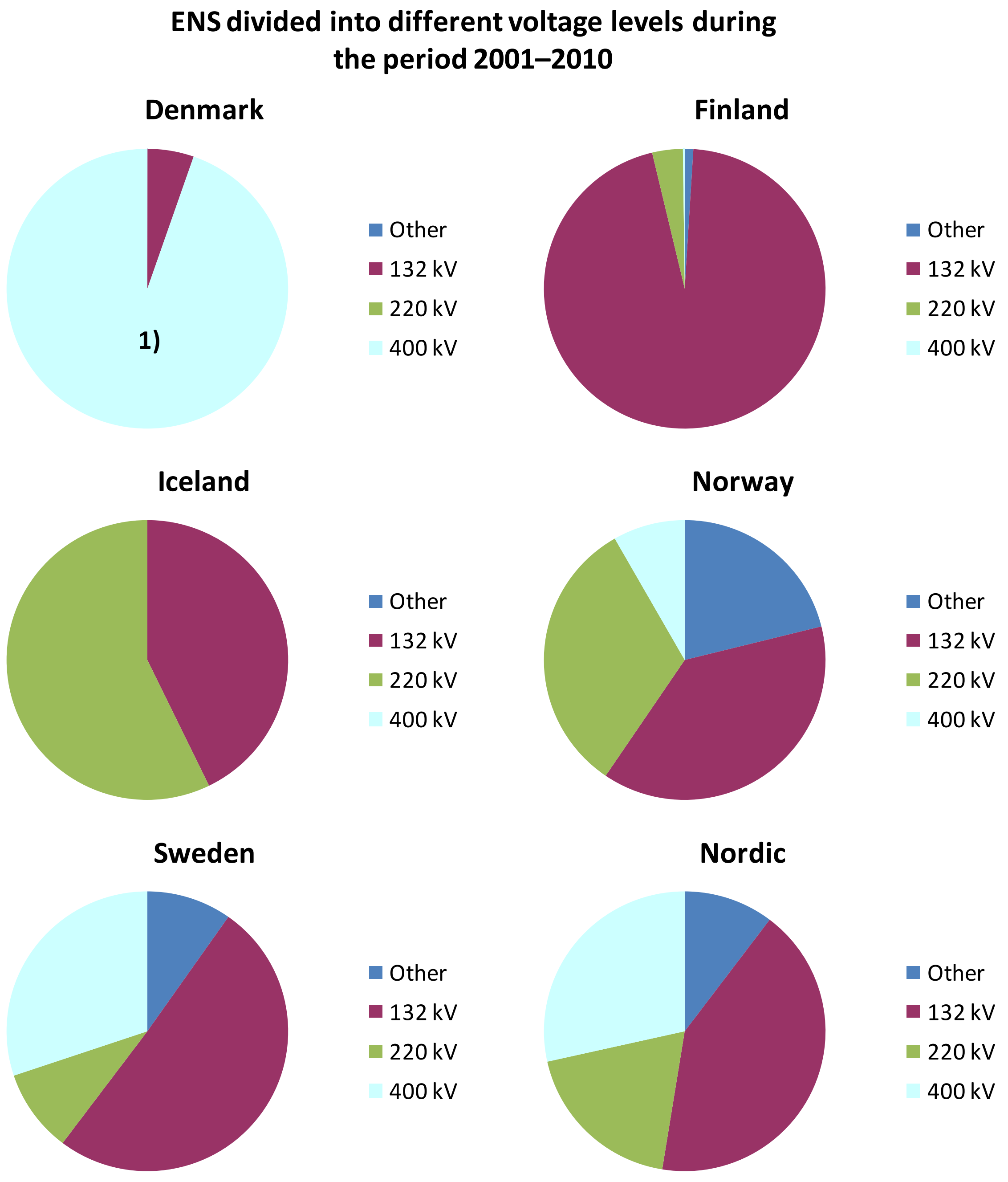

FIGURE 4.2 ENERGY NOT SUPPLIED (ENS) IN TERMS OF THE VOLTAGE LEVEL OF THE INITIATING FAULT DURING THE PERIOD 2001–2010.

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

4.2 ENERGY NOT SUPPLIED (ENS) AND TOTAL CONSUMPTION

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

TABLE 4.2 ENERGY NOT SUPPLIED (ENS) ACCORDING TO INSTALLATION

Country	Total con-sumption	ENS	ENS / consumption		ENS divided according to installation during the period 2001–2010 (%)			
	GWh 2010	MWh 2010	Ppm 2010	Ppm 2001–2010	Overhead line	Cable	Sta-tions	Other
Denmark	32847	14.7	0.4	28.0	11.7	0.0	4.7	83.5
Finland	87500	757.0	8.7	3.3	59.4	0.0	35.6	5.0
Iceland	17059	263.8	15.5	64.4	39.4	1.1	43.3	16.2
Norway	131129	903.5	6.9	16.0	30.5	0.5	46.5	22.5
Sweden	144000	2575.9	17.9	24.0	14.9	9.1	68.9	7.1
Nordic	412535	4514.9	10.9	18.8	22.7	4.5	50.9	21.9

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

Figure 4.3 presents the development of energy not supplied during the period 2001–2010. One should note that there is a considerable difference from year to year depending on occasional events, such as storms. These events have a significant effect on each country's yearly statistics.

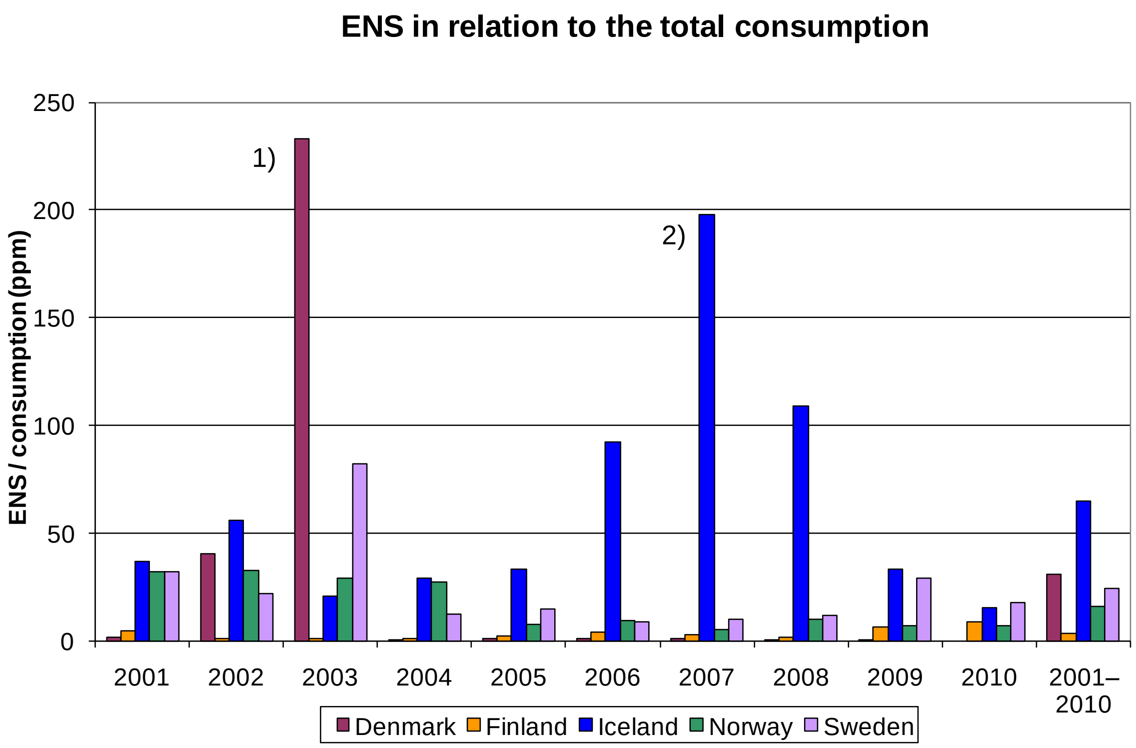

FIGURE 4.3 ENERGY NOT SUPPLIED (ENS) / CONSUMPTION (PPM).

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

4.3 ENERGY NOT SUPPLIED (ENS) DIVIDED ACCORDING TO MONTH

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

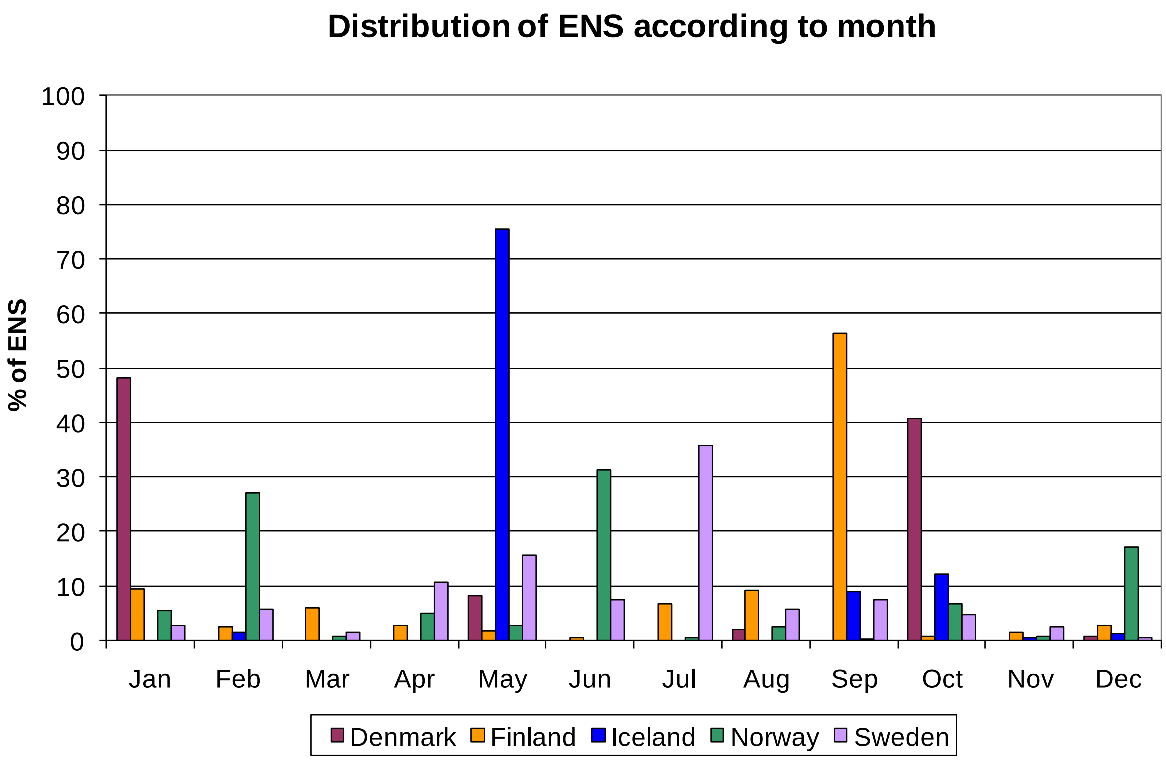

FIGURE 4.4 PERCENTAGE DISTRIBUTION OF ENERGY NOT SUPPLIED (ENS) ACCORDING TO MONTH IN 2010.

4.4 ENERGY NOT SUPPLIED (ENS) DIVIDED ACCORDING TO CAUSE

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

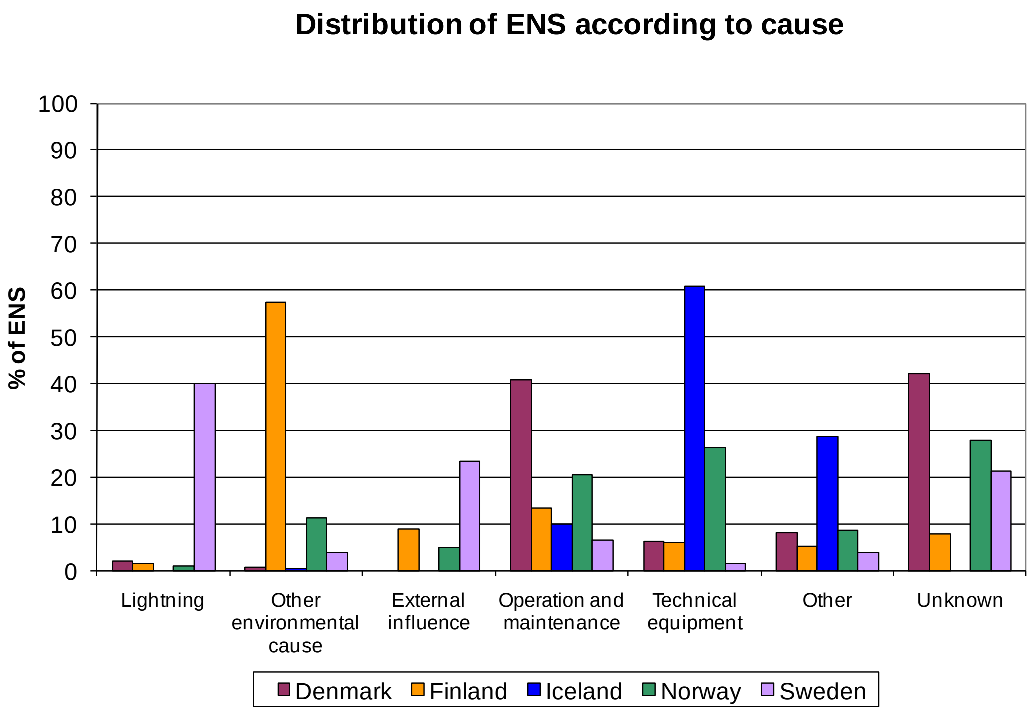

FIGURE 4.5 PERCENTAGE DISTRIBUTION OF ENERGY NOT SUPPLIED (ENS) ACCORDING TO THE CAUSE OF THE PRIMARY FAULT IN 2010.

4.5 Energy not supplied (ENS) divided according to component

Table 4.3 shows the amount of energy not supplied in 2010 and the annual average for the period 2001–2010. Table 4.4 shows the distribution of energy not supplied according to component.

Table 4.3 Energy not supplied (ENS) in 2010 and the annual average for the period 2001–2010

	Denmark		**Finland**		**Iceland**		**Norway**		**Sweden**		**Nordic**	
Time period	2010	2001–2010	2010	2001–2010	2010	2001–2010	2010	2001–2010	2010	2001–2010	2010	2001–2010
ENS (MWh)	15	961	757	263	264	738	903	2026	2582	3488	4521	7475

TABLE 4.4 PERCENTAGE DISTRIBUTION OF ENERGY NOT SUPPLIED IN TERMS OF COMPONENT

Fault location	Denmark		Finland		Iceland		Norway		Sweden		Nordic	
	2010	2001–2010	2010	2001–2010	2010	2001–2010	2010	2001–2010	2010	2001–2010	2010	2001–2010
Overhead line	0.0	0.4	89.5	59.4	0.5	39.3	15.5	30.9	20.5	14.9	29.8	21.3
Cable	0.0	0.0	0.0	0.0	0.0	1.1	0.0	0.5	2.2	9.1	1.2	4.5
Sum of line faults	**0.0**	**0.4**	**89.5**	**59.4**	**0.5**	**40.4**	**15.5**	**31.3**	**22.6**	**24.0**	**31.0**	**25.8**
Power transformer	44.2	0.8	1.5	1.9	0.0	0.2	5.6	0.9	5.7	10.1	4.8	5.1
Instrument transformer	0.0	0.0	0.0	3.5	0.0	0.0	9.0	4.1	6.5	2.8	5.5	2.6
Circuit breaker	0.0	3.5	3.0	3.4	0.0	3.8	18.9	2.5	6.0	1.9	7.7	2.5
Disconnector	0.0	0.2	0.0	2.7	0.0	13.1	0.6	4.6	1.0	33.2	0.7	18.1
Surge arrester and spark gap	0.0	0.0	0.0	2.2	0.0	0.0	0.0	2.5	0.0	0.2	0.0	0.8
Busbar	0.0	0.2	0.0	2.6	0.0	8.3	0.0	1.6	0.1	1.4	0.1	2.0
Control equipment	47.6	11.5	5.2	17.7	69.2	14.1	15.7	28.2	3.6	3.9	10.2	13.0
Common ancillary equipment	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1
Other substation faults	0.0	0.0	0.9	0.9	0.3	0.0	34.7	3.6	51.0	16.5	36.2	8.7
Sum of substation faults	**91.8**	**16.1**	**10.5**	**35.6**	**69.5**	**39.5**	**84.5**	**47.9**	**73.9**	**70.0**	**65.2**	**52.9**
Shunt capacitor	0.0	0.0	0.0	0.0	0.0	3.7	0.0	0.0	0.0	1.0	0.0	0.8
Series capacitor	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Reactor	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SVC and statcom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Synchronous compensator	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sum of compen-sation faults	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**3.7**	**0.0**	**0.0**	**0.0**	**1.0**	**0.0**	**0.8**
System fault	0.0	83.5	0.0	0.0	30.0	16.3	0.0	6.8	0.5	0.7	2.0	14.5
Faults in adjoining statistical area	8.2	0.0	0.0	5.0	0.0	0.0	0.0	13.9	3.0	4.4	1.7	6.0
Unknown	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sum of other faults	**8.2**	**83.5**	**0.0**	**5.0**	**30.0**	**16.3**	**0.0**	**20.7**	**3.5**	**5.0**	**3.8**	**20.5**

One should notice that some countries register the total amount 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. This chapter presents the fault statistics for different grid components. One should take note of both the causes and consequences of the fault when analysing the fault frequencies of different devices. For example, overhead lines normally have more faults than cables. On the other hand, cables normally have considerably longer repair times than overhead lines.

Definition of a component fault:

The inability of a component to perform its required function [5].

This chapter gives an overview of all faults registered in the component groups used in the ENTSO-E Nordic statistics, followed by more detailed statistics relating to each specific component group. Ten-year average values have been calculated for most components. For overhead lines, even a longer period has been used due to their long lifetime. The averages are calculated on the basis of the number of components with the number of faults for each time period, which takes into consideration the annual variation in the number of components. This chapter also presents fault trend curves for some components. The trend curves show the variation in the fault frequencies of consecutive five-year periods. These curves are divided into 220–400 kV and 132 kV voltage levels for all the components except for cables, which are not divided. Readers who need more detailed data should use the national statistics.

5.1 OVERVIEW OF ALL FAULTS

Table 5.1 presents the number of faults and disturbances during 2010. For Iceland, the fault statistics cover data from *Landsnet*, the only transmission company in Iceland. The Transmission System Operators of the other four countries collect data from several grid owners, and the representation of their statistics is not fully consistent.

TABLE 5.1 NUMBER OF FAULTS AND GRID DISTURBANCES IN 2010

	Denmark	Finland	Iceland	Norway	Sweden
Number of faults in 2010	50	499	32	187	583
Number of disturbances in 2010	47	487	26	158	581
Fault/disturbance ratio in 2010	1.06	1.02	1.23	1.18	1.00
The average fault/disturbance ratio during 2001–2010	1.18	1.08	1.28	1.29	1.05

5.1.1 OVERVIEW OF FAULTS DIVIDED ACCORDING TO VOLTAGE LEVEL

Table 5.2 presents the division of faults and energy not supplied in terms of voltage level and country. 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)]	2010	2001–2010 (annual average)	2010	2001–2010 (annual average)
400 kV	Denmark	25	1595	3	9.5	0.0	329.1
	Finland	50	4662	27	21.9	0.0	0.5
	Iceland	0	0	-	-	-	-
	Norway	64	2708	30	52.1	118.5	157.3
	Sweden	62	10969	151	122.8	3.0	1051.1
220 kV	Denmark	2	105	1	0.4	0.0	0.0
	Finland	24	2584	23	23.6	10.6	9.3
	Iceland	32	868	11	15.5	233.1	426.8
	Norway	271	6165	54	102.2	67.2	665.1
	Sweden	106	4068	78	69.1	656.8	334.0
132 kV	Denmark	238	4515	41	67.7	13.5	51.3
	Finland	906	17261	432	262.8	746.4	250.7
	Iceland	59	1368	21	32.7	30.7	318.6
	Norway	724	10677	103	180.1	717.9	864.7
	Sweden	758	15284	340	384.0	1916.1	1762.6

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

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

ENTSO-E AISBL • Avenue Cortenbergh 100 • 1000 Brussels • Belgium • Tel +32 2 741 09 50 • Fax +32 2 741 09 51 • info@entsoe.eu • www.entsoe.eu

TABLE 5.3 PERCENTAGE DIVISION OF FAULTS ACCORDING TO COMPONENT

Fault location	Denmark		Finland		Iceland		Norway		Sweden		Nordic	
	2010	2001–2010	2010	2001–2010	2010	2001–2010	2010	2001–2010	2010	2001–2010	2010	2001–2010
Overhead line	40.0	56.6	80.2	76.0	21.9	38.4	37.4	38.8	60.7	55.8	63.0	55.1
Cable	14.0	3.6	0.0	0.0	0.0	0.6	1.6	0.8	0.5	0.6	1.0	0.7
Sum of line faults	**54.0**	**60.2**	**80.2**	**76.0**	**21.9**	**39.0**	**39.0**	**39.6**	**61.3**	**56.4**	**63.9**	**55.8**
Power transformer	4.0	4.1	1.8	1.2	3.1	3.3	4.8	1.9	1.7	5.2	2.3	3.3
Instrument transformer	2.0	0.9	0.2	0.4	0.0	0.0	2.1	1.7	1.0	1.0	0.9	1.0
Circuit breaker	2.0	6.3	0.8	1.2	0.0	5.8	5.9	3.4	1.0	3.6	1.6	3.3
Disconnector	2.0	1.6	0.0	0.6	0.0	0.2	6.4	1.8	0.3	0.8	1.1	1.0
Surge arresters and spark gap	0.0	0.5	0.0	0.2	0.0	0.4	1.1	1.1	0.0	0.3	0.1	0.5
Busbar	2.0	0.4	0.0	0.3	0.0	0.8	1.1	1.2	1.7	0.9	1.0	0.8
Control equipment[1)]	24.0	14.5	10.0	12.5	31.3	25.0	10.7	28.6	1.0	10.8	7.2	16.7
Common ancillary equipment	0.0	0.4	0.0	0.2	0.0	0.0	1.1	1.2	0.0	0.8	0.1	0.7
Other substation faults	0.0	2.5	2.4	1.5	6.3	8.3	20.9	6.6	9.8	6.8	8.2	5.4
Sum of substation faults	**36.0**	**31.1**	**15.2**	**18.2**	**40.6**	**43.8**	**54.0**	**47.5**	**16.6**	**30.1**	**22.5**	**32.7**
Shunt capacitor	0.0	0.1	0.4	0.7	0.0	1.9	0.0	1.1	0.3	0.7	0.3	0.8
Series capacitor	0.0	0.0	0.4	0.6	0.0	0.2	0.0	0.0	15.1	2.6	6.7	1.2
Reactor	0.0	1.9	0.0	0.3	0.0	0.0	0.0	0.5	3.0	1.3	1.3	0.9
SVC and statcom	0.0	0.1	0.2	0.0	0.0	0.0	7.0	1.5	1.4	1.3	1.6	1.0
Synchronous compensator	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.3	0.4	0.1	0.4
Sum of compensation faults	**0.0**	**2.1**	**1.0**	**1.7**	**0.0**	**2.1**	**7.0**	**3.9**	**20.1**	**6.2**	**10.1**	**4.2**
System fault	2.0	2.9	0.2	0.1	37.5	14.5	0.0	1.9	0.3	3.5	1.2	2.7
Faults in adjoining statistical area	8.0	3.7	3.4	3.9	0.0	0.0	0.0	7.1	1.7	3.8	2.3	4.6
Unknown	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0
Sum of other faults	**10.0**	**6.6**	**3.6**	**4.1**	**37.5**	**15.1**	**0.0**	**9.0**	**2.0**	**7.3**	**3.5**	**7.3**

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

5.2 FAULTS IN OVERHEAD LINES

Overhead lines constitute a large part of the Nordic transmission grid. Therefore, the tables in this section show the division of faults in 2010 as well as the average values for the period 1996–2010. The tables also give the faults divided by cause during the period 1996–2010. Along with the tables, the annual division of faults during the period 2001–2010 is presented graphically for all voltage levels. The section also presents the trend curves for overhead line faults. With the help of the trend curve, it may be possible to determine the trend of faults also in the future.

ENTSO-E AISBL • Avenue Cortenbergh 100 • 1000 Brussels • Belgium • Tel +32 2 741 09 50 • Fax +32 2 741 09 51 • info@entsoe.eu • www.entsoe.eu

5.2.1 400 kV OVERHEAD LINES

Table 5.4 shows the line lengths, faults of 400 kV lines, the causes of faults and the percentage values of 1-phase faults and permanent faults. The data consists of the values for the year 2010 and for the 15-years period 1996–2010. Figure 5.1 presents the annual line fault values per line length during the 10-year period 2001–2010.

TABLE 5.4 DIVISION OF FAULTS ACCORDING TO CAUSE FOR 400 KV OVERHEAD LINES

Country	Line km	Number of faults	Number of faults per 100 km		Faults divided by cause during the period 1996–2010 (%)								
	2010	2010	2010	1996–2010	Lightning	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown	1-phase faults	Permanent faults
Denmark	1228	1	0.08	0.33	18.6	59.3	8.5	5.1	5.1	1.7	1.7	50.8	5.1
Finland	4662	8	0.17	0.25	78.3	5.9	1.3	3.3	2.6	2.6	5.9	58.6	7.9
Norway	2683	12	0.45	1.03	24.8	67.3	0.3	0.3	1.8	2.1	3.4	66.2	7.7
Sweden	10720	38	0.35	0.35	52.2	18.8	1.8	2.7	3.2	1.1	20.4	81.8	7.8
Nordic	19293	59	0.31	0.42	44.9	35.1	1.6	2.1	2.8	1.6	11.9	72.0	7.6

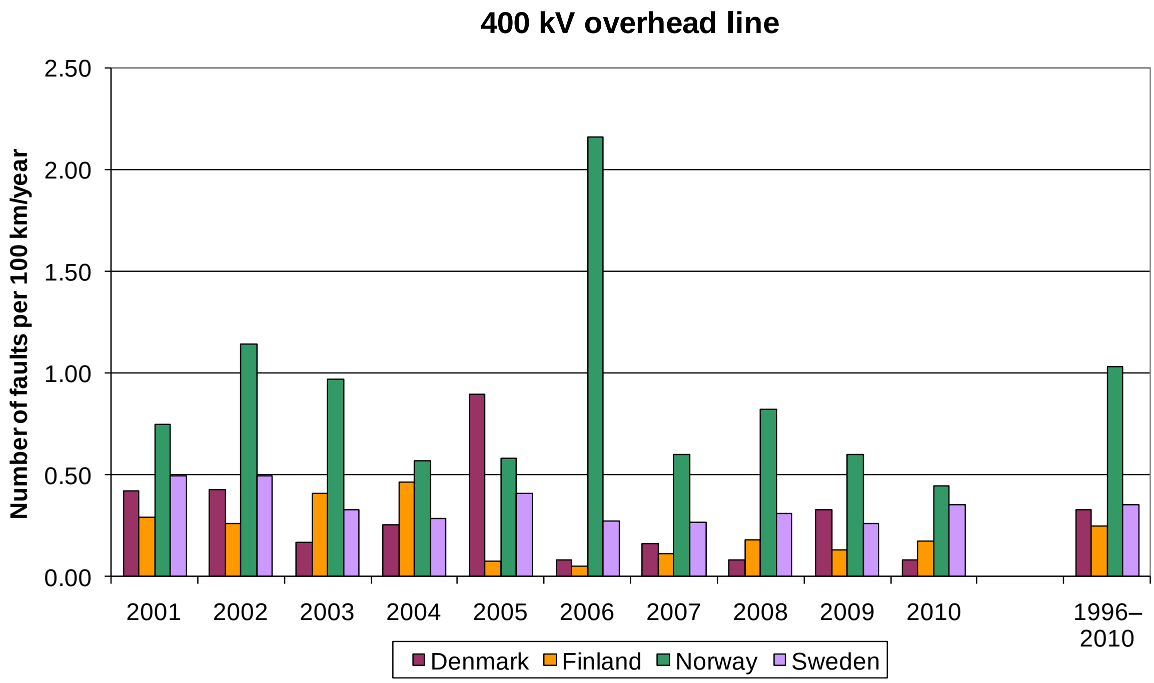

FIGURE 5.1 ANNUAL DIVISION OF FAULTS DURING THE PERIOD 2001–2010.

5.2.2 220 kV OVERHEAD LINES

Table 5.5 shows the line lengths, faults of 220 kV lines, the causes of faults and the percentage values of 1-phase faults and permanent faults. The data consists of the values for the year 2010 and for the 15-years period 1996–2010. Figure 5.2 presents the annual line fault values per line length during the 10-year period 2001–2010.

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 1996–2010 (%)								
	2010	2010	2010	1996–2010	Lightning	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown	1-phase faults	Permanent faults
Denmark	105	1	0.95	0.51	50.0	12.5	25.0	0.0	0.0	0.0	12.5	87.5	0.0
Finland	2584	16	0.62	0.77	46.3	2.8	2.1	0.7	0.4	1.1	46.6	71.7	2.8
Iceland	867	3	0.35	0.40	27.5	55.0	0.0	0.0	17.5	0.0	0.0	52.5	22.5
Norway	5715	13	0.23	0.68	55.7	31.6	1.0	0.3	2.2	2.7	6.3	59.3	12.2
Sweden	4035	39	0.97	0.88	69.8	4.1	3.8	4.3	3.8	0.7	13.4	55.0	7.4
Nordic	13306	72	0.54	0.75	58.6	16.0	2.4	1.9	2.9	1.5	16.6	60.0	8.8

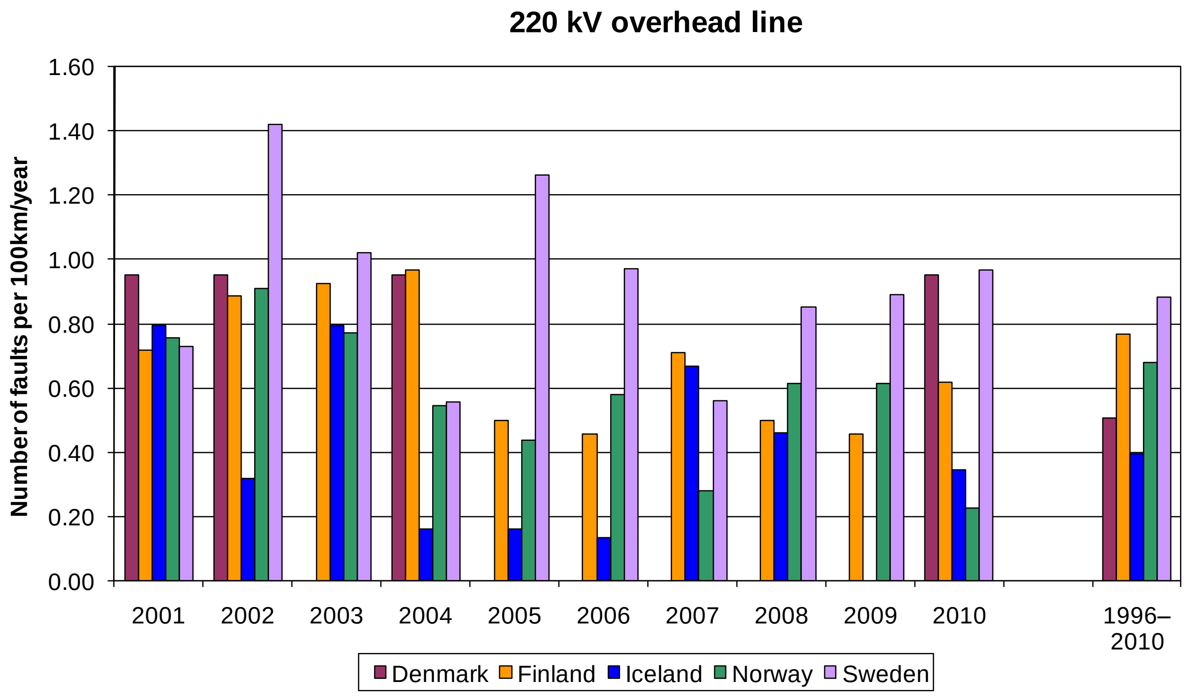

FIGURE 5.2 ANNUAL DIVISION OF FAULTS DURING THE PERIOD 2001–2010.

5.2.3 132 kV OVERHEAD LINES

Table 5.6 shows the line lengths, faults of 132 kV lines, the causes of faults and the percentage values of 1-phase faults and permanent faults. The data consists of the values for the year 2010 and for the 15-years period 1996–2010. Figure 5.3 presents the annual line fault values per line length during the 10-year period 2001–2010.

TABLE 5.6 DIVISION OF FAULTS ACCORDING TO CAUSE FOR 132 KV OVERHEAD LINES

Country	Line km 2010	Number of faults 2010	Number of faults per 100 km 2010	Number of faults per 100 km 1996–2010	Faults divided by cause during the period 1996–2010 (%) Lightning	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown	1-phase faults	Permanent faults
Denmark	3669	18	0.49	1.05	23.4	45.4	17.7	2.3	1.2	2.6	7.4	46.0	5.1
Finland	17065	376	2.20	1.95	40.4	7.1	1.6	1.2	0.4	0.7	48.6	77.6	2.9
Iceland	1272	4	0.31	1.28	3.0	86.1	3.4	0.8	6.3	0.0	0.4	42.2	12.2
Norway	10475	45	0.43	1.02	55.1	29.6	2.8	1.1	6.2	3.8	1.6	23.2[1)]	16.9
Sweden	15105	279	1.85	2.21	62.4	5.1	2.5	2.5	2.5	1.8	23.1	40.6	5.3
Nordic	47586	722	1.52	1.69	50.0	14.0	3.2	1.8	2.4	1.8	26.8	50.7	6.4

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

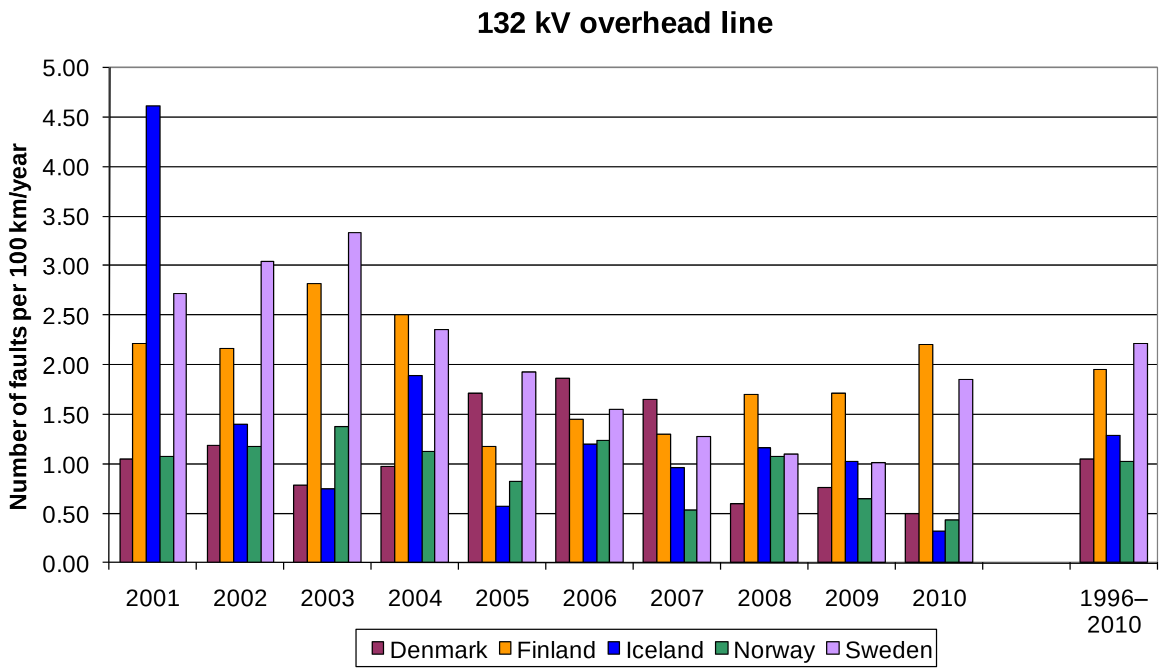

FIGURE 5.3 ANNUAL DIVISION OF FAULTS DURING THE PERIOD 2001–2010.

5.2.4 LINE FAULT TRENDS

Figure 5.4 and Figure 5.5 present faults divided by line length for 220–400 kV lines and 132 kV lines, respectively. The trend curve is proportioned to line length in order to get comparable results between countries.

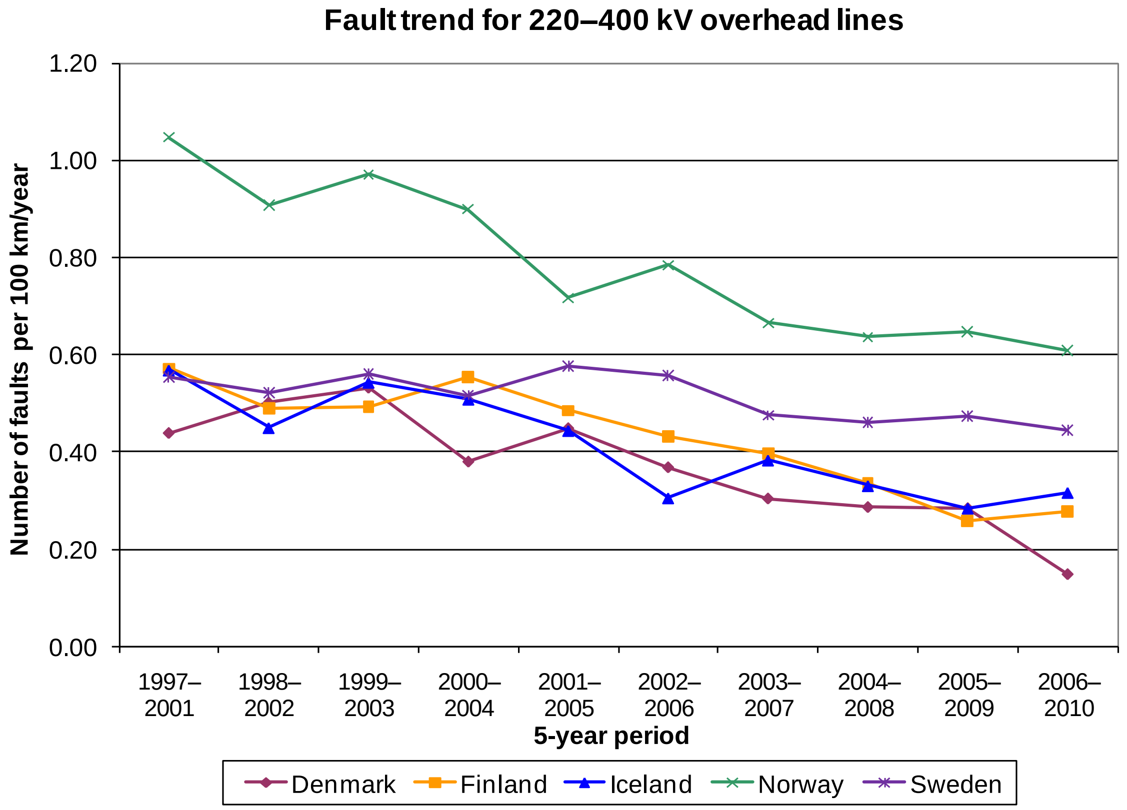

FIGURE 5.4 FAULT TREND FOR OVERHEAD LINES AT VOLTAGE LEVEL 220–400 KV.

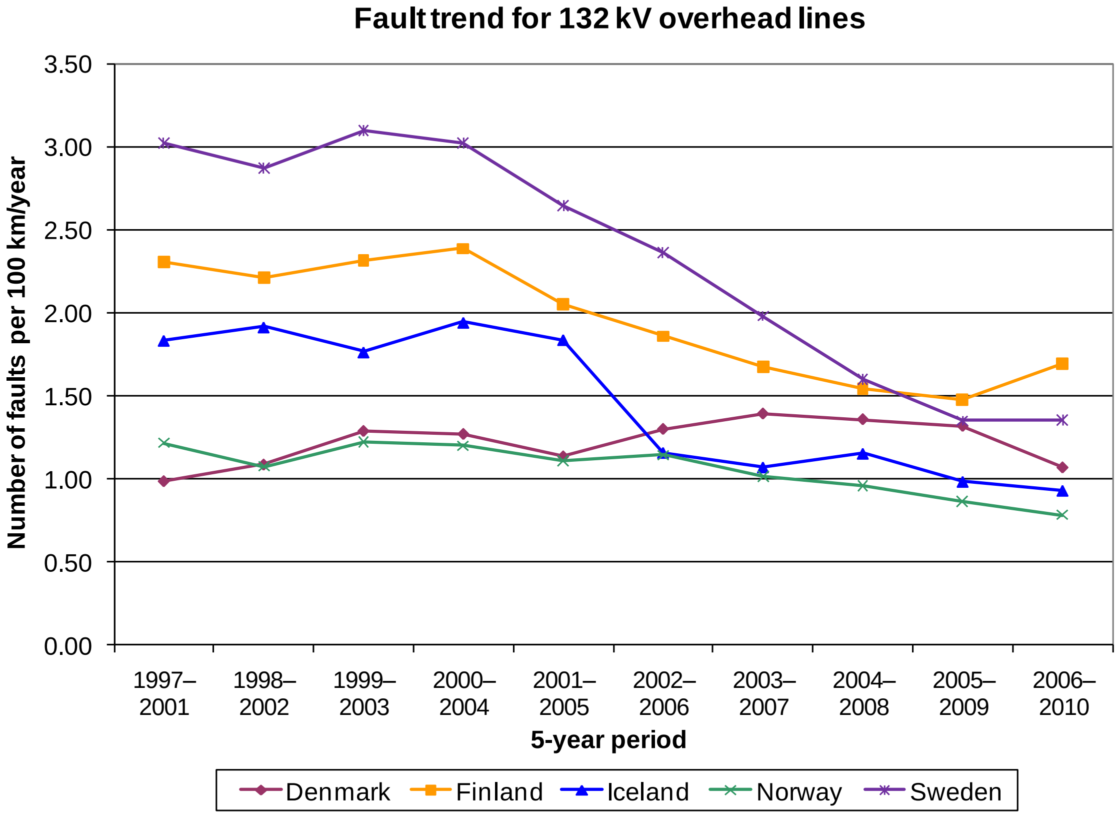

FIGURE 5.5 FAULT TREND FOR OVERHEAD LINES AT VOLTAGE LEVEL 132 KV.

5.3 FAULTS IN CABLES

The tables in this section present faults in cables at each respective voltage level, with fault division for the year 2010 and for the period 2001–2010. In addition, the division of faults according to cause is given for the whole ten-year period. The annual division of faults during the period 2001–2010 is presented graphically for 132 kV cables only. Also fault trends are presented.

TABLE 5.7 DIVISION OF FAULTS ACCORDING TO CAUSE FOR 400 KV CABLES

Country	Line km 2010	Number of faults 2010	Number of faults per 100 km		Faults divided by cause during the period 2001–2010 (%)						
			2010	2001–2010	Lightning	Other environmental cause	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Denmark	367	0	0.00	0.15	0.0	0.0	0.0	33.3	33.3	0.0	33.3
Norway	25	0	0.00	1.62	0.0	0.0	0.0	0.0	50.0	25.0	25.0
Sweden	249	0	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nordic	641	0	0.00	0.28	0.0	0.0	0.0	14.3	42.9	14.3	28.6

TABLE 5.8 DIVISION OF FAULTS ACCORDING TO CAUSE FOR 220 KV CABLES

Country	Line km 2010	Number of faults 2010	Number of faults per 100 km 2010	Number of faults per 100 km 2001–2010	Faults divided by cause during the period 2001–2010 (%) Lightning	Other environmental cause	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Norway	450	0	0.00	0.08	0.0	33.3	0.0	33.3	0.0	0.0	33.3
Sweden	33	0	0.00	0.74	0.0	0.0	0.0	11.1	77.8	0.0	11.1
Nordic	483	0	0.00	0.24	0.0	8.3	0.0	16.7	58.3	0.0	16.7

TABLE 5.9 DIVISION OF FAULTS ACCORDING TO CAUSE FOR 132 KV CABLES

Country	Line km 2010	Number of faults 2010	Number of faults per 100 km 2010	Number of faults per 100 km 2001–2010	Faults divided by cause during the period 2001–2010 (%) Lightning	Other environmental cause	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Denmark	846	7	0.83	0.48	0.0	0.0	23.1	11.5	53.8	7.7	3.8
Finland	196	0	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Iceland	96	0	0.00	0.64	0.0	0.0	0.0	0.0	100.0	0.0	0.0
Norway[1)]	202	3	1.49	1.34	3.8	0.0	3.8	23.1	50.0	11.5	7.7
Sweden	179	1	0.56	1.02	0.0	0.0	20.0	12.0	32.0	16.0	20.0
Nordic	1518	11	0.72	0.72	1.2	0.0	15.0	15.0	47.5	11.2	10.0

1) Cables in Norway include resonant earthed cables.

Figure 5.6 presents the annual cable fault values per cable length faults during the 10-year period 2001–2010 for 132 kV cables.

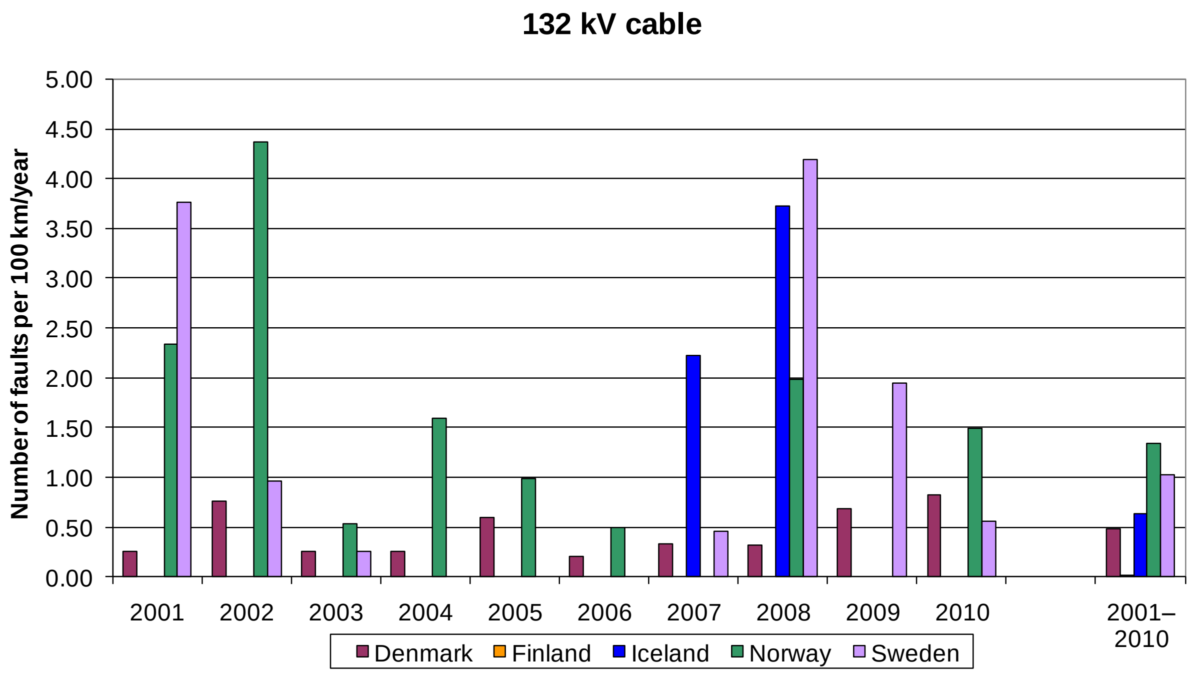

FIGURE 5.6 ANNUAL DIVISION OF FAULTS DURING THE PERIOD 2001–2010.

Figure 5.7 presents the cable fault trends only for Denmark, Norway and Sweden. Due to the low number of cables in Finland and Iceland there is not enough data for a trend curve. With due caution, the trend curve can be used to estimate the likely fault frequencies in the future.

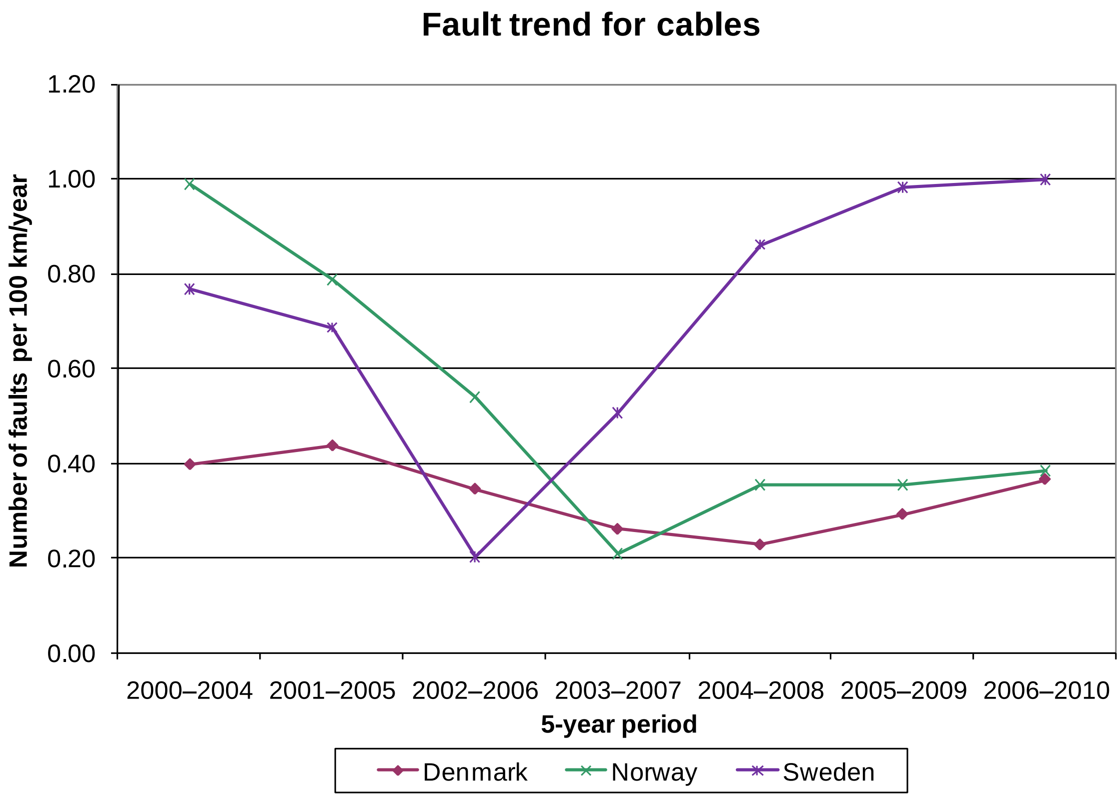

FIGURE 5.7 FAULT TREND FOR CABLES AT ALL VOLTAGE LEVEL.

5.4 FAULTS IN POWER TRANSFORMERS

The tables in this section present the division of faults for the year 2010 and for the period 2001–2010 in power transformers at each respective voltage level. In addition, the tables present the division of faults according to cause during the ten-year period 2001–2010. The annual division of faults during the period 2001–2010 is presented graphically for all voltage levels. For power transformers, the statistics state the rated voltage of the winding with the highest voltage, as stated in Section 6.2 in the guidelines [1]. Each transformer is counted only once. The trends for transformer faults are presented too.

TABLE 5.10 DIVISION OF FAULTS ACCORDING TO CAUSE FOR 400 KV POWER TRANSFORMERS

Country	Number of devices 2010	Number of faults 2010	Number of faults per 100 devices		Faults divided by cause during the period 2001–2010 (%)						
			2010	2001–2010	Lightning	Other environmental cause	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Denmark	25	0	0.00	3.48[1)]	12.5	12.5	0.0	12.5	12.5	0.0	50.0
Finland	50	2	4.00	2.48	0.0	27.3	0.0	18.2	36.4	9.1	9.1
Norway	64	0	0.00	1.12	0.0	0.0	0.0	14.3	57.1	0.0	28.6
Sweden	62	0	0.00	0.96	0.0	0.0	0.0	75.0	12.5	12.5	0.0
Nordic	201	2	1.00	1.59	2.9	11.8	0.0	29.4	29.4	5.9	20.6

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

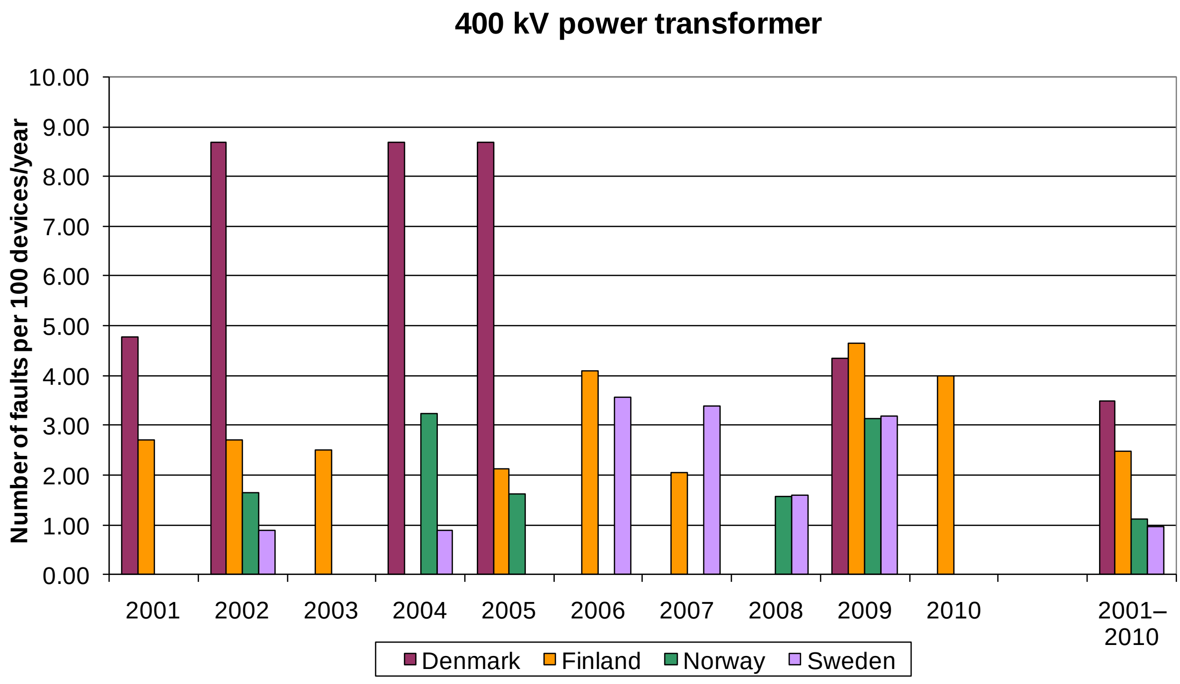

FIGURE 5.8 ANNUAL DIVISION OF FAULTS DURING THE PERIOD 2001–2010.

TABLE 5.11 DIVISION OF FAULTS ACCORDING TO CAUSE FOR 220 kV POWER TRANSFORMERS

Country	Number of devices 2010	Number of faults 2010	Number of faults per 100 devices		Faults divided by cause during the period 2001–2010 (%)						
			2010	2001–2010	Lightning	Other environmental cause	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Denmark	2	0	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Finland	24	1	4.17	1.73	0.0	0.0	0.0	25.0	0.0	0.0	75.0
Iceland	32	1	3.13	3.87	0.0	0.0	0.0	9.1	81.8	0.0	9.1
Norway	271	3	1.11	1.25	2.9	2.9	0.0	23.5	47.1	17.6	5.9
Sweden	106	2	1.89	2.95	39.4	3.0	9.1	15.2	18.2	0.0	15.2
Nordic	435	7	1.61	1.88	17.1	2.4	3.7	18.3	37.8	7.3	13.4

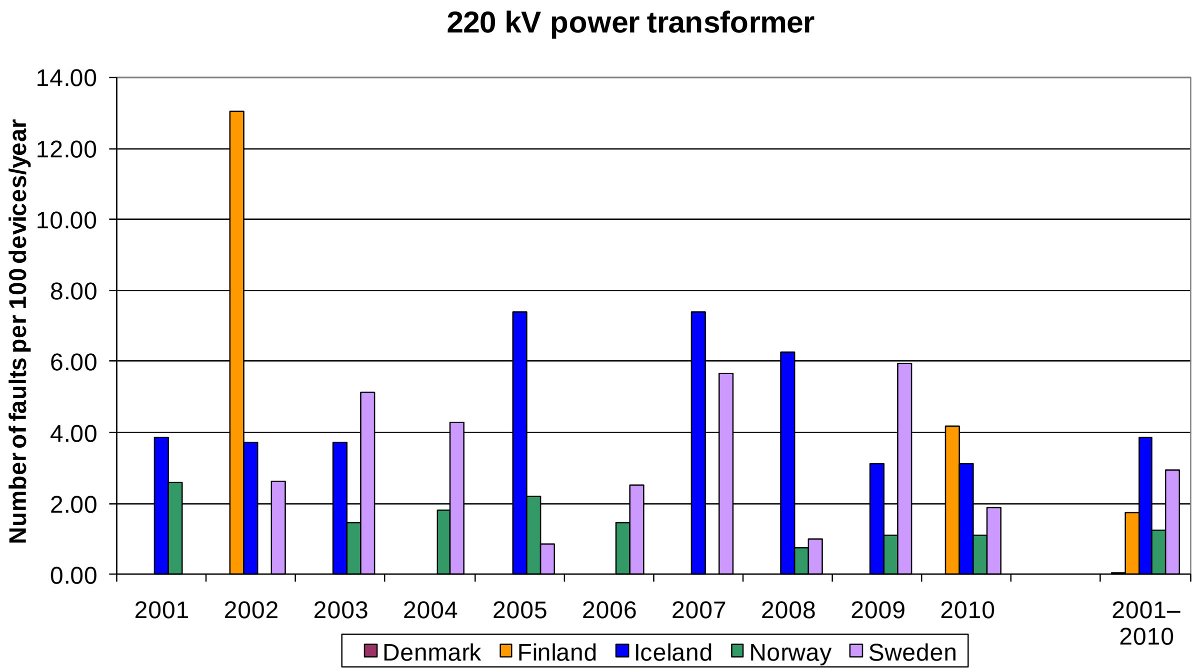

FIGURE 5.9 ANNUAL DIVISION OF FAULTS DURING THE PERIOD 2001–2010.

TABLE 5.12 DIVISION OF FAULTS ACCORDING TO CAUSE FOR 132 KV POWER TRANSFORMERS

Country	Number of devices 2010	Number of faults 2010	Number of faults per 100 devices		Faults divided by cause during the period 2001–2010 (%)						
			2010	2001–2010	Lightning	Other environmental cause	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Denmark	238	2	0.84	1.10	8.0	8.0	4.0	36.0	20.0	0.0	24.0
Finland	906	6	0.66	0.51	0.0	4.3	21.7	21.7	21.7	0.0	30.4
Iceland	59	0	0.00	0.88	0.0	0.0	0.0	50.0	25.0	0.0	25.0
Norway	724	6	0.83	0.48	2.9	20.6	5.9	14.7	29.4	23.5	2.9
Sweden[1)]	758	8	1.06	4.39	17.9	2.9	2.9	17.9	25.8	11.1	21.5
Nordic	2685	22	0.82	1.76	14.5	4.9	4.4	19.5	25.5	10.7	20.5

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

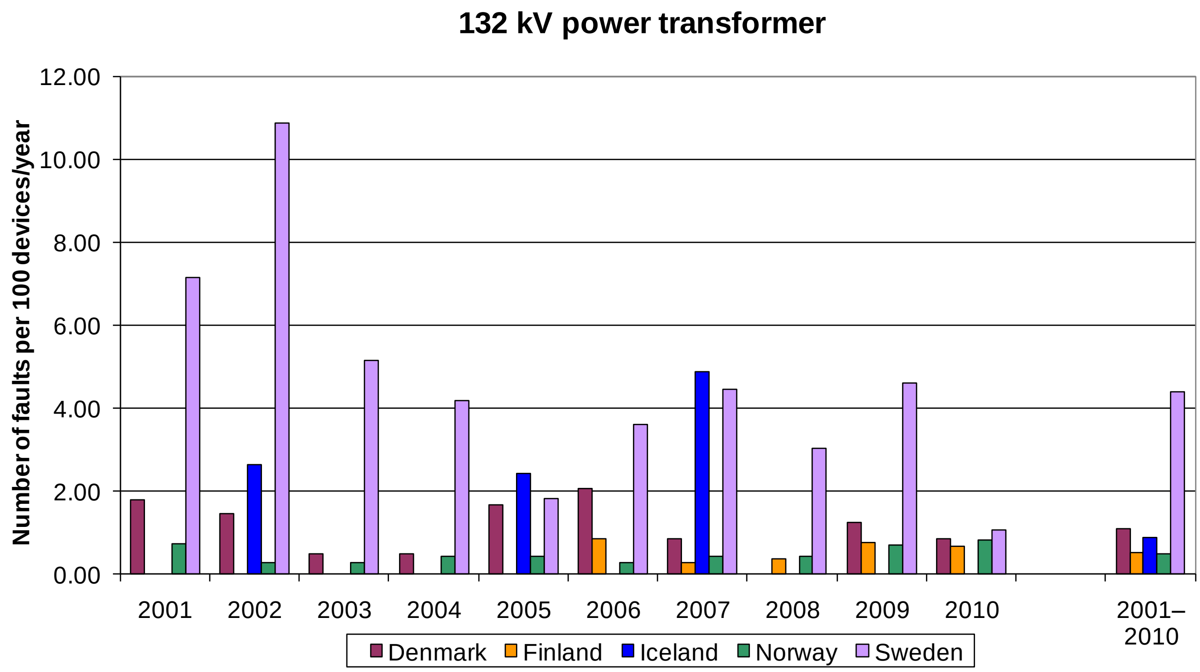

FIGURE 5.10 ANNUAL DIVISION OF FAULTS DURING THE PERIOD 2001–2010.

Figure 5.11 and Figure 5.12 present the trend of faults for power transformers. This allows the trend to be estimated in the future.

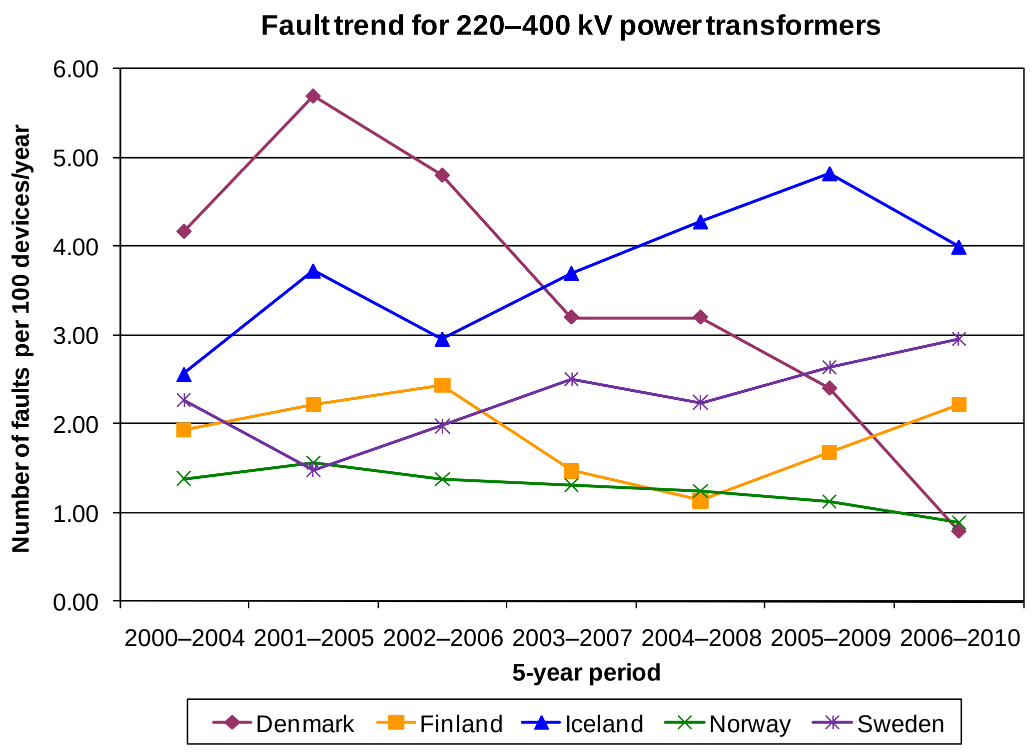

FIGURE 5.11 FAULT TREND FOR POWER TRANSFORMERS AT VOLTAGE LEVEL 220–400 KV.

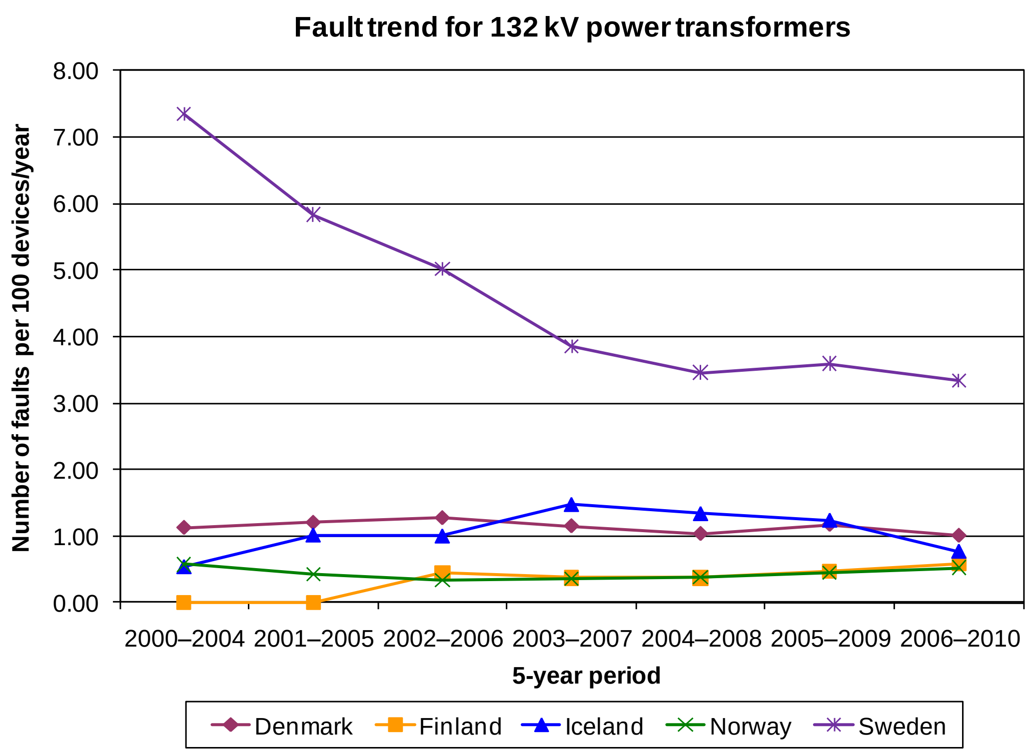

FIGURE 5.12 FAULT TREND FOR POWER TRANSFORMERS AT VOLTAGE LEVEL 132 KV.

5.5 FAULTS IN INSTRUMENT TRANSFORMERS

This section presents the faults in instrument transformers for the year 2010 and for the period 2001–2010 at each respective voltage level. In addition, the tables present the division of faults according to cause during the ten-year period. Both current and voltage transformers are included among instrument transformers. A three-phase instrument transformer is treated as one unit. If a single-phase transformer is installed, it is also treated as a single unit.

TABLE 5.13 DIVISION OF FAULTS ACCORDING TO CAUSE FOR 400 KV INSTRUMENT TRANSFORMERS

Country	Number of devices 2010	Number of faults 2010	Number of faults per 100 devices		Faults divided by cause during the period 2001–2010 (%)						
			2010	2001–2010	Lightning	Other environmental cause	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Denmark	537	0	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Finland	407	0	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Norway	930	1	0.11	0.07	0.0	0.0	0.0	33.3	50.0	16.7	0.0
Sweden	1068	1	0.09	0.13	0.0	0.0	0.0	25.0	66.7	0.0	8.3
Nordic	2942	2	0.07	0.07	0.0	0.0	0.0	27.8	61.1	5.6	5.6

TABLE 5.14 DIVISION OF FAULTS ACCORDING TO CAUSE FOR 220 KV INSTRUMENT TRANSFORMERS

Country	Number of devices 2010	Number of faults 2010	Number of faults per 100 devices		Faults divided by cause during the period 2001–2010 (%)						
			2010	2001–2010	Lightning	Other environmental cause	External influences	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	155	0	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Iceland	444	0	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Norway	2805	3	0.11	0.07	10.0	10.0	0.0	5.0	65.0	10.0	0.0
Sweden	1089	0	0.00	0.08	0.0	0.0	0.0	0.0	100.0	0.0	0.0
Nordic	4505	3	0.07	0.07	6.9	6.9	0.0	3.4	75.9	6.9	0.0

TABLE 5.15 DIVISION OF FAULTS ACCORDING TO CAUSE FOR 132 KV INSTRUMENT TRANSFORMERS

Country	Number of devices 2010	Number of faults 2010	Number of faults per 100 devices		Faults divided by cause during the period 2001–2010 (%)						
			2010	2001–2010	Lightning	Other environmental cause	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Denmark	4553	1	0.02	0.02	0.0	14.3	0.0	14.3	42.9	0.0	28.6
Finland	3257	1	0.03	0.08	27.3	0.0	9.1	0.0	54.5	9.1	0.0
Iceland	638	0	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Norway	7768	0	0.00	0.05	10.0	0.0	0.0	10.0	55.0	7.5	17.5
Sweden	5082	5	0.10	0.07	18.4	0.0	2.6	13.2	57.9	2.6	5.3
Nordic	21298	7	0.03	0.05	14.6	1.0	2.1	10.4	55.2	5.2	11.5

ENTSO-E AISBL • Avenue Cortenbergh 100 • 1000 Brussels • Belgium • Tel +32 2 741 09 50 • Fax +32 2 741 09 51 • info@entsoe.eu • www.entsoe.eu

Figure 5.13 and Figure 5.14 present the fault trends for instrument transformers at voltage levels 220–400 kV and 132 kV, respectively.

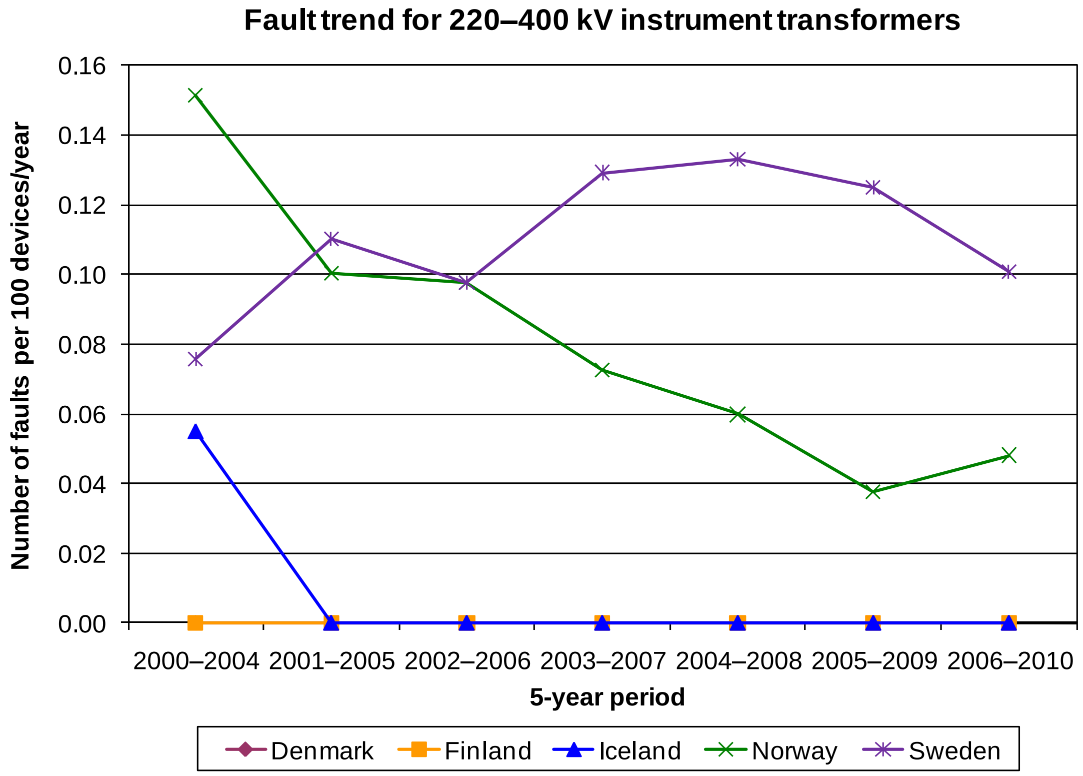

FIGURE 5.13 FAULT TREND FOR INSTRUMENT TRANSFORMERS AT VOLTAGE LEVEL 220–400 KV.

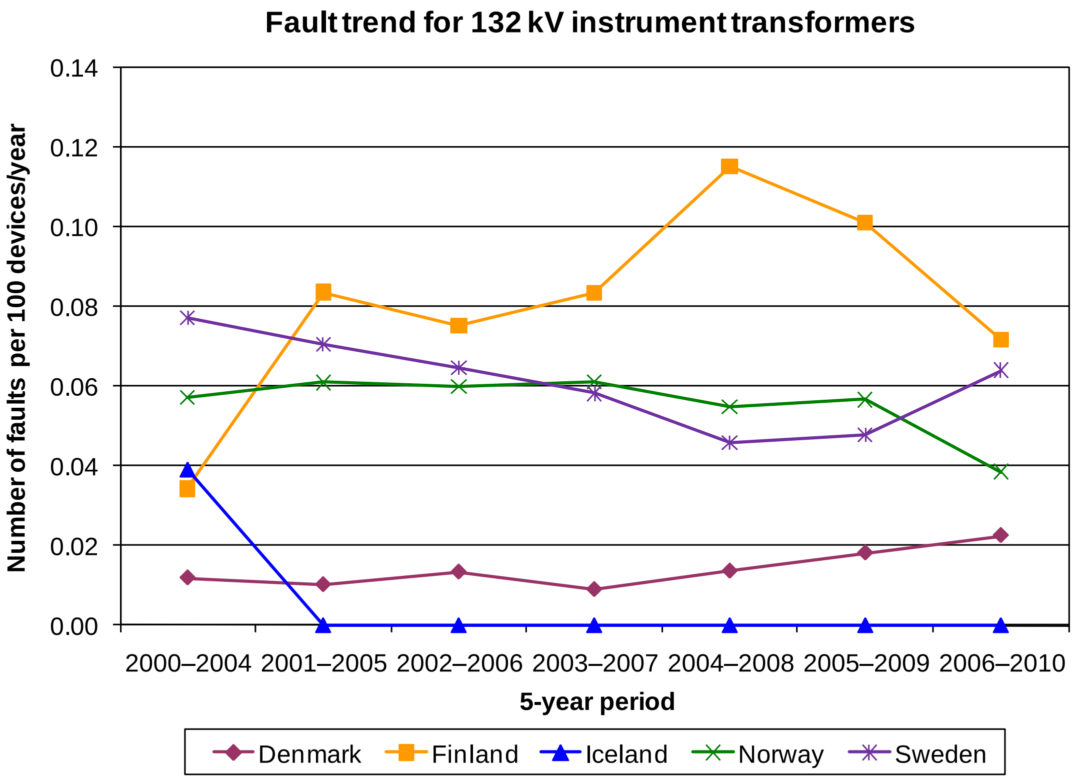

FIGURE 5.14 FAULT TREND FOR INSTRUMENT TRANSFORMERS AT VOLTAGE LEVEL 132 KV.

5.6 FAULTS IN CIRCUIT BREAKERS

The tables in this section present circuit breaker faults for the year 2010 and for the period 2001–2010 at each respective voltage level. The tables also present the division of faults according to cause during the ten-year period.

One should note that a significant part of the faults are caused by 400 kV shunt reactor circuit breakers, which usually operate very often compared with other circuit breakers. Disturbances caused by erroneous circuit breaker operations are registered as faults in circuit breakers, with operation and maintenance as their cause.

TABLE 5.16 DIVISION OF FAULTS ACCORDING TO CAUSE FOR 400 KV CIRCUIT BREAKERS

Country	Number of devices 2010	Number of faults 2010	Number of faults per 100 devices		Faults divided by cause during the period 2001–2010 (%)						
			2010	2001–2010	Lightning	Other environmental cause	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Denmark	171	0	0.00	0.73	0.0	10.0	10.0	20.0	50.0	10.0	0.0
Finland	237	0	0.00	0.25	0.0	0.0	20.0	20.0	60.0	0.0	0.0
Norway	262	0	0.00	0.72	0.0	0.0	0.0	33.3	55.6	5.6	5.6
Sweden[1)]	520	0	0.00	1.76	0.0	2.7	0.0	4.0	74.7	13.3	5.3
Nordic	1190	0	0.00	1.06	0.0	2.8	1.9	11.1	68.5	11.1	4.6

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

TABLE 5.17 DIVISION OF FAULTS ACCORDING TO CAUSE FOR 220 KV CIRCUIT BREAKERS

Country	Number of devices 2010	Number of faults 2010	Number of faults per 100 devices		Faults divided by cause during the period 2001–2010 (%)						
			2010	2001–2010	Lightning	Other environmental cause	External influences	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	96	0	0.00	0.63	0.0	0.0	0.0	0.0	83.3	16.7	0.0
Iceland	79	0	0.00	3.35	0.0	8.7	0.0	8.7	69.6	0.0	13.0
Norway	724	2	0.28	0.69	0.0	0.0	0.0	34.7	57.1	0.0	8.2
Sweden	426	1	0.23	0.50	5.0	0.0	0.0	15.0	70.0	0.0	10.0
Nordic	1327	3	0.23	0.77	1.0	2.0	0.0	22.4	64.3	1.0	9.2

TABLE 5.18 DIVISION OF FAULTS ACCORDING TO CAUSE FOR 132 KV CIRCUIT BREAKERS

Country	Number of devices 2010	Number of faults 2010	Number of faults per 100 devices		Faults divided by cause during the period 2001–2010 (%)						
			2010	2001–2010	Lightning	Other environmental cause	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Denmark	826	1	0.12	0.55	0.0	2.3	0.0	34.1	56.8	6.8	0.0
Finland	2160	4	0.19	0.20	24.1	6.9	0.0	27.6	34.5	3.4	3.4
Iceland	144	0	0.00	0.56	0.0	0.0	0.0	14.3	71.4	0.0	14.3
Norway	2119	9	0.42	0.33	2.9	0.0	0.0	52.9	38.2	1.5	4.4
Sweden	1964	5	0.25	0.78	25.6	3.1	2.3	19.4	38.8	2.3	8.5
Nordic	7213	19	0.26	0.45	15.2	2.5	1.1	30.7	41.9	2.9	5.8

Figure 5.15 and Figure 5.16 present the fault trends for circuit breakers at voltage levels 220–400 kV and 132 kV, respectively.

ENTSO-E AISBL • Avenue Cortenbergh 100 • 1000 Brussels • Belgium • Tel +32 2 741 09 50 • Fax +32 2 741 09 51 • info@entsoe.eu • www.entsoe.eu

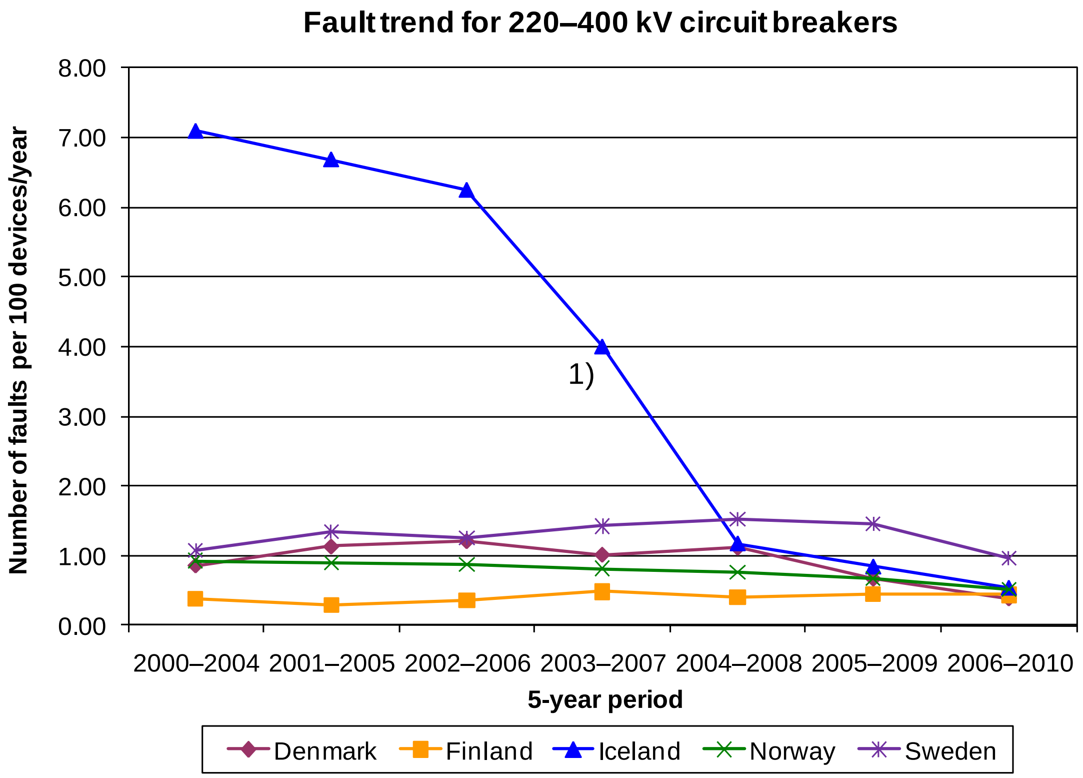

FIGURE 5.15 FAULT TREND FOR CIRCUIT BREAKERS AT VOLTAGE LEVEL 220–400 KV.

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

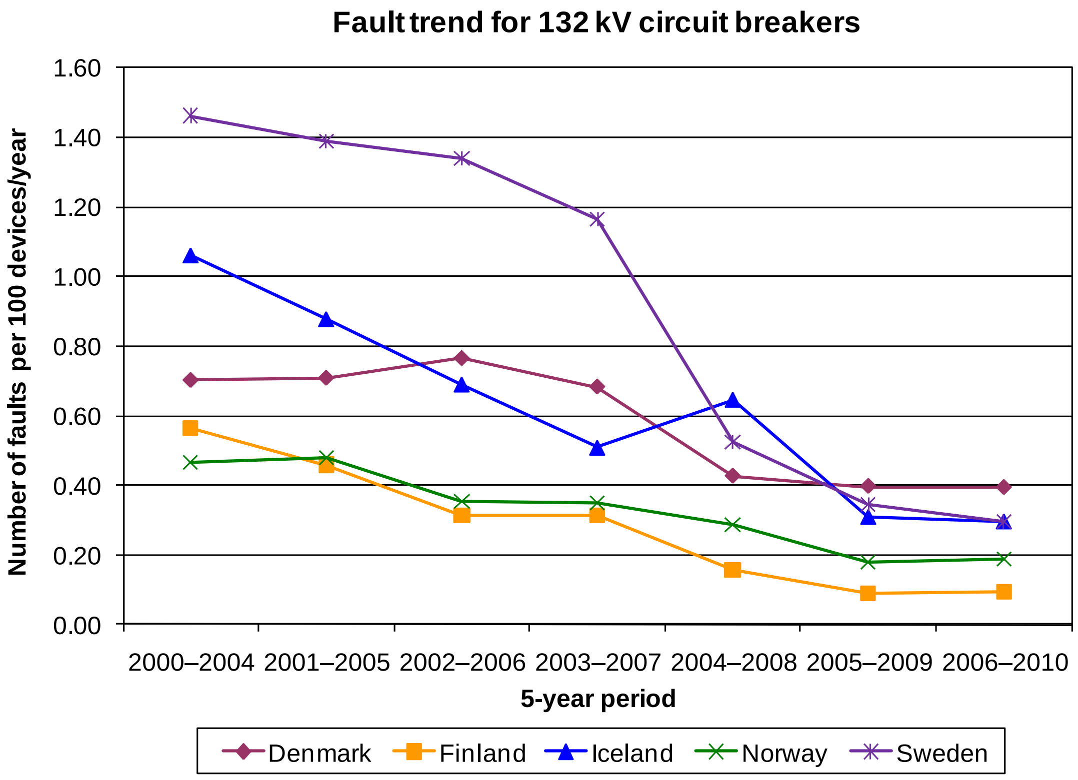

FIGURE 5.16 FAULT TREND FOR CIRCUIT BREAKERS AT VOLTAGE LEVEL 132 KV.

5.7 FAULTS IN CONTROL EQUIPMENT

The tables in this section present faults in control equipment at each respective voltage level for the year 2010 and for the period 2001–2010. In addition, the tables present the division of faults according to cause during the ten-year period.

When parts of the control system are integrated into the component, it may be uncertain whether a fault really is registered in the control equipment or in the actual component. Faults in control equipment that is integrated in another installation will normally be counted as faults in that installation. However, this definition has not been applied in all the countries. The Nordic guidelines of these statistics [1] gives more detailed definitions.

TABLE 5.19 DIVISION OF FAULTS ACCORDING TO CAUSE FOR 400 KV CONTROL EQUIPMENT

Country	Number of devices 2010	Number of faults 2010	Number of faults per 100 devices		Faults divided by cause during the period 2001–2010 (%)						
			2010	2001–2010	Lightning	Other environmental cause	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Denmark	171	1	0.58	1.45	5.6	0.0	0.0	22.2	44.4	5.6	22.2
Finland	237	8	3.38	5.45	0.0	0.0	0.0	38.5	6.4	37.6	17.4
Norway	262	2	0.76	7.57	0.0	1.1	0.5	31.1	49.5	3.2	14.7
Sweden	521	0	0.00	8.83	0.3	0.8	0.0	12.3	82.6	2.7	1.4
Nordic	1191	11	0.92	6.90	0.3	0.7	0.1	21.9	60.2	8.5	8.2

TABLE 5.20 DIVISION OF FAULTS ACCORDING TO CAUSE FOR 220 KV CONTROL EQUIPMENT

Country	Number of devices 2010	Number of faults 2010	Number of faults per 100 devices		Faults divided by cause during the period 2001–2010 (%)						
			2010	2001–2010	Lightning	Other environmental cause	External influences	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	96	5	5.21	5.93	0.0	0.0	0.0	42.9	41.1	8.9	7.1
Iceland	79	2	2.53	10.19	4.3	8.6	0.0	28.6	52.9	5.7	0.0
Norway	724	6	0.83	6.26	0.9	0.7	0.5	32.8	43.2	3.8	18.1
Sweden	420	1	0.24	3.43	0.0	0.0	2.9	32.1	52.6	9.5	2.9
Nordic	1321	14	1.06	5.54	1.0	1.3	0.9	33.0	45.8	5.5	12.5

TABLE 5.21 DIVISION OF FAULTS ACCORDING TO CAUSE FOR 132 KV CONTROL EQUIPMENT

Country	Number of devices 2010	Number of faults 2010	Number of faults per 100 devices		Faults divided by cause during the period 2001–2010 (%)						
			2010	2001–2010	Lightning	Other environmental cause	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Denmark	826	11	1.33	1.10	5.0	7.5	2.5	41.2	26.2	10.0	7.5
Finland	2160	37	1.71	1.70	2.8	0.0	2.4	39.3	27.0	10.3	18.3
Iceland	144	8	5.56	4.54	0.0	1.8	1.8	21.4	71.4	1.8	1.8
Norway	2119	12	0.57	2.42	0.6	2.0	0.4	31.5	34.1	5.3	26.0
Sweden	1851	5	0.27	0.81	9.2	0.0	0.0	43.5	26.0	6.1	15.3
Nordic	7100	73	1.03	1.69	2.6	1.7	1.1	35.2	32.7	6.8	19.9

5.8 FAULTS IN COMPENSATION DEVICES

In 2000, Nordel's guidelines for compensation equipment changed. Therefore, the following four categories are used: reactors, series capacitors, shunt capacitors and SVC devices. The following tables present the faults in compensation devices for the year 2010 and for the period 2001–2010. In addition, the tables present the division of faults according to cause during the ten-year period 2001 –2010.

TABLE 5.22 DIVISION OF FAULTS ACCORDING TO CAUSE FOR REACTORS

Country	Number of devices 2010	Number of faults 2010	Number of faults per 100 devices		Faults divided by cause during the period 2001–2010 (%)						
			2010	2001–2010	Lightning	Other environmental cause	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Denmark	18	0	0.00	5.28	0.0	0.0	0.0	26.7	53.3	0.0	20.0
Finland[1)]	67	0	0.00	1.89	0.0	0.0	0.0	0.0	63.6	27.3	9.1
Norway	36	0	0.00	5.81	0.0	5.3	0.0	31.6	52.6	5.3	5.3
Sweden	76	18	23.68	15.24	0.0	31.7	3.7	8.5	42.7	7.3	6.1
Nordic	197	18	9.14	7.33	0.0	21.3	2.4	13.4	47.2	7.9	7.9

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

TABLE 5.23 DIVISION OF FAULTS ACCORDING TO CAUSE FOR SERIES CAPACITORS

Country	Number of devices 2010	Number of faults 2010	Number of faults per 100 devices		Faults divided by cause during the period 2001–2010 (%)						
			2010	2001–2010	Lightning	Other environmental cause	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Finland	9	2	22.22	27.03	0.0	0.0	10.0	10.0	30.0	0.0	50.0
Iceland	1	0	0.00	10.00	0.0	0.0	0.0	0.0	100.0	0.0	0.0
Norway	3	0	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sweden	12	89	741.67	130.83	0.6	0.6	0.0	1.3	16.6	70.7	10.2
Nordic	25	91	364.00	76.07	0.6	0.6	1.1	2.2	18.5	62.4	14.6

TABLE 5.24 DIVISION OF FAULTS ACCORDING TO CAUSE FOR SHUNT CAPACITORS

Country	Number of devices 2010	Number of faults 2010	Number of faults per 100 devices		Faults divided by cause during the period 2001–2010 (%)						
			2010	2001–2010	Lightning	Other environmental cause	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Denmark	15	0	0.00	1.31	0.0	0.0	100.0	0.0	0.0	0.0	0.0
Finland	55	2	3.64	6.30	0.0	18.2	59.1	0.0	0.0	13.6	9.1
Iceland	10	0	0.00	10.75	0.0	20.0	0.0	0.0	80.0	0.0	0.0
Norway	194	0	0.00	2.19	0.0	0.0	2.4	14.3	50.0	31.0	2.4
Sweden	199	2	1.01	3.60	4.9	7.3	12.2	2.4	39.0	0.0	34.1
Nordic	473	4	0.85	3.20	1.7	7.7	17.9	6.0	38.5	13.7	14.5

ENTSO-E AISBL • Avenue Cortenbergh 100 • 1000 Brussels • Belgium • Tel +32 2 741 09 50 • Fax +32 2 741 09 51 • info@entsoe.eu • www.entsoe.eu

TABLE 5.25 DIVISION OF FAULTS ACCORDING TO CAUSE FOR SVC DEVICES

Country	Number of devices 2010	Number of faults 2010	Number of faults per 100 devices		Faults divided by cause during the period 2001–2010 (%)						
			2010	2001–2010	Lightning	Other environmental cause	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Norway	15	13	86.67	41.84	0.0	1.7	0.0	5.1	50.8	28.8	13.6
Sweden	3	8	266.67	89.77	0.0	7.6	3.8	13.9	65.8	1.3	7.6
Nordic	18	21	116.67	59.40	0.0	5.0	2.2	10.1	59.7	12.9	10.1

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 was introduced in the Nordel statistics in 2000. More information can be found in Section 5.3 in the guidelines [1]. For the most part, this chapter covers statistics only for the year 2010. However, a ten-year trend line for the reliability of some power system components is presented at the end of the chapter.

Definition of a power system unit:

A group of components which are delimited by one or more circuit breakers [3].

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 [6].

6.1 COVERAGE OF THE OUTAGE STATISTICS

The Swedish outage data for 2010 includes approximately 30% of the power system units operating at 132 kV and 100% of the units at the 220 kV and 400 kV voltage levels. Before the year 2007, the Swedish data did not include outages from the 132 kV voltage level, and therefore the number of the different power system units is higher the year 2006 and before.

6.2 OUTAGES IN POWER SYSTEM UNITS

The tables and figures in this section present outages in the following power system units: lines, transformers, busbars, reactors, and shunt capacitors.

TABLE 6.1 GROUPING OF LINES ACCORDING TO THE NUMBER OF OUTAGES IN 2010

Line[1)]		Number of system units grouped by number of outages						
Country	**Number of system units**	**No outages**	**1 outage**	**2 outages**	**3 outages**	**4 outages**	**5 outages**	**>5 outages**
Denmark	315	278	34	2	1	0	0	0
Finland	315	138	88	38	22	10	4	15
Iceland	58	39	14	4	1	0	0	0
Norway	641	602	27	4	4	3	1	0
Sweden	375	253	64	36	15	6	1	0

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

ENTSO-E AISBL • Avenue Cortenbergh 100 • 1000 Brussels • Belgium • Tel +32 2 741 09 50 • Fax +32 2 741 09 51 • info@entsoe.eu • www.entsoe.eu

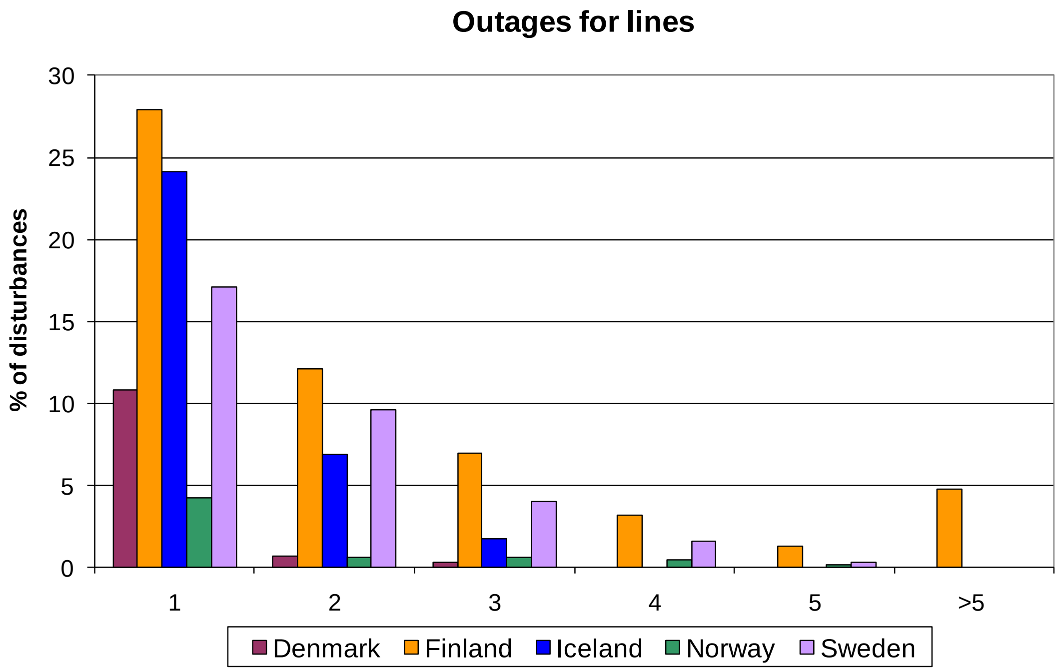

FIGURE 6.1 GROUPING OF LINES ACCORDING TO NUMBER OF OUTAGES IN 2010.

TABLE 6.2 GROUPING OF TRANSFORMERS ACCORDING TO THE NUMBER OF OUTAGES IN 2010

Transformer		Number of system units grouped by number of outages						
Country	Number of system units	No outages	1 outage	2 outages	3 outages	4 outages	5 outages	>5 outages
Denmark	259	242	17	0	0	0	0	0
Finland	980	970	10	0	0	0	0	0
Iceland	92	87	2	2	1	0	0	0
Norway	800	793	7	0	0	0	0	0
Sweden	309	307	1	1	0	0	0	0

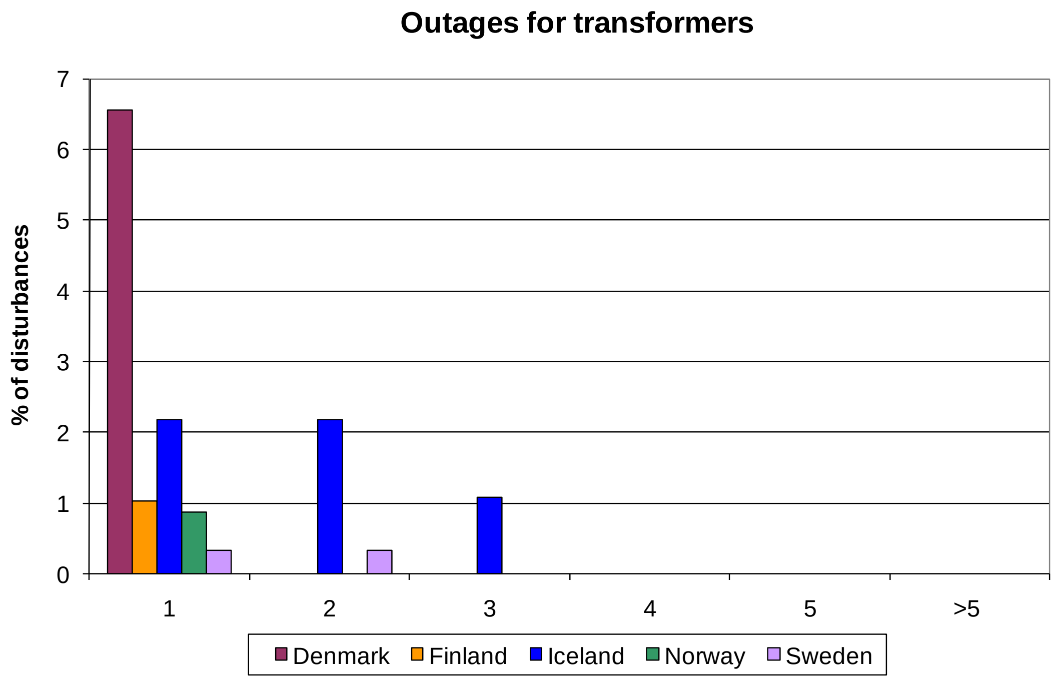

FIGURE 6.2 GROUPING OF TRANSFORMERS ACCORDING TO NUMBER OF OUTAGES IN 2010.

TABLE 6.3 GROUPING OF BUSBARS ACCORDING TO THE NUMBER OF OUTAGES IN 2010

Busbar		Number of system units grouped by number of outages						
Country	Number of system units	No outages	1 outage	2 outages	3 outages	4 outages	5 outages	>5 outages
Denmark	150	148	2	0	0	0	0	0
Finland	927	927	0	0	0	0	0	0
Iceland	53	53	0	0	0	0	0	0
Norway	435	433	2	0	0	0	0	0
Sweden	231	219	10	2	0	0	0	0

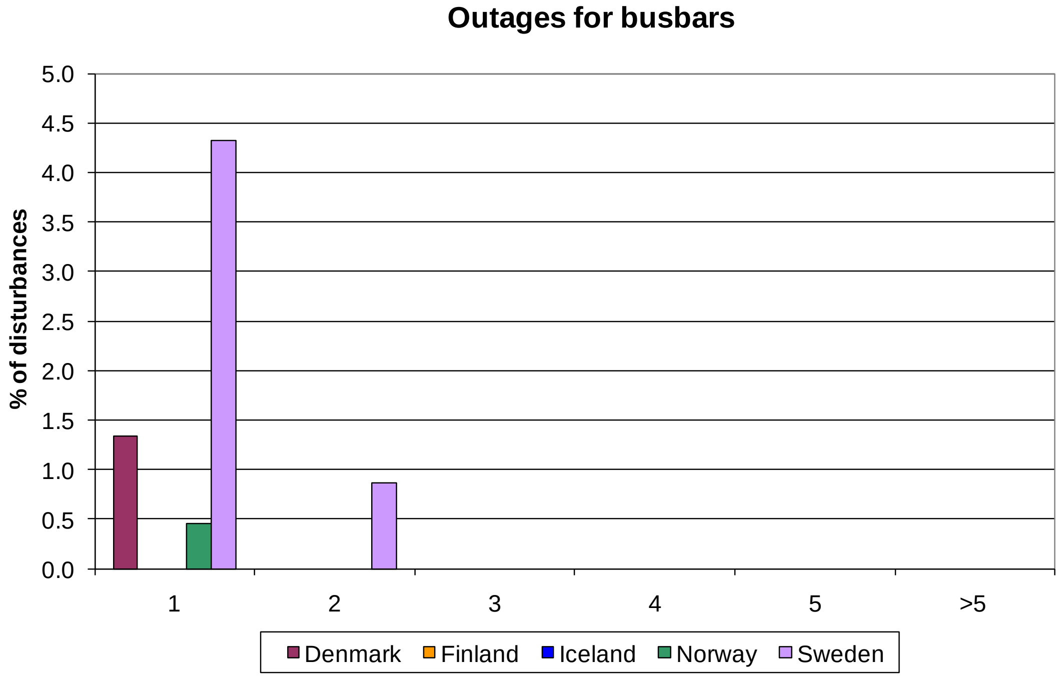

FIGURE 6.3 GROUPING OF BUSBARS ACCORDING TO NUMBER OF OUTAGES IN 2010.

TABLE 6.4 GROUPING OF REACTORS ACCORDING TO THE NUMBER OF OUTAGES IN 2010

Reactor		Number of system units grouped by number of outages						
Country	**Number of system units**	**No outages**	**1 outage**	**2 outages**	**3 outages**	**4 outages**	**5 outages**	**>5 outages**
Denmark	18	17	1	0	0	0	0	0
Finland	67	67	0	0	0	0	0	0
Norway	36	36	0	0	0	0	0	0
Sweden	36	25	7	2	1	1	0	0

TABLE 6.5 GROUPING OF SHUNT CAPACITORS ACCORDING TO THE NUMBER OF OUTAGES IN 2010

Shunt capacitor		Number of system units grouped by number of outages						
Country	**Number of system units**	**No outages**	**1 outage**	**2 outages**	**3 outages**	**4 outages**	**5 outages**	**>5 outages**
Denmark	15	15	0	0	0	0	0	0
Finland	55	53	2	0	0	0	0	0
Iceland	10	8	1	0	0	0	0	1
Norway	194	194	0	0	0	0	0	0
Sweden	43	41	2	0	0	0	0	0

ENTSO-E AISBL • Avenue Cortenbergh 100 • 1000 Brussels • Belgium • Tel +32 2 741 09 50 • Fax +32 2 741 09 51 • info@entsoe.eu • www.entsoe.eu

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 intentionally postponed, the intentional waiting time is not included in the duration of the outage. The section presents the outage duration statistics for lines, transformers, busbars, reactors, and shunt capacitors.

TABLE 6.6 NUMBER OF LINES WITH DIFFERENT OUTAGE DURATIONS IN 2010

Line[1)]		Number of system units grouped by total outage duration time								
Country	Number	No outages	<3 minutes	3–10 minutes	10–30 minutes	30–60 minutes	60–120 minutes	120–240 minutes	240–480 minutes	>480 minutes
Denmark	315	278	18	2	0	3	1	4	2	7
Finland	315	138	139	12	6	3	4	3	3	7
Iceland	58	39	1	1	1	8	5	1	1	1
Norway	641	602	20	4	3	2	2	2	4	2
Sweden	375	253	93	2	8	7	1	6	4	1

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

TABLE 6.7 NUMBER OF TRANSFORMERS WITH DIFFERENT OUTAGE DURATIONS IN 2010

Transformer		Number of system units grouped by total outage duration time								
Country	Number	No outages	<3 minutes	3–10 minutes	10–30 minutes	30–60 minutes	60–120 minutes	120–240 minutes	240–480 minutes	>480 minutes
Denmark	259	242	7	1	0	2	0	1	0	6
Finland	980	970	3	2	2	0	0	2	0	1
Iceland	92	87	0	0	0	1	0	1	2	1
Norway	800	793	1	1	0	0	0	0	2	3
Sweden	309	307	0	1	1	0	0	0	0	0

TABLE 6.8 NUMBER OF BUSBARS WITH DIFFERENT OUTAGE DURATIONS IN 2010

Busbar		Number of system units grouped by total outage duration time								
Country	Number	No outages	<3 minutes	3–10 minutes	10–30 minutes	30–60 minutes	60–120 minutes	120–240 minutes	240–480 minutes	>480 minutes
Denmark	150	148	0	1	0	0	1	0	0	0
Finland	927	927	0	0	0	0	0	0	0	0
Iceland	53	53	0	0	0	0	0	0	0	0
Norway	435	433	2	0	0	0	0	0	0	0
Sweden	231	219	1	4	1	1	2	2	0	1

ENTSO-E AISBL • Avenue Cortenbergh 100 • 1000 Brussels • Belgium • Tel +32 2 741 09 50 • Fax +32 2 741 09 51 • info@entsoe.eu • www.entsoe.eu

TABLE 6.9 NUMBER OF REACTORS WITH DIFFERENT OUTAGE DURATIONS IN 2010

Reactor		Number of system units grouped by total outage duration time								
Country	Number	No outages	<3 minutes	3–10 minutes	10–30 minutes	30–60 minutes	60–120 minutes	120–240 minutes	240–480 minutes	>480 minutes
Denmark	18	17	0	0	1	0	0	0	0	0
Finland	67	67	0	0	0	0	0	0	0	0
Norway	36	36	0	0	0	0	0	0	0	0
Sweden	36	25	1	0	0	2	1	3	1	3

TABLE 6.10 NUMBER OF SHUNT CAPACITORS WITH DIFFERENT OUTAGE DURATIONS IN 2010

Shunt capacitor		Number of system units grouped by total outage duration time								
Country	Number	No outages	<3 minutes	3–10 minutes	10–30 minutes	30–60 minutes	60–120 minutes	120–240 minutes	240–480 minutes	>480 minutes
Denmark	15	15	0	0	0	0	0	0	0	0
Finland	55	53	0	0	0	1	0	0	0	1
Iceland	10	8	0	0	0	1	0	0	0	1
Norway	194	194	0	0	0	0	0	0	0	0
Sweden	43	41	1	0	0	0	0	1	0	0

6.4 CUMULATIVE DURATION OF OUTAGES IN SOME POWER SYSTEM UNITS

Figure 6.4 presents the cumulative distribution curve for outage durations in the following power system units: lines, busbars and transformers. All five countries are included in the data of Figure 6.4.

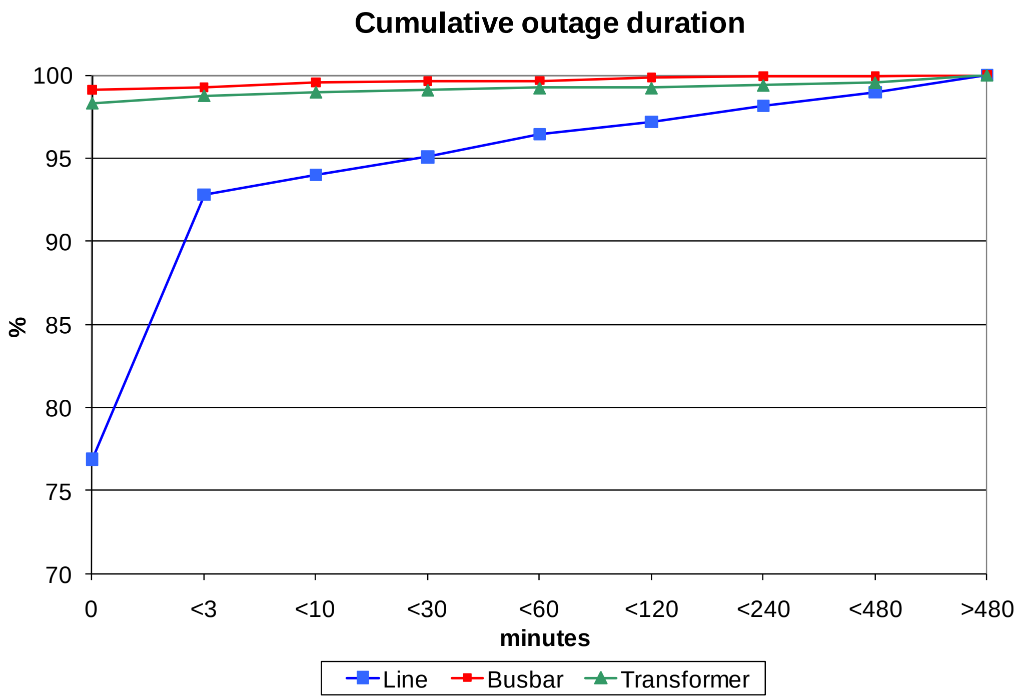

FIGURE 6.4 CUMULATIVE DURATION OF OUTAGES IN SELECTED POWER SYSTEMS UNITS.

Figure 6.4 shows that approximately 77% of lines, 98% of transformers and 99% of busbars had no outages in 2010.

6.5 RELIABILITY TRENDS FOR SOME POWER SYSTEM UNITS

Figure 6.5 presents a reliability trend for lines, busbars and transformers during the period 2001–2010. All five countries are included in the data of Figure 6.4 and Figure 6.5.

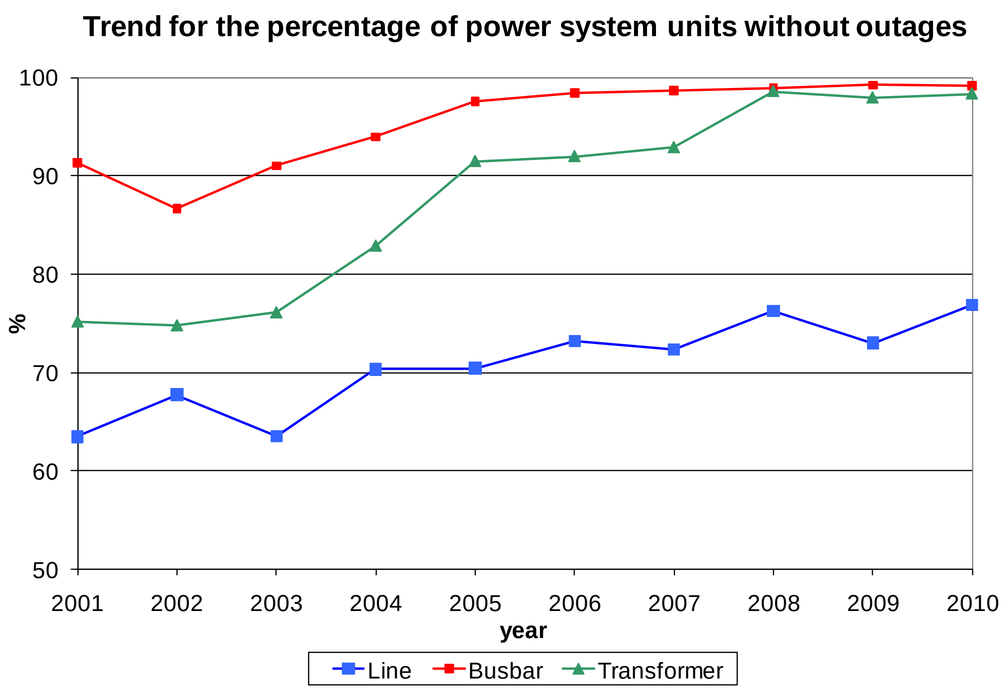

FIGURE 6.5 THE YEARLY PERCENTAGE OF THE POWER SYSTEM UNITS THAT HAD NO OUTAGES DURING THE PERIOD 2001–2010.

7 HVDC STATISTICS

This section presents a summary of HVDC disturbances and maintenances, outages and transfer limitations as well as the amount of energy not transferred (ENT) resulted from them. The data for the statistics has been collected according to the new guidelines prepared by the ENTSO-E Regional Group Nordic. The data covers only the year 2010, since this is the first time HVDC links are included in these statistics.

This first year it was not possible to extract data on transfer limitations for Fenno-Skan and the Konti-Skan links. Statistical data for SwePol Link and Baltic Cable will be added in next year's report.

The scope of these statistics differs from the HVDC statistics made by CIGRÉ. CIGRÉ statistics concentrate on the performance of the HVDC links, including the substations rather than the available transmission capacity, limitations and outages of the HVDC links, the main interest of these statistics.

7.1 GENERAL INFORMATION ON THE HVDC LINKS

Table 7.1 presents the main properties of the HVDC links covered in the statistics.

TABLE 7.1 TECHNICAL DETAILS OF THE HVDC LINKS

Name of the link	Com-mis-sioning year	Market connec-tion (Y/N)	Type of HVDC conver-ter	Rated power, mono-polar (MW)	Parallel mono-polar capacity (MW)	Bipolar capacity (MW)	Direction of power (N–S, E–W)
Estlink	2006	Y	VSC	350			N–S
Fenno–Skan	1989	Y	LCC	550 / 500			E–W
Konti–Skan 1	2008	Y	LCC	370 / 340	740 / 680		E–W
Konti–Skan 2	1988	Y	LCC	370 / 340			E–W
NorNed	2008	Y	LCC	700 / 700			N–S
Skagerak 1	1976–1977	Y	LCC	250 / 250	1000 / 950	1000 / 950	N–S
Skagerak 2		Y	LCC	250 / 250			N–S
Skagerak 3	1993	Y	LCC	500 / 500			N–S

TABLE 7.2 TECHNICAL DETAILS OF THE HVDC LINKS

Name of the link	Total length of the link (km)	Length of oil cable (km)	Length of mass cable (km)	Length of PEX cable (km)	Length of DC overhead line (km)	Length of DC back-to-back connection (km)	Normal ramping time (minutes)
Estlink	105			105			
Fenno–Skan	233	200			33		
Konti–Skan 1	150						
Konti–Skan 2	150						
NorNed	580						

Skagerak 1	240				113		
Skagerak 2	240				113		
Skagerak 3	240				113		

7.2 DISTURBANCES AND MAINTENANCES

Figure 7.1 presents the number of disturbances and maintenances that have lead to an outage. The outage is defined as an event when there is no power transferred on the link, preceded by a circuit breaker action either at the local or remote side converter station. If there is no power transferred on the link, but circuit breaker has not operated, this is considered as a limitation, not an outage.

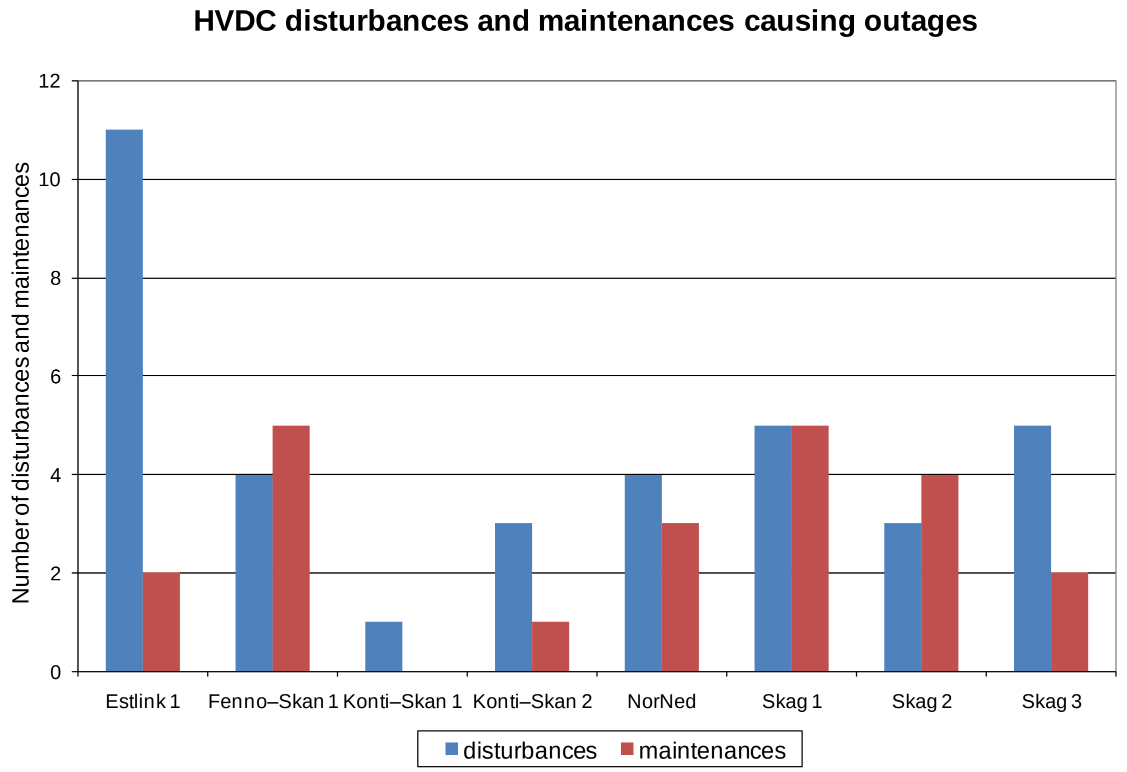

FIGURE 7.1 HVDC DISTURBANCES AND MAINTENANCES CAUSING OUTAGES IN 2010

Figure 7.2 presents HVDC disturbances and maintenances related to limitations.

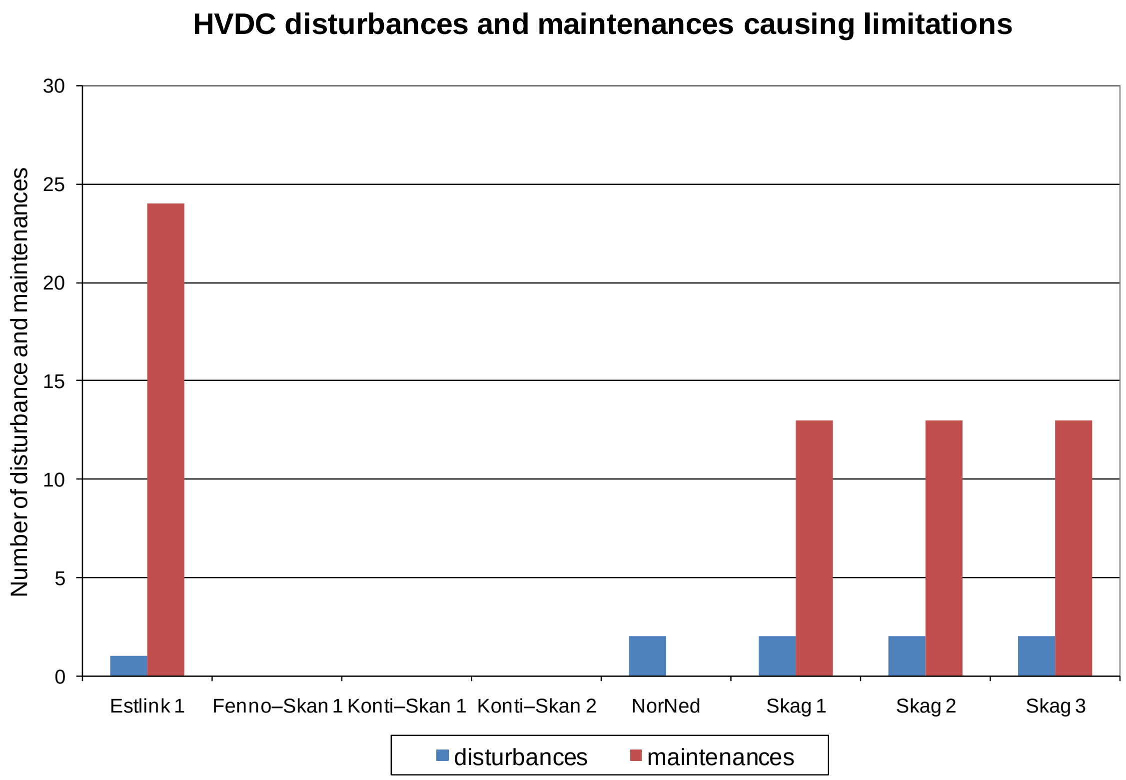

FIGURE 7.2 HVDC DISTURBANCES AND MAINTENANCES CAUSING TRANSFER LIMITATIONS IN 2010

Figure 7.3 presents all HVDC disturbances and maintenances, regardless of whether a circuit breaker has operated or not.

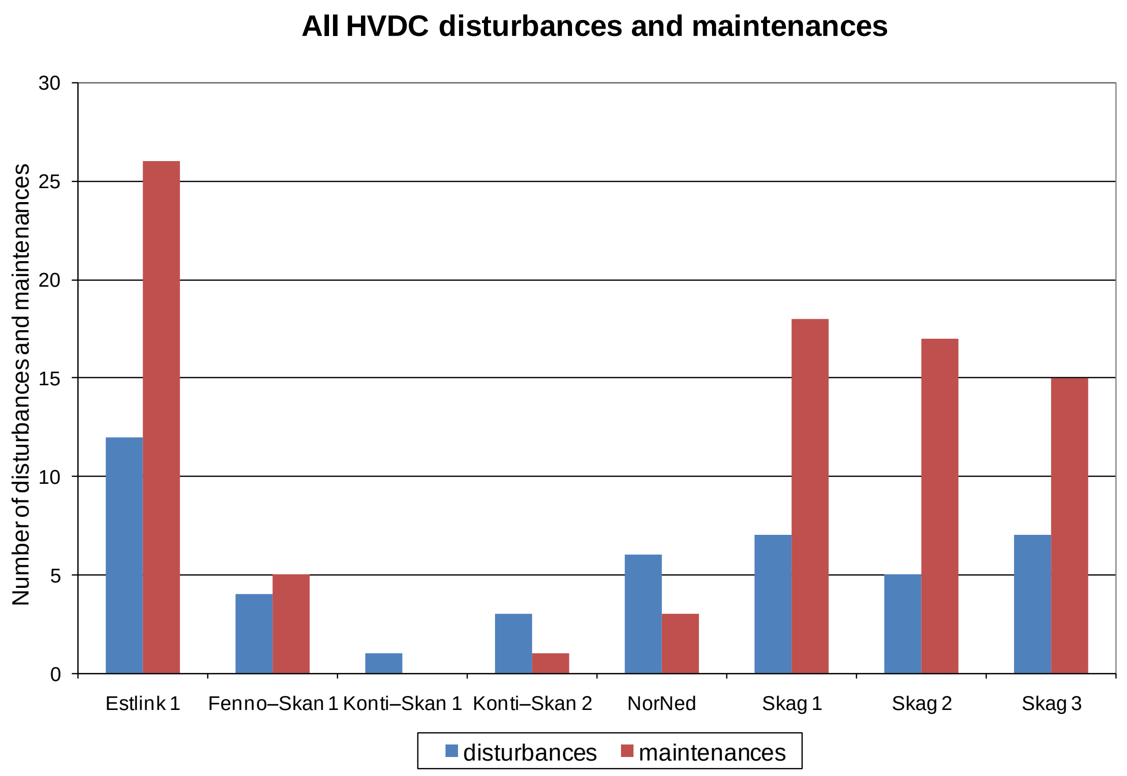

FIGURE 7.3 ALL HVDC DISTURBANCES IN 2010

7.3 UNAVAILABILITY

Figure 7.4 presents the unavailability of different HVDC links due to outages.

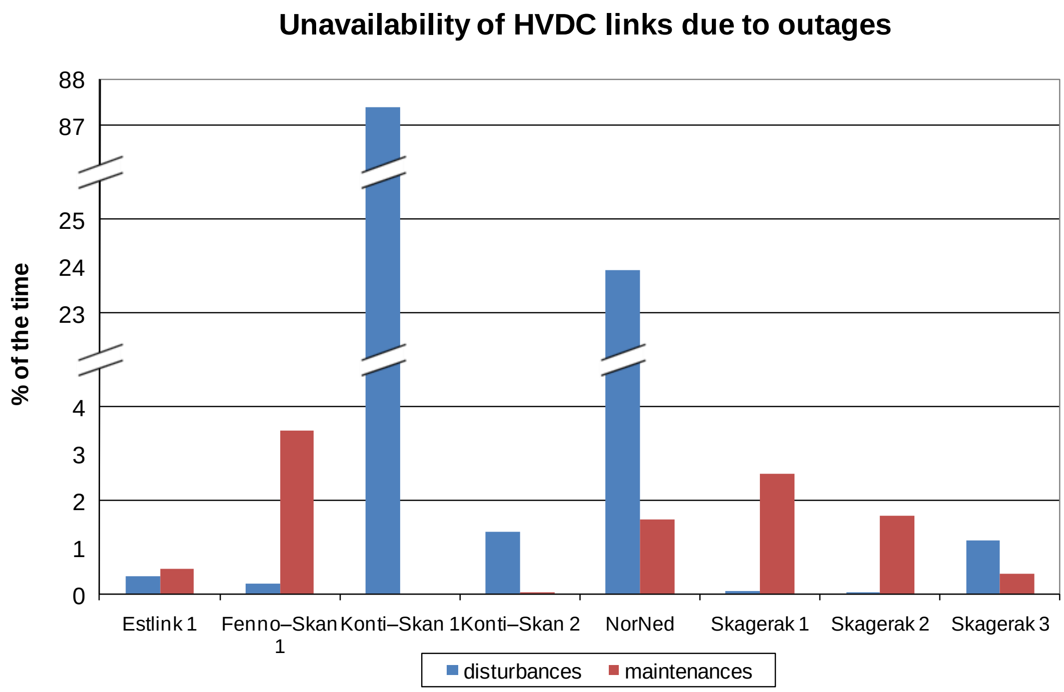

FIGURE 7.4 UNAVAILABILITY DUE TO OUTAGES IN 2010

Table 7.1 presents the unavailability due to outages separately for each month.

TABLE 7.1 MONTHLY UNAVAILABILITY (%) DUE TO OUTAGES IN 2010

Link	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Estlink	0	0	1	1	0	5	2	0	0	0	0	0
Fenno–Skan 1	0	0	0	0	11	0	0	0	0	29	0	2
Konti–Skan 1	100	100	100	100	100	100	100	100	100	100	50	0
Konti–Skan 2	0	0	0	0	0	0	0	0	16	0	0	0
NorNed	8	100	100	85	0	1	0	0	15	0	1	4
Skagerak 1	0	1	0	16	0	1	1	0	13	0	0	0
Skagerak 2	0	0	0	18	0	0	2	0	0	0	0	0
Skagerak 3	0	0	0	5	0	14	0	0	0	0	0	0

ENTSO-E AISBL • Avenue Cortenbergh 100 • 1000 Brussels • Belgium • Tel +32 2 741 09 50 • Fax +32 2 741 09 51 • info@entsoe.eu • www.entsoe.eu

Figure 7.5 presents the percentage of the time when links have been affected by limitations. One should note that Figure 7.5 includes only the incidents where the link has been available but its capacity has been limited. Therefore, total outages are not included in this figure.

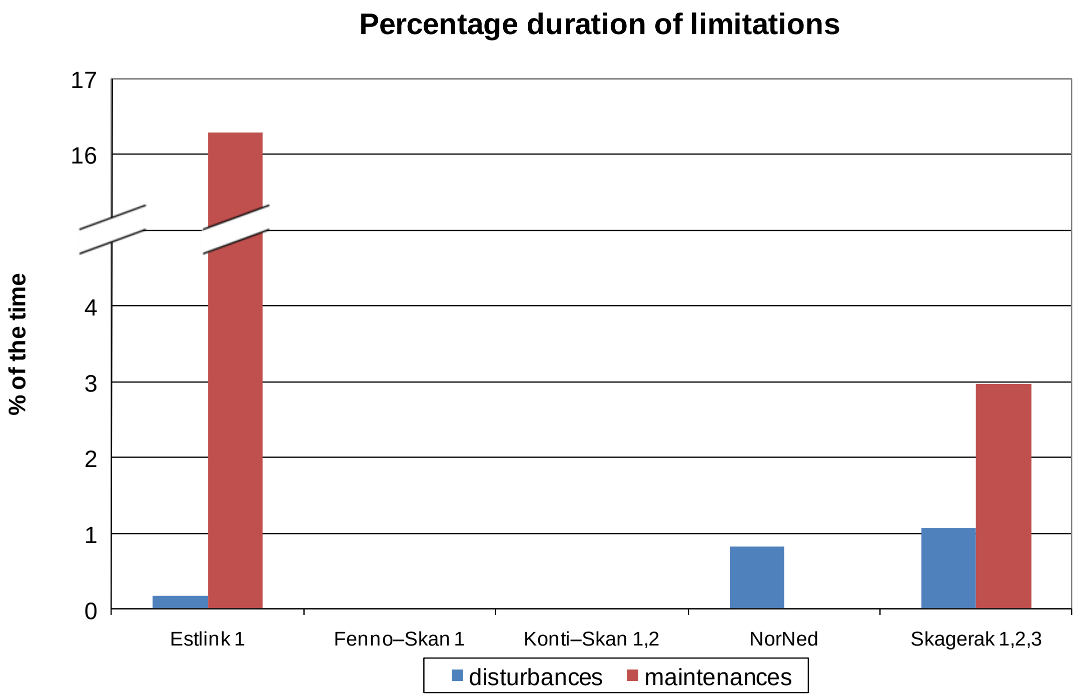

FIGURE 7.5 THE PERCENTAGE OF THE TIME WHEN LINKS HAVE BEEN AFFECTED BY LIMITATIONS IN 2010

7.4 ENERGY NOT TRANSFERRED (ENT)

This section presents the statistics of energy not transferred (ENT) for different HVDC links.

7.4.1 THE AMOUNT OF ENERGY NOT TRANSFERRED (ENT)

Figure 7.6 presents the amount of energy not transferred (ENT) due to outages for different HVDC links. ENT is calculated by multiplying the outage duration with the rated power of the link. Table 7.2 presents the distribution of ENT resulted from outages according to the month for different HVDC links.

Figure 7.7 presents the amount of ENT resulted from transfer limitations. For limitations, ENT is calculated by multiplying the time when the limitation is used with the difference between the rated power and limited capacity. If the limitation is not used, that is, if the transferred power is lower than the limited capacity, the limitation is not registered.

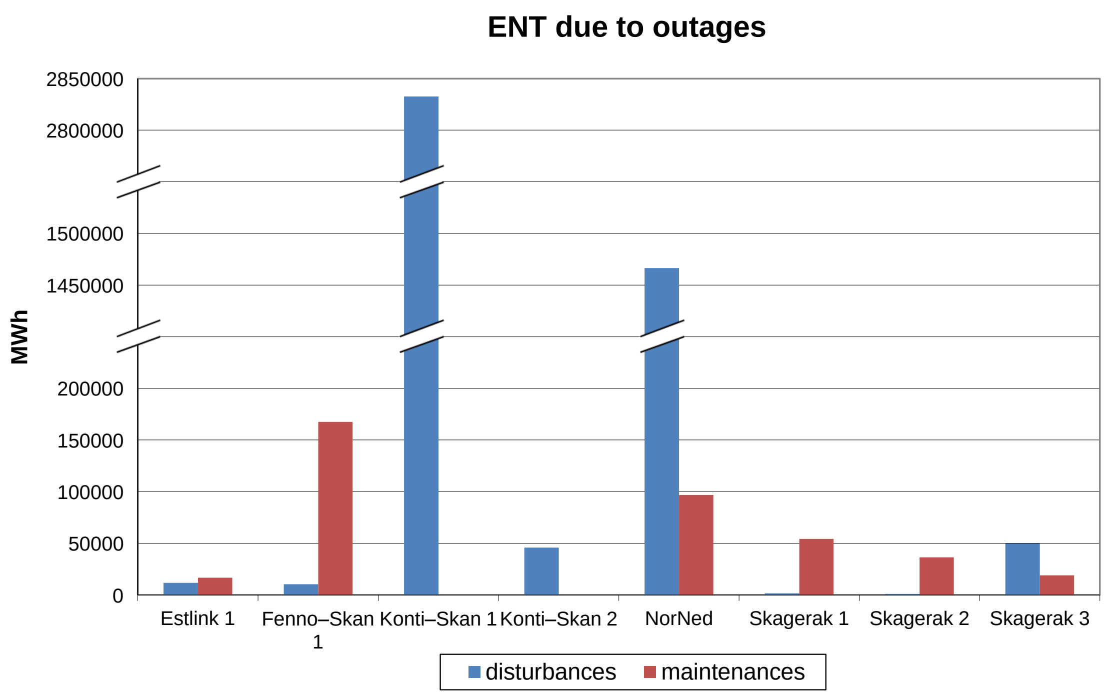

FIGURE 7.6 ENERGY NOT TRANSFERRED (ENT) DUE TO OUTAGES IN 2010

TABLE 7.2 PERCENTAGE DISTRIBUTION OF ENT DUE TO OUTAGES PER MONTH IN 2010

Link	ENT (MWh)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sum
Estlink	28280	0	3	14	10	0	45	22	0	2	2	0	2	100
Fenno–Skan 1	177888	0	0	0	0	26	1	1	0	0	66	0	5	100
Konti–Skan 1	2832720	10	9	10	9	10	9	10	10	9	10	5	0	100
Konti–Skan 2	45737	0	0	0	0	2	0	0	0	98	0	0	0	100
NorNed	1563333	3	30	33	27	0	0	0	0	5	0	0	1	100
Skagerak 1	55608	0	2	0	52	0	4	0	0	41	0	0	0	100
Skagerak 2	37254	0	0	0	86	0	0	11	0	0	0	2	0	100
Skagerak 3	68842	0	0	2	25	0	71	0	0	0	2	0	0	100

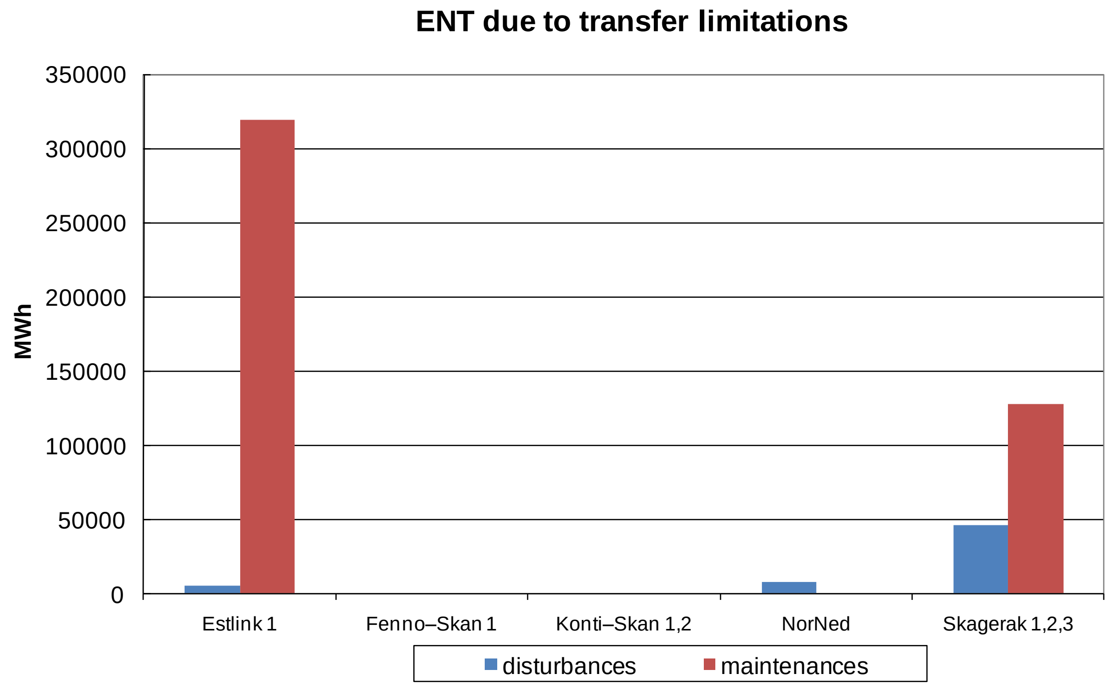

FIGURE 7.7 ENERGY NOT TRANSFERRED (ENT) DUE TO LIMITATIONS IN 2010

Figure 7.8 presents the total amount of ENT, that is, the summary of Figure 7.6 and Figure 7.7. In case of links consisting of multiple parallel cables, the total ENT is calculated only for all the cables together.

Figure 7.9 shows the total amount of ENT in relation to the rated yearly capacity of the link. For links with different capacity depending on the direction of power, the smaller capacity value is used for calculations.

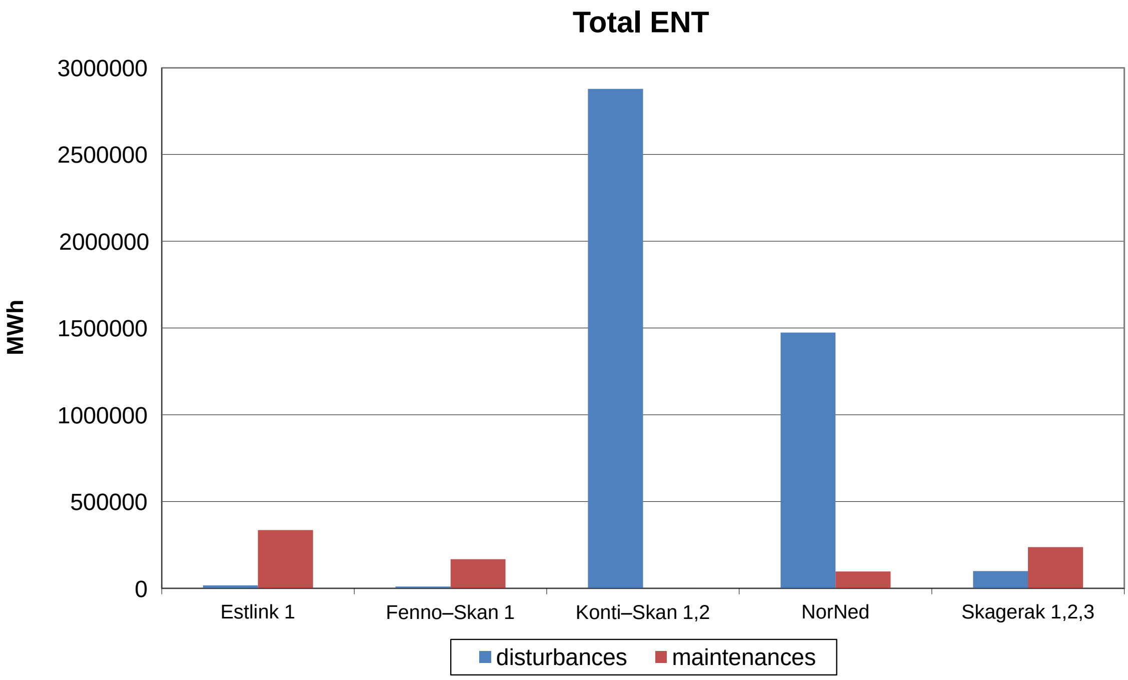

FIGURE 7.8 ENERGY NOT TRANSFERRED (ENT) DUE TO OUTAGES AND LIMITATIONS IN 2010

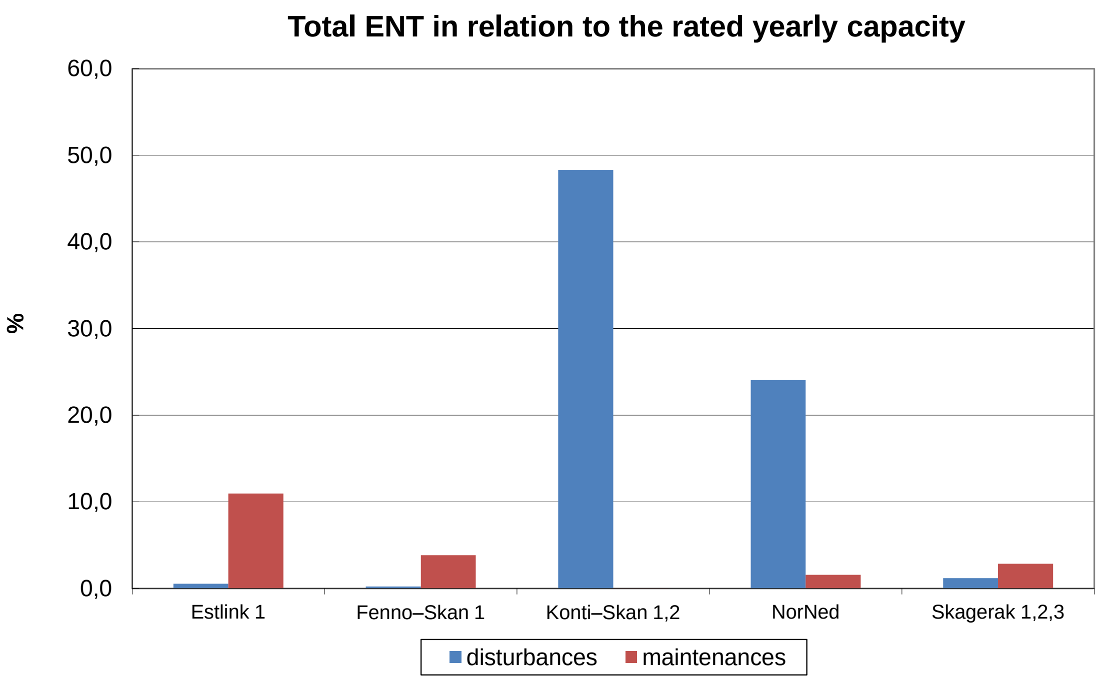

FIGURE 7.9 TOTAL ENERGY NOT TRANSFERRED (ENT) IN RELATION TO THE RATED YEARLY CAPACITY IN 2010

7.4.2 Energy not transferred (ENT) divided according to cause

Figure 7.10 shows the distribution of ENT due to outages according to the fault origin.

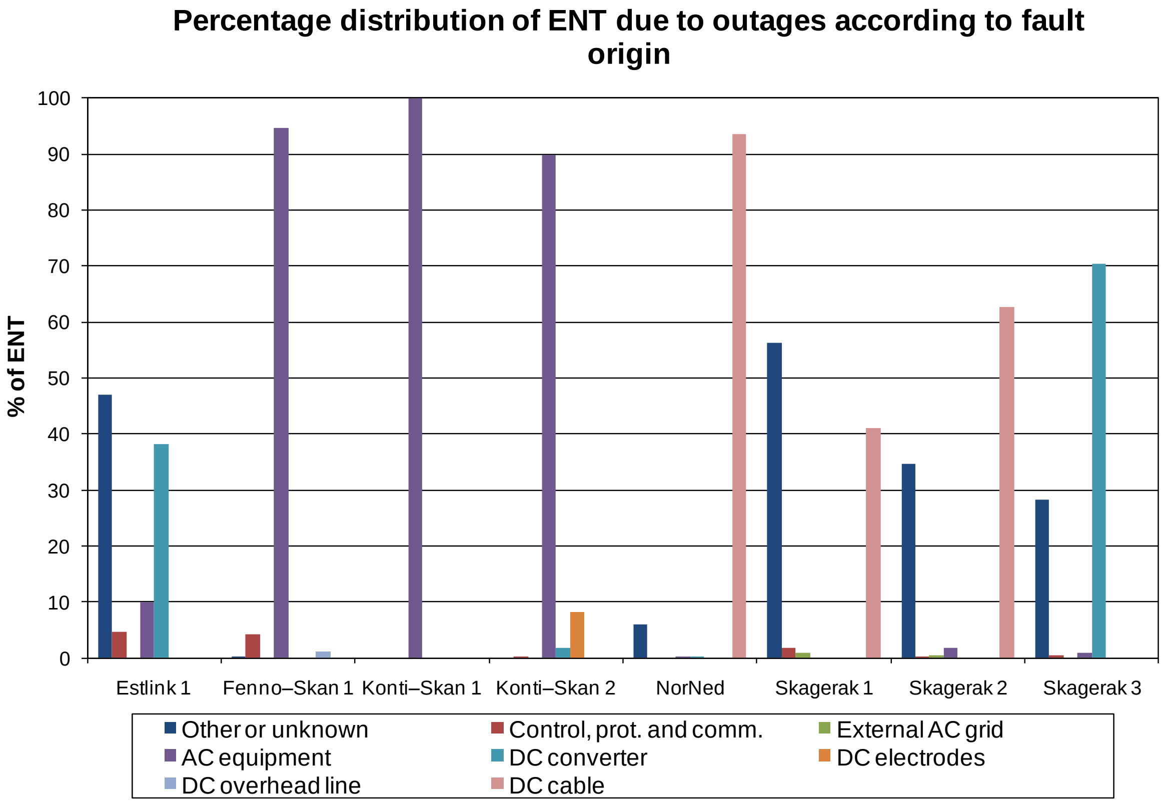

Figure 7.10 Energy not transferred (ENT) due to outages distributed according to fault origin in 2010

Figure 7.11 presents the distribution of ENT due to limitations according to fault origin.

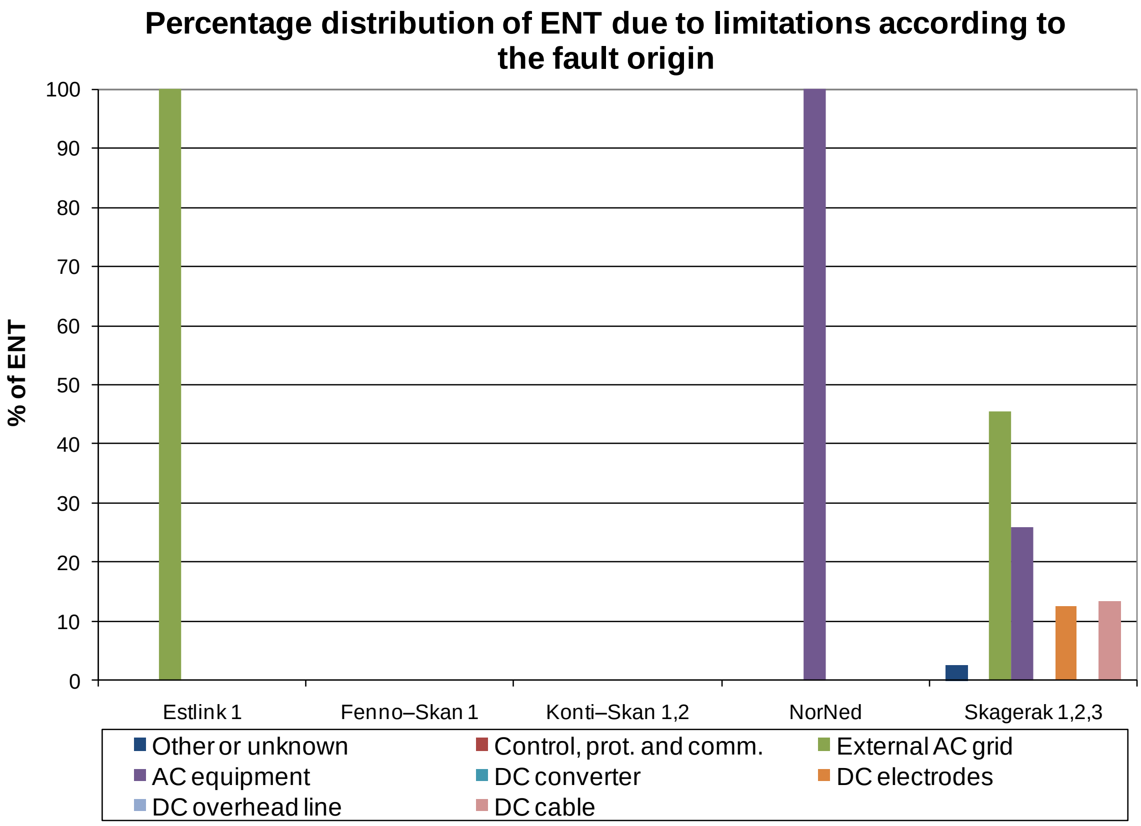

FIGURE 7.11 ENERGY NOT TRANSFERRED (ENT) DUE TO LIMITATION DISTRIBUTED ACCORDING TO FAULT ORIGIN IN 2010

Table 7.3 and Table 7.4 present the numerical values behind Figure 7.10 and Figure 7.11, respectively.

TABLE 7.3 PERCENTAGE DISTRIBUTION OF ENT DUE TO OUTAGES ACCORDING TO FAULT ORIGIN

Fault origin	Link	Percentage distribution of ENT due to outages
		2010
Other or unknown	Estlink 1	47.0
	Fenno–Skan 1	0.4
	Konti–Skan 1	0.0
	Konti–Skan 2	0.0
	NorNed	6.0
	Skagerak 1	56.3
	Skagerak 2	34.7
	Skagerak 3	28.2
Control, protection and communication	Estlink 1	4.6
	Fenno–Skan 1	4.2
	Konti–Skan 1	0.0
	Konti–Skan 2	0.1
	NorNed	0.0
	Skagerak 1	1.8
	Skagerak 2	0.2
	Skagerak 3	0.5
External AC grid	Estlink 1	0.0
	Fenno–Skan 1	0.0
	Konti–Skan 1	0.0
	Konti–Skan 2	0.0
	NorNed	0.0
	Skagerak 1	0.8
	Skagerak 2	0.5
	Skagerak 3	0.0
AC equipment	Estlink 1	10.0
	Fenno–Skan 1	94.3
	Konti–Skan 1	100.0
	Konti–Skan 2	89.8
	NorNed	0.2
	Skagerak 1	0.0
	Skagerak 2	1.8
	Skagerak 3	0.9
DC converter	Estlink 1	38.3
	Fenno–Skan 1	0.0

ENTSO-E AISBL • Avenue Cortenbergh 100 • 1000 Brussels • Belgium • Tel +32 2 741 09 50 • Fax +32 2 741 09 51 • info@entsoe.eu • www.entsoe.eu

	Konti–Skan 1	0.0
	Konti–Skan 2	1.8
	NorNed	0.2
	Skagerak 1	0.0
	Skagerak 2	0.0
	Skagerak 3	70.5
DC electrodes	Estlink 1	0.0
	Fenno–Skan 1	0.0
	Konti–Skan 1	0.0
	Konti–Skan 2	8.3
	NorNed	0.0
	Skagerak 1	0.0
	Skagerak 2	0.0
	Skagerak 3	0.0
DC overhead line	Estlink 1	0.0
	Fenno–Skan 1	1.0
	Konti–Skan 1	0.0
	Konti–Skan 2	0.0
	NorNed	0.0
	Skagerak 1	0.0
	Skagerak 2	0.0
	Skagerak 3	0.0
DC cable	Estlink 1	0.0
	Fenno–Skan 1	0.0
	Konti–Skan 1	0.0
	Konti–Skan 2	0.0
	NorNed	93.5
	Skagerak 1	41.1
	Skagerak 2	62.8
	Skagerak 3	0.0

ENTSO-E AISBL • Avenue Cortenbergh 100 • 1000 Brussels • Belgium • Tel +32 2 741 09 50 • Fax +32 2 741 09 51 • info@entsoe.eu • www.entsoe.eu

TABLE 7.4 PERCENTAGE DISTRIBUTION OF ENT DUE TO LIMITATIONS ACCORDING TO FAULT ORIGIN

Fault origin	Link	Percentage distribution of ENT due to limitations 2010
Other or unknown	Estlink 1	0.0
	Fenno–Skan 1	-
	Konti–Skan 1,2	-
	NorNed	0.0
	Skagerak 1,2,3	2.6
Control, protection and communication	Estlink 1	0.0
	Fenno–Skan 1	-
	Konti–Skan 1,2	-
	NorNed	0.0
	Skagerak 1,2,3	0.0
External AC grid	Estlink 1	100
	Fenno–Skan 1	-
	Konti–Skan 1,2	-
	NorNed	0.0
	Skagerak 1,2,3	45.5
AC equipment	Estlink 1	0.0
	Fenno–Skan 1	-
	Konti–Skan 1,2	-
	NorNed	100.0
	Skagerak 1,2,3	25.9
DC converter	Estlink 1	0.0
	Fenno–Skan 1	-
	Konti–Skan 1,2	-
	NorNed	0.0
	Skagerak 1,2,3	0.0
DC electrodes	Estlink 1	0.0
	Fenno–Skan 1	-
	Konti–Skan 1,2	-
	NorNed	0.0
	Skagerak 1,2,3	12.6
DC overhead line	Estlink 1	0.0
	Fenno–Skan 1	-
	Konti–Skan 1,2	-
	NorNed	0.0
	Skagerak 1,2,3	0.0
DC cable	Estlink 1	0.0
	Fenno–Skan 1	-
	Konti–Skan 1,2	-
	NorNed	0.0
	Skagerak 1,2,3	13.4

7.4.3 ENERGY NOT TRANSFERRED (ENT) DUE TO LIMITATIONS DIVIDED ACCORDING TO DIRECTION

Figure 7.12 presents the distribution of ENT according to the direction of the limitation. Figure 7.13 presents the same information in relation to the rated yearly capacity of the link. The rated yearly capacity is calculated by multiplying the rated power of the link with the number of hours in a year.

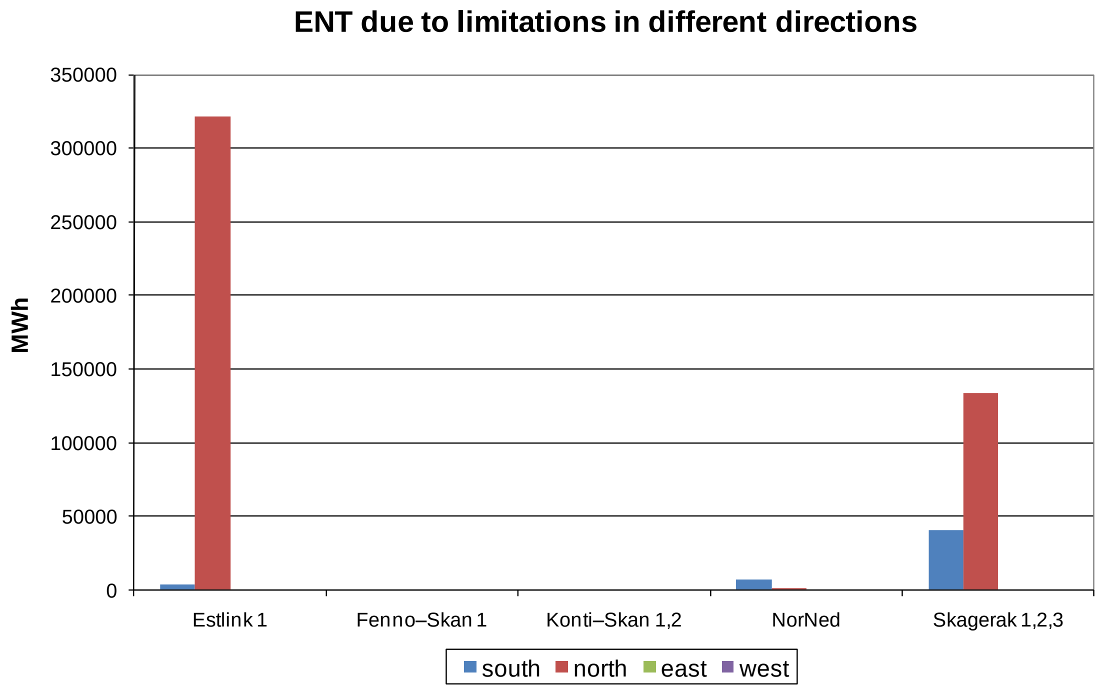

FIGURE 7.12 ENERGY NOT TRANSFERRED (ENT) DUE TO LIMITATIONS IN DIFFERENT DIRECTIONS IN 2010

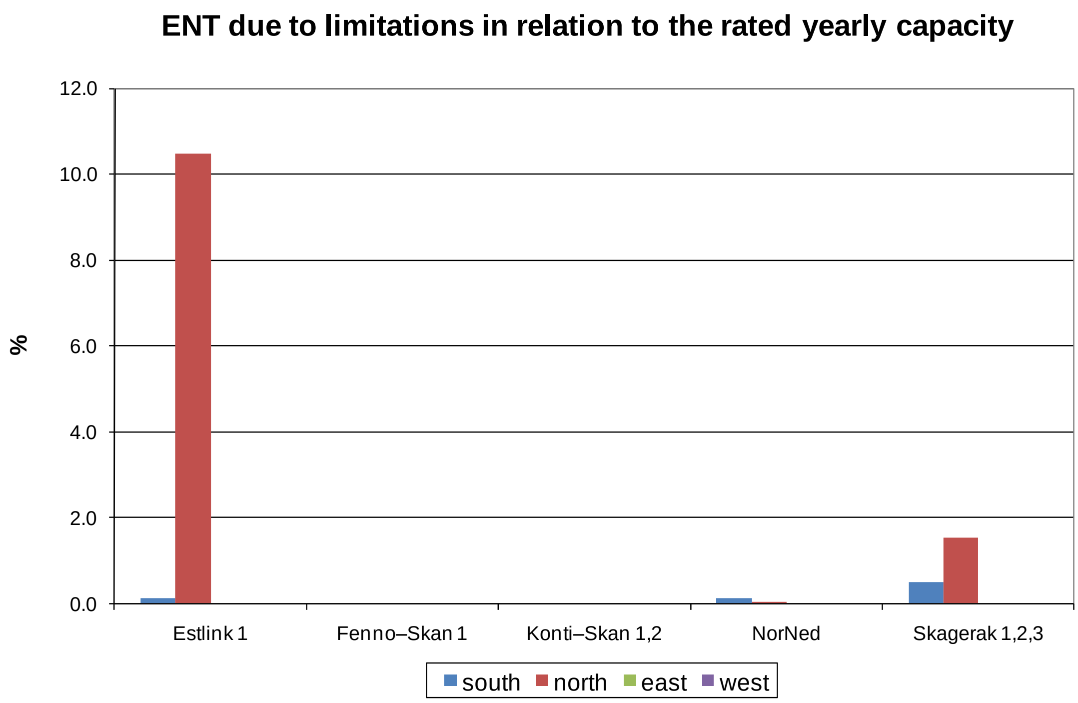

FIGURE 7.13 PERCENTAGE OF ENERGY NOT TRANSFERRED (ENT) DUE TO LIMITATIONS IN RELATION TO THE RATED YEARLY CAPACITY IN 2010

7.5 FAULT TYPES AND FAULT ORIGINS

Table 7.5 shows the distribution of different fault types together with fault origins. The cells with the gray background present division of faults in each case.

TABLE 7.5 HVDC FAULT TYPES AND FAULT ORIGINS IN THE ENTSO-E NORDIC REGION IN 2010

Fault origin		Temporary primary fault	Temporary secondary fault	Permanent primary fault	Permanent secondary fault	Latent fault	Limiting fault	Limitations due to AC grid
Other or unknown	**Total number of faults**	**1**	**0**	**3**	**0**	**0**	**0**	**-**
	Links (number of faults)	Skagerak3 (1)		Estlink (1) Fenno-Skan (2)				
Control, protection and communication	**Total number of faults**	**5**	**0**	**4**	**0**	**4**	**0**	**-**
	Links (number of faults)	Fenno-Skan (1) Skagerak1 (2) Skagerak2 (1) Skagerak3 (1)		Estlink (3) Skagerak3 (1)		Skagerak1 (2) Skagerak2 (1) Skagerak3 (1)		
External AC grid	**Total number of faults**	**4**	**0**	**0**	**0**	**0**	**0**	**0**
	Links (number of faults)	Skagerak1 (3) Skagerak2 (1)						
AC equipment	**Total number of faults**	**4**	**0**	**6**	**0**	**0**	**0**	**-**
	Links (number of faults)	Skagerak1 (1) Skagerak2 (2) Skagerak3 (1)		Estlink (1) Fenno-Skan (1) Konti-Skan1 (1) NorNed (3)				
DC converter	**Total number of faults**	**1**	**0**	**7**	**0**	**0**	**0**	**-**
	Links (number of faults)	NorNed (1)		Estlink (6) Skagerak3 (1)				
DC electrodes	**Total number of faults**	**0**	**0**	**3**	**0**	**0**	**0**	**-**
	Links (number of faults)			Skagerak1 (1) Skagerak2 (1) Skagerak3 (1)				

DC overhead line	**Total number of faults**	**0**	**0**	**0**	**0**	**0**	**0**	**-**
	Links (number of faults)							
DC cable	**Total number of faults**	**1**	**0**	**1**	**0**	**0**	**0**	**-**
	Links (number of faults)	NorNed (1)		NorNed (1)				
All		**16**	**0**	**24**	**0**	**4**	**0**	**0**

ENTSO-E AISBL • Avenue Cortenbergh 100 • 1000 Brussels • Belgium • Tel +32 2 741 09 50 • Fax +32 2 741 09 51 • info@entsoe.eu • www.entsoe.eu

8 REFERENCES

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

2. **ENTSO-E.** The ENTSO-E Interconnected System Grid Map. [Online] http://ww.entsoe.eu/index.php?id=77.

3. **Nordel.** Guidelines for the Classification of Grid Disturbances. [Online] 2009. http://www.entsoe.eu/index.php?id=63.

4. **IEEE.** Standard Terms for Reporting and Analyzing Outage Occurrence and Outage States of Electrical Transmission Facilities. IEEE Std 859-1987. IEEE Std 859-1987.

5. **IEC 50(191-05-01).** International Electrotechnical Vocabulary, Dependability and Quality of Service. 50(191-05-01).

ENTSO-E AISBL • Avenue Cortenbergh 100 • 1000 Brussels • Belgium • Tel +32 2 741 09 50 • Fax +32 2 741 09 51 • info@entsoe.eu • www.entsoe.eu

Appendix 1: The calculation of energy not supplied

Energy not supplied (ENS) is calculated in various ways in different countries.

In Denmark, the ENS of the transmission grid is calculated as the transformer load just before the grid disturbance or interruption multiplied by the outage duration. Transformer load covers load/consumption and generation at lower/medium voltage.

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

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

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

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

Appendix 2: Contact persons in the Nordic countries

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

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

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

Norway: Jørn Schaug-Pettersen
Statnett SF
Postboks 5192 Majorstuen, NO-0302 Oslo
Tel. +47 23 90 35 55, Fax +47 22 52 70 01
E-mail: jsp@statnett.no

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

Production of the report:
Liisa Haarla and Ilkka Luukkonen
Aalto University
School of Electrical Engineering
P.O. BOX 13000, 00076 Aalto, Finland
Tel. +358 9 451 5428, Fax +358 9 451 5012
E-mail: liisa.haarla@aalto.fi or ilkka.luukkonen@aalto.fi

Appendix 3: Contact persons for the distribution network statistics

ENTSO-E Regional Group Nordic provides no statistics for distribution networks (voltage <100 kV). However, there are more or less developed national statistics for these voltage levels.

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

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

Finland: Tuomas Maasalo
Energiateollisuus ry
Fredrikinkatu 51–53 B, P.O. Box 100, FI-00101 Helsinki
Tel. +358 50 566 3632, Fax +358 9 5305 2900
E-mail: tuomas.maasalo@energia.fi

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

Norway: Jørn Schaug-Pettersen
Statnett SF
Postboks 5192 Majorstuen, NO-0302 Oslo
Tel. +47 23 90 35 55, Fax +47 22 52 70 01
E-mail: jsp@statnett.no

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