European Network of
Transmission System Operators
for Electricity

# NORDIC GRID DISTURBANCE STATISTICS 2011

26.02.2013

REGIONAL GROUP NORDIC

# 1 INTRODUCTION

This report is an overview of the Danish, Finnish, Icelandic, Norwegian and Swedish transmission grid disturbance statistics for the year 2011. 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 the Nordic Guidelines for Classification of Grid Disturbances [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 2002–2011. 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 2011

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

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Chapter 3 discusses the disturbances and focuses on the analysis and allocation of the causes of disturbances. The division of disturbances during the year 2011 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 brief summary of HVDC disturbances, maintenances, outages and limitations. Also fault types and origins are presented. The HVDC section was included first time in the report for the year 2010 and for this report, it has been developed further. In the following years, the report will have more detailed information on the availability of the HVDC links.

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. FIGURE 1.1 THE NORDIC MAIN GRID [2]**

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.



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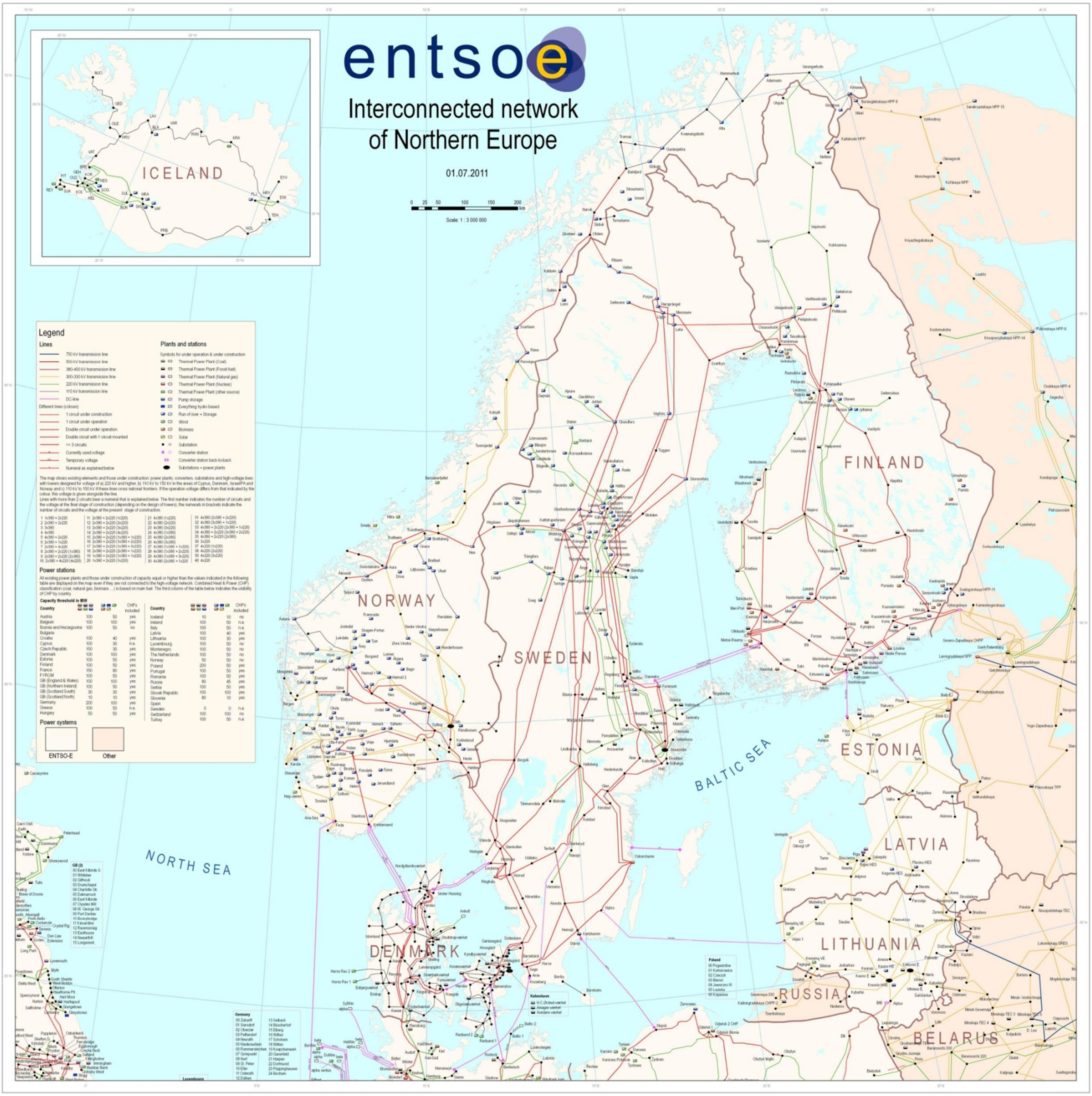


**FIGURE 1.1 THE NORDIC MAIN GRID [2]**

**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% | 98%[1)] |

[1)] 98% for Swedish 132 kV grid is because one regional grid owner did not deliver the data.

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.

# 2 SUMMARY

In 2011, the energy not supplied (ENS) due to faults in the Nordic main grid was relatively high. ENS totalled 15.75 GWh, which is clearly above the ten-year annual average. The annual average of ENS was 8.11 GWh in the ENTSO-E Nordic region during the period 2002–2011. 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 2011. The corresponding annual averages are calculated for the period 2002–2011. In addition, the summaries present the most important issues in 2011 defined by each Transmission System Operator.

## 2.1 SUMMARY FOR DENMARK

For Denmark, the energy not supplied in 2011 was 8.3 MWh (ten-year average 956 MWh). The number of grid disturbances was 48 (ten-year average 68) and 7 of them caused ENS. On average, 5 disturbances per year caused ENS in 2002-2011.

On March 14th 2011 an internal failure in a 150 kV transformer bushing (of OIP type) caused an extremely power full fire in the 150/60 kV substation “Håndværkervej” in Aalborg (northern part of Jutland). During the fire-fighting – which included support from the local airports crash tender - the entire substation was manually disconnected for safety reasons. Within 45 minutes all 18.000 customers which had been interrupted were re-supplied through re-routing in the local 10 kV network. During the fire-fighting, which lasted more than six hours, the fire developed further and an additional 150/60 kV transformer, two 60/10 kV transformers and one 60 kV reactor were damaged due to the fire and the high temperatures. Due to the manually disconnection and re-routing of the customers, the failure resulted in approx. 5,8 MWh ENS.

Later, on April 18th 2011 a 150 kV failure occurred in the 400/150/60 kV substation “Tjele” (middle part of Jutland, substation including interconnection to Kristiansand (N)). Due to an internal error in a 150 kV reactor bushing a 150 kV busbar were disconnected and approx. 28.500 customers were disconnected for 15 minutes. The failure led to a minor fire which was quickly extinguished. The failure resulted in approx. 2,4 MWh ENS.

## 2.2 SUMMARY FOR FINLAND

For Finland, the energy not supplied in 2011 was 511 MWh (ten-year average 288 MWh). The number of grid disturbances was 613 (ten-year average 341) and 95 of them caused ENS. On average, 63 disturbances per year caused ENS in 2002–2011. In 2011, 51% of ENS occurred due to 'technical equipment' and 28% of ENS occurred due to 'other environmental causes'. Most of the disturbances were caused by 'other environmental causes' and occurred during the summer months. The percentage of unknown disturbances decreased, because of change in classification policy in Fingrid in July 2011: more effort is put to clarify causes. In the previous year 2010, 46% was unknown and in 2011 only 22% was unknown. Almost all of the unknown disturbances occurred in 110 kV lines.

57% of ENS was caused by only four disturbances. The highest amount of ENS (112 MWh) in a single disturbance was caused by 'technical equipment' in November; there were a manufacturing defect in control equipment.

Christmas storms 26.-27.12.2011 caused high ENS due to fallen trees on 110 kV lines.

## 2.3 Summary for Iceland

For Iceland, the energy not supplied in 2011 was 641 MWh (ten-year average 772 MWh). The total number of disturbances was 24 (ten-year average 33) and 10 of them caused ENS. On average, 22 disturbances per year caused ENS in 2002–2011.

Nearly 80% of the ENS in Iceland was caused by two disturbances. A tower fell in the 132 kV network ring on the western region causing 30% of total ENS this year. In the second disturbance (Nearly 50% of ENS), a DC fault in a substation led to a widespread disturbance in the east part of the country and a power intensive industry in the region tripped.

## 2.4 Summary for Norway

In Norway, the energy not supplied in 2011 was 13102 MWh (ten-year average 2940 MWh). The number of grid disturbances was 382 (ten-year average 306) and 138 of them caused ENS. On average, 100 disturbances per year caused ENS in 2002-2011.

In January, three power transformers in the substations Minne and Frogner was damaged due to overvoltage when a cable was cut by a mechanical digger. The last transformer in this area did not have the capacity to deliver sufficient power. So during the high load hours some areas had to be cyclic disconnected for some weeks.

In December, very strong wind during the hurricane 'Dagmar' ended in 1132 grid disturbances and was alone responsible for 2/3 of all ENS for the whole year from1 kV to 420 kV.

## 2.5 Summary for Sweden

In Sweden, the energy not supplied in 2011 was 1483 MWh (ten-year average 3097 MWh). The total number of disturbances was 621 (ten-year average 581) and 188 of those caused

ENS. On average, 140 disturbances per year caused ENS in 2002–2011. Lightning caused 33 % of ENS and 46 % of ENS was caused by failure in technical equipments.

When energizing a system transformer in parallel with an identical unit a 400 kV line tripped due to malfunction of harmonics blocking leading to 22,5 MWh of ENS and several hydro production units were disconnected.



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# 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 2011, together with the development of the number of disturbances over the ten-year period 2002–2011. 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 2002–2011

The number of disturbances during the year 2011 in the Nordic main grid was 1688, which is clearly above the ten-year average of 1329. 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 2011 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 2002–2011.

**TABLE 3.1 NUMBER OF GRID DISTURBANCES IN 2011**

| Year 2011 | **Denmark** | **Finland** | **Iceland** | **Norway** | **Sweden** |
|---|---|---|---|---|---|
| Number of disturbances | 48 | 613 | 24 | 382 | 621 |

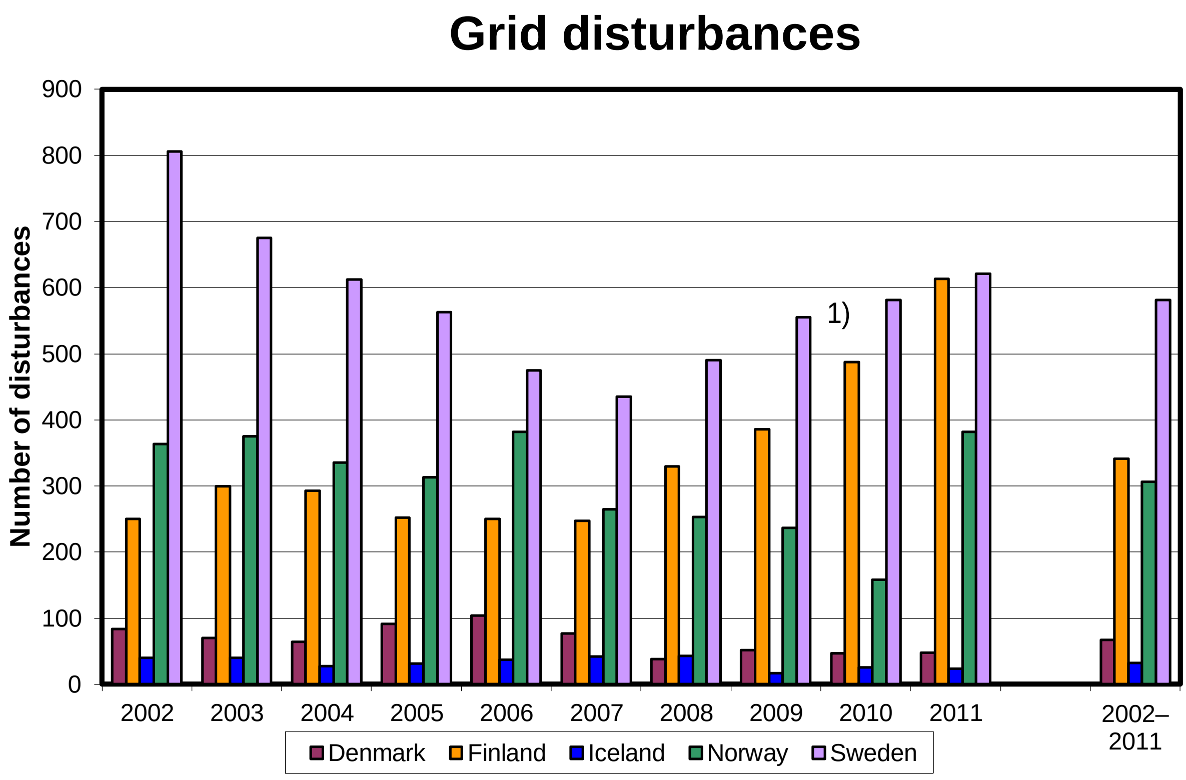


**FIGURE 3.1 NUMBER OF GRID DISTURBANCES IN EACH NORDIC COUNTRY DURING THE PERIOD 2002–2011.**

1) The increased number of lightning faults affects the number of grid disturbances in Finland and Sweden.

## 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 2011. In addition, Figure 3.3 shows the ten-year average distribution of disturbances during the period 2002–2011.

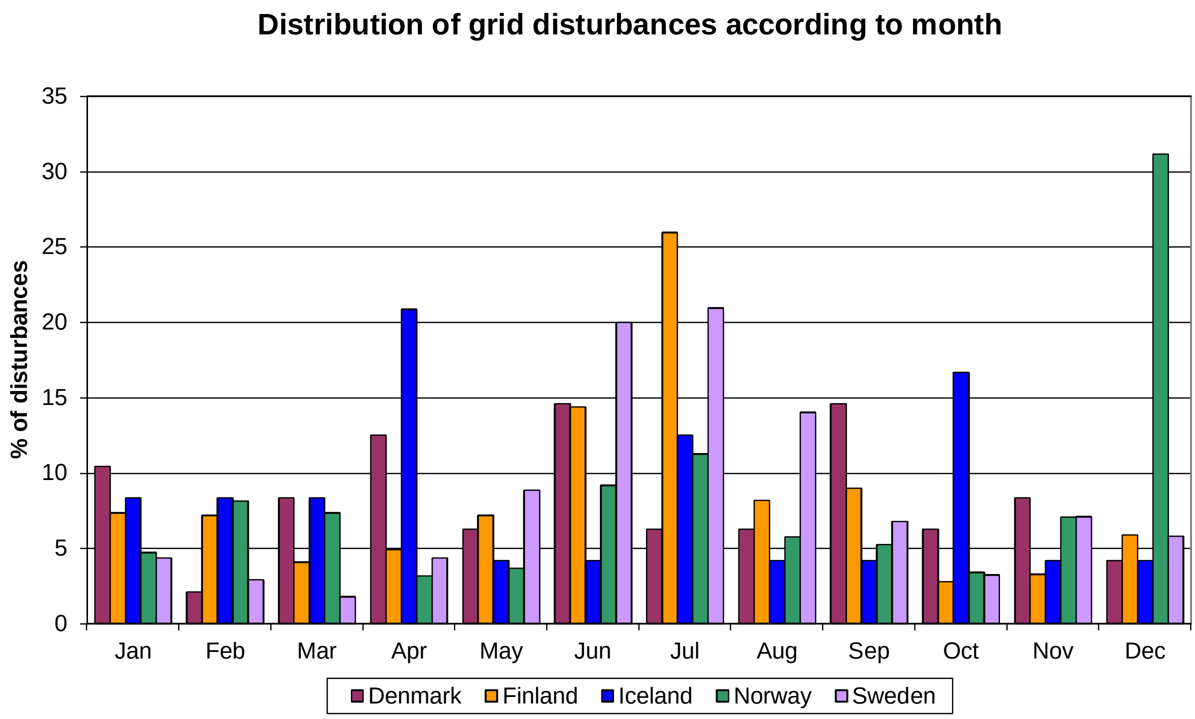


**FIGURE 3.2 PERCENTAGE DISTRIBUTION OF GRID DISTURBANCES ACCORDING TO MONTH IN EACH COUNTRY IN 2011.**

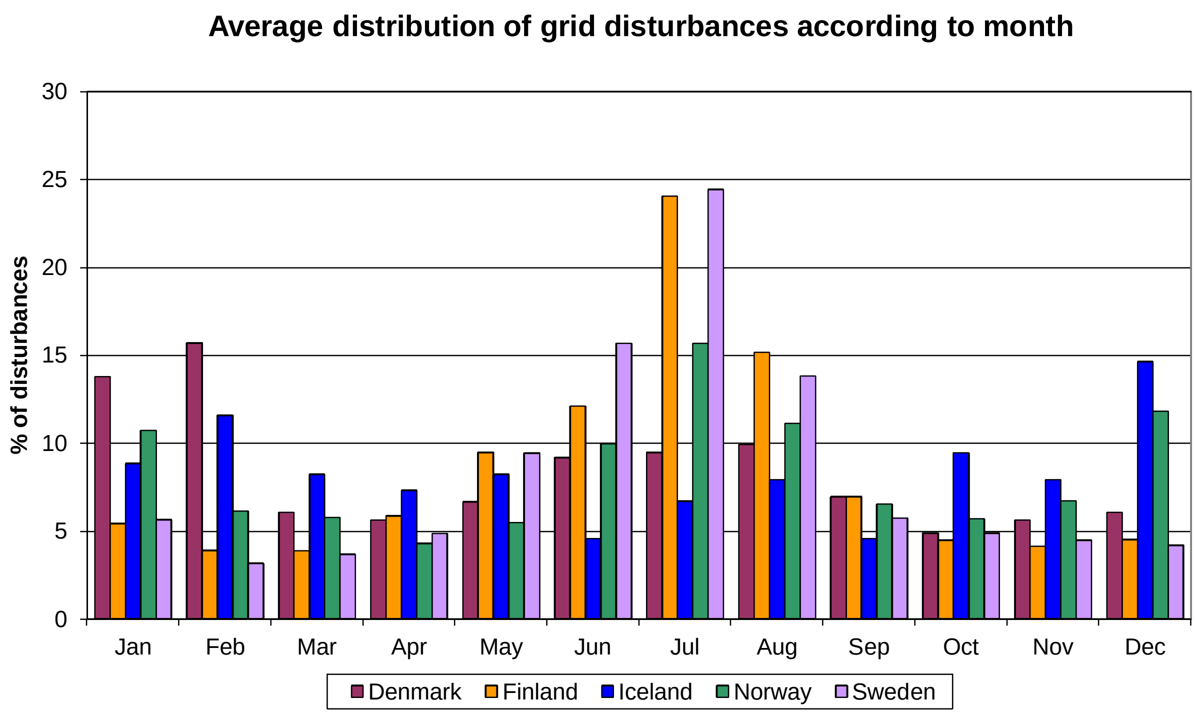


**FIGURE 3.3 AVERAGE PERCENTAGE DISTRIBUTION OF GRID DISTURBANCES ACCORDING TO MONTH FOR THE PERIOD 2002–2011.**

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 2011

| Country | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Denmark | 10 | 2 | 8 | 13 | 6 | 15 | 6 | 6 | 15 | 6 | 8 | 4 |
| Finland | 7 | 7 | 4 | 5 | 7 | 14 | 26 | 8 | 9 | 3 | 3 | 6 |
| Iceland | 8 | 8 | 8 | 21 | 4 | 4 | 13 | 4 | 4 | 17 | 4 | 4 |
| Norway | 5 | 8 | 7 | 3 | 4 | 9 | 11 | 6 | 5 | 3 | 7 | 31 |
| Sweden | 4 | 3 | 2 | 4 | 9 | 20 | 21 | 14 | 7 | 3 | 7 | 6 |
| Nordic | 6 | 6 | 4 | 5 | 7 | 15 | 20 | 10 | 7 | 3 | 6 | 11 |

TABLE 3.3 PERCENTAGE DIVISION OF GRID DISTURBANCES DURING THE YEARS 2002–2011

| Country | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Denmark | 14 | 16 | 6 | 6 | 7 | 9 | 9 | 10 | 7 | 5 | 6 | 6 |
| Finland | 5 | 4 | 4 | 6 | 9 | 12 | 24 | 15 | 7 | 4 | 4 | 5 |
| Iceland | 9 | 12 | 8 | 7 | 8 | 5 | 7 | 8 | 5 | 9 | 8 | 15 |
| Norway | 11 | 6 | 6 | 4 | 5 | 10 | 16 | 11 | 7 | 6 | 7 | 12 |
| Sweden | 6 | 3 | 4 | 5 | 9 | 16 | 24 | 14 | 6 | 5 | 4 | 4 |
| Nordic | 7 | 5 | 4 | 5 | 8 | 13 | 21 | 13 | 6 | 5 | 5 | 6 |

## 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.

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] | |
|---|---|---|---|---|---|
| | | 2011 | 2002–2011 | 2011 | 2002–2011 |
| Lightning | Denmark | 17 | 16 | 0 | 0 |
| | Finland | 30 | 30 | 4 | 5 |
| | Iceland | 4 | 3 | 5 | 2 |
| | Norway | 21 | 23 | 2 | 4 |
| | Sweden | 45 | 40 | 33 | 14 |
| Other environmental causes | Denmark | 6 | 24 | 0 | 0 |
| | Finland | 32 | 9 | 28 | 22 |
| | Iceland | 33 | 30 | 48 | 55 |
| | Norway | 38 | 20 | 81 | 51 |
| | Sweden | 3 | 4 | 0 | 4 |
| External influences | Denmark | 23 | 15 | 0 | 0 |
| | Finland | 1 | 2 | 2 | 11 |
| | Iceland | 0 | 2 | 0 | 0 |
| | Norway | 1 | 2 | 0 | 1 |
| | Sweden | 2 | 2 | 1 | 4 |
| Operation and maintenance | Denmark | 8 | 15 | 2 | 4 |
| | Finland | 5 | 7 | 3 | 15 |
| | Iceland | 33 | 11 | 43 | 21 |
| | Norway | 7 | 13 | 1 | 9 |
| | Sweden | 8 | 8 | 2 | 12 |
| Technical equipment | Denmark | 17 | 13 | 98 | 12 |
| | Finland | 7 | 5 | 51 | 29 |
| | Iceland | 25 | 27 | 2 | 15 |
| | Norway | 18 | 22 | 2 | 22 |
| | Sweden | 13 | 15 | 46 | 46 |
| Other | Denmark | 6 | 6 | 0 | 84 |
| | Finland | 4 | 6 | 6 | 11 |
| | Iceland | 4 | 23 | 1 | 6 |
| | Norway | 11 | 14 | 13 | 11 |
| | Sweden | 8 | 10 | 1 | 10 |
| Unknown | Denmark | 23 | 12 | 0 | 0 |
| | Finland[2] | 22 | 40 | 6 | 7 |
| | Iceland | 0 | 4 | 0 | 1 |
| | Norway | 5 | 6 | 0 | 2 |
| | Sweden | 22 | 20 | 16 | 10 |

[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.



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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.

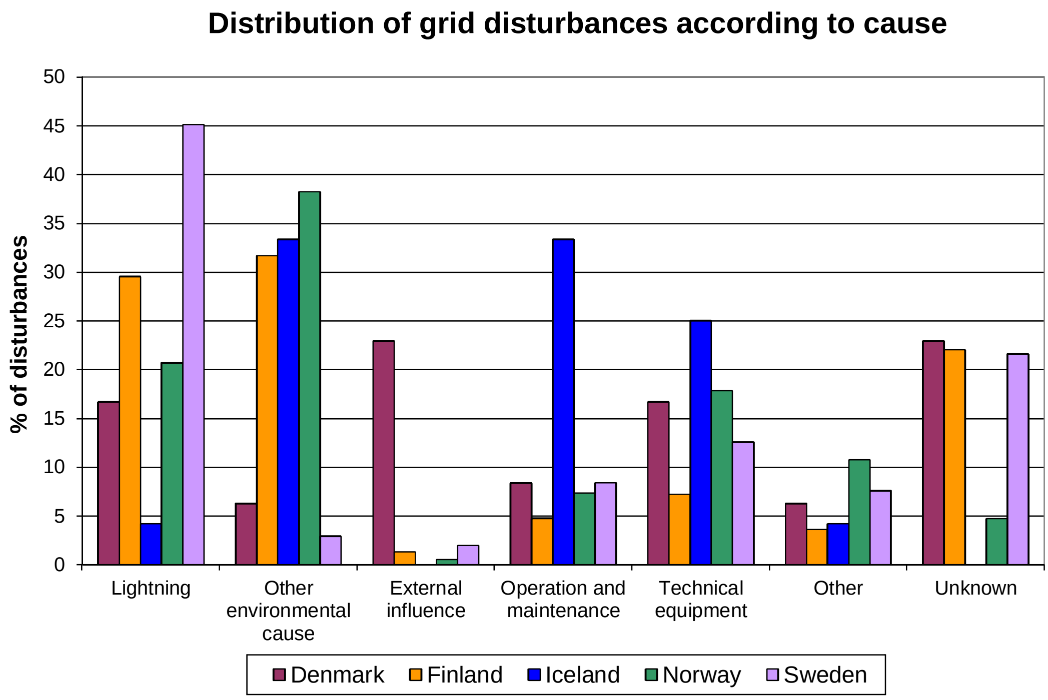


**FIGURE 3.4 PERCENTAGE DISTRIBUTION OF GRID DISTURBANCES ACCORDING TO CAUSE IN 2011.**

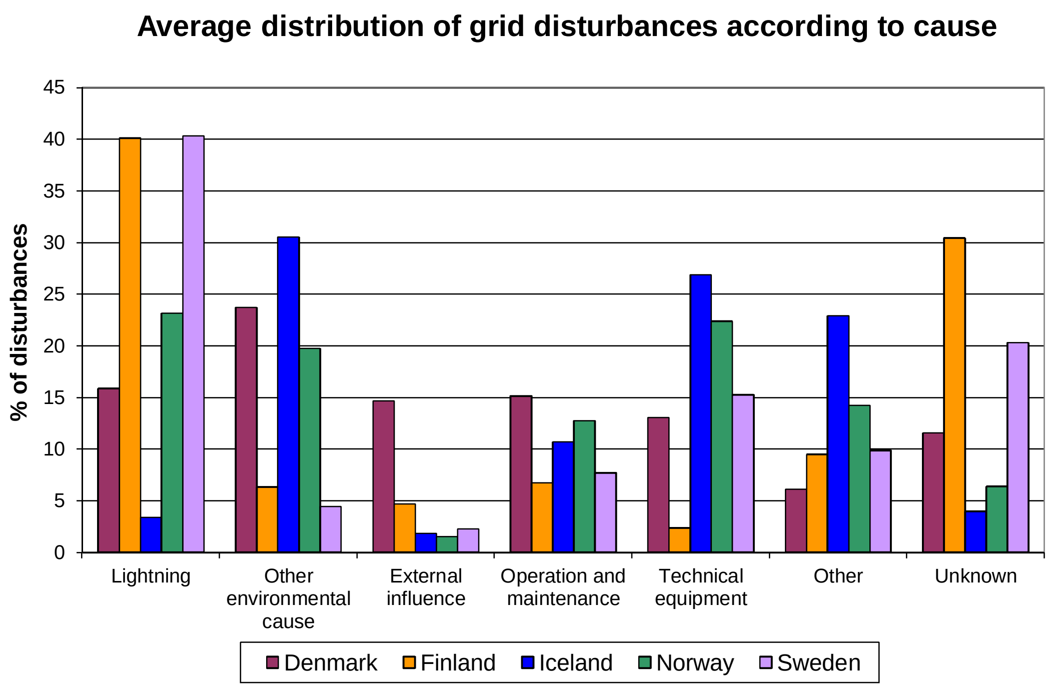


**FIGURE 3.5 AVERAGE PERCENTAGE DISTRIBUTION OF GRID DISTURBANCES ACCORDING TO CAUSE DURING THE PERIOD 2002–2011.**



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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 2011 | Annual average of ENS MWh 2002–2011 | ENS divided into different voltage levels during the period 2002–2011 (%) | | | |
|---|---|---|---|---|---|---|
| | | | 132 kV | 220 kV | 400 kV | Other[1)] |
| Denmark | 8.3[2)] | 956.0 | 4.9 | 0.0 | 95.1[3)] | 0.0 |
| Finland | 511.1 | 288.4 | 91.9 | 3.1 | 4.1 | 0.9 |
| Iceland | 640.6 | 772.4 | 44.0 | 56.0 | 0.0 | 0.0 |
| Norway | 13102.2 | 2939.6 | 31.1 | 20.3 | 39.1 | 9.4 |
| Sweden | 1483.0 | 3153.0 | 55.2 | 9.5 | 33.3[3)] | 1.9 |
| Nordic | 15745.3 | 8109.4 | 40.8 | 16.5 | 38.5 | 4.2 |

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.

Figure 4.1A and 4.2B summarise the energy not supplied according to the different voltage levels for the year 2011 and for the period 2002–2011, respectively. Voltage level refers to the initiating fault of the respective disturbance.

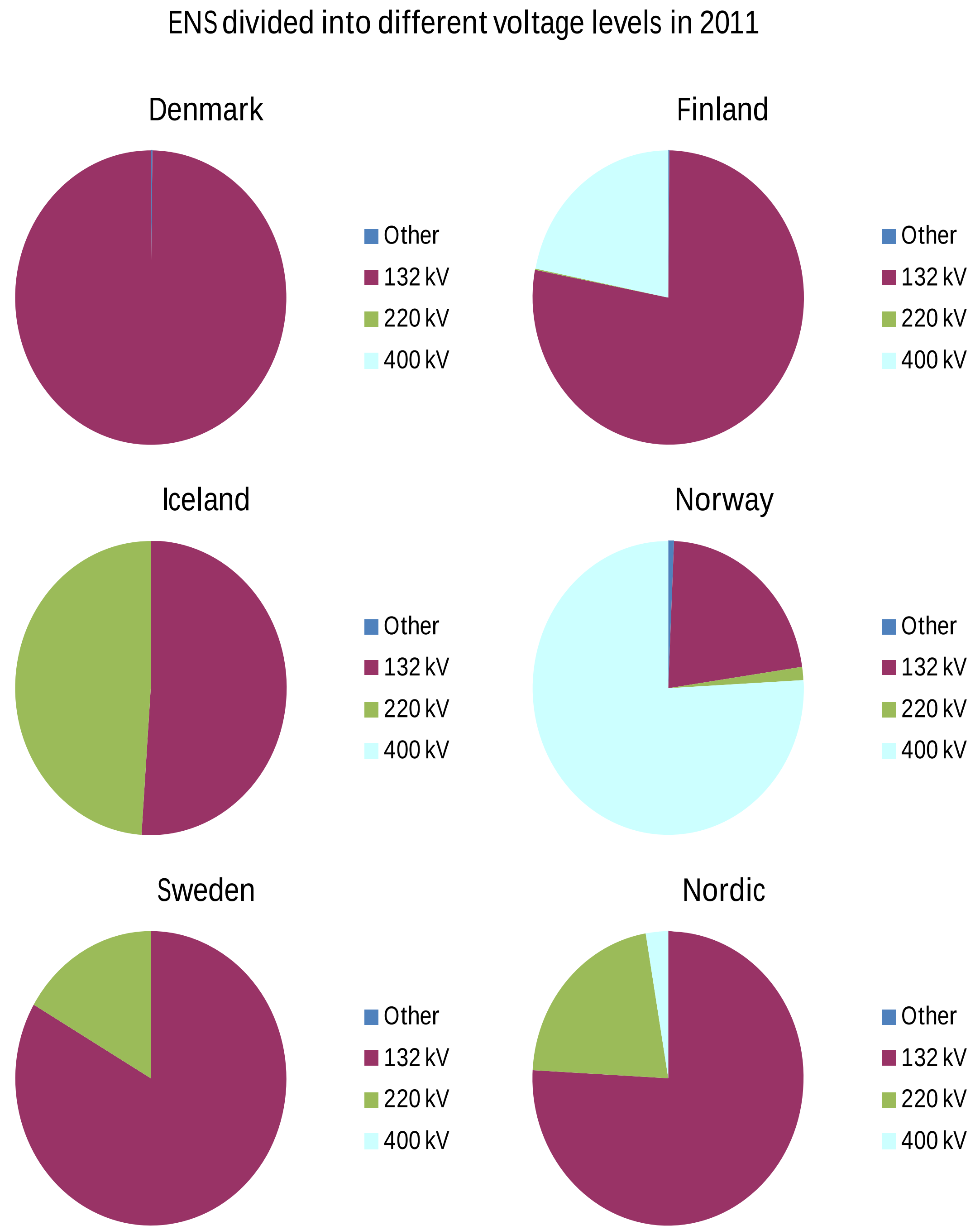


**FIGURE 4.1A ENERGY NOT SUPPLIED (ENS) IN TERMS OF THE VOLTAGE LEVEL OF THE INITIATING FAULT IN 2011.**

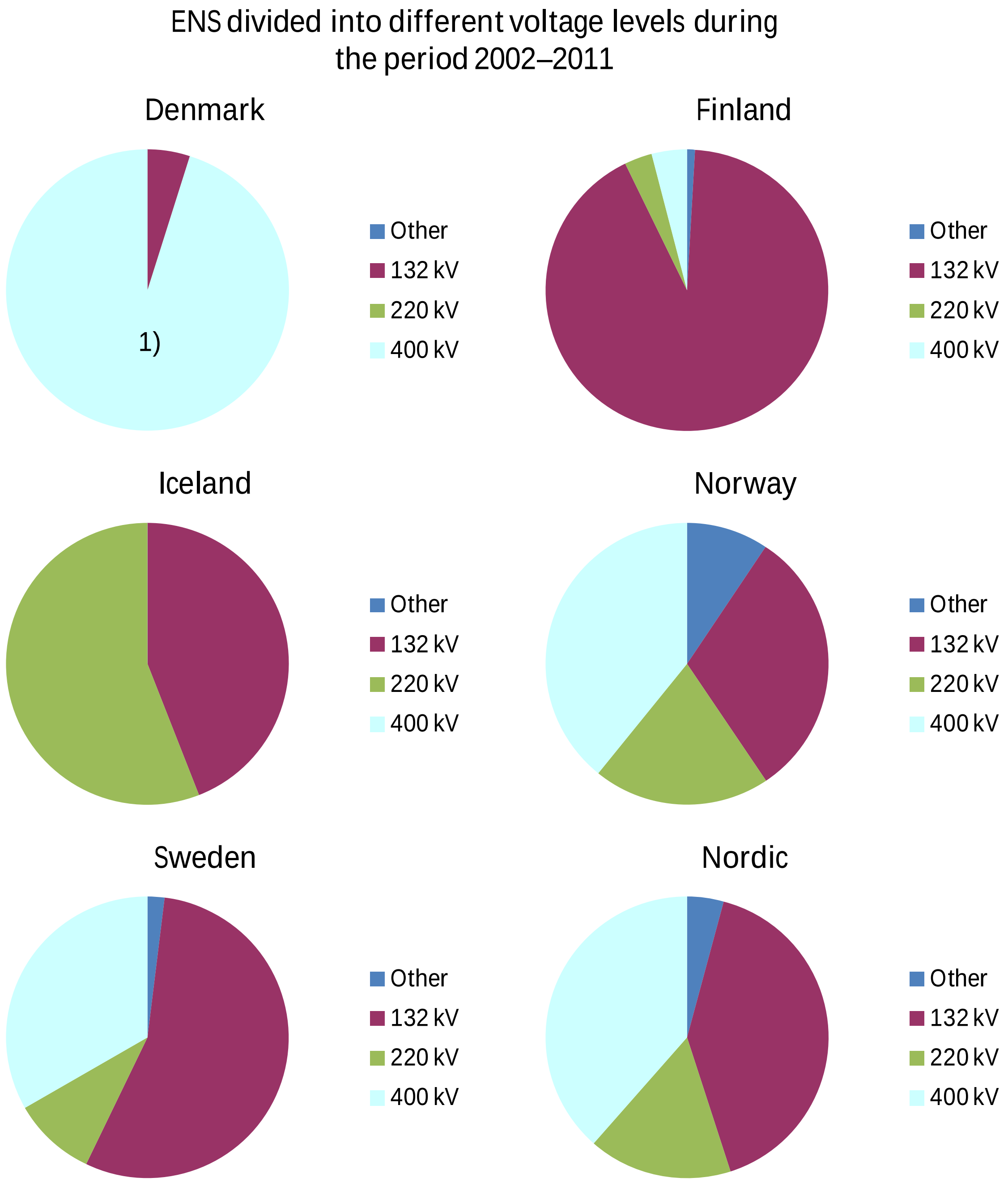


**FIGURE 4.1B ENERGY NOT SUPPLIED (ENS) IN TERMS OF THE VOLTAGE LEVEL OF THE INITIATING FAULT DURING THE PERIOD 2002–2011.**

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 2002–2011 (%) | | | |
|---|---|---|---|---|---|---|---|---|
| | GWh 2011 | MWh 2011 | Ppm 2011 | Ppm 2002–2011 | Overhead line | Cable | Sta-tions | Other |
| Denmark | 32061 | 8.3 | 0.3 | 28.1 | 11.8 | 0.0 | 4.3 | 83.9 |
| Finland | 84241 1) | 511.1 | 6.1 | 3.5 | 59.0 | 0.0 | 35.8 | 5.2 |
| Iceland | 17210 | 640.6 | 37.2 | 62.5 | 41.4 | 1.1 | 42.0 | 15.6 |
| Norway | 123141 | 13102.2 | 106.4 | 23.3 | 57.3 | 0.3 | 33.5 | 8.8 |
| Sweden | 139000 | 1483.0 | 10.7 | 21.8 | 16.9 | 1.3 | 75.5 | 5.9 |
| Nordic | 395812 | 15745.2 | 39.8 | 20.3 | 34,8 | 0.7 | 47.3 | 17.1 |

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

*1)* Data from Statistics Finland

Figure 4.1 presents the development of energy not supplied during the period 2002–2011. 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.

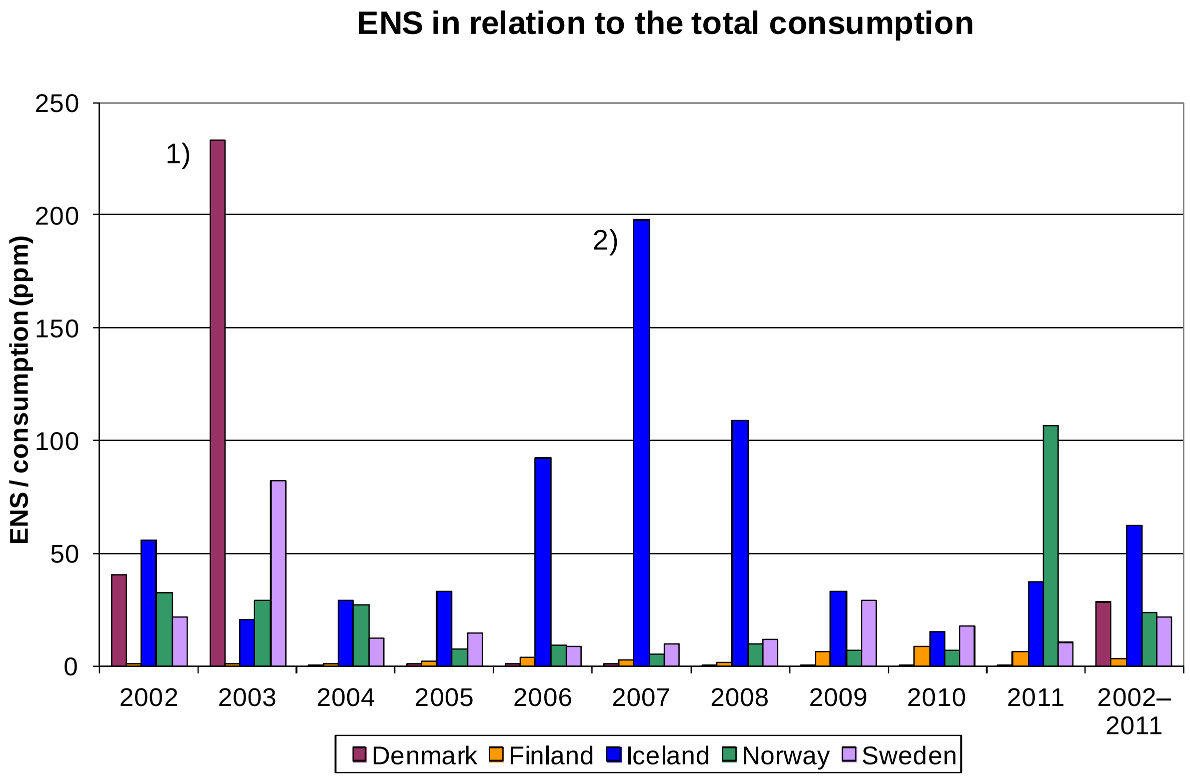


**FIGURE 4.1 ENERGY NOT SUPPLIED (ENS) / CONSUMPTION (PPM).**

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

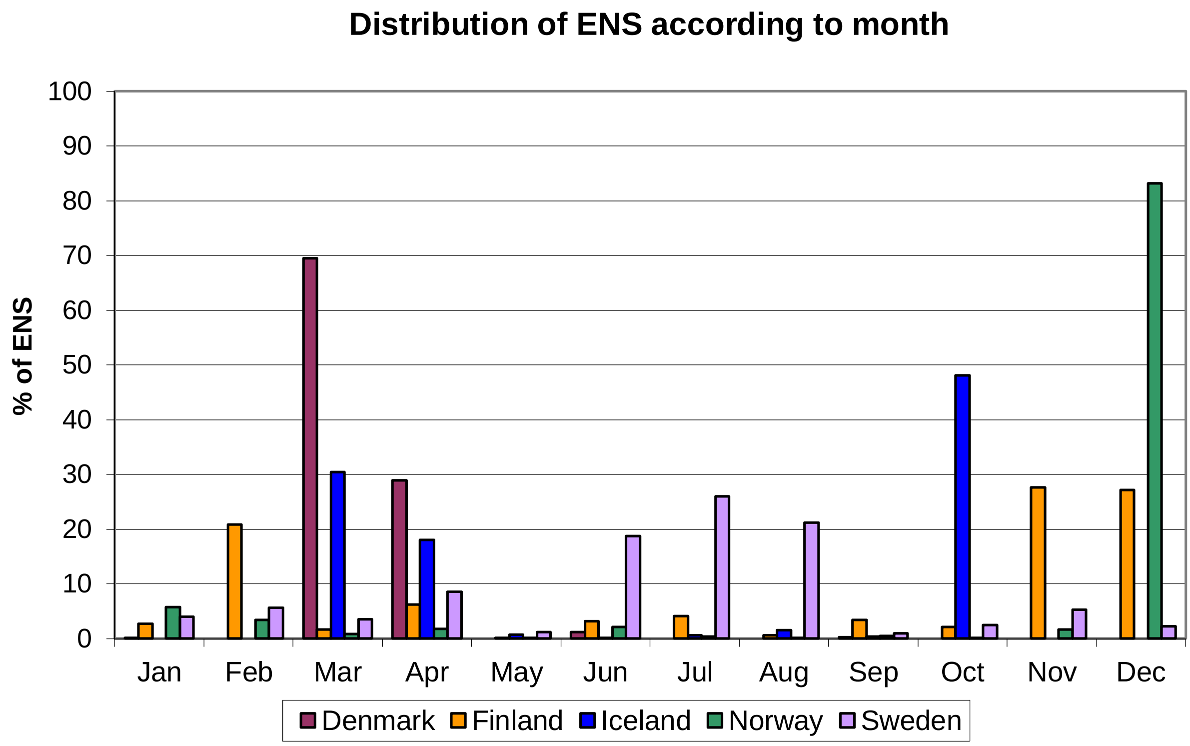


**FIGURE 4.2 PERCENTAGE DISTRIBUTION OF ENERGY NOT SUPPLIED (ENS) ACCORDING TO MONTH IN 2011.**

## 4.4 ENERGY NOT SUPPLIED (ENS) DIVIDED ACCORDING TO CAUSE

Figure 4.3 presents the distribution of energy not supplied according to cause in different countries.

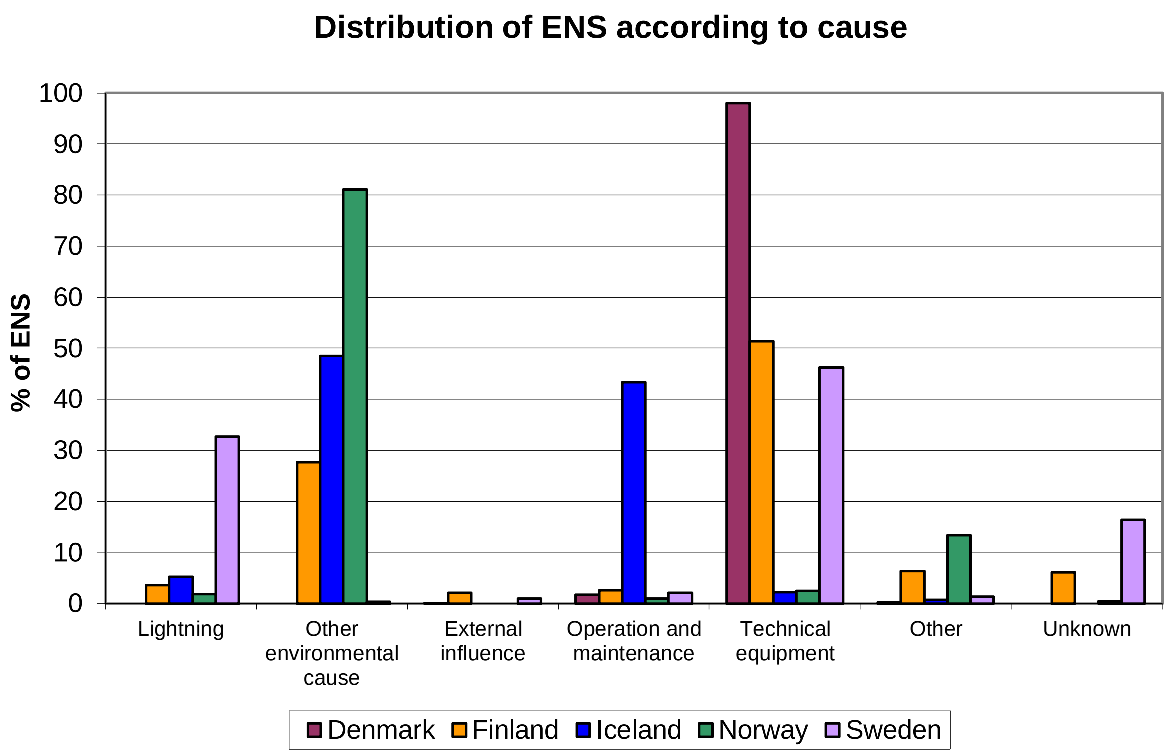


**FIGURE 4.3 PERCENTAGE DISTRIBUTION OF ENERGY NOT SUPPLIED (ENS) ACCORDING TO THE CAUSE OF THE PRIMARY FAULT IN 2011.**

## 4.5 ENERGY NOT SUPPLIED (ENS) DIVIDED ACCORDING TO COMPONENT

Table 4.3 shows the amount of energy not supplied in 2011 and the annual average for the period 2002–2011. Table 4.4 shows the distribution of energy not supplied according to component.

**TABLE 4.3 ENERGY NOT SUPPLIED (ENS) IN 2011 AND THE ANNUAL AVERAGE FOR THE PERIOD 2002–2011**

| | **Denmark** | | **Finland** | | **Iceland** | | **Norway** | | **Sweden** | | **Nordic** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Time period | 2011 | 2002–2011 | 2011 | 2002–2011 | 2011 | 2002–2011 | 2011 | 2002–2011 | 2011 | 2002–2011 | 2011 | 2002–2011 |
| ENS (MWh) | 8 | 956 | 511 | 288 | 641 | 772 | 13102 | 2940 | 1389 | 3141 | 15651 | 8098 |

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

| Fault location | Denmark | | Finland | | Iceland | | Norway | | Sweden | | Nordic | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2011 | 2002–2011 | 2011 | 2002–2011 | 2011 | 2002–2011 | 2011 | 2002–2011 | 2011 | 2002–2011 | 2011 | 2002–2011 |
| Overhead line | 1.3 | 0.4 | 43.8 | 59.0 | 53.7 | 41.3 | 85.8 | 57.3 | 59.0 | 17.0 | 80.7 | 33.5 |
| Cable | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.1 | 0.1 | 0.3 | 1.9 | 1.3 | 0.3 | 0.7 |
| **Sum of line faults** | **1.3** | **0.4** | **43.8** | **59.0** | **53.7** | **42.4** | **85.9** | **57.6** | **60.9** | **18.3** | **80.9** | **34.2** |
| Power transformer | 69.9 | 0.3 | 1.7 | 2.0 | 0.7 | 0.2 | 5.9 | 3.2 | 6.2 | 10.9 | 5.6 | 5.5 |
| Instrument transformer | 0.0 | 0.0 | 0.0 | 2.5 | 0.0 | 0.0 | 0.0 | 2.8 | 13.9 | 3.3 | 1.2 | 2.4 |
| Circuit breaker | 0.0 | 3.5 | 0.4 | 2.8 | 0.1 | 3.6 | 0.1 | 1.5 | 8.4 | 2.3 | 0.8 | 2.3 |
| Disconnector | 0.0 | 0.2 | 0.0 | 2.5 | 0.0 | 12.6 | 0.1 | 2.3 | 0.0 | 36.8 | 0.1 | 16.4 |
| Surge arrester and spark gap | 0.0 | 0.0 | 14.7 | 4.6 | 0.0 | 0.0 | 0.9 | 2.1 | 0.0 | 0.1 | 1.2 | 0.9 |
| Busbar | 0.0 | 0.2 | 0.0 | 2.3 | 0.0 | 5.7 | 3.3 | 2.6 | 0.0 | 1.5 | 2.8 | 2.2 |
| Control equipment | 0.2 | 11.5 | 33.5 | 17.2 | 44.8 | 16.2 | 0.6 | 15.2 | 0.6 | 3.4 | 3.5 | 10.4 |
| Common ancillary equipment | 0.0 | 0.0 | 0.0 | 0.6 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.1 |
| Other substation faults | 0.0 | 0.0 | 2.4 | 1.3 | 0.0 | 0.0 | 3.2 | 3.9 | 7.1 | 17.4 | 3.3 | 8.2 |
| **Sum of substation faults** | **70.2** | **15.7** | **52.6** | **35.8** | **45.6** | **38.4** | **14.1** | **33.5** | **36.2** | **75.7** | **18.6** | **48.3** |
| Shunt capacitor | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3.6 | 0.0 | 0.0 | 0.0 | 1.1 | 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 | 28.4 | 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 compensation faults** | **28.4** | **0.0** | **0.0** | **0.0** | **0.0** | **3.6** | **0.0** | **0.0** | **0.0** | **1.1** | **0.0** | **0.8** |
| System fault | 0.0 | 83.9 | 0.0 | 0.0 | 0.7 | 15.6 | 0.0 | 4.7 | 2.4 | 0.8 | 0.2 | 13.4 |
| Faults in adjoining statistical area | 0.2 | 0.0 | 3.6 | 5.2 | 0.0 | 0.0 | 0.0 | 4.2 | 0.4 | 4.2 | 0.2 | 3.3 |
| Unknown | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **Sum of other faults** | **0.2** | **83.9** | **3.6** | **5.2** | **0.7** | **15.6** | **0.0** | **8.8** | **2.9** | **5.0** | **0.4** | **16.7** |

One should notice that some countries register the total amount of energy not supplied in a disturbance in terms of the initiating fault. Therefore, the data is not necessarily comparable.

# 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* [4].

The scope of the statistics, according to the guidelines [1] is the following:

*"The statistics comprise:*
- *Grid disturbances*
- *Faults causing or aggravating a grid disturbance*
- *Disconnection of end users in connection with grid disturbances*
- *Outage in parts of the electricity system in conjunction with grid disturbances*

*The statistics do not comprise:*
- *Faults in production units*
- *Faults detected during maintenance*
- *Planned operational interruptions in parts of the electricity system*
- *Behaviour of circuit breakers and relay protection if they do not result in or extend a grid disturbance"*

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 THE FAULTS CONNECTED TO DISTURBANCES

Table 5.1 presents the number of faults and disturbances during 2011. 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 2011

| | Denmark | Finland | Iceland | Norway | Sweden |
|---|---|---|---|---|---|
| Number of faults in 2011 | 49 | 668 | 29 | 451 | 621 |
| Number of disturbances in 2011 | 48 | 613 | 24 | 382 | 621 |
| Fault/disturbance ratio in 2011 | 1.02 | 1.09 | 1.21 | 1.18 | 1.00 |
| The average fault/disturbance ratio during 2002–2011 | 1.15 | 1.07 | 1.30 | 1.27 | 1.04 |

### 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)] | 2011 | 2002–2011 (annual average) | 2011 | 2002–2011 (annual average) |
| 400 kV | Denmark | 25 | 1595 | 5 | 9.2 | 0.0 | 329.1 |
| | Finland | 55 | 4679 | 42 | 21.3 | 111.8 | 11.7 |
| | Iceland | 0 | 0 | - | - | - | - |
| | Norway | 64 | 2708 | 82 | 55.7 | 9941.0 | 1139.8 |
| | Sweden | 61 | 10959 | 127 | 125.4 | 0.0 | 1050.6 |
| 220 kV | Denmark | 2 | 105 | 0 | 0.3 | 0.0 | 0.0 |
| | Finland | 24 | 2671 | 30 | 24.2 | 0.5 | 9.0 |
| | Iceland | 32 | 852 | 10 | 13.8 | 313.2 | 436.9 |
| | Norway | 271 | 6165 | 129 | 102.4 | 182.8 | 610.7 |
| | Sweden | 92 | 4305 | 70 | 70.2 | 247.3 | 299.1 |
| 132 kV | Denmark | 237 | 4516 | 42 | 66.1 | 8.3 | 46.7 |
| | Finland | 917 | 17303 | 566 | 300.4 | 398.0 | 265.4 |
| | Iceland | 56 | 1339 | 16 | 28.0 | 327.4 | 343.1 |
| | Norway | 724 | 10677 | 234 | 183.4 | 2892.2 | 1001.8 |
| | Sweden | 728 | 15892 | 416 | 380.9 | 1235.7 | 1741.9 |

[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.



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TABLE 5.3 PERCENTAGE DIVISION OF FAULTS ACCORDING TO COMPONENT

| Fault location | Denmark | | Finland | | Iceland | | Norway | | Sweden | | Nordic | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2011 | 2002–2011 | 2011 | 2002–2011 | 2011 | 2002–2011 | 2011 | 2002–2011 | 2011 | 2002–2011 | 2011 | 2002–2011 |
| Overhead line | 67.3 | 56.2 | 74.6 | 76.0 | 3.5 | 20.2 | 52.1 | 40.8 | 73.0 | 56.7 | 58.6 | 55.4 |
| Cable | 0.0 | 3.5 | 0.3 | 0.1 | 0.3 | 0.5 | 0.2 | 0.7 | 0.8 | 0.5 | 0.4 | 0.6 |
| **Sum of line faults** | **67.3** | **59.6** | **74.9** | **76.1** | **3.8** | **20.8** | **52.3** | **41.5** | **73.8** | **57.2** | **59.0** | **56.1** |
| Power transformer | 8.2 | 4.1 | 1.6 | 1.3 | 1.7 | 2.9 | 4.7 | 2.2 | 3.4 | 5.0 | 3.0 | 3.2 |
| Instrument transformer | 2.0 | 0.9 | 1.2 | 0.6 | 0.0 | 0.0 | 1.1 | 1.6 | 1.0 | 0.9 | 1.0 | 1.0 |
| Circuit breaker | 2.0 | 6.2 | 0.6 | 1.1 | 0.6 | 4.0 | 4.0 | 3.4 | 0.8 | 3.3 | 1.4 | 2.9 |
| Disconnector | 0.0 | 1.5 | 0.1 | 0.6 | 0.0 | 0.1 | 1.8 | 1.8 | 0.0 | 0.8 | 0.4 | 1.0 |
| Surge arresters and spark gap | 0.0 | 0.5 | 0.6 | 0.3 | 0.0 | 0.3 | 1.8 | 1.2 | 0.0 | 0.2 | 0.6 | 0.5 |
| Busbar | 0.0 | 0.4 | 0.7 | 0.4 | 0.0 | 0.4 | 1.6 | 1.3 | 0.2 | 0.9 | 0.6 | 0.8 |
| Control equipment[1)] | 10.2 | 15.1 | 14.2 | 12.1 | 91.6 | 53.3 | 14.2 | 26.5 | 1.1 | 10.0 | 21.7 | 17.1 |
| Common ancillary equipment | 0.0 | 0.4 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 1.2 | 1.4 | 0.9 | 0.4 | 0.7 |
| Other substation faults | 0.0 | 2.2 | 0.6 | 1.5 | 0.3 | 5.2 | 16.9 | 8.5 | 7.2 | 7.6 | 6.0 | 6.0 |
| **Sum of substation faults** | **22.4** | **31.3** | **19.8** | **18.0** | **94.2** | **66.2** | **45.9** | **47.5** | **15.0** | **29.6** | **34.3** | **33.3** |
| Shunt capacitor | 0.0 | 0.1 | 0.4 | 0.6 | 0.0 | 1.4 | 0.2 | 1.1 | 0.0 | 0.6 | 0.2 | 0.8 |
| Series capacitor | 0.0 | 0.0 | 1.3 | 0.8 | 0.3 | 0.3 | 0.0 | 0.0 | 4.0 | 2.7 | 1.7 | 1.3 |
| Reactor | 4.1 | 2.2 | 0.1 | 0.3 | 0.0 | 0.0 | 0.0 | 0.5 | 1.4 | 1.3 | 0.6 | 0.8 |
| SVC and statcom | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 1.1 | 1.4 | 4.0 | 1.6 | 1.4 | 1.0 |
| Synchronous compensator | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 | 0.8 | 0.2 | 0.4 | 0.1 | 0.4 |
| **Sum of compensation faults** | **4.1** | **2.4** | **1.9** | **1.8** | **0.3** | **1.6** | **1.8** | **3.7** | **9.6** | **6.7** | **4.0** | **4.3** |
| System fault | 2.0 | 3.1 | 0.3 | 0.2 | 0.6 | 10.5 | 0.0 | 1.8 | 0.3 | 3.3 | 0.3 | 2.5 |
| Faults in adjoining statistical area | 4.1 | 3.6 | 3.1 | 3.9 | 1.0 | 0.4 | 0.0 | 5.3 | 1.3 | 3.2 | 1.6 | 3.8 |
| Unknown | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **Sum of other faults** | **6.1** | **6.7** | **3.4** | **4.1** | **1.6** | **11.4** | **0.0** | **7.2** | **1.6** | **6.6** | **1.9** | **6.4** |

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 2011 as well as the average values for the period 1996–2011. The tables also give the faults divided by cause during the period 1996–2011. Along with the tables, the annual division of faults during the period 2002–2011 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.

### 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 2011 and for the 16-years period 1996–2011. Figure 5.1 presents the annual line fault values per line length during the 10-year period 2002–2011.

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

| Country | Line km 2011 | Number of faults 2011 | Number of faults per 100 km 2011 | Number of faults per 100 km 1996–2011 | Faults divided by cause during the period 1996–2011 (%) Lightning | Other environmental causes | External influences | Operation and maintenance | Technical equipment | Other | Unknown | 1-phase faults | Permanent faults |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Denmark | 1228 | 3 | 0.24 | 0.32 | 21.0 | 58.1 | 8.1 | 4.8 | 4.8 | 1.6 | 1.6 | 48.4 | 4.8 |
| Finland | 4679 | 18 | 0.38 | 0.26 | 75.3 | 7.6 | 1.2 | 5.9 | 2.4 | 2.4 | 5.3 | 57.6 | 7.6 |
| Norway | 2683 | 45 | 1.68 | 1.08 | 23.8 | 68.6 | 0.2 | 0.2 | 1.9 | 2.1 | 3.1 | 68.9 | 7.8 |
| Sweden | 10951 | 52 | 0.47 | 0.36 | 51.5 | 18.2 | 2.3 | 2.9 | 2.9 | 1.1 | 21.1 | 81.4 | 7.1 |
| Nordic | 19541 | 118 | 0.60 | 0.43 | 44.0 | 35.5 | 1.7 | 2.5 | 2.6 | 1.6 | 12.0 | 72.7 | 7.3 |

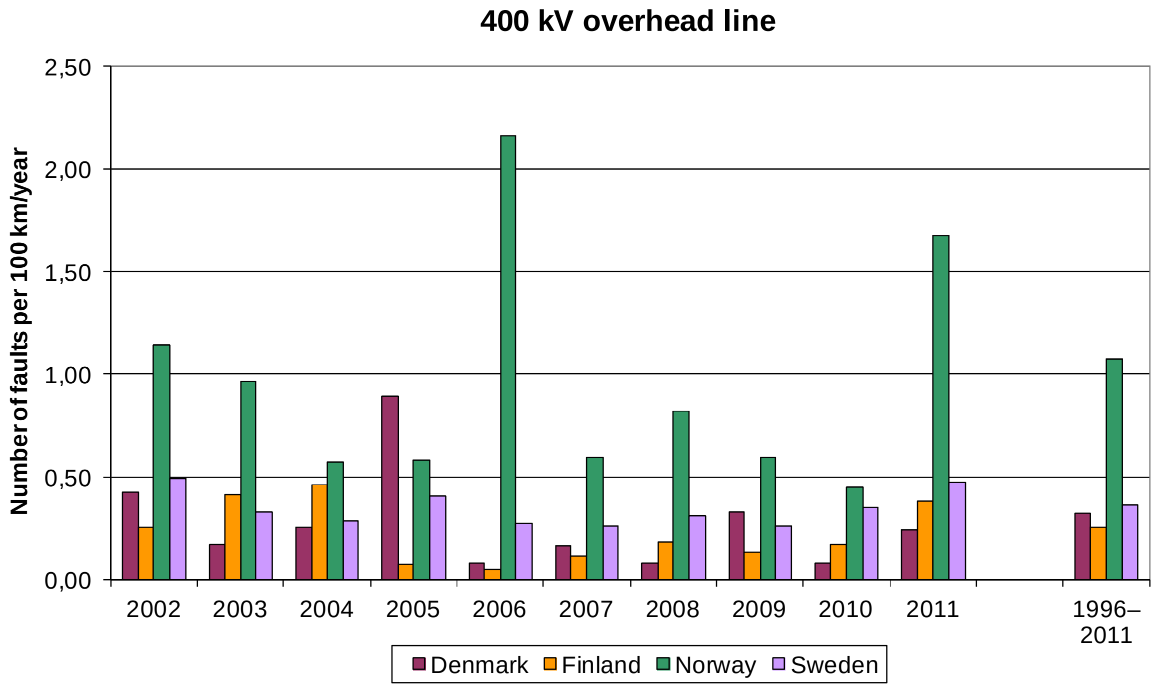


**FIGURE 5.1 ANNUAL DIVISION OF FAULTS DURING THE PERIOD 2002–2011.**

## 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 2011 and for the 16-years period 1996–2011. Figure 5.2 presents the annual line fault values per line length during the 10-year period 2002–2011.

**TABLE 5.5 DIVISION OF FAULTS ACCORDING TO CAUSE FOR 220 KV OVERHEAD LINES**

| Country | Line km 2011 | Number of faults 2011 | Number of faults per 100 km 2011 | Number of faults per 100 km 1996–2011 | Faults divided by cause during the period 1996–2011 (%) Lightning | Other environmental causes | External influences | Operation and maintenance | Technical equipment | Other | Unknown | 1-phase faults | Permanent faults |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Denmark | 105 | 0 | 0.00 | 0.48 | 50.0 | 12.5 | 25.0 | 0.0 | 0.0 | 0.0 | 12.5 | 87.5 | 0.0 |
| Finland | 2671 | 26 | 0.97 | 0.78 | 47.9 | 4.5 | 1.9 | 0.6 | 0.3 | 1.0 | 43.7 | 72.2 | 2.6 |
| Iceland | 851 | 2 | 0.24 | 0.38 | 28.6 | 54.8 | 0.0 | 0.0 | 16.7 | 0.0 | 0.0 | 50.0 | 21.4 |
| Norway | 5715 | 61 | 1.07 | 0.70 | 53.1 | 34.6 | 0.9 | 0.6 | 2.0 | 2.8 | 5.9 | 62.9 | 11.3 |
| Sweden | 4241 | 49 | 1.16 | 0.89 | 69.5 | 3.8 | 3.8 | 4.5 | 3.4 | 0.6 | 14.4 | 56.1 | 6.9 |
| Nordic | 13583 | 138 | 1.02 | 0.76 | 57.8 | 17.5 | 2.3 | 2.1 | 2.6 | 1.5 | 16.2 | 61.8 | 8.2 |

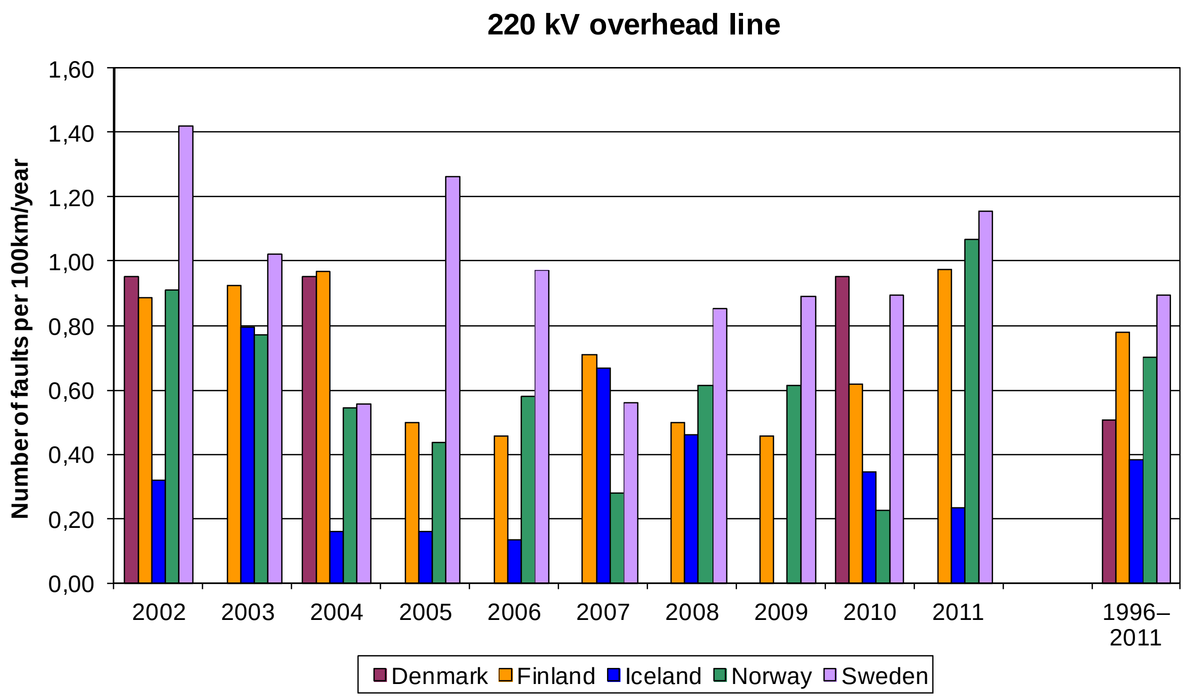


**FIGURE 5.2 ANNUAL DIVISION OF FAULTS DURING THE PERIOD 2002–2011.**

## 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 2011 and for the 16-years period 1996–2011. Figure 5.3 presents the annual line fault values per line length during the 10-year period 2002–2011.

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

| Country | Line km 2011 | Number of faults 2011 | Number of faults per 100 km | | Faults divided by cause during the period 1996–2011 (%) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2011 | 1996–2011 | Lightning | Other environmental causes | External influences | Operation and maintenance | Technical equipment | Other | Unknown | 1-phase faults | Permanent faults |
| Denmark | 3665 | 30 | 0.82 | 1.04 | 23.2 | 43.7 | 18.5 | 2.4 | 1.2 | 2.5 | 8.5 | 46.9 | 5.0 |
| Finland | 17104 | 454 | 2.65 | 2.01 | 39.6 | 11.1 | 1.6 | 1.2 | 0.4 | 0.6 | 45.5 | 78.2 | 3.0 |
| Iceland | 1231 | 9 | 0.73 | 1.25 | 2.8 | 85.4 | 3.3 | 0.8 | 7.3 | 0.0 | 0.4 | 40.7 | 11.8 |
| Norway | 10475 | 129 | 1.23 | 1.04 | 54.0 | 31.0 | 2.6 | 1.1 | 6.0 | 3.9 | 1.7 | 26.8[1] | 17.7 |
| Sweden | 15625 | 356 | 2.28 | 2.22 | 62.4 | 5.0 | 2.4 | 2.8 | 2.6 | 1.7 | 23.1 | 39.5 | 5.3 |
| Nordic | 48100 | 978 | 2.03 | 1.71 | 49.5 | 15.2 | 3.1 | 1.9 | 2.4 | 1.7 | 26.2 | 51.5 | 6.5 |

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

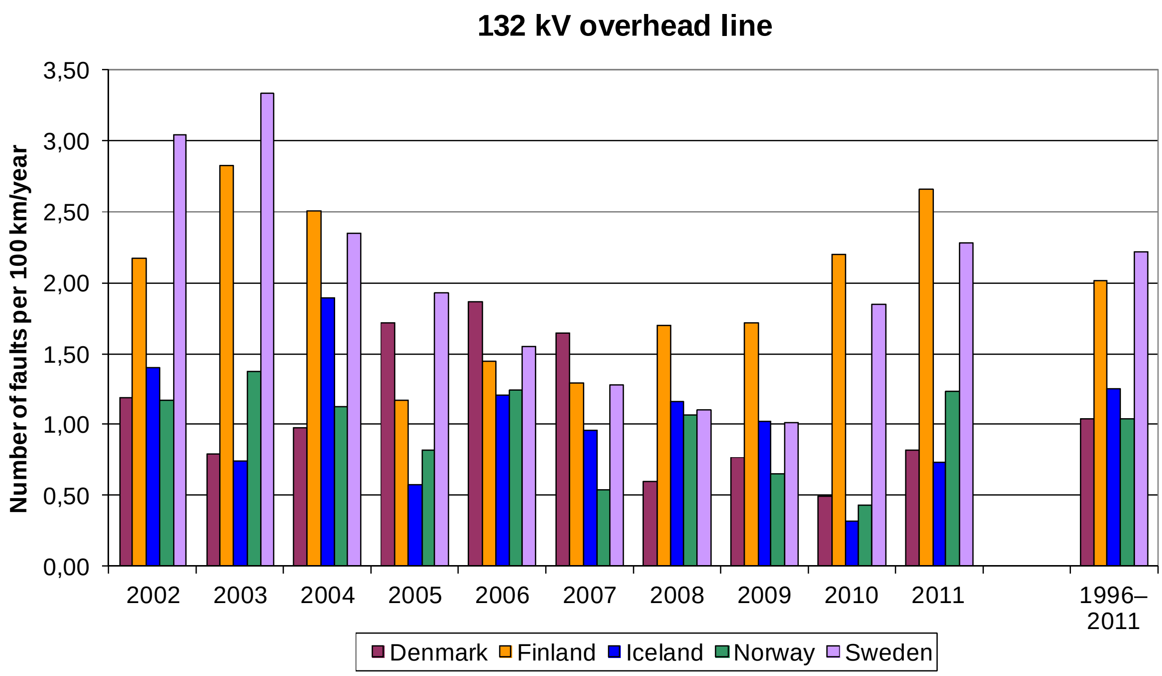


**FIGURE 5.3 ANNUAL DIVISION OF FAULTS DURING THE PERIOD 2002–2011.**

## 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.

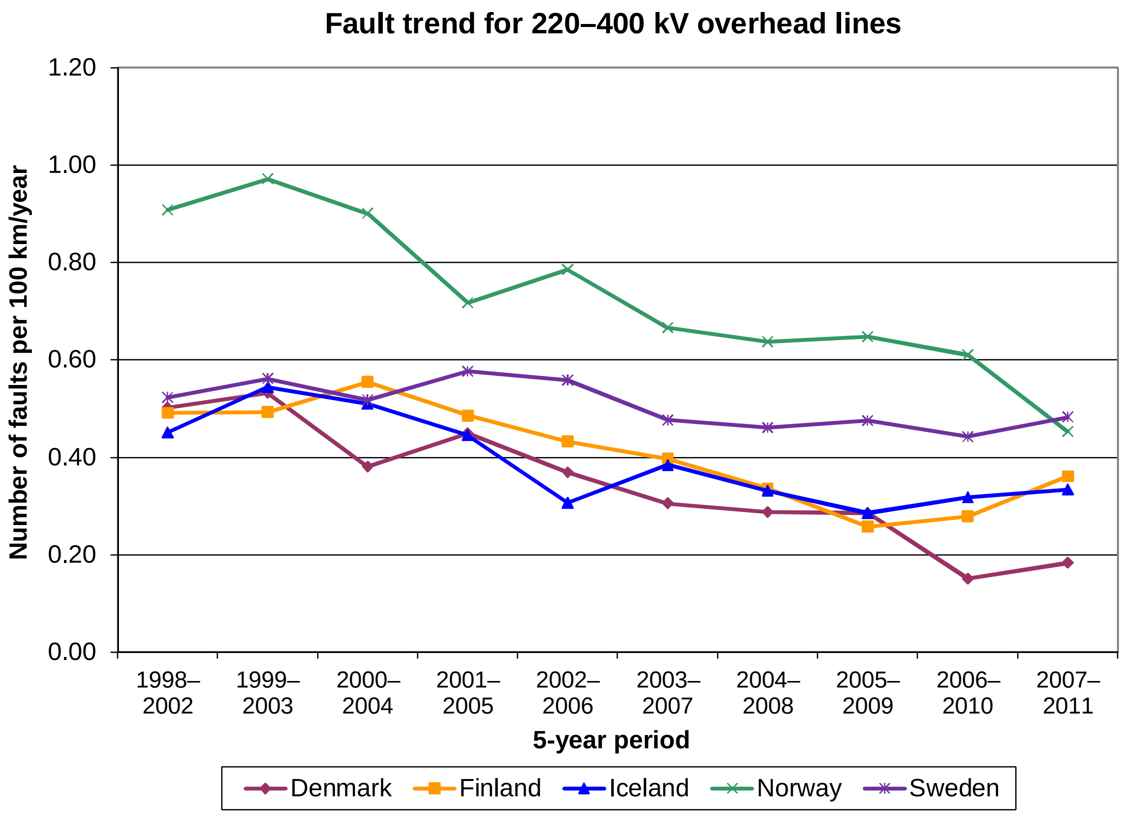


**FIGURE 5.4 FAULT TREND FOR OVERHEAD LINES AT VOLTAGE LEVEL 220–400 KV.**

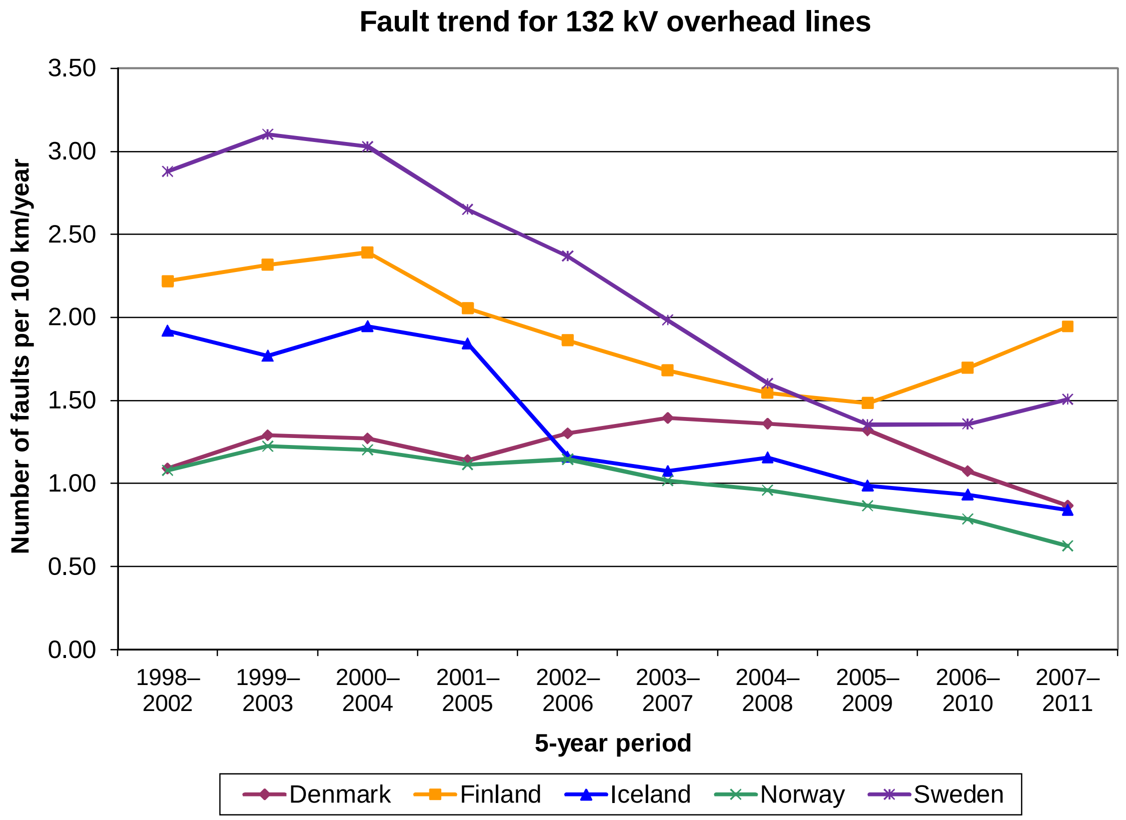


**FIGURE 5.5 FAULT TREND FOR OVERHEAD LINES AT VOLTAGE LEVEL 132 KV.**

## 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 2011 and for the period 2002–2011. 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 2002–2011 is presented graphically for 132 kV cables only. Also fault trends are presented.

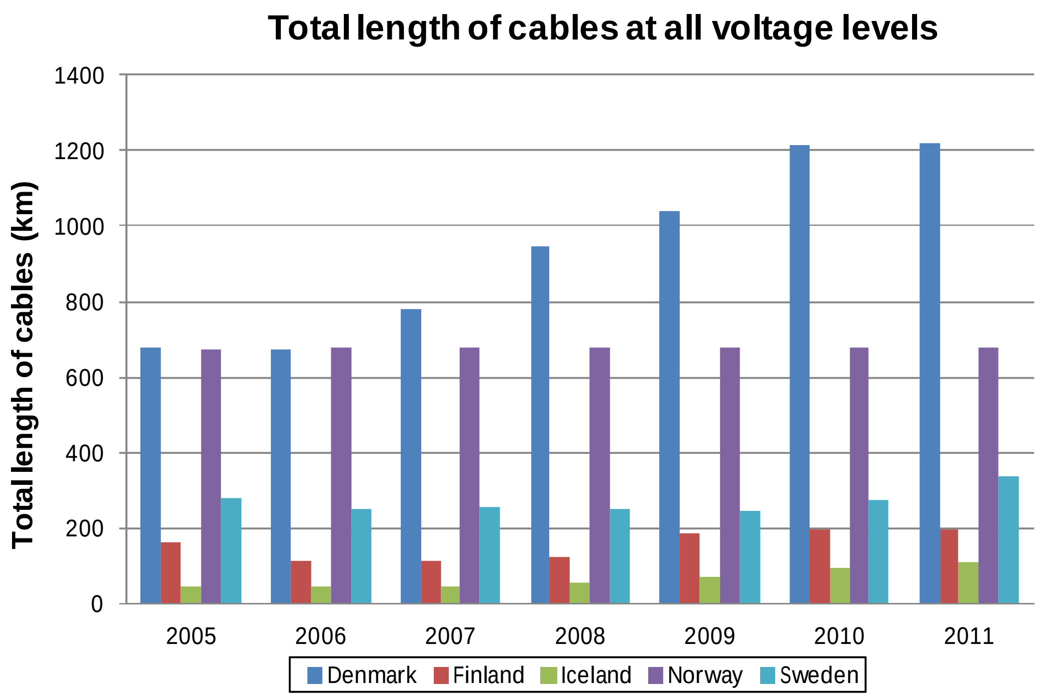


**FIGURE 5.6 TOTAL LENGTH OF CABLES AT ALL VOLTAGE LEVELS DURING THE PERIOD 2005-2011.**

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

| Country | Line km 2011 | Number of faults 2011 | Number of faults per 100 km 2011 | Number of faults per 100 km 2002–2011 | Faults divided by cause during the period 2002–2011 (%): Lightning | Other environmental cause | External influences | Operation and maintenance | Technical equipment | Other | Unknown |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Denmark | 367 | 0 | 0.00 | 0.09 | 0.0 | 0.0 | 0.0 | 50.0 | 50.0 | 0.0 | 0.0 |
| Norway | 25 | 0 | 0.00 | 1.62 | 0.0 | 0.0 | 0.0 | 0.0 | 50.0 | 25.0 | 25.0 |
| Sweden | 8 | 0 | 0.00 | 0.00 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Nordic | 400 | 0 | 0.00 | 0.23 | 0.0 | 0.0 | 0.0 | 16.7 | 50.0 | 16.7 | 16.7 |

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

| Country | Line km 2011 | Number of faults 2011 | Number of faults per 100 km 2011 | Number of faults per 100 km 2002–2011 | Faults divided by cause during the period 2002–2011 (%): Lightning | Other environmental cause | External influences | Operation and maintenance | Technical equipment | Other | Unknown |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Iceland | 1 | 0 | 0 | 0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Norway | 450 | 0 | 0.00 | 0.05 | 0.0 | 0.0 | 0.0 | 50.0 | 0.0 | 0.0 | 50.0 |
| Sweden | 64 | 1 | 1.57 | 2.82 | 0.0 | 0.0 | 0.0 | 11.1 | 77.8 | 0.0 | 11.1 |
| Nordic | 514 | 1 | 0.19 | 0.25 | 0.0 | 0.0 | 0.0 | 18.2 | 63.6 | 0.0 | 18.2 |

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

| Country | Line km 2011 | Number of faults 2011 | Number of faults per 100 km 2011 | Number of faults per 100 km 2002–2011 | Faults divided by cause during the period 2002–2011 (%) Lightning | Other environmental cause | External influences | Operation and maintenance | Technical equipment | Other | Unknown |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Denmark | 851 | 0 | 0.00 | 0.43 | 0.0 | 0.0 | 20.0 | 12.0 | 56.0 | 8.0 | 4.0 |
| Finland | 199 | 2 | 1.00 | 0.18 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | 0.0 | 0.0 |
| Iceland | 108 | 1 | 0.93 | 0.73 | 0.0 | 0.0 | 0.0 | 25.0 | 75.0 | 0.0 | 0.0 |
| Norway[1)] | 202 | 1 | 0.50 | 1.17 | 4.3 | 0.0 | 4.3 | 26.1 | 47.8 | 4.3 | 13.0 |
| Sweden | 267 | 4 | 1.50 | 0.84 | 0.0 | 0.0 | 18.2 | 9.1 | 50.0 | 0.0 | 22.7 |
| Nordic | 1627 | 8 | 0.49 | 0.63 | 1.3 | 0.0 | 13.2 | 15.8 | 53.9 | 3.9 | 11.8 |

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

Figure 5.7 presents the annual cable fault values per cable length faults during the 10-year period 2002–2011 for 132 kV cables.

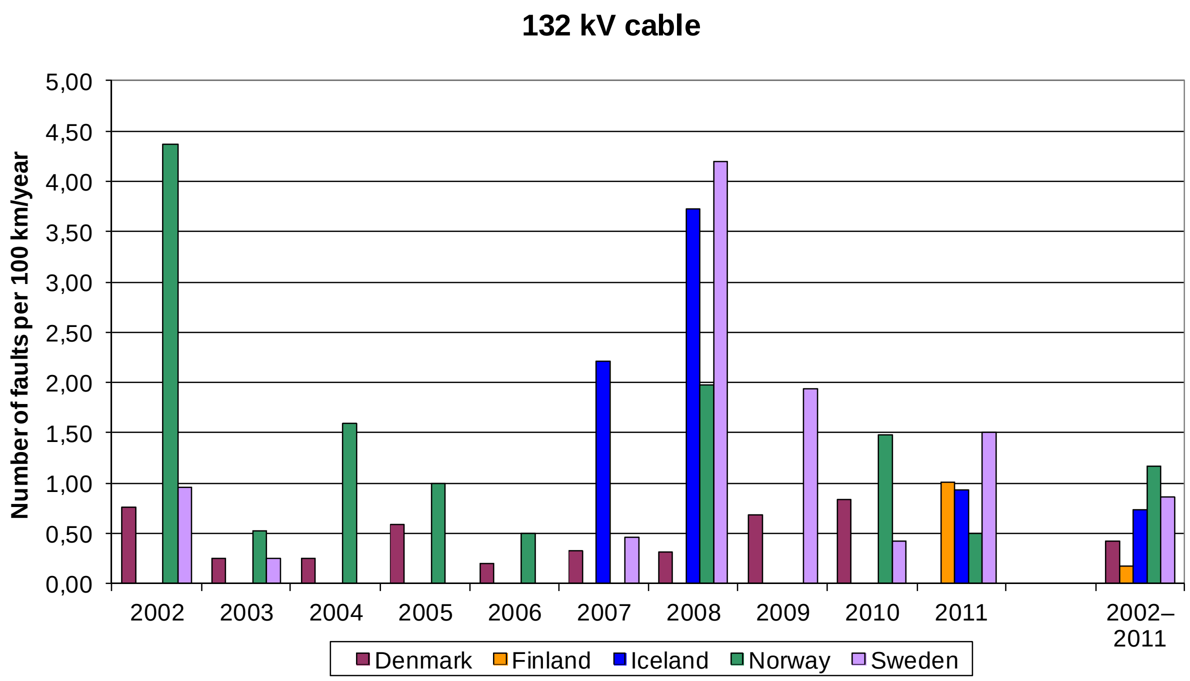


**FIGURE 5.7 ANNUAL DIVISION OF FAULTS DURING THE PERIOD 2002–2011.**

Figure 5. 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.

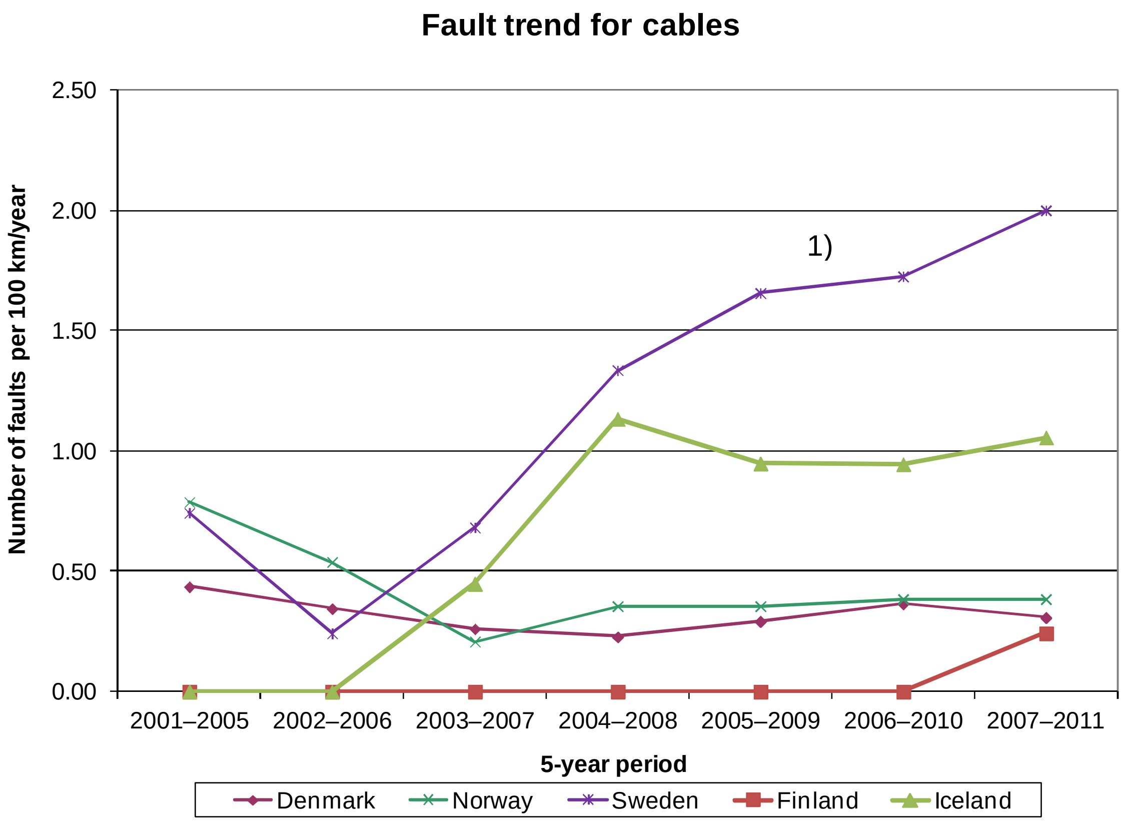


**FIGURE 5.8 FAULT TREND FOR CABLES AT ALL VOLTAGE LEVEL.**

1) The explanation for the increasing fault trend for Sweden is that there were several cable faults in 2008, as seen in Figure 5.7.

## 5.4 FAULTS IN POWER TRANSFORMERS

The tables in this section present the division of faults for the year 2011 and for the period 2002–2011 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 2002–2011. The annual division of faults during the period 2002–2011 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.



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

| Country | Number of devices 2011 | Number of faults 2011 | Number of faults per 100 devices | | Faults divided by cause during the period 2002–2011 (%) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2011 | 2002–2011 | Lightning | Other environmental cause | External influences | Operation and maintenance | Technical equipment | Other | Unknown |
| Denmark | 25 | 1 | 4.00 | 3.42[1)] | 12.5 | 12.5 | 0.0 | 12.5 | 25.0 | 0.0 | 37.5 |
| Finland | 55 | 1 | 1.82 | 2.38 | 0.0 | 27.3 | 0.0 | 18.2 | 45.5 | 0.0 | 9.1 |
| Norway | 64 | 8 | 12.50 | 2.39 | 0.0 | 0.0 | 0.0 | 20.0 | 46.7 | 20.0 | 13.3 |
| Sweden | 61 | 0 | 0.00 | 1.02 | 0.0 | 0.0 | 0.0 | 75.0 | 12.5 | 12.5 | 0.0 |
| Nordic | 205 | 10 | 4.88 | 1.99 | 2.4 | 9.5 | 0.0 | 28.6 | 35.7 | 9.5 | 14.3 |

[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.

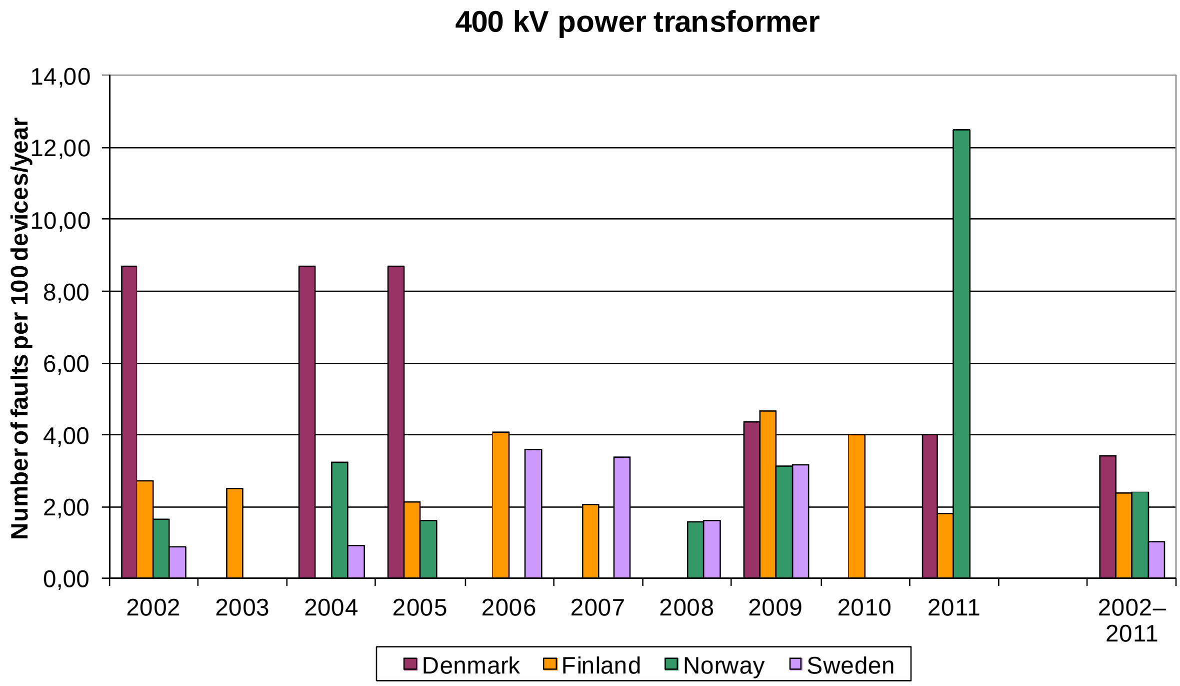


**FIGURE 5.9 ANNUAL DIVISION OF FAULTS DURING THE PERIOD 2002–2011.**

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

| Country | Number of devices 2011 | Number of faults 2011 | Number of faults per 100 devices 2011 | Number of faults per 100 devices 2002–2011 | Faults divided by cause during the period 2002–2011 (%) 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 | 2.15 | 0.0 | 0.0 | 0.0 | 20.0 | 0.0 | 0.0 | 80.0 |
| Iceland | 32 | 0 | 0.00 | 3.45 | 0.0 | 0.0 | 0.0 | 0.0 | 90.0 | 0.0 | 10.0 |
| Norway | 271 | 3 | 1.11 | 1.10 | 0.0 | 3.3 | 0.0 | 20.0 | 50.0 | 20.0 | 6.7 |
| Sweden | 92 | 4 | 4.35 | 3.39 | 35.1 | 2.7 | 8.1 | 13.5 | 21.6 | 0.0 | 18.9 |
| Nordic | 421 | 8 | 1.90 | 1.88 | 15.9 | 2.4 | 3.7 | 14.6 | 39.0 | 7.3 | 17.1 |

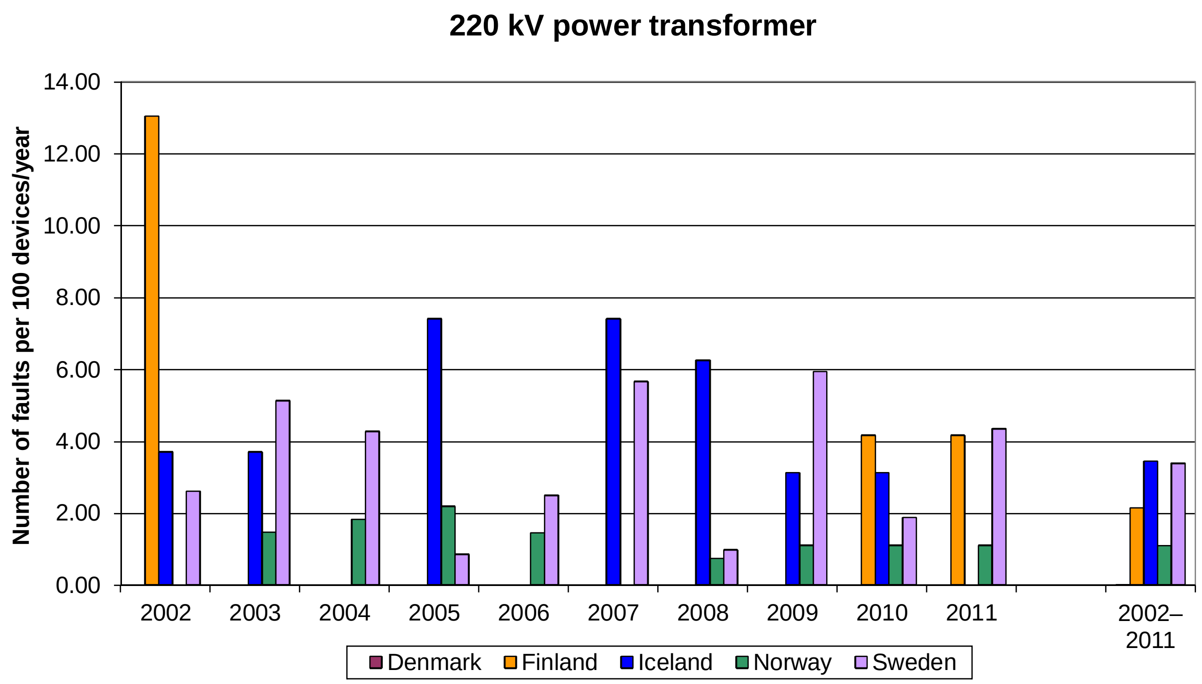


**FIGURE 5.10 ANNUAL DIVISION OF FAULTS DURING THE PERIOD 2002–2011.**



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

| Country | Number of devices 2011 | Number of faults 2011 | Number of faults per 100 devices | | Faults divided by cause during the period 2002–2011 (%) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2011 | 2002–2011 | Lightning | Other environmental cause | External influences | Operation and maintenance | Technical equipment | Other | Unknown |
| Denmark | 237 | 3 | 1.27 | 1.05 | 8.3 | 8.3 | 4.2 | 37.5 | 20.8 | 0.0 | 20.8 |
| Finland | 917 | 9 | 0.98 | 0.59 | 9.4 | 3.1 | 15.6 | 18.7 | 21.9 | 0.0 | 31.2 |
| Iceland | 56 | 1 | 1.79 | 1.05 | 0.0 | 0.0 | 0.0 | 40.0 | 40.0 | 0.0 | 20.0 |
| Norway | 724 | 10 | 1.38 | 0.54 | 0.0 | 33.3 | 5.1 | 15.4 | 20.5 | 20.5 | 5.1 |
| Sweden[1)] | 728 | 17 | 2.34 | 3.92 | 17.6 | 3.1 | 2.7 | 18.0 | 26.3 | 9.8 | 22.4 |
| Nordic | 2662 | 40 | 1.50 | 1.62 | 14.1 | 6.8 | 4.2 | 19.4 | 25.1 | 9.3 | 21.1 |

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

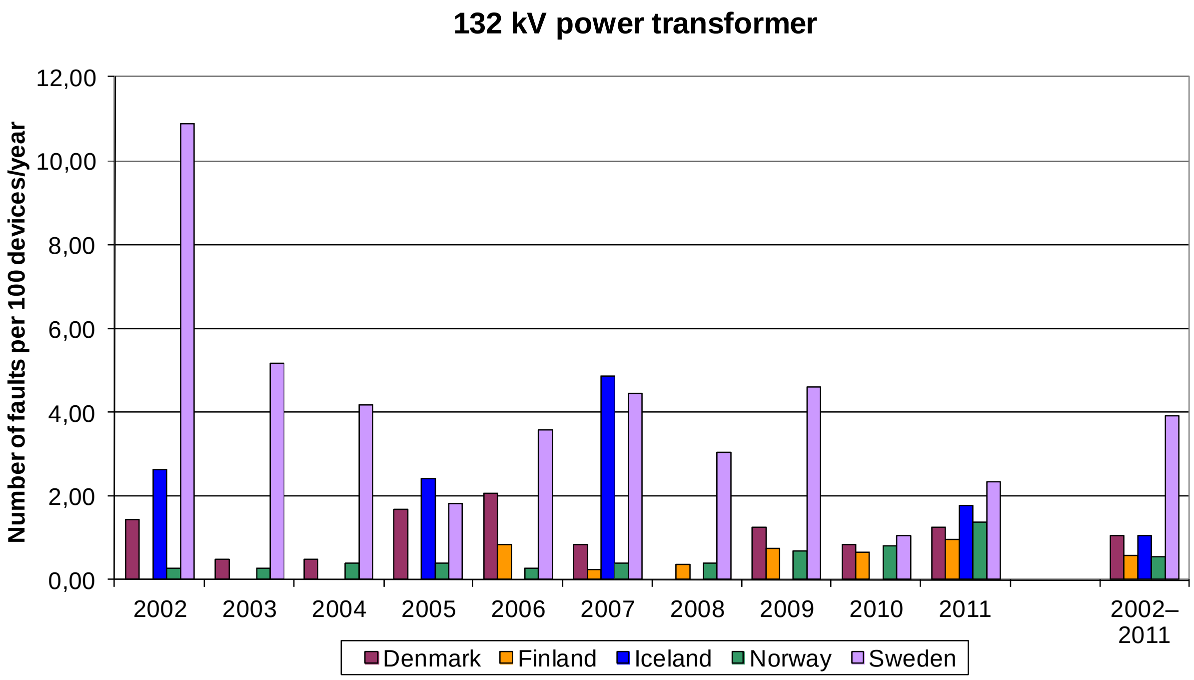


**FIGURE 5.6 ANNUAL DIVISION OF FAULTS DURING THE PERIOD 2002–2011.**

Figure 5.7 and Figure 5.8 present the trend of faults for power transformers. This allows the trend to be estimated in the future.



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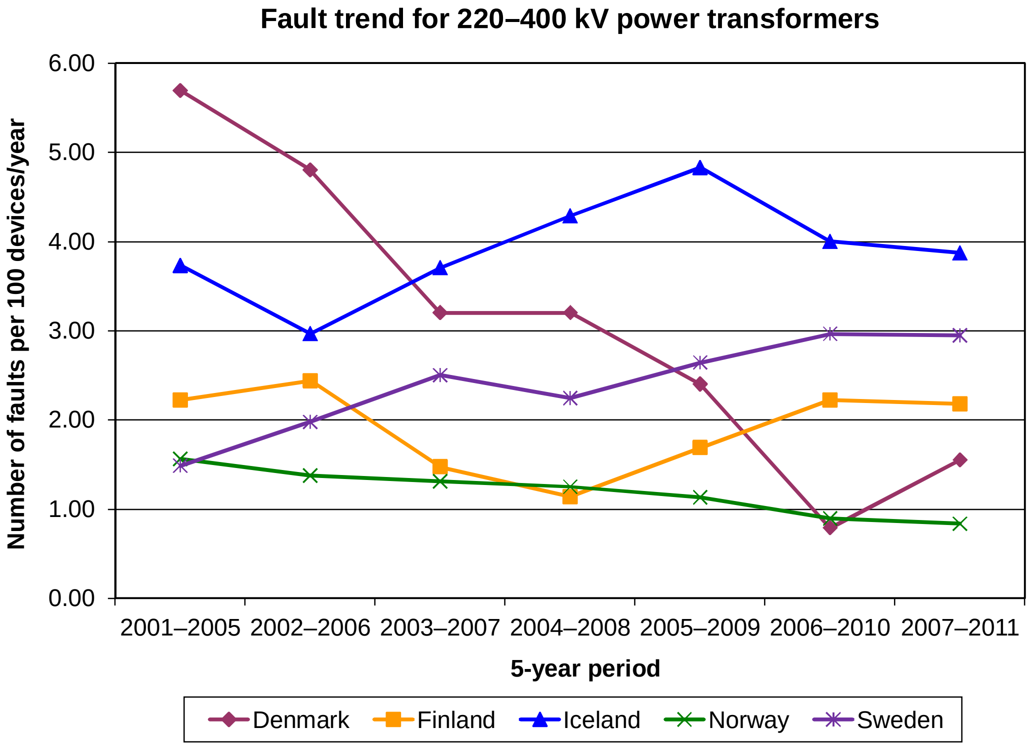


**FIGURE 5.7 FAULT TREND FOR POWER TRANSFORMERS AT VOLTAGE LEVEL 220–400 KV.**

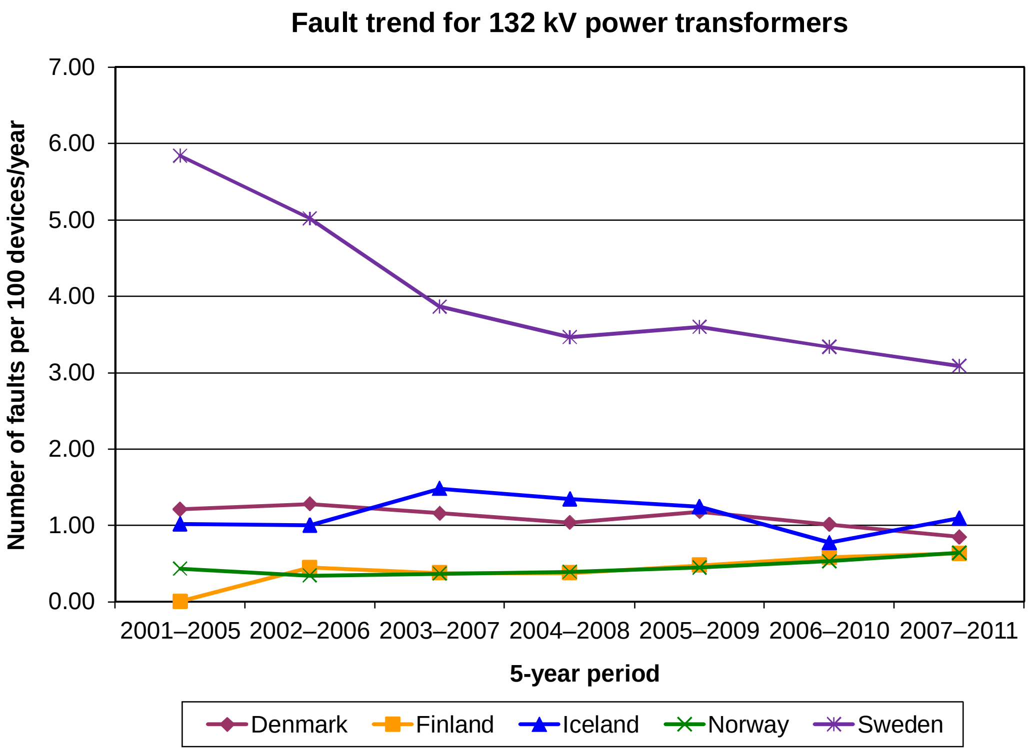


**FIGURE 5.8 FAULT TREND FOR POWER TRANSFORMERS AT VOLTAGE LEVEL 132 KV.**

## 5.5 FAULTS IN INSTRUMENT TRANSFORMERS

This section presents the faults in instrument transformers for the year 2011 and for the period 2002–2011 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 2011 | Number of faults 2011 | Number of faults per 100 devices | | Faults divided by cause during the period 2002–2011 (%) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2011 | 2002–2011 | 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 | 427 | 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 | 66.7 | 0.0 | 0.0 |
| Sweden | 1052 | 0 | 0.00 | 0.11 | 0.0 | 0.0 | 0.0 | 30.0 | 60.0 | 0.0 | 10.0 |
| Nordic | 2946 | 1 | 0.03 | 0.06 | 0.0 | 0.0 | 0.0 | 31.2 | 62.5 | 0.0 | 6.2 |

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

| Country | Number of devices 2011 | Number of faults 2011 | Number of faults per 100 devices | | Faults divided by cause during the period 2002–2011 (%) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2011 | 2002–2011 | 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 | 154 | 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 | 0.08 | 9.1 | 9.1 | 0.0 | 4.5 | 63.6 | 9.1 | 4.5 |
| Sweden | 1099 | 0 | 0.00 | 0.07 | 0.0 | 0.0 | 0.0 | 0.0 | 100.0 | 0.0 | 0.0 |
| Nordic | 4110 | 3 | 0.07 | 0.07 | 6.9 | 6.9 | 0.0 | 3.4 | 72.4 | 6.9 | 3.4 |

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

| Country | Number of devices 2011 | Number of faults 2011 | Number of faults per 100 devices 2011 | Number of faults per 100 devices 2002–2011 | Faults divided by cause during the period 2002–2011 (%) 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 | 3318 | 8[1)] | 0.24 | 0.11 | 11.1 | 0.0 | 5.6 | 0.0 | 55.6 | 5.6 | 22.2 |
| Iceland | 611 | 0 | 0.00 | 0.00 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Norway | 7768 | 1 | 0.01 | 0.04 | 14.3 | 0.0 | 0.0 | 8.6 | 57.1 | 8.6 | 11.4 |
| Sweden | 3828 | 6 | 0.16 | 0.07 | 15.0 | 0.0 | 2.5 | 12.5 | 60.0 | 2.5 | 7.5 |
| Nordic | 20078 | 16 | 0.08 | 0.05 | 13.0 | 1.0 | 2.0 | 9.0 | 57.0 | 5.0 | 13.0 |

[1)] Four successive faults on January 15th for the same device, on May 31st three successive faults for the same device and one fault on June 29th.

Figure 5.9 and Figure 5.10 present the fault trends for instrument transformers at voltage levels 220–400 kV and 132 kV, respectively.

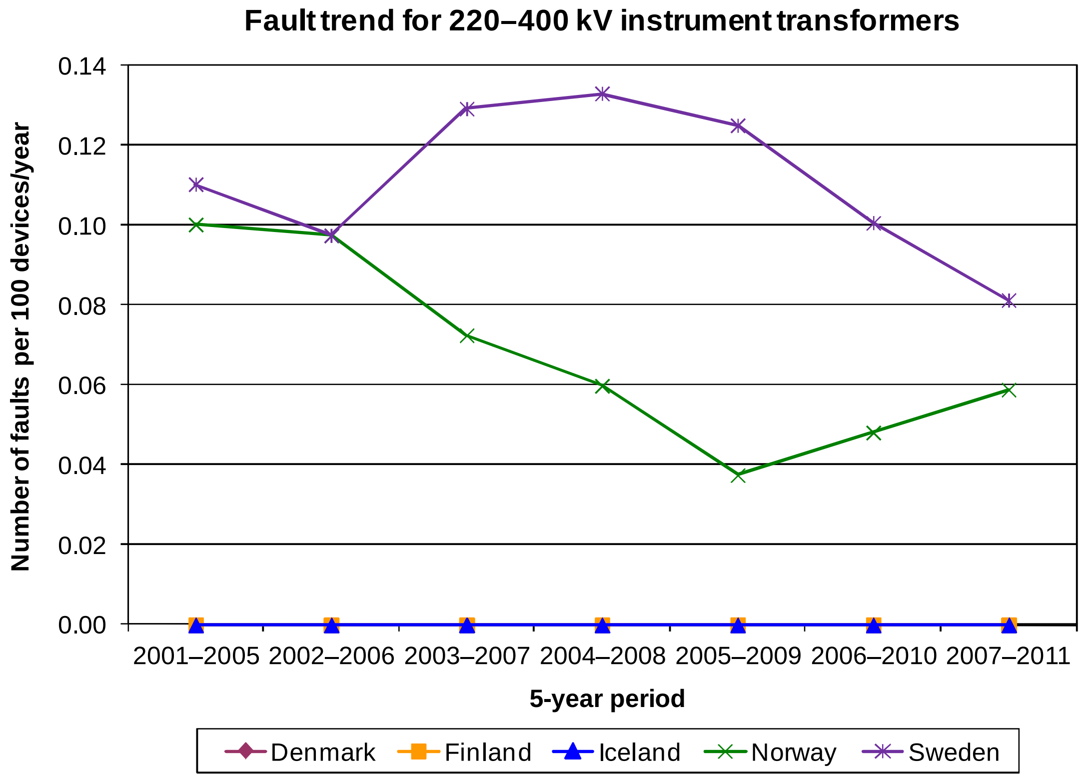


**FIGURE 5.9 FAULT TREND FOR INSTRUMENT TRANSFORMERS AT VOLTAGE LEVEL 220–400 KV.**

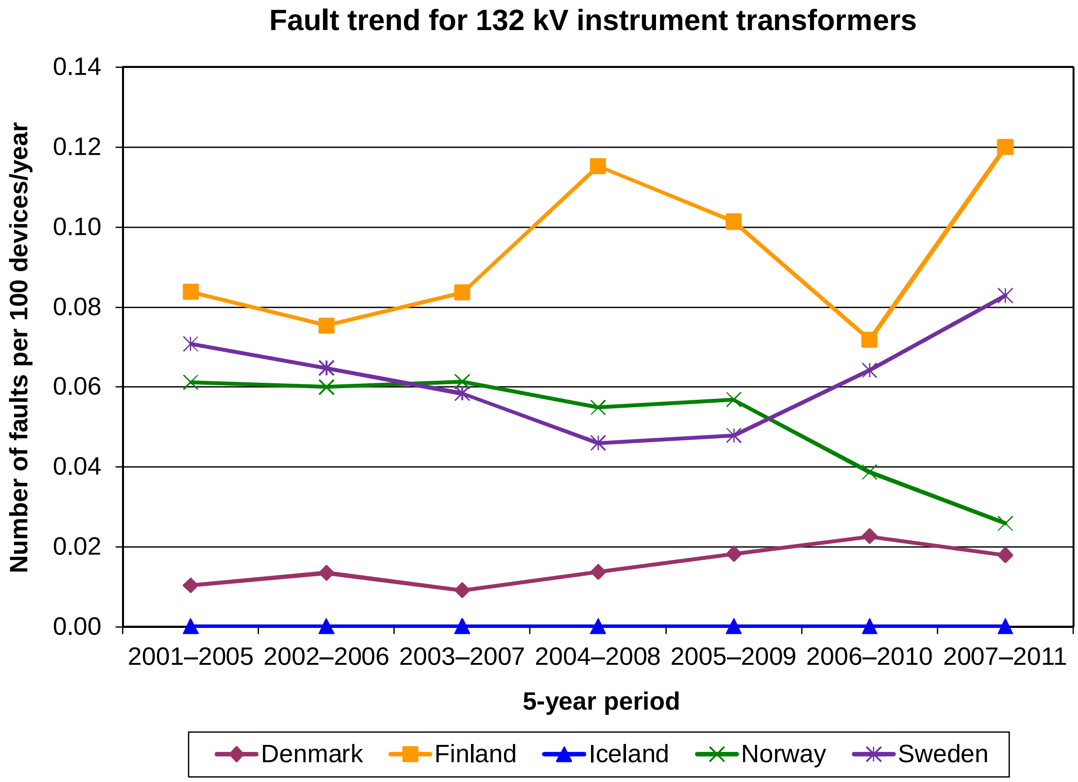


**FIGURE 5.10 FAULT TREND FOR INSTRUMENT TRANSFORMERS AT VOLTAGE LEVEL 132 KV.**

## 5.6 FAULTS IN CIRCUIT BREAKERS

The tables in this section present circuit breaker faults for the year 2011 and for the period 2002–2011 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 2011 | Number of faults 2011 | Number of faults per 100 devices | | Faults divided by cause during the period 2002–2011 (%) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2011 | 2002–2011 | Lightning | Other environmental cause | External influences | Operation and maintenance | Technical equipment | Other | Unknown |
| Denmark | 171 | 1 | 0.58 | 0.76 | 0.0 | 9.1 | 9.1 | 18.2 | 54.5 | 9.1 | 0.0 |
| Finland | 247 | 1 | 0.40 | 0.24 | 0.0 | 0.0 | 20.0 | 0.0 | 80.0 | 0.0 | 0.0 |
| Norway | 262 | 1 | 0.38 | 0.71 | 0.0 | 0.0 | 0.0 | 33.3 | 55.6 | 5.6 | 5.6 |
| Sweden[1)] | 505 | 4 | 0.79 | 1.60 | 0.0 | 2.9 | 0.0 | 5.7 | 82.9 | 1.4 | 7.1 |
| Nordic | 1185 | 7 | 0.59 | 1.00 | 0.0 | 2.9 | 1.9 | 11.5 | 75.0 | 2.9 | 5.8 |

[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 2011 | Number of faults 2011 | Number of faults per 100 devices | | Faults divided by cause during the period 2002–2011 (%) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2011 | 2002–2011 | 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 | 2.98 | 0.0 | 4.8 | 0.0 | 9.5 | 71.4 | 0.0 | 14.3 |
| Norway | 724 | 7 | 0.97 | 0.67 | 0.0 | 0.0 | 0.0 | 31.2 | 60.4 | 0.0 | 8.3 |
| Sweden | 328 | 0 | 0.00 | 0.43 | 5.9 | 0.0 | 0.0 | 17.6 | 64.7 | 0.0 | 11.8 |
| Nordic | 1229 | 7 | 0.57 | 0.72 | 1.1 | 1.1 | 0.0 | 21.7 | 65.2 | 1.1 | 9.8 |

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

| Country | Number of devices 2011 | Number of faults 2011 | Number of faults per 100 devices | | Faults divided by cause during the period 2002–2011 (%) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2011 | 2002–2011 | Lightning | Other environmental cause | External influences | Operation and maintenance | Technical equipment | Other | Unknown |
| Denmark | 820 | 0 | 0.00 | 0.50 | 0.0 | 2.5 | 0.0 | 32.5 | 57.5 | 7.5 | 0.0 |
| Finland | 2200 | 3 | 0.14 | 0.17 | 21.4 | 7.1 | 0.0 | 28.6 | 35.7 | 3.6 | 3.6 |
| Iceland | 146 | 3 | 2.05[1)] | 0.71 | 0.0 | 0.0 | 0.0 | 22.2 | 66.7 | 0.0 | 11.1 |
| Norway | 2119 | 10 | 0.47 | 0.31 | 4.6 | 0.0 | 0.0 | 56.9 | 33.8 | 1.5 | 3.1 |
| Sweden | 2099 | 1 | 0.05 | 0.65 | 27.9 | 3.6 | 2.7 | 18.9 | 34.2 | 2.7 | 9.9 |
| Nordic | 7384 | 17 | 0.23 | 0.40 | 15.8 | 2.8 | 1.2 | 32.0 | 39.1 | 3.2 | 5.9 |

1) In Iceland, a very few incidents will cause a large increase in these numbers due to few devices in their system.

Figure 5.11 and Figure 5.12 present the fault trends for circuit breakers at voltage levels 220–400 kV and 132 kV, respectively.

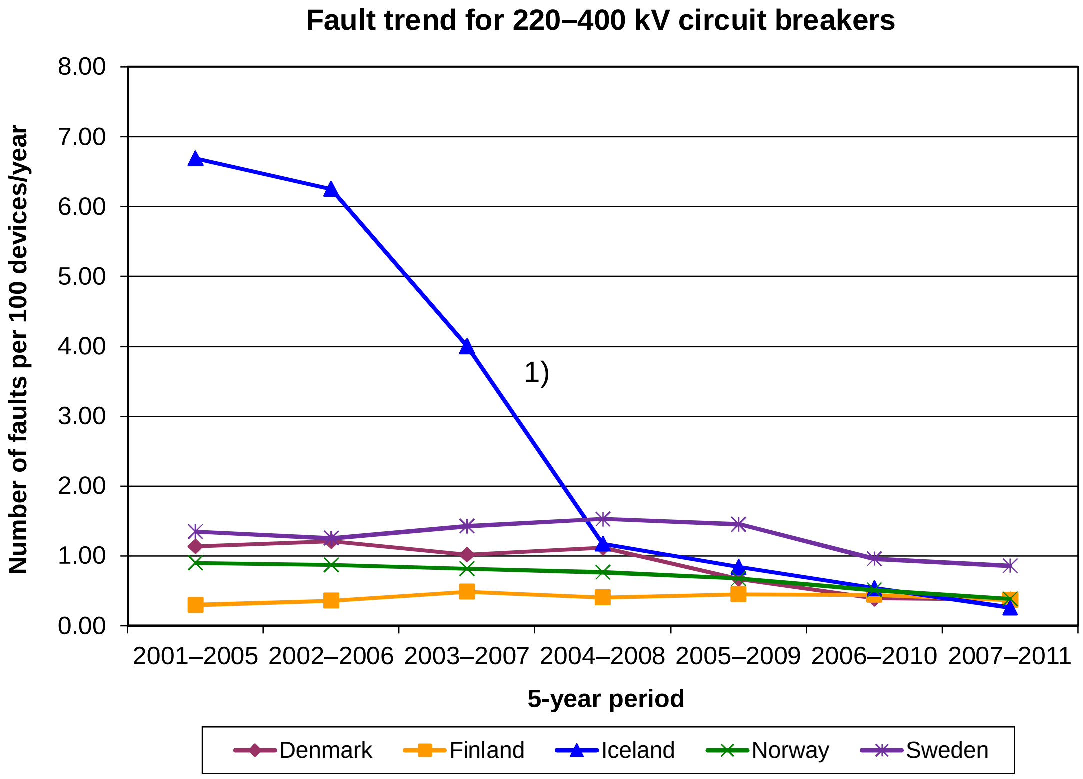


**FIGURE 5.11 FAULT TREND FOR CIRCUIT BREAKERS AT VOLTAGE LEVEL 220–400 KV.**

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).

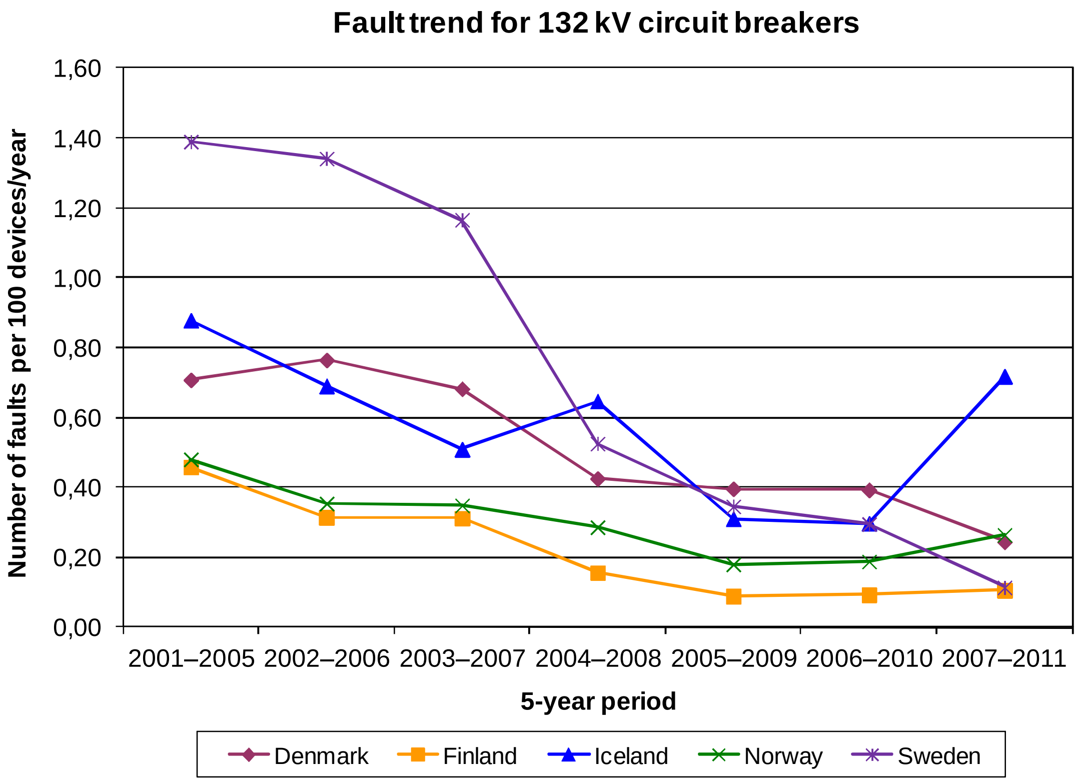


**FIGURE 5.12 FAULT TREND FOR CIRCUIT BREAKERS AT VOLTAGE LEVEL 132 KV.**

## 5.7 FAULTS IN CONTROL EQUIPMENT

The tables in this section present faults in control equipment at each respective voltage level for the year 2011 and for the period 2002–2011. 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 [1] give more detailed definitions.

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

| Country | Number of devices 2011 | Number of faults 2011 | Number of faults per 100 devices | | Faults divided by cause during the period 2002–2011 (%) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2011 | 2002–2011 | Lightning | Other environmental cause | External influences | Operation and maintenance | Technical equipment | Other | Unknown |
| Denmark | 131 | 0 | 0.00 | 1.33 | 0.0 | 0.0 | 0.0 | 23.5 | 47.1 | 5.9 | 23.5 |
| Finland | 247 | 13 | 5.26 | 4.17 | 0.0 | 0.0 | 0.0 | 55.2 | 11.5 | 14.9 | 18.4 |
| Norway | 261 | 10 | 3.83 | 6.82 | 0.0 | 1.2 | 0.0 | 32.4 | 49.7 | 2.9 | 13.9 |
| Sweden | 506 | 0 | 0.00 | 7.87 | 0.3 | 0.9 | 0.0 | 10.1 | 84.5 | 3.0 | 1.2 |
| Nordic | 1145 | 23 | 2.01 | 6.03 | 0.2 | 0.8 | 0.0 | 23.2 | 63.2 | 4.7 | 7.8 |

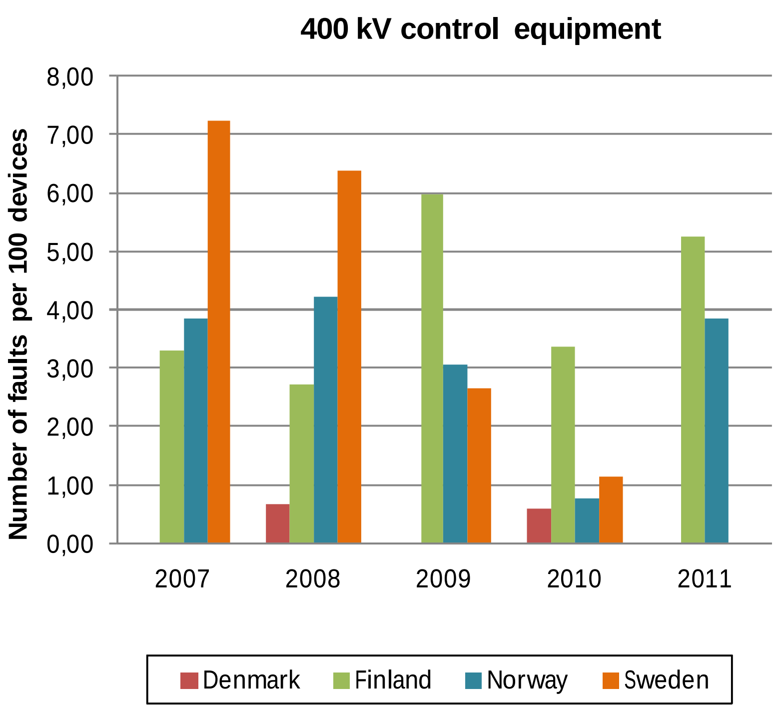


**FIGURE 5.18 ANNUAL DIVISION OF FAULTS DURING THE PERIOD 2007-2011.**

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

| Country | Number of devices 2011 | Number of faults 2011 | Number of faults per 100 devices | | Faults divided by cause during the period 2002–2011 (%) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2011 | 2002–2011 | 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 | 2 | 2.08 | 5.39 | 0.0 | 0.0 | 0.0 | 43.1 | 41.2 | 7.8 | 7.8 |
| Iceland | 79 | 3 | 3.80 | 7.67 | 5.6 | 1.9 | 0.0 | 25.9 | 59.3 | 7.4 | 0.0 |
| Norway | 721 | 24 | 3.33 | 5.63 | 0.7 | 0.7 | 0.2 | 33.7 | 43.2 | 4.5 | 16.7 |
| Sweden | 323 | 0 | 0.00 | 3.05 | 0.0 | 0.0 | 3.4 | 31.1 | 52.1 | 10.9 | 2.5 |
| Nordic | 1221 | 29 | 2.38 | 4.92 | 1.0 | 0.6 | 0.8 | 33.3 | 46.2 | 6.2 | 11.9 |

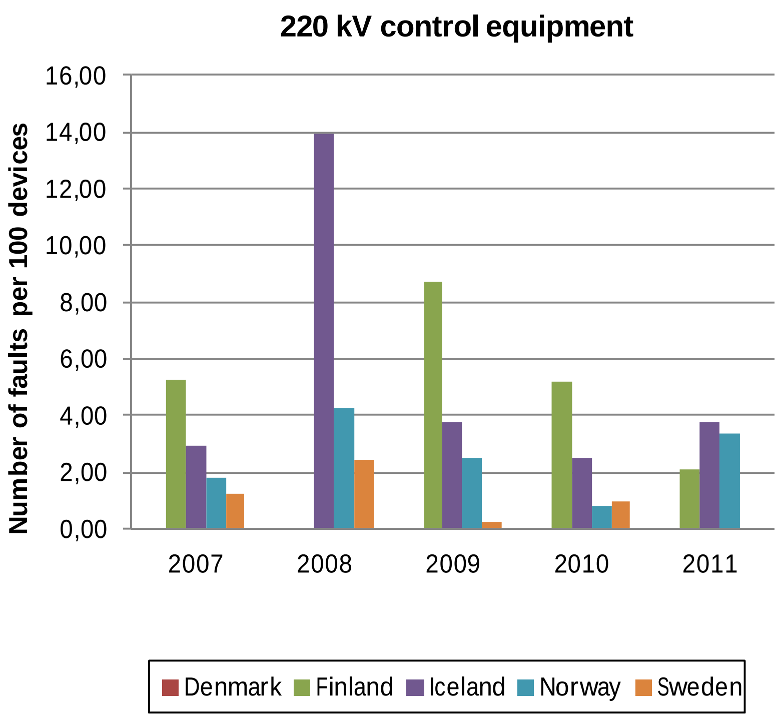


**FIGURE 5.19 ANNUAL DIVISION OF FAULTS DURING THE PERIOD 2007-2011.**

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

| Country | Number of devices 2011 | Number of faults 2011 | Number of faults per 100 devices 2011 | Number of faults per 100 devices 2002–2011 | Faults divided by cause during the period 2002–2011 (%) Lightning | Other environmental cause | External influences | Operation and maintenance | Technical equipment | Other | Unknown |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Denmark | 814 | 5 | 0.61 | 1.10 | 4.9 | 7.3 | 2.4 | 42.7 | 26.8 | 7.3 | 8.5 |
| Finland | 2200 | 80 | 3.64 | 1.92 | 2.5 | 0.0 | 1.6 | 41.1 | 26.4 | 8.3 | 20.1 |
| Iceland | 144 | 3 | 2.08 | 4.19 | 0.0 | 0.0 | 1.9 | 18.9 | 75.5 | 1.9 | 1.9 |
| Norway | 2064 | 30 | 1.45 | 2.24 | 1.1 | 2.2 | 0.2 | 29.9 | 33.2 | 6.6 | 26.9 |
| Sweden | 2029 | 7 | 0.34 | 0.76 | 7.9 | 0.0 | 0.0 | 49.2 | 20.6 | 7.1 | 15.1 |
| Nordic | 7251 | 125 | 1.72 | 1.66 | 2.6 | 1.5 | 0.9 | 36.1 | 31.3 | 7.0 | 20.6 |

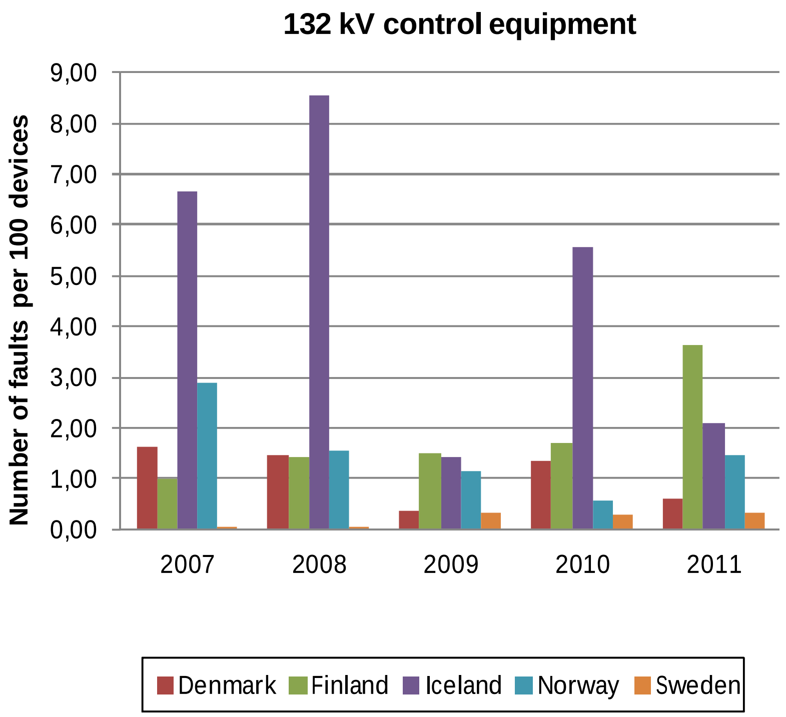


**FIGURE 5.20 ANNUAL DIVISION OF FAULTS DURING THE PERIOD 2007-2011.**

## 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 2011 and for the period 2002–2011. In addition, the tables present the division of faults according to cause during the ten-year period 2002–2011.

**TABLE 5.22 DIVISION OF FAULTS ACCORDING TO CAUSE FOR REACTORS**

| Country | Number of devices 2011 | Number of faults 2011 | Number of faults per 100 devices | | Faults divided by cause during the period 2002–2011 (%) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2011 | 2002–2011 | Lightning | Other environmental cause | External influences | Operation and maintenance | Technical equipment | Other | Unknown |
| Denmark | 18 | 2 | 11.11 | 6.30 | 0.0 | 0.0 | 0.0 | 23.5 | 58.8 | 0.0 | 17.6 |
| Finland[1)] | 70 | 1 | 1.43 | 1.84 | 0.0 | 0.0 | 0.0 | 0.0 | 72.7 | 18.2 | 9.1 |
| Norway | 36 | 0 | 0.00 | 5.47 | 0.0 | 5.6 | 0.0 | 27.8 | 55.6 | 5.6 | 5.6 |
| Sweden | 74 | 9 | 12.16 | 13.84 | 0.0 | 32.9 | 3.8 | 8.9 | 39.2 | 8.9 | 6.3 |
| Nordic | 198 | 12 | 6.06 | 7.07 | 0.0 | 21.6 | 2.4 | 12.8 | 47.2 | 8.0 | 8.0 |

[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 2011 | Number of faults 2011 | Number of faults per 100 devices | | Faults divided by cause during the period 2002–2011 (%) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2011 | 2002–2011 | Lightning | Other environmental cause | External influences | Operation and maintenance | Technical equipment | Other | Unknown |
| Finland | 9 | 9 | 100.00 | 38.16 | 0.0 | 0.0 | 6.9 | 6.9 | 51.7 | 0.0 | 34.5 |
| Iceland | 1 | 1 | 100.00 | 20.00 | 0.0 | 50.0 | 0.0 | 0.0 | 50.0 | 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 | 25 | 208.33 | 135.83 | 0.6 | 0.6 | 0.0 | 1.2 | 12.3 | 77.9 | 7.4 |
| Nordic | 25 | 35 | 140.00 | 82.20 | 0.5 | 1.0 | 1.0 | 2.1 | 18.6 | 65.5 | 11.3 |

**TABLE 5.24 DIVISION OF FAULTS ACCORDING TO CAUSE FOR SHUNT CAPACITORS**

| Country | Number of devices 2011 | Number of faults 2011 | Number of faults per 100 devices | | Faults divided by cause during the period 2002–2011 (%) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2011 | 2002–2011 | Lightning | Other environmental cause | External influences | Operation and maintenance | Technical equipment | Other | Unknown |
| Denmark | 15 | 0 | 0.00 | 1.32 | 0.0 | 0.0 | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Finland | 68 | 3 | 4.41 | 5.88 | 0.0 | 17.4 | 56.5 | 0.0 | 0.0 | 13.0 | 13.0 |
| Iceland | 10 | 0 | 0.00 | 10.64 | 0.0 | 20.0 | 0.0 | 0.0 | 80.0 | 0.0 | 0.0 |
| Norway | 194 | 1 | 0.52 | 2.19 | 2.4 | 0.0 | 2.4 | 14.6 | 47.6 | 31.0 | 2.4 |
| Sweden | 171 | 0 | 0.00 | 2.98 | 5.3 | 7.9 | 10.5 | 2.6 | 39.5 | 0.0 | 34.2 |
| Nordic | 458 | 4 | 0.87 | 3.00 | 2.6 | 7.8 | 17.4 | 6.1 | 37.4 | 13.9 | 14.8 |

**TABLE 5.25 DIVISION OF FAULTS ACCORDING TO CAUSE FOR SVC DEVICES**

| Country | Number of devices 2011 | Number of faults 2011 | Number of faults per 100 devices | | Faults divided by cause during the period 2002–2011 (%) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2011 | 2002–2011 | Lightning | Other environmental cause | External influences | Operation and maintenance | Technical equipment | Other | Unknown |
| Denmark | 1 | 0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Finland | 1 | 0 | 0.0 | 33.33 | 0.0 | 0.0 | 0.0 | 0.0 | 100 | 0.0 | 0.0 |
| Norway | 15 | 5 | 33.33 | 38.19 | 0.0 | 1.8 | 0.0 | 5.5 | 50.9 | 29.1 | 12.7 |
| Sweden | 3 | 25 | 833.33 | 162.30 | 0.0 | 6.1 | 3.0 | 14.1 | 71.7 | 1.0 | 4.0 |
| Nordic | 20 | 30 | 150.00 | 73.11 | 0.0 | 4.5 | 1.9 | 11.0 | 64.5 | 11.0 | 7.1 |

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's 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 2011. 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 system unit is

"*a group of components which are delimited by one or more circuit breakers"* [1 page 8].

Definition of an outage state is

*"the component or unit is not in the in-service state; that is, it is partially or fully isolated from the system"* [1 page 8, 5].

## 6.1 COVERAGE OF THE OUTAGE STATISTICS

The Swedish outage data for 2011 includes approximately 48% 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 2011

| 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 | 320 | 293 | 22 | 3 | 2 | 0 | 0 | 0 |
| Finland | 315 | 99 | 109 | 43 | 27 | 14 | 9 | 14 |
| Iceland | 58 | 43 | 10 | 2 | 0 | 1 | 2 | 0 |
| Norway | 1233 | 1160 | 45 | 5 | 5 | 6 | 4 | 8 |
| Sweden | 614 | 393 | 141 | 49 | 20 | 4 | 0 | 7 |

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

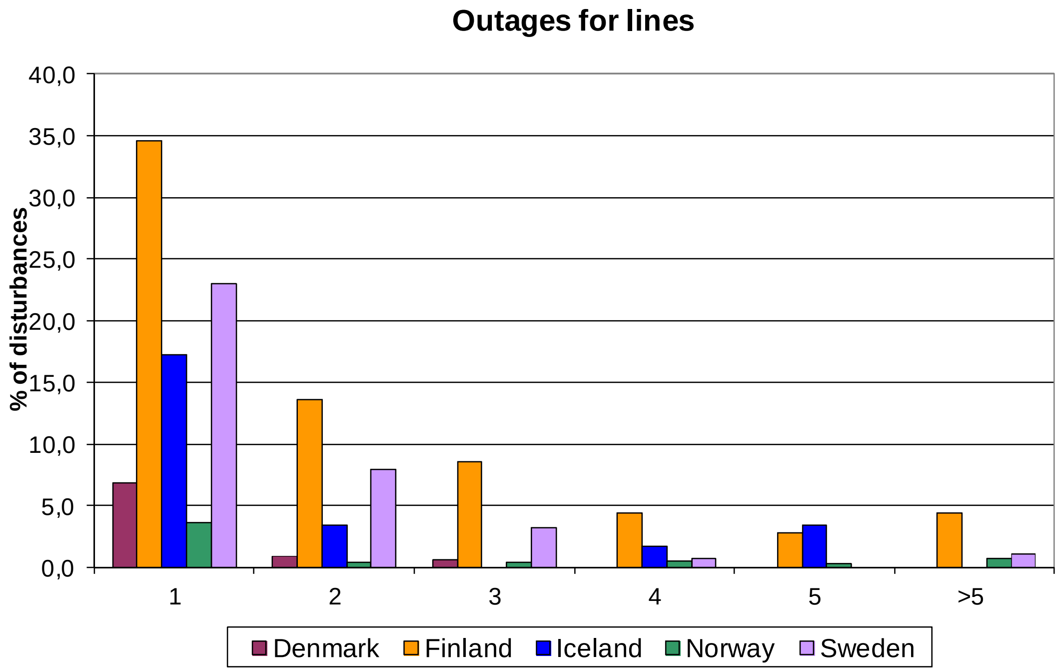


FIGURE 6.1 GROUPING OF LINES ACCORDING TO NUMBER OF OUTAGES IN 2011.

**TABLE 6.2 GROUPING OF TRANSFORMERS ACCORDING TO THE NUMBER OF OUTAGES IN 2011**

| 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 | 260 | 251 | 9 | 0 | 0 | 0 | 0 | 0 |
| Finland | 996 | 985 | 10 | 1 | 0 | 0 | 0 | 0 |
| Iceland | 88 | 83 | 5 | 0 | 0 | 0 | 0 | 0 |
| Norway | 1059 | 1045 | 8 | 5 | 1 | 0 | 0 | 0 |
| Sweden | 492 | 463 | 26 | 2 | 0 | 0 | 1 | 0 |

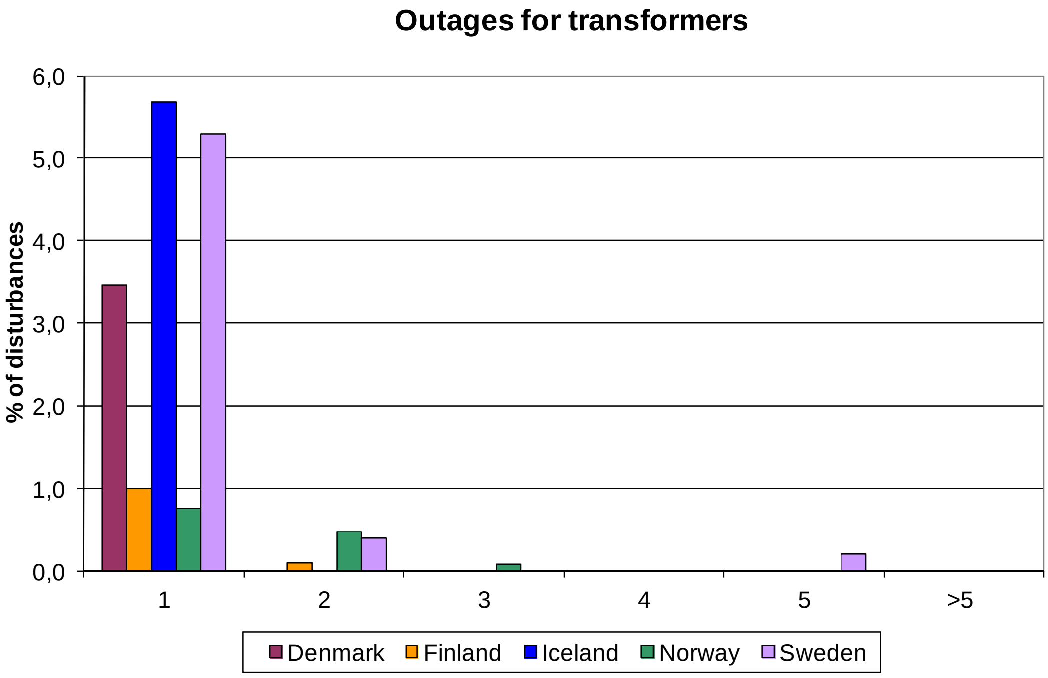


**FIGURE 6.2 GROUPING OF TRANSFORMERS ACCORDING TO NUMBER OF OUTAGES IN 2011.**

**TABLE 6.3 GROUPING OF BUSBARS ACCORDING TO THE NUMBER OF OUTAGES IN 2011**

| 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 | 146 | 146 | 0 | 0 | 0 | 0 | 0 | 0 |
| Finland | 937 | 935 | 0 | 1 | 1 | 0 | 0 | 0 |
| Iceland | 52 | 50 | 2 | 0 | 0 | 0 | 0 | 0 |
| Norway | 435 | 430 | 5 | 0 | 0 | 0 | 0 | 0 |
| Sweden | 417 | 414 | 3 | 0 | 0 | 0 | 0 | 0 |

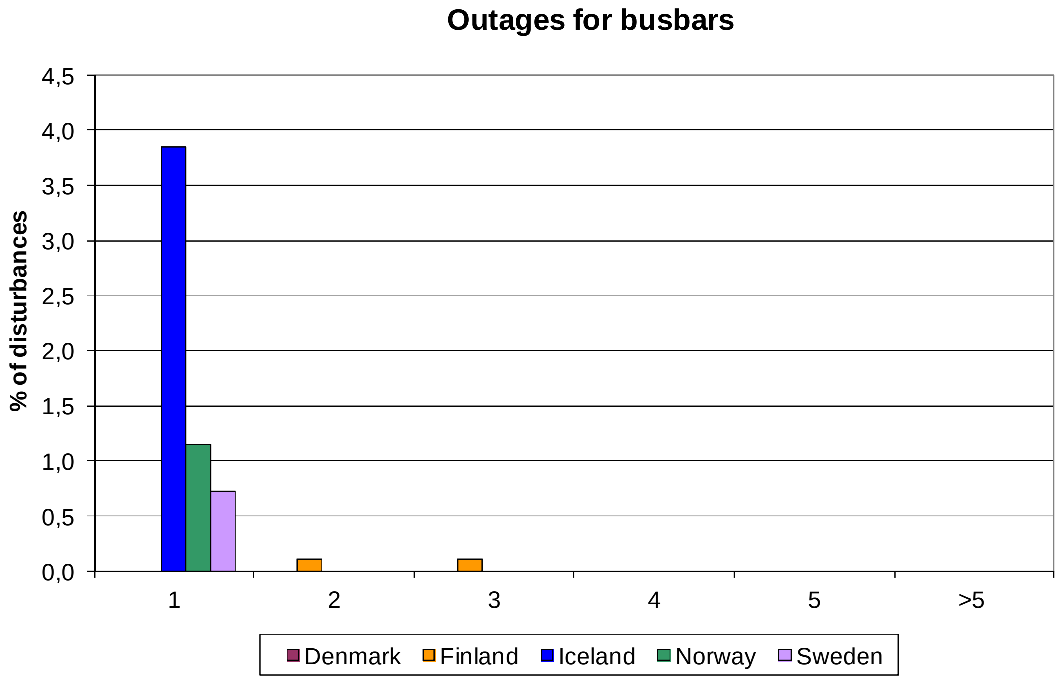


**FIGURE 6.3 GROUPING OF BUSBARS ACCORDING TO NUMBER OF OUTAGES IN 2011.**

**TABLE 6.4 GROUPING OF REACTORS ACCORDING TO THE NUMBER OF OUTAGES IN 2011**

| 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 | 16 | 2 | 0 | 0 | 0 | 0 | 0 |
| Finland | 70 | 69 | 1 | 0 | 0 | 0 | 0 | 0 |
| Norway | 36 | 36 | 0 | 0 | 0 | 0 | 0 | 0 |
| Sweden | 41 | 35 | 4 | 2 | 0 | 0 | 0 | 0 |

**TABLE 6.5 GROUPING OF SHUNT CAPACITORS ACCORDING TO THE NUMBER OF OUTAGES IN 2011**

| 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 | 68 | 65 | 3 | 0 | 0 | 0 | 0 | 0 |
| Iceland | 10 | 8 | 2 | 0 | 0 | 0 | 0 | 0 |
| Norway | 194 | 193 | 1 | 0 | 0 | 0 | 0 | 0 |
| Sweden | 28 | 27 | 0 | 1 | 0 | 0 | 0 | 0 |

## 6.3 DURATION OF OUTAGES IN DIFFERENT POWER SYSTEM UNITS

Outage duration is registered from the start of the outage to the time when the system is ready to be taken into operation. If the connection is 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 2011**

| 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 | 320 | 293 | 22 | 2 | 2 | 0 | 0 | 0 | 0 | 1 |
| Finland | 315 | 99 | 162 | 15 | 8 | 9 | 2 | 3 | 5 | 12 |
| Iceland | 58 | 43 | 0 | 4 | 2 | 0 | 2 | 1 | 1 | 5 |
| Norway | 1233 | 1160 | 41 | 7 | 7 | 4 | 2 | 1 | 1 | 10 |
| Sweden | 614 | 393 | 139 | 31 | 17 | 12 | 3 | 7 | 5 | 7 |

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

**TABLE 6.7 NUMBER OF TRANSFORMERS WITH DIFFERENT OUTAGE DURATIONS IN 2011**

| 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 | 260 | 251 | 6 | 0 | 1 | 1 | 1 | 0 | 0 | 0 |
| Finland | 996 | 985 | 1 | 0 | 0 | 2 | 4 | 1 | 0 | 3 |
| Iceland | 88 | 83 | 0 | 1 | 1 | 0 | 1 | 2 | 0 | 0 |
| Norway | 1059 | 1045 | 1 | 3 | 2 | 0 | 0 | 3 | 2 | 3 |
| Sweden | 492 | 463 | 9 | 14 | 2 | 1 | 1 | 2 | 0 | 0 |

**TABLE 6.8 NUMBER OF BUSBARS WITH DIFFERENT OUTAGE DURATIONS IN 2011**

| 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 | 146 | 146 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Finland | 937 | 935 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Iceland | 52 | 50 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| Norway | 435 | 430 | 2 | 0 | 1 | 1 | 1 | 0 | 0 | 0 |
| Sweden | 417 | 414 | 1 | 0 | 2 | 0 | 0 | 0 | 0 | 0 |

**TABLE 6.9 NUMBER OF REACTORS WITH DIFFERENT OUTAGE DURATIONS IN 2011**

| 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 | 16 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| Finland | 70 | 69 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Norway | 36 | 36 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Sweden | 41 | 35 | 0 | 0 | 1 | 1 | 2 | 1 | 1 | 0 |

**TABLE 6.10 NUMBER OF SHUNT CAPACITORS WITH DIFFERENT OUTAGE DURATIONS IN 2011**

| 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 | 68 | 65 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 2 |
| Iceland | 10 | 8 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 |
| Norway | 194 | 193 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Sweden | 28 | 27 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |



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## 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.

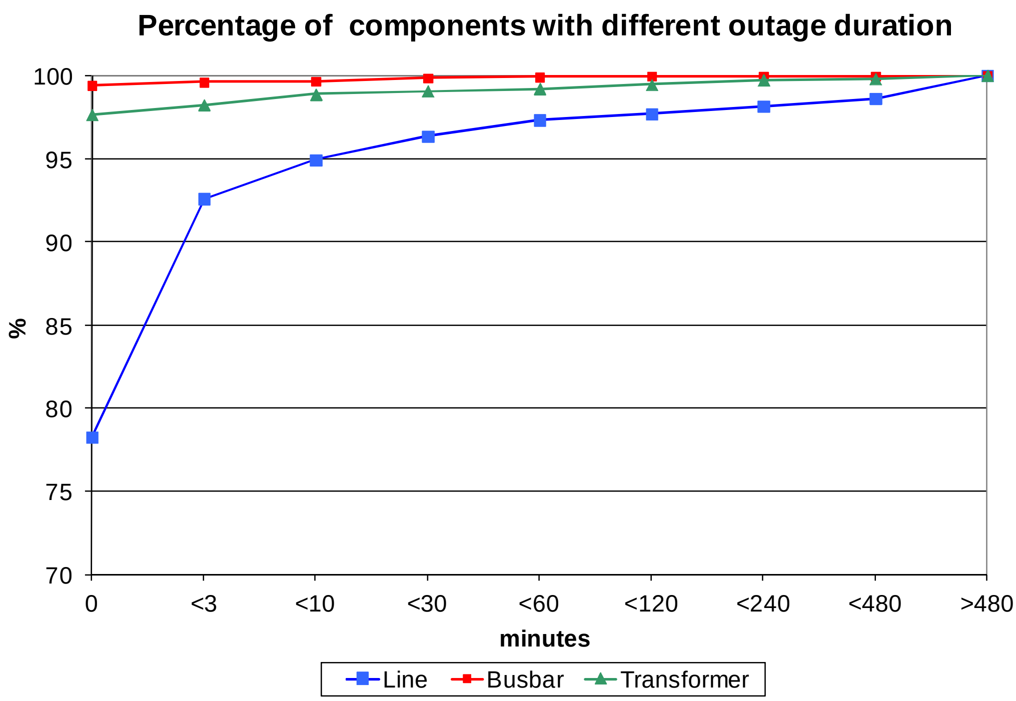


**FIGURE 6.4 PERCENTAGE OF COMPONENTS WITH DIFFERENT OUTAGE DURATION IN 2011 .**

Figure 6.4 shows that approximately 78% of lines, 97% of transformers and 99% of busbars had no outages in 2011.

## 6.5 RELIABILITY TRENDS FOR SOME POWER SYSTEM UNITS

Figure 6.5 presents a reliability trend for lines, busbars and transformers during the period 2002–2011. All five countries are included in the data of Figure 6.5.

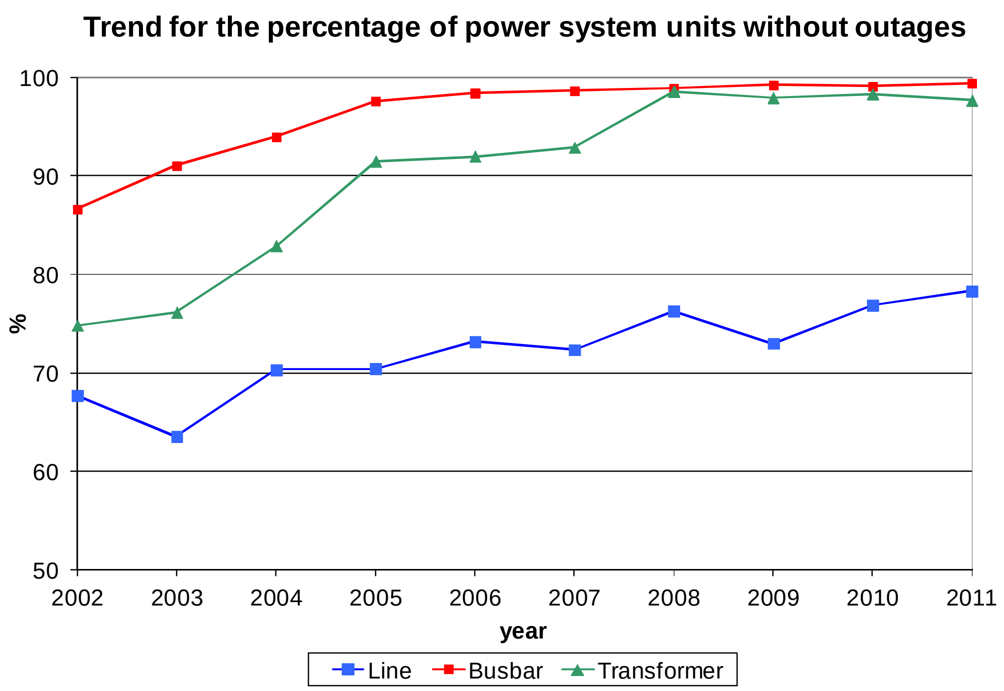


**FIGURE 6.5 THE YEARLY PERCENTAGE OF THE POWER SYSTEM UNITS THAT HAD NO OUTAGES DURING THE PERIOD 2002–2011.**

# 7 HVDC STATISTICS

## 7.1 THE CONTENTS OF HVDC STATISTICS – METHODS AND DEFINITIONS

This section presents a summary of HVDC disturbances and maintenances for the year 2011. During the following years, the aim is to have a more detailed statistics on the availability of the HVDC links as described in this section. For 2011, however, we do not have the data for such a detailed reporting.

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. The way the used and not used capacity of HVDC links is calculated here, is described in this section. The annual or monthly maximum technical capacity of the link is the maximum energy that can be transmitted to the cable on the exporting side (including losses) if there are no outages or limitations:

$$E_{\mathrm{max}} = P_{\mathrm{R}} \times 24 \times d \;, \qquad (7.1)$$

where $P_{\mathrm{R}}$ is the rated capacity and $d$ is the number of days in a month. Figure 7.1 describes how this capacity is used and not used.

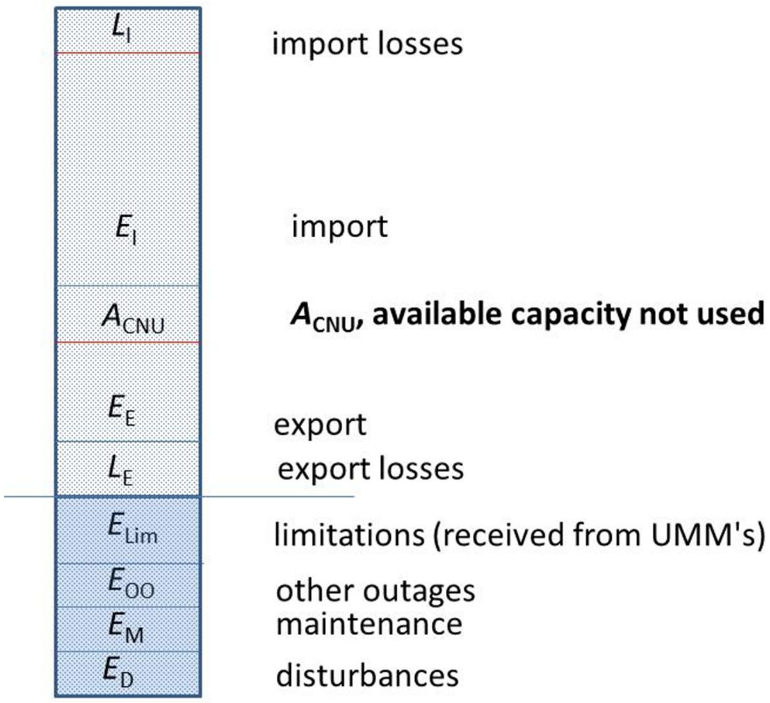


FIGURE 7.1 THE THEORETICAL VALUE FOR THE MAXIMUM TRANSMITTED ENERGY VIA THE LINK DIVIDED INTO USED CAPACITY (EXPORT AND IMPORT), LOSSES, AND TO THE CAPACITY NOT USED DUE TO OUTAGES AND LIMITATIONS. THE REMAINING VALUE IS TECHNICAL CAPACITY NOT USED.

The lower part of the column presented in Figure 7.1 is calculated in such a way that the rated power multiplied with the duration of the outages due to disturbances and maintenance or possible other outages is summed. Limitations are also summed here. Every value is an energy value and represents the capacity of the link not used. The upper part of the column is estimated by adding the export and import losses together with the exported and imported energy values to a sum for transmission. The remaining capacity value is the technical capacity not used, which is explained below.

The usage of capacities of HVDC links can be calculated by using the data received from SCADA, grid operation, market department and Urgent Market Messages. This chapter describes how the data is defined and used in calculations in this report.

An outage is a state when a component is disconnected from the system, and the transfer capacity is reduced to zero. There are different types of outages, two of which are emphasized in this chapter:

- **Maintenance outages $E_M$** are outages due to all technical and corresponding administrative actions, including supervising actions, intended to retain an entity in, or restore it to, a state in which it can perform its required function.
- **Disturbance outages $E_D$** are outages due to a disturbance on the link, related stations or in the nearby AC grid causing a total outage of the link.

A **limitation $E_{Lim}$** is a condition when a HVDC link`s technical transmitting capacity is limited, i.e. the technical power transmission of the link is less than the rated power. This limitation should not be confused with market related limitations of capacity (see next section). The causes of limitations can be e.g. faults in the link components and the faults, congestions or outages in the near AC grid causing a limitation in the transmitting capacity of the link.

**Unavailable technical capacity $E_1$**, is the sum of capacity that is not available due to outages (disturbance, maintenance, other) and limitations:

$$E_1 = E_{\mathrm{D}} + E_{\mathrm{M}} + E_{\mathrm{OO}} + E_{\mathrm{Lim}} = P_{\mathrm{R}} \times (h_{\mathrm{D}} + h_{\mathrm{M}} + h_{\mathrm{OO}}) + P_{\mathrm{Lim}} h_{\mathrm{Lim}} \quad (7.2)$$

where $h_D$ is the duration (in hours) of the outages caused by the disturbances, $h_M$ is (in hours) of the maintenance, $h_{OO}$ is the duration (in hours) of **other outages $E_{OO}$**, and $P_{lim}$ is the maximal power transmitted during a limitation.

The counterpart to $E_1$ is the **available technical capacity $E_{AV}$**, which consists of the remaining of the maximum technical capacity; that is the capacity used for transmission and a remaining category; technical capacity not used $A_{TCNU}$ (explained below):

$$E_{AV} = E_{\mathrm{MAX}} - E_1 = E_2 + A_{\mathrm{TCNU}}$$

**Exported $E_E$** energy is the transmitted energy exported from the reporting side of the cable, arrived and measured on the remote side. It does not include **export losses $L_E$**, which is the difference of energy leaving the exporting side and energy arriving at the importing side of the cable. The opposite line of reasoning would explain **import $E_I$** and **import losses $L_I$**.

Used capacity; exported and imported energy including losses are summed and denoted **transmission $E_2$**:

$$E_2 = L_E + L_I + E_E + E_I \tag{7.3}$$

**Technical capacity not used $A_{TCNU}$** can now be calculated:

$$\begin{aligned} &A_{TCNU} = E_{MAX} - E_1 - E_2 = \\ &E_{MAX} - (P_R \times (h_D + h_M + h_{OO}) + P_{Lim} h) - (L_E + L_I + E_E + E_I) \end{aligned} \tag{7.4}$$

The ‘technical capacity not used’ category is what remains when all other categories are mapped and calculated. The contents of this category is complex and consisting of both technical and market related details. The most important of these are:

- Ramping. When the power flow is changed, the capacity is fully released to the market, but the nominal voltage and hence the full transmission capacity is not immediately obtained, merely after a ramping time. Cables with relatively rapid changes of transmission direction will therefore lose more capacity to this category.
- The price differences between the markets on each side of the cable are too small to promote transmission, in spite of technical availability. Often, electric energy is transmitted in spite of equal (or even negative) prices, since the trading is settled in advance. This will, however, be less common as the market coupling mechanisms will become better informed and more immediate. This will also lead to temporary transmission limitations to promote price differences and hence avoid unnecessary losses.
- Cable capacity can be bought as power reserves, to secure system stability. In case of such; the cable will be technically available, but restricted by the market in case of outages in the AC grid.



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## 7.2 TECHNICAL DETAILS OF THE HVDC LINKS

Tables 7.1 and 7.2 present 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) |
|---|---|---|---|---|---|---|---|
| Baltic Cable | 1994 | Y | LCC | 600/600 | | | N–S |
| Estlink | 2006 | Y | VSC | 350 | | | N–S |
| Fenno-Skan 1 | 1989 | Y | LCC | 550 / 500 | 1350/1350 | 1350/1350 | E–W |
| Fenno-Skan 2 | 2011 | Y | LCC | 800/800 | | | E–W |
| Kontek | 1986 | Y | LCC | 600/600 | | | N–S |
| Konti-Skan 1 | 2008 | Y | LCC | 370 / 340 | 740/680 | | E–W |
| Konti-Skan 2 | 1988 | Y | LCC | 370 / 340 | 740/680 | | 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 |
| Store Baelt | 2010 | Y | LCC | 600/600 | | | E–W |
| SwePol | 2000 | Y | LCC | 600/600 | | | N–S |
| Valhal | 2009 | N | VSC | 78/78 | | | E–W |
| Vyborg link | 1981, 1982, 1984, 2000 | | | 1400 | | | E–W |

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) |
|---|---|---|---|---|---|---|---|
| Baltic Cable | 250 | | 250 | | | | |
| Estlink | 105 | | | 105 | | | |
| Fenno-Skan 1 | 233 | 200 | | | 33 | | |
| Fenno-Skan 2 | 299 | 196 | | | 103 | | |
| Kontek | | | | | | | |
| Konti-Skan 1 | 150 | | | | | | |
| Konti-Skan 2 | 150 | | | | | | |
| NorNed | 580 | | | | | | |
| Skagerak 1 | 240 | | | | 113 | | |
| Skagerak 2 | 240 | | | | 113 | | |
| Skagerak 3 | 240 | | | | 113 | | |
| Store Baelt | | | | | | | |
| SwePol | 254 | | 254 | | | | |
| Valhal | 292 | | | | | | |
| Vyborg link | < 1 | - | - | - | - | < 1 | |

Overview of the HVDC statistics

For an overview of all HVDC data; the statistics are presented in Figure 7.2 on an aggregated level. This makes a comparison between the cables possible. It should be kept in mind that the usages of the cables show big variations, from the most market dependent cables, to cables mostly used in one direction and cables used for technical reasons; to control power flow for system stability and according to set agreements.

The categories used for the overview presentation are presented in chapter 7.1:

- Unavailable technical capacity
- Transmission
- Technical capacity not used

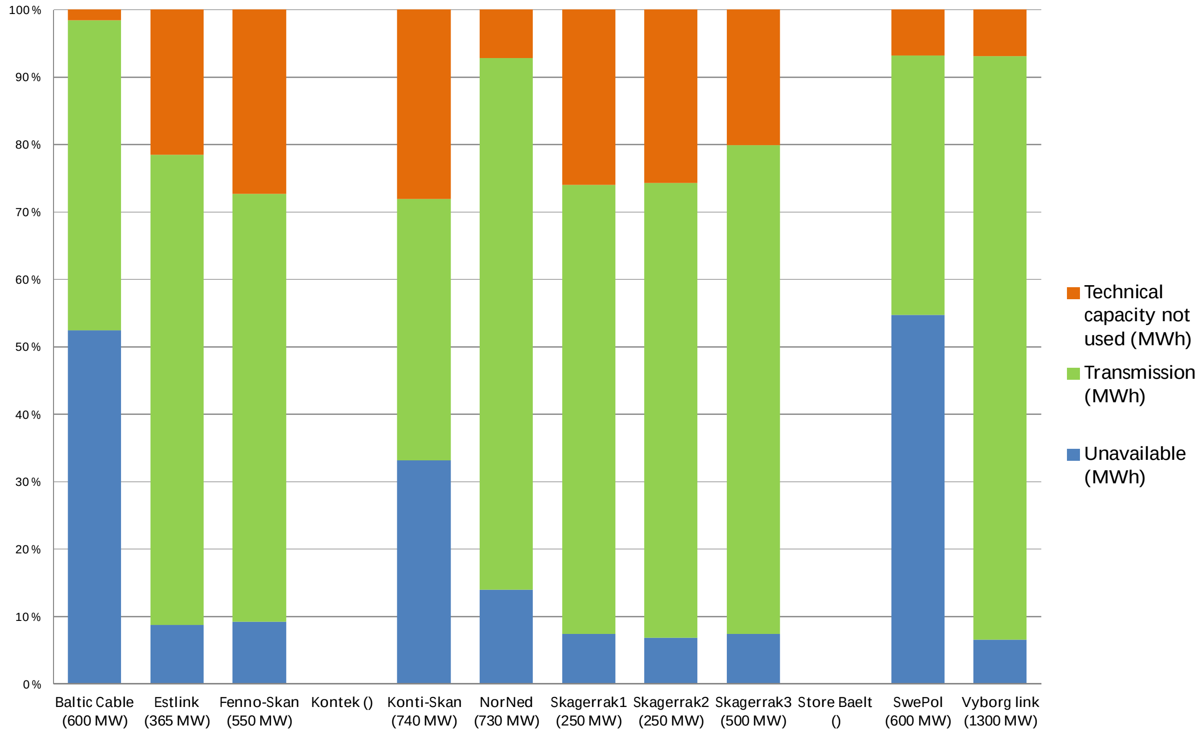


**FIGURE 7.2 HVDC PRESENTATION IN 2011**

## 7.3 UNAVAILABILITY

Figure 7.3 presents the unavailability of different HVDC links due to outages.

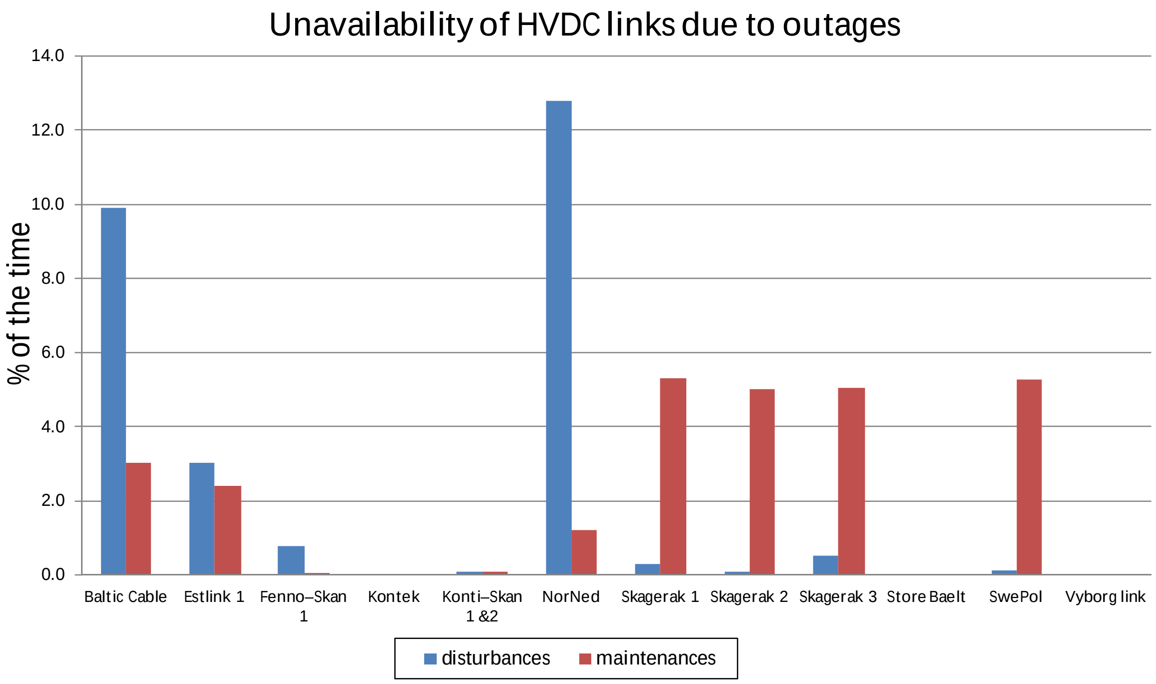


**FIGURE 7.3 UNAVAILABILITY DUE TO OUTAGES IN 2011**

Table 7.3 presents the unavailability due to outages separately for each month.

**TABLE 7.3 MONTHLY UNAVAILABILITY (%) DUE TO OUTAGES IN 2011**

| Link | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Baltic Cable | 0 | 0 | 0 | 64 | 90 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Estlink | 4 | 27 | 0 | 0 | 6 | 1 | 1 | 25 | 1 | 2 | 0 | 0 |
| Fenno-Skan 1 | 0 | 0 | 0 | 0 | 9 | 1 | 0 | 0 | 0 | 0 | 3 | 1 |
| Konti-Skan 1&2 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 0 |
| NorNed | 0 | 1 | 0 | 100 | 0 | 0 | 0 | 0 | 15 | 0 | 0 | 0 |
| Skagerak 1 | 4 | 1 | 0 | 0 | 0 | 46 | 0 | 1 | 15 | 0 | 0 | 2 |
| Skagerak 2 | 0 | 0 | 1 | 0 | 0 | 46 | 0 | 1 | 14 | 0 | 0 | 0 |
| Skagerak 3 | 0 | 0 | 3 | 0 | 0 | 48 | 0 | 1 | 14 | 0 | 1 | 0 |
| SwePol | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 63 | 1 | 0 |
| Vyborg link | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |



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## 7.4 DISTURBANCES AND MAINTENANCES

Figure 7.4 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.

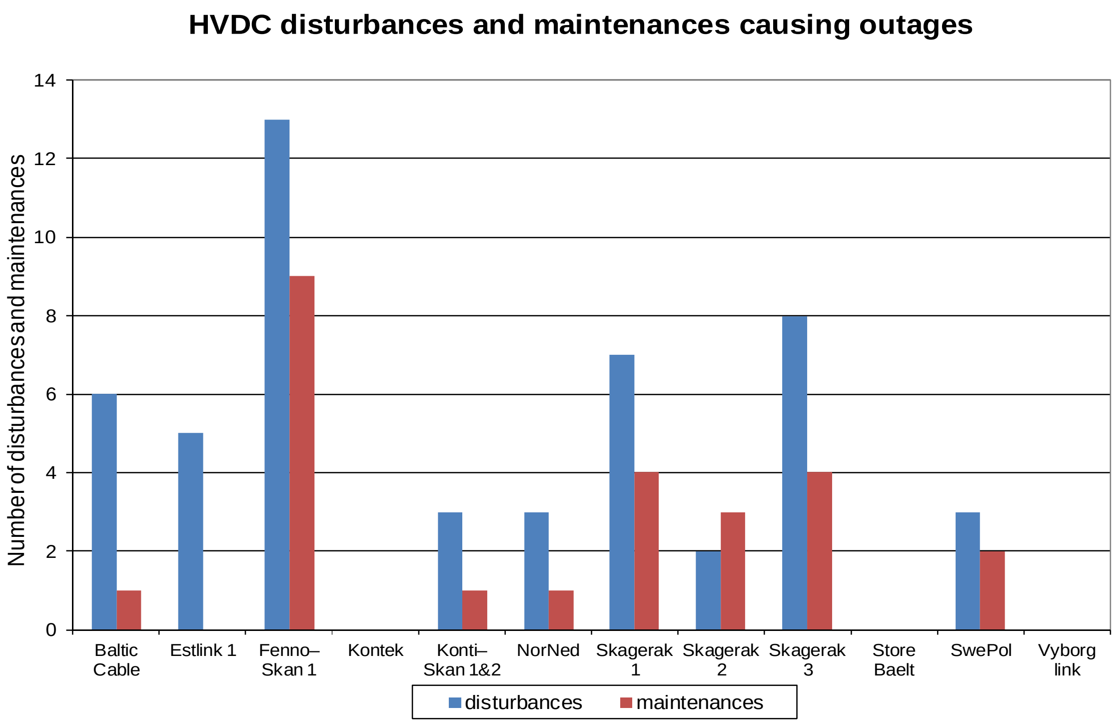


**FIGURE 7.4 HVDC DISTURBANCES AND MAINTENANCES CAUSING OUTAGES IN 2011**

Figure 7.5 presents HVDC disturbances and maintenances related to limitations.

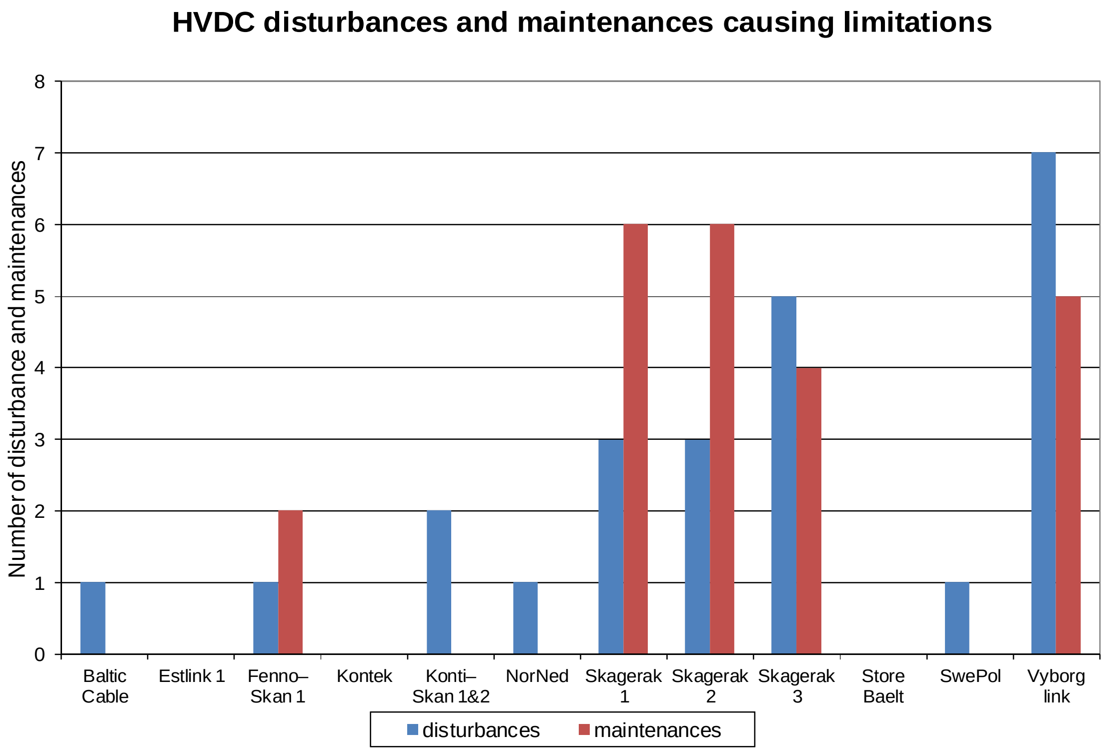


**FIGURE 7.5 HVDC DISTURBANCES AND MAINTENANCES CAUSING TRANSFER LIMITATIONS IN 2011**

Figure 7.6 presents all HVDC disturbances and maintenances, regardless of whether a circuit breaker has operated or not.

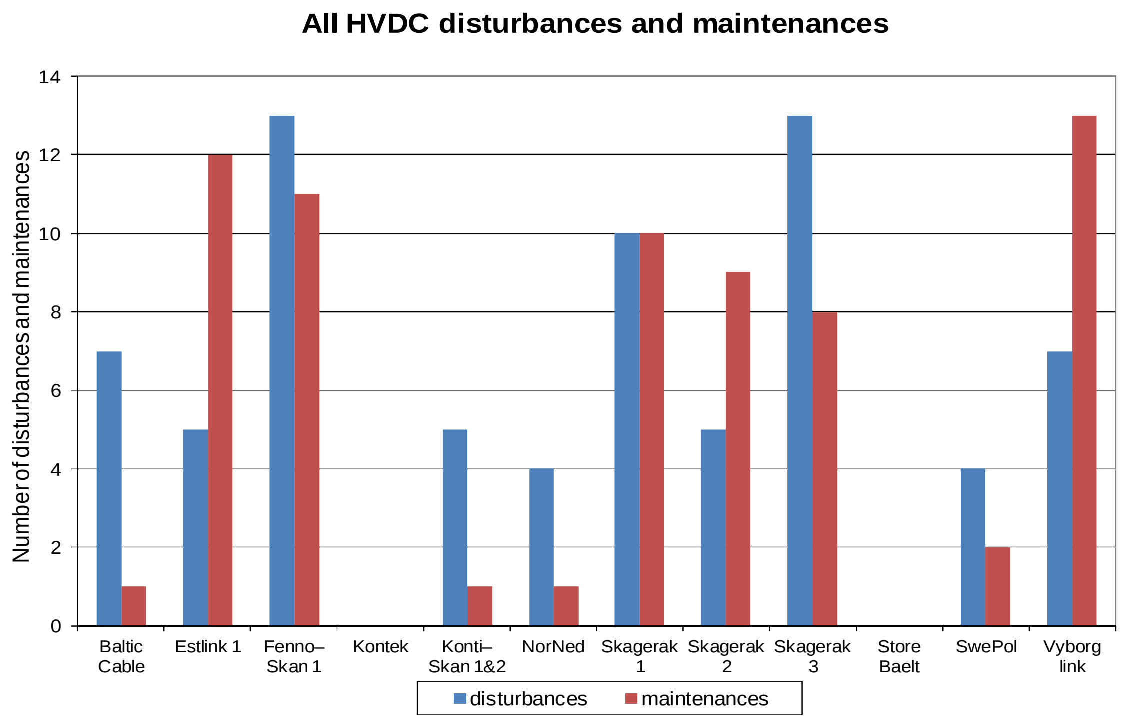


**FIGURE 7.6 ALL HVDC DISTURBANCES AND MAINTENANCES IN 2011**

## 7.5 FAULT TYPES AND FAULT ORIGINS

Table 7.4 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 7.4 HVDC FAULT TYPES AND FAULT ORIGINS IN THE ENTSO-E NORDIC REGION IN 2011**

| Fault origin | | Temporary primary fault | Temporary secondary fault | Permanent primary fault | Permanent secondary fault | Latent fault | Limiting fault | Unknown fault | Limitations due to AC grid |
|---|---|---|---|---|---|---|---|---|---|
| Other or unknown | Total number of faults | 13 | 0 | 2 | 0 | 0 | 0 | 6 | - |
| | Links (number of faults) | Baltic Cable (1) Fenno-Skan1 (2) Skagerak1 (2) Skagerak3 (2) Skagerak3 (6) | | Baltic Cable (1) Skagerak3 (1) | | | | Estlink (3) Fenno-Skan1 (1) Skagerak1 (1) Skagerak3 (1) | |
| Control, protection and communi cation | Total number of faults | 11 | 0 | 2 | 0 | 0 | 0 | 8 | - |
| | Links (number of faults) | Baltic Cable (1) Fenno-Skan1 (5) Skagerak1 (1) Skagerak2 (1) SwePol (2) Vyborg link (1) | | Skagerak1 (1) Skagerak3 (1) | | | | Fenno-Skan1 (8) | |
| External AC grid | Total number of faults | 10 | 2 | 0 | 0 | 0 | 2 | 0 | 5 |
| | Links (number of faults) | Skagerak1 (2) Skagerak2 (1) Skagerak3 (1) Vyborg link (6) | Baltic Cable (1) NorNed (1) | | | | Konti-Skan1&2 (1) Skagerak 1 (1) | | Konti-Skan1&2 (1) Skagerak2 (1) Skagerak3 (1) SwePol (2) |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **AC equipment** | **Total number of faults** | **8** | **0** | **1** | **0** | **0** | **0** | **1** | **-** |
| | Links (number of faults) | Baltic Cable (1) Estlink (1) Fenno-Skan1 (2) Konti-Skan1&2 (1) Skagerak1 (3) | | Estlink (1) | | | | Fenno-Skan1 (1) | |
| **DC converter** | **Total number of faults** | **3** | **0** | **0** | **0** | **0** | **1** | **0** | **-** |
| | Links (number of faults) | Konti-Skan1&2 (1) NorNed (2) | | | | | Konti-Skan1&2 (1) | | |
| **DC electrodes** | **Total number of faults** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **-** |
| | Links (number of faults) | | | | | | | | |
| **DC overhead line** | **Total number of faults** | **1** | **0** | **0** | **0** | **0** | **0** | **0** | **-** |
| | Links (number of faults) | Skagerak3 (1) | | | | | | | |
| **DC cable** | **Total number of faults** | **1** | **0** | **2** | **0** | **0** | **0** | **0** | **-** |
| | Links (number of faults) | Baltic Cable (1) | | Baltic Cable (1) NorNed (1) | | | | | |
| **All** | | **47** | **2** | **7** | **0** | **0** | **3** | **15** | **5** |



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# 8 REFERENCES

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

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



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# 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

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# 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:

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