European Network of
Transmission System Operators
for Electricity

NORDIC AND BALTIC GRID DISTURBANCE STATISTICS 2015

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REGIONAL GROUP NORDIC

1 INTRODUCTION

1.1 DESCRIPTION OF THE REPORT

This report is an overview of the Nordic and Baltic HVAC transmission grid disturbance statistics for the year 2015. Transmission System Operators providing the statistical data are *Energinet.dk* in Denmark, *Elering* in Estonia, *Fingrid Oyj* in Finland, *Landsnet* in Iceland, *Augstsprieguma tīkls* in Latvia, *Litgrid* in Lithuania, *Statnett SF* in Norway and *Svenska kraftnät* in Sweden. The statistics can be found at ENTSO-E website, www.entsoe.eu. 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. Figure 1.2.1 presents the grids of the statistics.

Although this summary originates from the Nordic and Baltic co-operation that aims to use the combined experience of the eight 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 report is made according to the Nordel Guidelines for Classification of Grid Disturbances [1] and includes the faults causing disturbances in the 100–420 kV grids. The guidelines for the Classification of Grid Disturbances were prepared by Nordel[1] during the years 1999–2000 and have been in use since 2000. Most charts include data for the period 2006–2015 for the Nordic countries and for the period 2014–2015 for the Baltic countries. In some cases, where older data has been available, even longer periods have been used. 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.

The guidelines and disturbance statistics were in the “Scandinavian” language until 2006. 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.

Despite common guidelines, there are slight differences in the 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.

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

The report is organised as follows. 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 and Baltic power system. In addition, each Transmission System Operator has presented the most important issues of the year 2015.

Chapter 3 discusses the disturbances and focuses on the analysis and allocation of the causes of disturbances. The distribution of disturbances during the year 2015 for each country is presented; for example, the consequences of the disturbances in the form of energy not supplied.

Chapter 4 presents the tables and figures of energy not supplied for each country and Chapter 5 discusses the faults in different components. A summary of all the faults is followed by the presentation of more detailed statistics.

1.2 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 the ENTSO-E Nordic and Baltic disturbance statistics. The relevant contact information is given in Appendix 3.

There are no common Nordic and Baltic disturbance statistics for voltage levels lower than 100 kV. However, Appendix 4 presents the relevant contact persons for these statistics.

FIGURE 1.2.1 THE NORDIC AND BALTIC MAIN GRIDS [2]

1.3 Voltage levels in the Nordic and Baltic networks

Table 1.3.1 presents the transmission system voltage levels of the networks in the Nordic and Baltic countries. In the statistics, voltage levels are grouped as statistical voltages according to the table.

Table 1.3.1 Nominal voltage levels (U_N) in the respective statistical voltages and the percentage of the grid at the respective nominal voltage level (P)

Country			Statistical voltage range, kV				
			380–420 kV	220–330 kV	220–330 kV	100–150 kV	100–150 kV
Denmark	U_N		400	-	220	150	132
	P	%	100	-	100	62	38
Finland	U_N		400	-	220	110	-
	P	%	100	-	100	100	
Iceland	U_N		-	-	220	132	-
	P	%	-	-	100	100	-
Norway	U_N		420	300	220	132	110
	P	%	100	90	10	98	2
Sweden	U_N		400	-	220	130	-
	P	%	100	-	100	100	-
Estonia	U_N		-	330	220	110	-
	P	%	-	92	8	100	-
Latvia	U_N		-	330	-	110	-
	P	%	-	100	-	100	-
Lithuania	U_N		-	330	-	110	-
	P	%	-	100	-	100	-

1.4 The scope and limitations of the statistics

Table 1.4.1 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 divided by the actual length of lines in the grid.

TABLE 1.4.1 PERCENTAGE OF NATIONAL NETWORKS INCLUDED IN THE STATISTICS

Voltage level	380–420 kV	220–330 kV	100–150 kV
Denmark	100 %	100 %	100 %
Estonia	-	100 %	100 %
Finland[1)]	100 %	100 %	94 %
Iceland	-	100 %	100 %
Latvia	-	100 %	100 %
Lithuania	-	100 %	100 %
Norway	100 %	100 %	100 %
Sweden	100 %	100 %	100 %

1) Percentage for Finland is reduced due to some small regional grids delivering incomplete data.

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

Finland: The data includes approximately 94 % of Finnish 110 kV lines and approximately 93 % of 110/20 kV transformers.

Iceland: The network statistics cover the whole 220 kV and 132 kV voltage levels.

Norway: A large part of the 110 and 132 kV network is resonant earthed. This category is combined with the 100–150 kV solid earthed network in these statistics.

The ten-year average values for the Baltic countries are not available in this report because they only have data since the year 2014. Hence, the average values for the Baltic countries are calculated from the years 2014–2015.

2 Summary

2.1 Overview of the Nordic and Baltic countries

In 2015, the energy not supplied (ENS) due to faults in the Nordic main grid was 5.1 GWh and 117 MWh in in the Baltic main grids. Totally, there was 5.2 GWh of ENS in the Nordic and Baltic main grid, which is below the ten-year average 7.0 GWh.

The energy not supplied and corresponding ten-year average values for the period 2006–2015 in each country are presented in the following sections. The sections also present the number of disturbances for each country as well as the number of disturbances that caused energy not supplied in 2015. In addition, the summaries present the most important issues in 2015 defined by each Transmission System Operator.

2.2 Summary of Denmark

In Denmark, the energy not supplied in 2015 was 25 MWh (ten-year average 19 MWh). The number of grid disturbances was 79 (ten-year average 63) and 7 of them caused ENS. On average, 7 disturbances per year caused ENS in 2009–2015.

In 2015, 50 % of ENS was caused by faults in technical equipment, 26 % of ENS caused by other environmental causes, and 24 % of ENS caused by operation and maintenance. Most of the disturbances were evenly divided between all causes except lightning and unknown causes.

The three biggest disturbances in 2015 were the following:

- a current transformer in station Malling between 400 and 150 kV broke because of corrosion or tear in February. It took almost 9 hours to reconnect the busbar and transformers. The consumers were without power in 6 minutes and the ENS was 10 MWh;
- a disturbance disconnected the whole station Vilsted because of salt (Other environmental causes) in November. The consumers were without power in 11 minutes and the ENS was 6.5 MWh;
- the busbar protection in station Bredebro was tested in August. The disturbance was caused by a combination of wrong communication configuration, which withheld the alarm to the scada system, and a change of relay settings, which wasn’t documented enough. The consumers were without power in 11 minutes and the ENS was 5.3 MWh.

2.3 Summary of Estonia

In Estonia, the energy not supplied in 2015 was 31 MWh (two-year average 30). The number of grid disturbances was 219 (two-year average 222) and 21 of them caused ENS. On average, 16 disturbances per year caused ENS in 2014–2015.

In 2015, 66 % of ENS was caused by an adjoining statistical area. The most significant reasons for ENS were fallen trees on overhead power lines, mostly as a result of cutting trees (23 %) and amortization of the equipment (3.4 %). Most of the disturbances were caused by other environmental causes that occurred during the summer months.

The three biggest disturbances in 2015 were the following:

- personnel dropped a tree on a transmission line on 10 February and caused an earth fault. The fault protection settings on one side of the line were incorrect causing the other side to trip;
- personnel dropped a tree on a transmission line on 28 July. One of the circuit breakers didn't switch off and caused another line to trip;
- personnel made a mistake in the switching schedule on 5 August. The bus fault protection worked but the bus carried a lot of dead end consumers.

2.4 Summary of Finland

In Finland, the energy not supplied in 2015 was 176 MWh (ten-year average 353 MWh). The number of grid disturbances was 454 (ten-year average 417) and 70 of them caused ENS. On average, 80 disturbances per year caused ENS in 2009–2015.

In 2015, 41 % of ENS was caused by overhead lines faults and 19 % by substation faults. The most significant reasons for ENS were unknown causes (36 %) and other environmental causes 21 %. Most of the disturbances were caused by other environmental causes and occurred during the summer months.

The biggest disturbances of 110–400 kV grids in 2015 were the following:

- 110 kV transmission line tripped due to a permanent 2-phase earth fault on 2 December. The line tripped due to a crane that fell. One person was seriously injured and 70,000 households had a power outage. The incident caused 22 MWh of ENS;
- 110 kV transmission line tripped due to 3-phase short-circuit and caused a voltage dip in Southern Finland on 22 October. The primary fault was on the 20 kV side of the substation. The incident caused 19 MWh of ENS;
- 110 kV transmission line tripped due to a permanent 2-phase earth fault on 3 June. The line tripped due to a fallen tree during a storm. The incident caused 18 MWh of ENS.

2.5 Summary of Iceland

In Iceland, the energy not supplied in 2015 was 735 MWh (ten-year average 1182 MWh). The total number of disturbances was 47 (ten-year average 34) and 29 of them caused ENS. On average, 19 disturbances per year caused ENS in 2009–2015. All of the disturbances were in 132 and 220 kV systems. Registered grid disturbances increased in 2015 as compared to 2014. Weather played a central role in most cases.

In 2015, 65 % of ENS was caused by substation faults and 19 % by other faults. The most significant reasons for ENS were technical equipment (77 %) and other environmental causes (17 %). Most of the disturbances were caused by other environmental causes and occurred during the winter months.

The biggest disturbances in the 132 and 220 kV network were the following:

- a communication disturbance with a 220 kV substation tripped all incoming transmission lines and production units for a power station connected to the substation on 31 January. The priority load was 150 MWh and the curtailable load was 286 MWh;
- a failure in the protection relay equipment tripped the transmission system which in turn activated a relay protection scheme on 22 July. The priority load was 144 MWh and the curtailable load was 7 MWh;
- a severe storm caused multiple trips in the transmission network during 7 and 8 December. The priority load was 330 MWh and the curtailable load was 3000 MWh.

2.6 SUMMARY OF LATVIA

In Latvia, the energy not supplied in 2015 was 54 MWh (two-year average 45 MWh). The number of grid disturbances was 112 (two-year average 132) and 18 of them caused ENS. On average, 19 disturbances per year caused ENS in 2014–2015.

In 2015, 59 % of ENS was caused by substation faults 41 % overhead line faults. The most significant reasons for ENS were technical equipment (37 %) and other environmental causes (32 %). Most of the disturbances were caused by external influences (22 %) and other environmental causes (22 %) that occurred almost only on overhead lines.

The biggest disturbance in 2015 happened when the isolator of a busbar disconnector broke due to manual operation. The fault affected 4 substations and caused, due to two secondary faults on control equipment, 36 % of the total ENS during 2015.

2.7 SUMMARY OF LITHUANIA

In Lithuania, the energy not supplied in 2015 was 32 MWh (two-year average 36 MWh). The number of grid disturbances was 138 (two-year average 149) and 19 of them caused ENS. On average, 22 disturbances per year caused ENS in 2014–2015.

In 2015, 83 % of ENS was caused by overhead line faults and 17 % by substation faults. The most significant reasons for ENS were external influences (66 %) and operation and maintenance (14 %). Most of the disturbances were caused by unknown causes and occurred during the summer months.

The biggest disturbance in 2015 occurred on a 110 kV transmission line. A transmission line tripped due to a permanent single-phase earth fault in 17 August and disconnected five substations. The line was in radial feeding mode because of maintenance work in other parts of the transmission grid and the earth fault was caused by a fallen tree. Later inspection clarified that the fallen tree was caused by activities of a third-part entity (external influence). The disturbance caused 11.9 MWh ENS and covered 37 % of a total ENS for 2015.

2.8 Summary of Norway

In Norway, the energy not supplied in 2015 was 2779 MWh (ten-year average 3441 MWh). The number of grid disturbances was 437 (ten-year average 305) and 86 of them caused ENS. On average, 94 disturbances per year caused ENS in 2009–2015.

In 2015, 61 % of ENS was caused by substation faults and 39 % by overhead line faults. The most significant reasons for ENS were other environmental causes (44 %) and operation and technical equipment (40 %). Most of the disturbances were caused by other environmental causes and occurred during the winter months. Compared to the last 5-years, there is an increase of faults on overhead lines.

The three biggest disturbances in 2015 were the following:

- a 420 kV line in Ofoten–Kvandal tripped during a storm and resulted in a N-1 violation and a full transit and overload in the parallel 132 kV network. After a short time, the 132 kV Network got a 3-phase fault with unsuccessful disconnection and then all the backup relay functions tripped. The final outcome of this incident was islanding, voltage collapse and a blackout. The total energy not supplied (ENS) was 931 MWh.
- high salt content in the air and on the overhead lines during the hurricane "Ole" resulted in outage of the main 132 kV lines to Lofoten. The lines had to be washed before reconnecting. The total energy not supplied (ENS) was 519 MWh.
- A loose loop in the 132 kV station Mosjoen resulted in a broken conductor and a double earth fault. All local load and an aluminum plant were disconnected. The total energy not supplied (ENS) was 434 MWh.

2.9 Summary of Sweden

In Sweden, the energy not supplied in 2015 was 1353 MWh (ten-year average 1825 MWh). The number of grid disturbances was 378 (ten-year average 527) and 122 of them caused ENS. On average,152 disturbances per year caused ENS in 2009–2015.

In 2015, 56 % of ENS was caused by faults on overhead lines and 30 % were caused by faults in substations. The most significant reasons for ENS were lightning (44 %) and technical equipment (20 %). Most of the disturbances were caused by unknown causes (probably caused by lightning, but not verified) and occurred during the summer months.

The biggest disturbances in 2015 were the following:

- The most severe disturbance was a multiple fault situation which occurred on two parallel lines on 400kV. The lines were redundant and resulted therefore in no calculated ENS. However, the remaining lines became extra stressed because the disturbance occurred in February when the load was high. The first fault occurred because there

was an error in the communication for the line differential protection which lead to an unwanted function. Ultimately after several reclosing attempts a failure occurred in a measurement transformer which took several days to find and restore. One of the lines could however be reconnected a few hours after the initial fault.
- Another severe disturbance was a fire in a cable joint late in December on 220kV. The fire lead to a disconnection of all objects connected to one of the busbars resulting in an outage for roughly 18000 customers.

3 DISTURBANCES

This chapter includes an overview of disturbances in the Nordic and Baltic countries. It also presents the connection between disturbances, energy not supplied, causes of faults, and distribution during the year 2015, together with the development of the number of disturbances over the ten-year period 2006–2015. 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.

Grid disturbances are defined as:

Outages, forced or unintended disconnection or failed reconnection as a result of faults in the power grid [1, 3].

The scope of grid disturbances in these statistics is the same as the scope for faults, which are presented in Chapter 5.1.

3.1 ANNUAL NUMBER OF DISTURBANCES DURING THE PERIOD 2006–2015

The number of disturbances during the year 2015 in the Nordic and Baltic main grids was 1864 and the combined ten-year average in the Nordic countries and two-year average in the Baltic countries was 1848. The number of grid disturbances is not directly comparable between countries because of the large differences between external conditions in the transmission networks of the Nordic and Baltic countries.

Table 3.1.1 presents the sum of disturbances during the year 2015 and the annual average for the period 2006–2015 for the complete 100–420 kV grids. Figure 3.1.1 shows the development of the number of disturbances during the period 2006–2015.

TABLE 3.1.1 THE NUMBER OF GRID DISTURBANCES IN 2015 AND THE ANNUAL AVERAGE

Country	Disturbances		Disturbances causing ENS	
	Number 2015	Average 2006–2015	Number 2015	Average 2009–2015 2)
Denmark	79	63	7	7
Estonia 1)	219	222	21	16
Finland	454	417	70	80
Iceland	47	34	29	18
Latvia 1)	112	132	18	19
Lithuania 1)	138	149	19	22
Norway	437	305	86	94
Sweden	378	527	122	152
Total	1864	1848	372	408

1) Baltic countries average is counted from 2014 forward because they only have data from 2014.
2) The time period is 2009–2015 because every country does not have complete data before 2009.

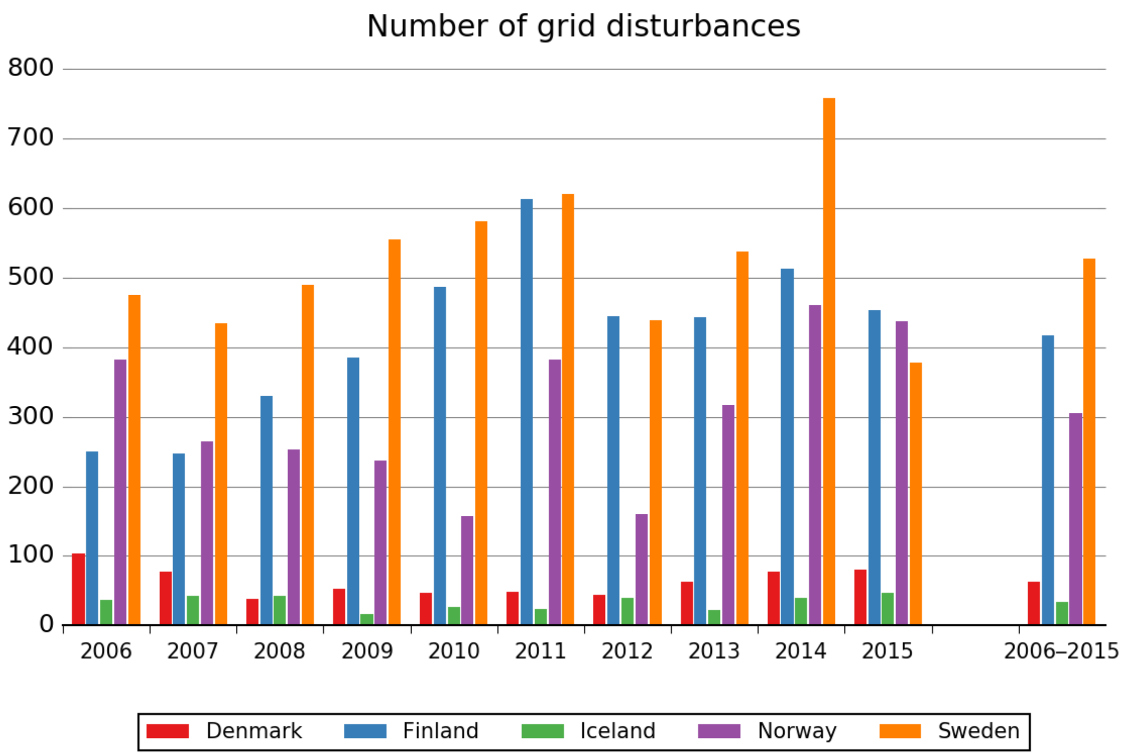

FIGURE 3.1.1 THE ANNUAL NUMBER OF GRID DISTURBANCES AND THE AVERAGE IN EACH NORDIC COUNTRY FOR THE PERIOD 2006–2015

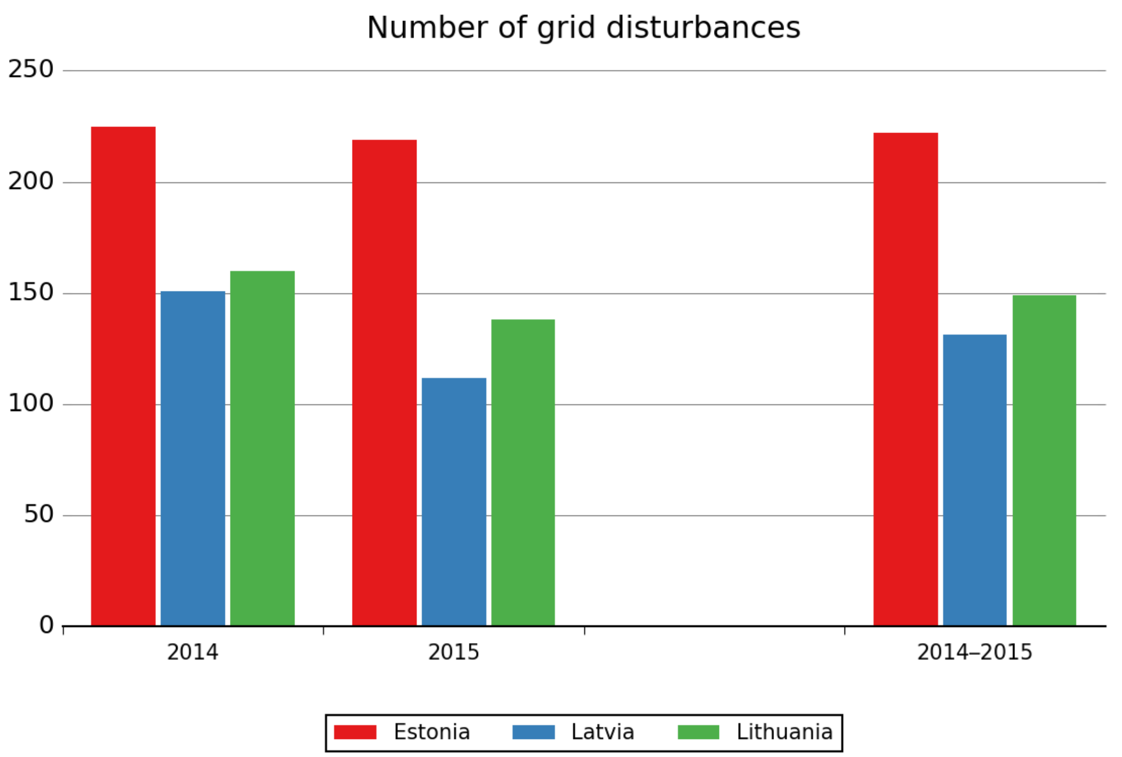

FIGURE 3.1.2 THE ANNUAL NUMBER OF GRID DISTURBANCES AND THE AVERAGE IN EACH BALTIC COUNTRY FOR THE PERIOD 2014–2015

3.2 DISTURBANCES DISTRIBUTED ACCORDING TO MONTH

Figure 3.2.1 and 3.2.2 presents the percentage distribution of grid disturbances for all voltage levels according to month in the Nordic and Baltic countries, respectively. Figure 3.2.3 presents the respective average values for the period 2006–2015 in the Nordic countries and Figure 3.2.4 presents the average values for the period 2014–2015 in the Baltic countries.

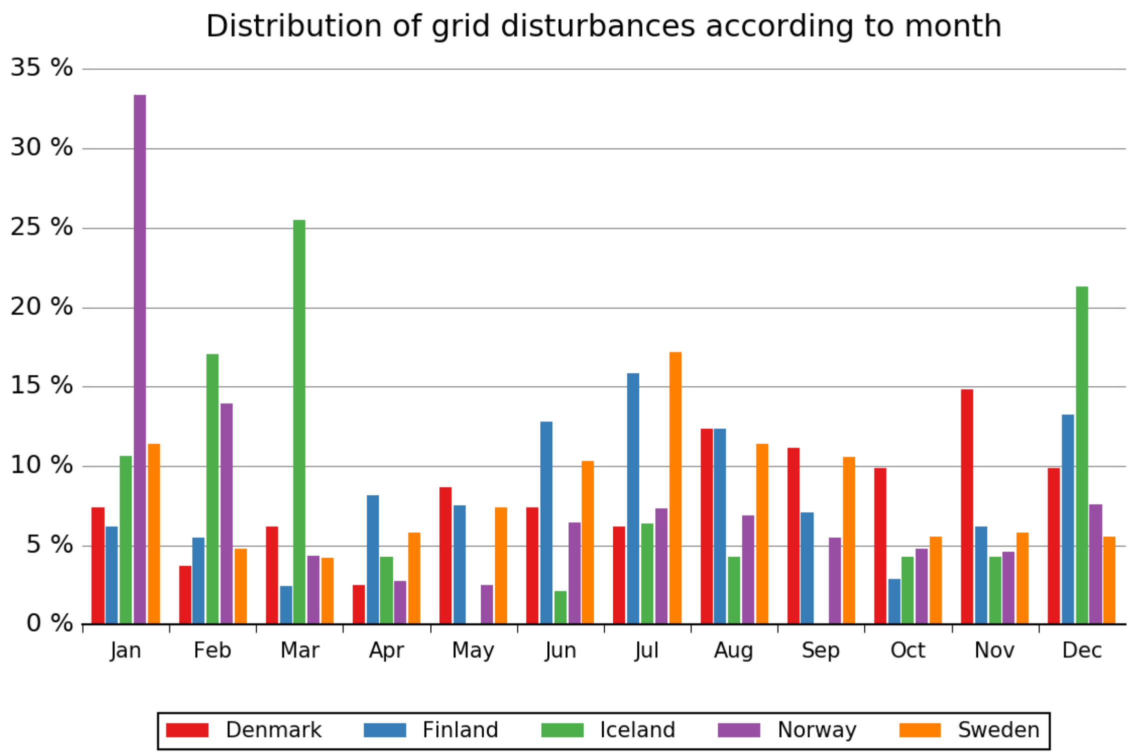

FIGURE 3.2.1 PERCENTAGE DISTRIBUTION OF GRID DISTURBANCES ACCORDING TO MONTH IN EACH NORDIC COUNTRY IN 2015

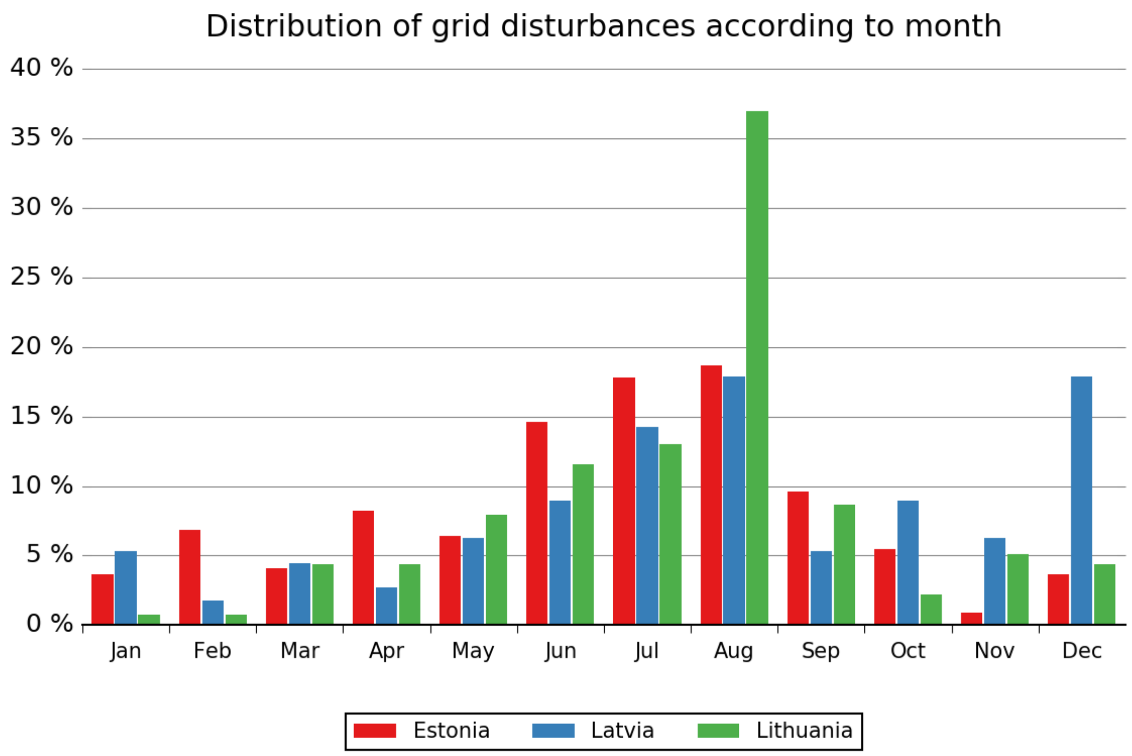

FIGURE 3.2.2 PERCENTAGE DISTRIBUTION OF GRID DISTURBANCES ACCORDING TO MONTH IN EACH BALTIC COUNTRY IN 2015

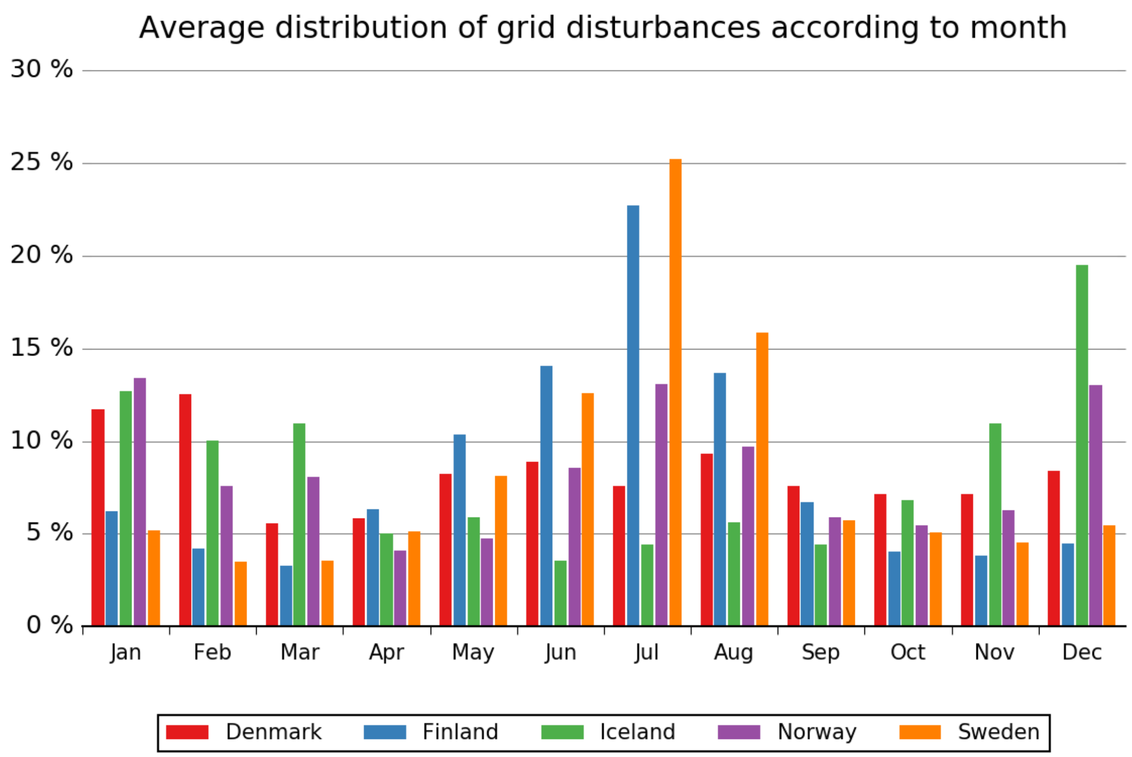

FIGURE 3.2.3 AVERAGE PERCENTAGE DISTRIBUTION OF GRID DISTURBANCES ACCORDING TO MONTH IN EACH NORDIC COUNTRY FOR THE PERIOD 2006–2015

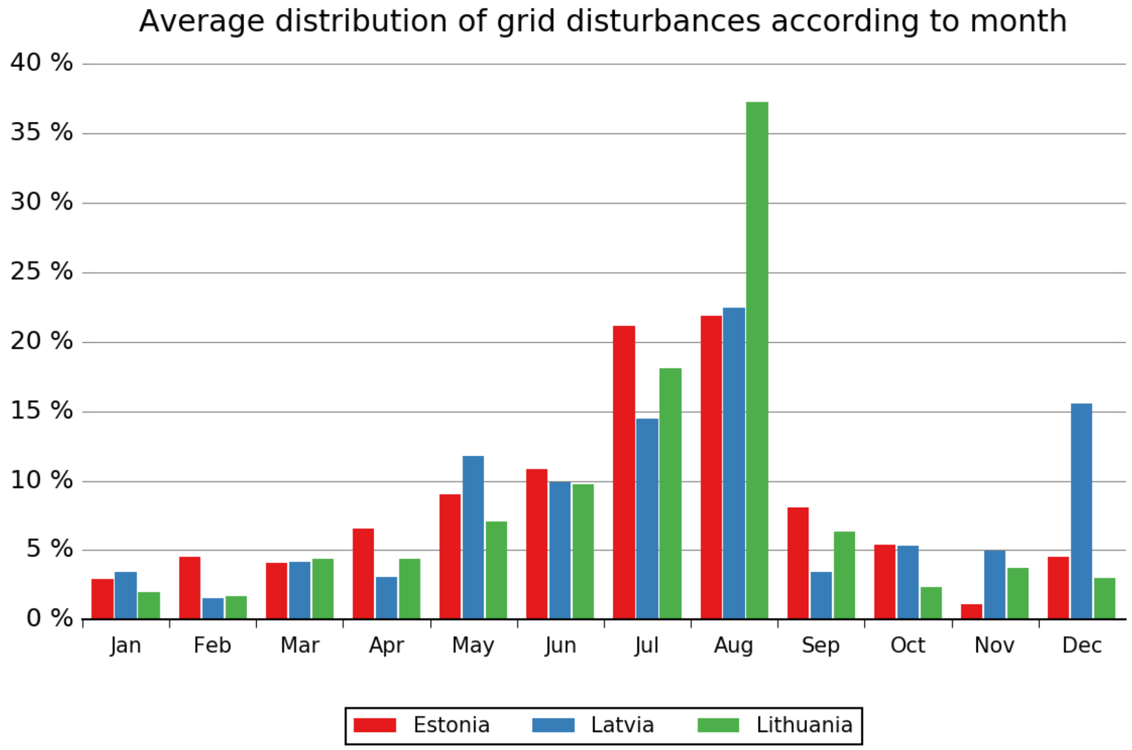

FIGURE 3.2.4 AVERAGE PERCENTAGE DISTRIBUTION OF GRID DISTURBANCES ACCORDING TO MONTH IN EACH BALTIC COUNTRY FOR THE PERIOD 2014–2015

Table 3.2.1 and Table 3.2.2 present the numerical values behind Figure 3.2.1, Figure 3.2.2, Figure 3.2.3 and Figure 3.2.4. The numbers in the tables are sums of all the disturbances in the 100–420 kV networks. For all countries, except Iceland, the number of disturbances is usually largest during the summer period. This is caused by lightning strokes during the summer.

TABLE 3.2.1 NUMBER OF GRID DISTURBANCES PER MONTH IN 2015

Country	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Denmark	6	3	4	2	7	6	5	9	9	8	12	8
Estonia	8	15	9	18	14	32	39	41	21	12	2	8
Finland	28	25	11	37	34	58	72	56	32	13	28	60
Iceland	5	8	12	2	0	1	3	2	0	2	2	10
Latvia	6	2	5	3	7	10	16	20	6	10	7	20
Lithuania	1	1	6	6	11	16	18	51	12	3	7	6
Norway	146	61	19	12	11	28	32	30	24	21	20	33
Sweden	43	18	16	22	28	39	65	43	40	21	22	21
Total	243	133	82	102	112	190	250	252	144	90	100	166

TABLE 3.2.2 AVERAGE NUMBER OF GRID DISTURBANCES PER MONTH DURING THE YEARS 2006–2015.

Country	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Denmark	8	8	4	4	5	6	5	6	5	5	5	5
Estonia[1)]	7	10	9	15	20	24	47	49	18	12	3	10
Finland	26	18	14	26	43	59	95	57	28	17	16	19
Iceland	4	3	4	2	2	1	2	2	2	2	4	7
Latvia[1)]	5	2	6	4	16	13	19	30	5	7	7	21
Lithuania[1)]	3	3	7	7	11	15	27	56	10	4	6	5
Norway	41	23	25	13	15	26	40	30	18	17	19	40
Sweden	27	18	19	27	43	66	133	84	30	27	24	29
Total	121	85	86	96	154	210	367	311	115	90	82	134

1) The average for the Baltic countries is counted from 2014 because their earliest data is from 2014.

3.3 DISTURBANCES DISTRIBUTED 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 primary and underlying causes. The exact definitions are listed in section 5.2.9 in the Nordel Guidelines [1]. This report uses seven different options for fault causes and list the primary cause of the event as the starting point. Table 3.3.1 and Table 3.3.2 present an overview of the causes of grid disturbances and energy not supplied in each Nordic and Baltic country, respectively.

Each country in this statistics has its own detailed way of gathering data according to fault cause as is explained in Appendix 2. The guidelines [1] describe the relations between the detailed fault causes and the common Nordic cause allocation.

TABLE 3.3.1 GROUPING OF GRID DISTURBANCES AND ENERGY NOT SUPPLIED (ENS) BY CAUSE IN EACH NORDIC COUNTRY

Cause	**Country**	**Percentage distribution of disturbance**		**Percentual distribution of disturbances that caused ENS**[1)]		**Percentual distribution of ENS**	
		2015	2006–2015	2015	2009–2015[2)]	2015	2006–2015
Lightning	Denmark	5	13	0	6	0	4
	Finland	9	25	7	20	0	6
	Iceland	2	3	0	3	0	2
	Norway	11	22	20	25	9	4
	Sweden	13	37	12	39	44	22
Other environmental causes	Denmark	18	20	14	4	26	4
	Finland	40	20	21	17	5	22
	Iceland	72	45	62	53	17	58
	Norway	45	29	29	27	44	65
	Sweden	10	5	7	4	3	3
External influence	Denmark	16	17	0	4	0	1
	Finland	2	2	1	4	1	10
	Iceland	2	2	3	2	3	1
	Norway	1	2	1	2	0	0
	Sweden	1	2	1	3	1	6
Operation and maintenance	Denmark	18	15	43	34	24	38
	Finland	6	7	10	10	19	15
	Iceland	11	10	14	10	3	16
	Norway	17	11	26	13	6	6
	Sweden	10	7	15	11	2	12
Technical equipment	Denmark	18	13	43	18	50	18
	Finland	3	5	6	7	12	24
	Iceland	11	20	17	13	77	16
	Norway	19	20	17	13	40	13
	Sweden	17	13	16	11	20	23
Other	Denmark	18	8	0	22	0	24
	Finland	29	12	19	10	38	15
	Iceland	2	17	3	19	0	7
	Norway	4	11	2	13	0	9
	Sweden	14	11	15	7	15	16
Unknown	Denmark	8	13	0	10	0	12
	Finland	13	30	36	33	24	8
	Iceland	0	1	0	1	0	0
	Norway	4	5	5	7	1	2
	Sweden	34	24	34	25	16	19

1) The way to calculate the ENS varies between the countries and is presented in Appendix 1.
2) The time span is 2009–2015 because there is not enough data available.

TABLE 3.3.2 GROUPING OF GRID DISTURBANCES AND ENERGY NOT SUPPLIED (ENS) BY CAUSE IN EACH BALTIC COUNTRY

Cause	Country	Percentage distribution of disturbance		Percentual distribution of disturbances that caused ENS[1)]		Percentual distribution of ENS	
		2015	2014–2015	2015	2014–2015	2015	2014–2015
Lightning	Estonia	5	9	0	0	0	0
	Latvia	3	11	0	3	0	1
	Lithuania	4	8	0	5	0	2
Other environmental causes	Estonia	28	32	14	9	1	1
	Latvia	22	22	44	46	31	30
	Lithuania	2	2	5	7	9	4
External influence	Estonia	1	2	5	19	0	3
	Latvia	22	24	28	30	29	38
	Lithuania	25	34	47	48	66	75
Operation and maintenance	Estonia	16	11	52	41	29	16
	Latvia	10	7	17	14	2	5
	Lithuania	9	11	26	27	14	11
Technical equipment	Estonia	39	33	10	9	3	11
	Latvia	16	10	11	8	37	24
	Lithuania	6	5	11	7	6	5
Other	Estonia	9	9	14	13	66	65
	Latvia	14	10	0	0	0	0
	Lithuania	14	7	0	0	0	0
Unknown	Estonia	2	2	5	9	0	3
	Latvia	13	16	0	0	0	2
	Lithuania	38	34	11	7	6	3

[1)] The way to calculate the ENS varies between the countries and is presented in Appendix 1.

Figure 3.3.1 and Figure 3.3.2 present disturbances for all voltage levels in terms of the primary fault for the year 2015. Figure 3.3.3 presents the average values for the period 2006–2015 in the Nordic countries and Figure 3.3.4 presents the average values for the period 2014–2015 in the Baltic countries.

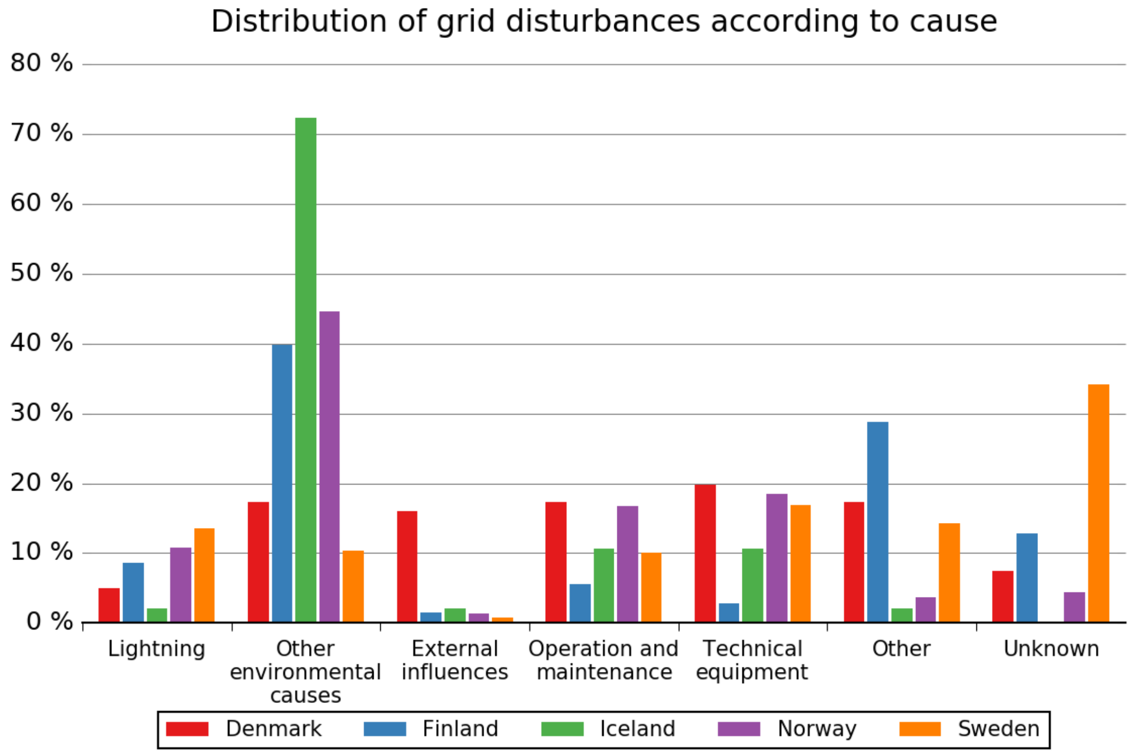

FIGURE 3.3.1 PERCENTAGE DISTRIBUTION OF GRID DISTURBANCES ACCORDING TO CAUSE IN EACH NORDIC COUNTRY IN 2015

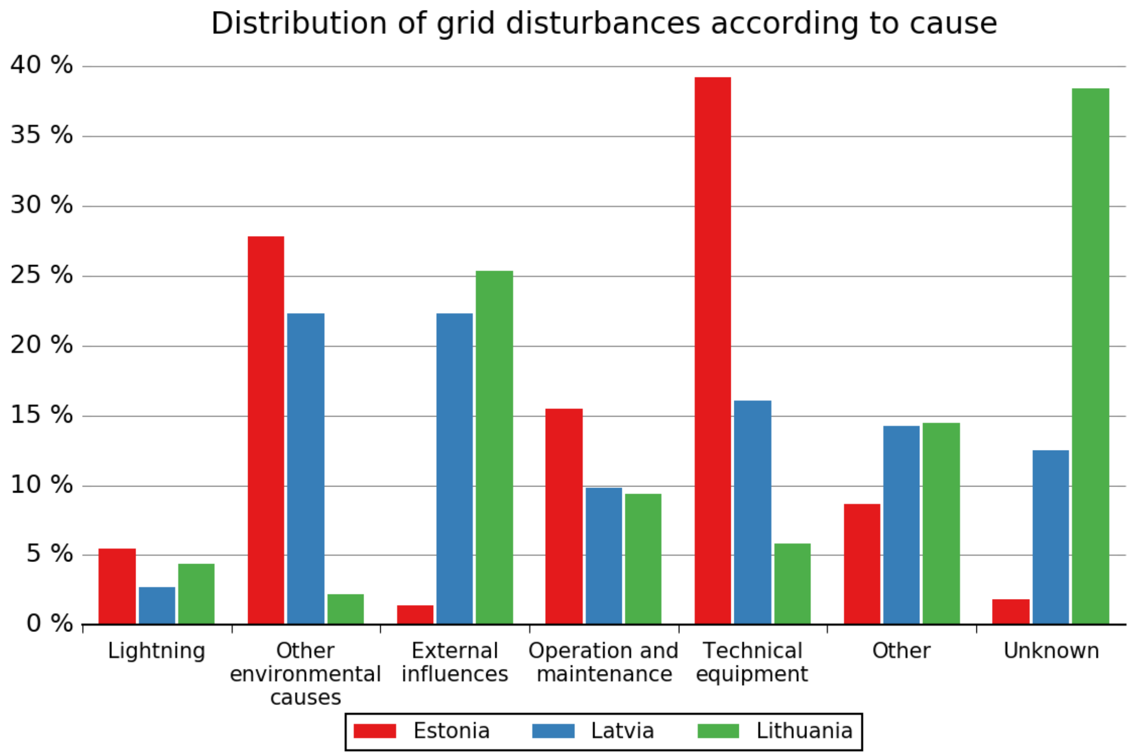

FIGURE 3.3.2 PERCENTAGE DISTRIBUTION OF GRID DISTURBANCES ACCORDING TO CAUSE IN EACH BALTIC COUNTRY IN 2015

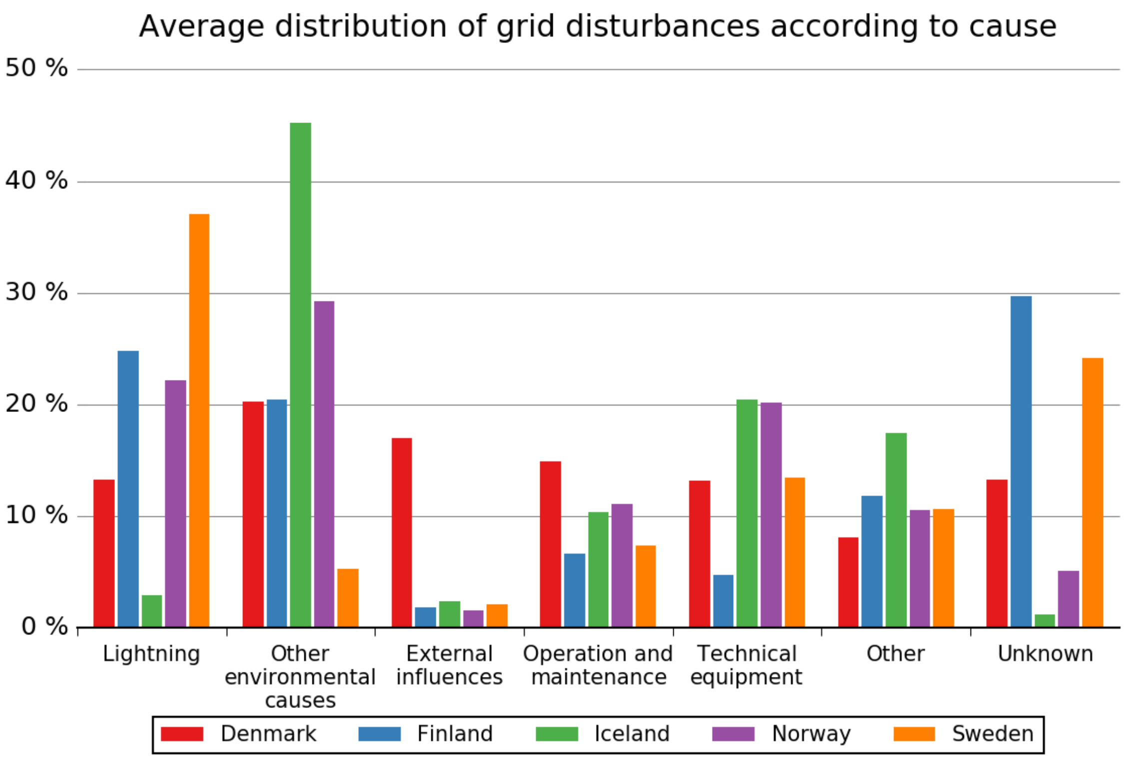

FIGURE 3.3.3 AVERAGE PERCENTAGE DISTRIBUTION OF GRID DISTURBANCES ACCORDING TO CAUSE IN EACH NORDIC COUNTRY FOR THE PERIOD 2006–2015

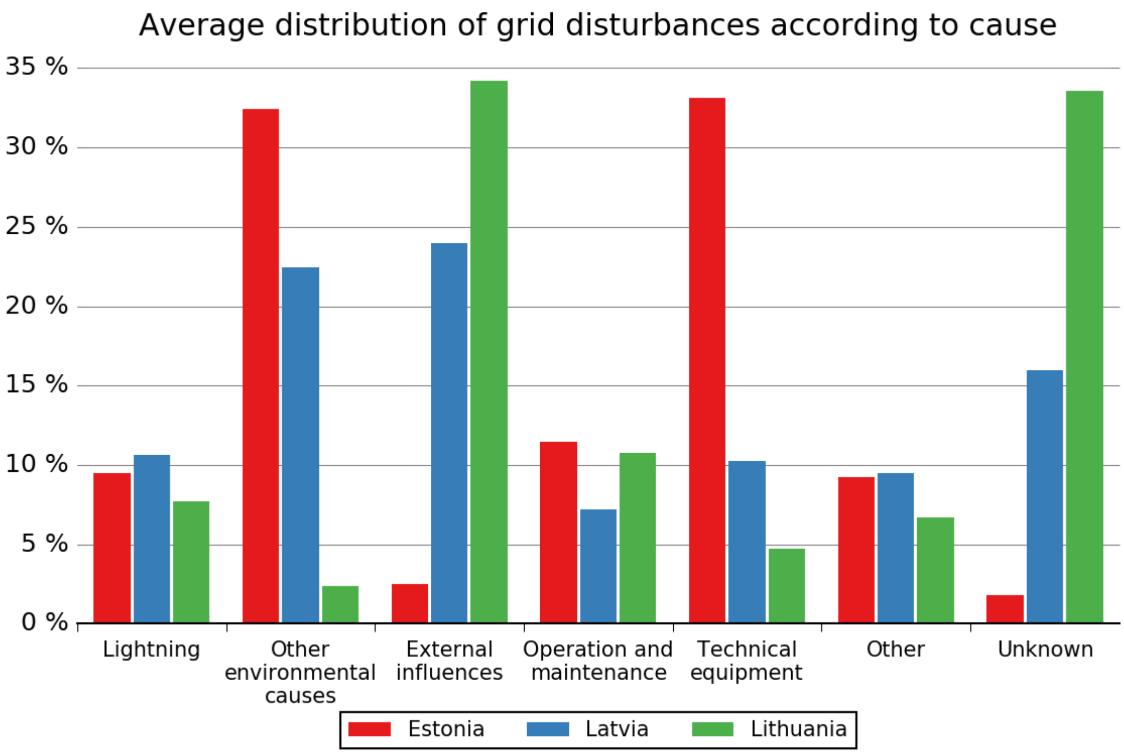

FIGURE 3.3.4 AVERAGE PERCENTAGE DISTRIBUTION OF GRID DISTURBANCES ACCORDING TO CAUSE IN EACH BALTIC COUNTRY FOR THE PERIOD 2014–2015

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 (ENS). One should remember that the amount of ENS 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.

Energy not supplied is defined as:

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 DISTRIBUTED ACCORDING TO VOLTAGE LEVEL

Table 4.1.1 shows the amount of energy not supplied and its distribution according to voltage level. The amount of ENS in Table 4.1.1 may be lower than in the other tables because Table 4.1.1 only includes ENS caused by faults in the own grid.

TABLE 4.1.1 ENERGY NOT SUPPLIED (ENS) ACCORDING TO THE VOLTAGE LEVEL OF THE PRIMARY FAULT

Country	Energy not supplied (MWh) 2015	Average ENS 2006–2015 (MWh)	Average ENS (%) divided into different voltage levels, 2006–2015			
			100–150 kV	220–330 kV	380–420 kV	Other 1)
Denmark	25	19	93	0	0	7
Finland	176	353	93	3	3	1
Iceland	735	1182	36	64	0	0
Norway	2779	3506	31	8	61	0
Sweden	1353	1749	81	16	3	1
		2014–2015	Average ENS (%) divided into different voltage levels, 2014–2015			
Estonia	31	30	80	20	0	0
Latvia	54	45	99	1	0	0
Lithuania	32	36	100	0	0	0
Total	5185	6919	77	14	8	1

1) The category other contains energy not supplied from system faults, auxiliary equipment, lower voltage level networks and the connections to foreign countries, etc. This is described further in the guidelines [1].

Figure 4.1.1 presents the energy not supplied according to the different voltage levels for the year 2015 and Figure 4.1.2 summarises the energy not supplied according to the different voltage levels for the period 2006–2015 in the Nordic countries and for the period 2014–2015 in the Baltic countries. A voltage level refers to the primary fault of the respective disturbance.

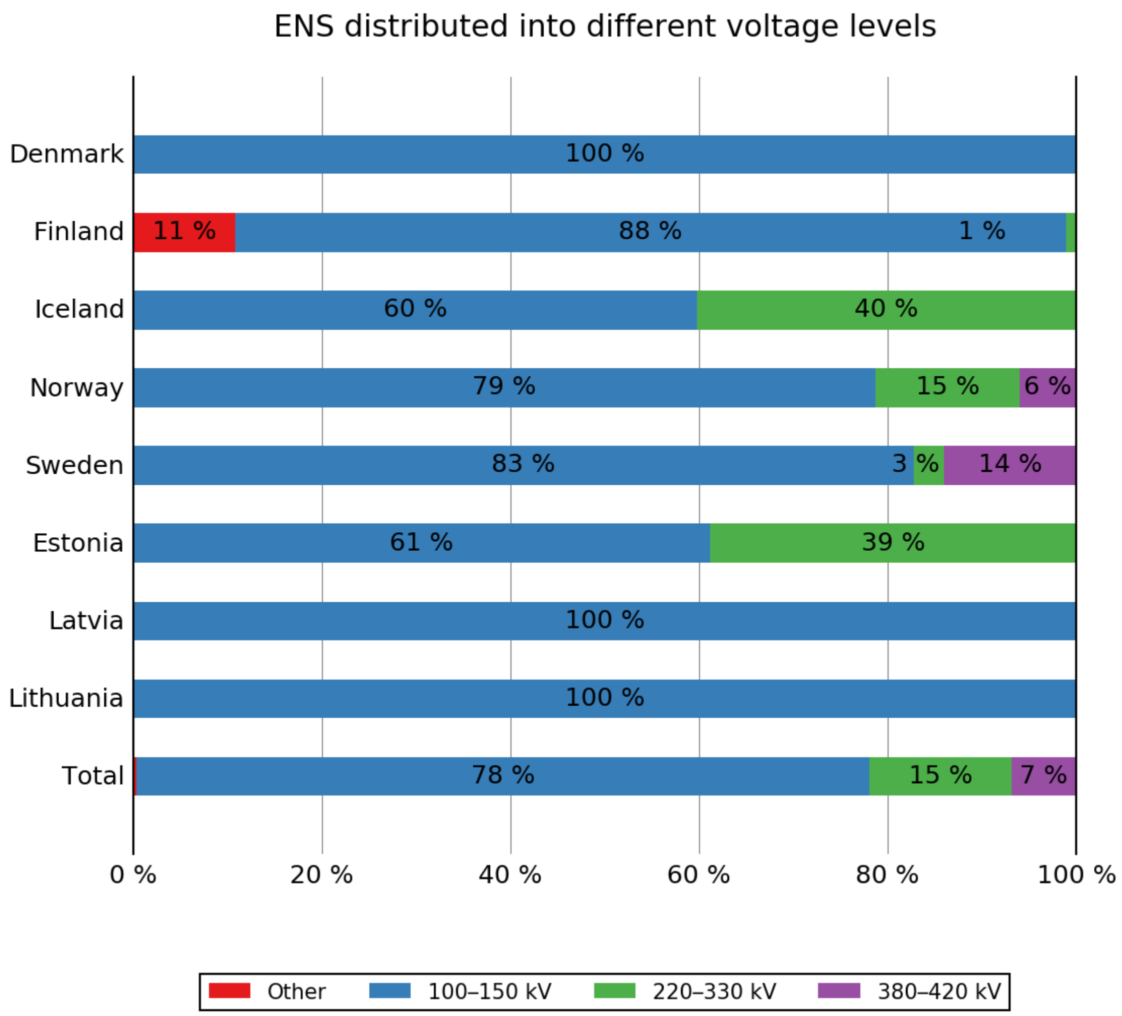

FIGURE 4.1.1 PERCENTAGE DISTRIBUTION OF ENERGY NOT SUPPLIED (ENS) IN TERMS OF THE VOLTAGE LEVEL OF THE PRIMARY FAULT IN 2015

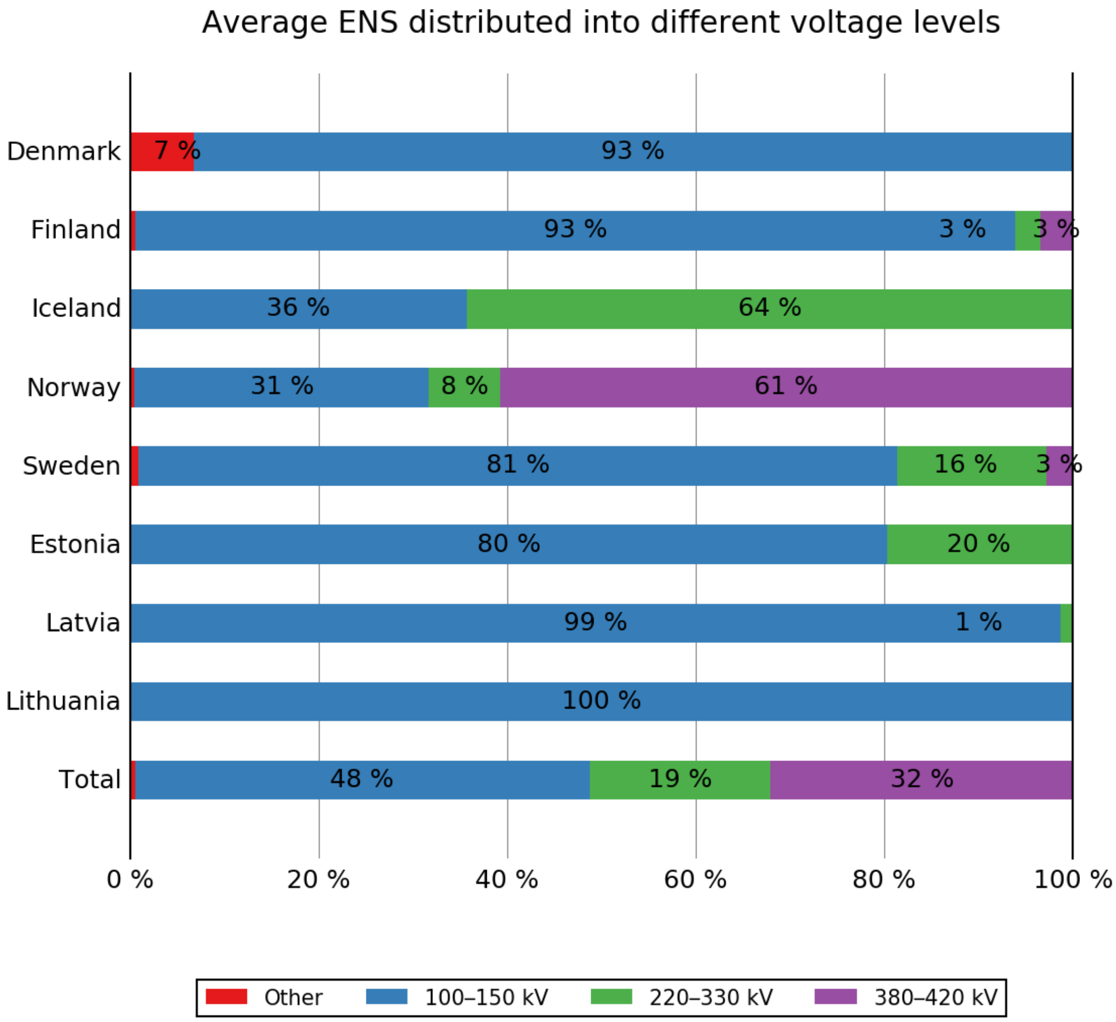

FIGURE 4.1.2 PERCENTAGE DISTRIBUTION OF ENERGY NOT SUPPLIED IN TERMS OF THE VOLTAGE LEVEL OF THE PRIMARY FAULT DURING THE PERIOD 2006–2015 FOR THE NORDIC COUNTRIES AND THE PERIOD 2014–2015 FOR THE BALTIC COUNTRIES

4.2 ENERGY NOT SUPPLIED (ENS) AND TOTAL CONSUMPTION

Table 4.2.1 shows the energy not supplied in relation to the total consumption of energy in each respective country and its distribution according to installation.

TABLE 4.2.1 ENERGY NOT SUPPLIED (ENS) AND ITS DISTRIBUTION ACCORDING TO INSTALLATION

Country	Consumption GWh	ENS MWh	ENS / consumption ppm	ENS / consumption ppm	ENS (%) divided according to installation Overhead lines	Cable	Station	Other
	2015	2015	2015	2006–2015	during the period 2006–2015			
Denmark	33616	26.4	0.8	0.6	4	0	76	20
Finland	82497	181.7	2.2	4.3	62	0	28	9
Iceland	18340	904.8	49.3	75.3	28	1	53	18
Norway	128605	2779.4	21.6	26.4	71	2	27	0
Sweden	136400	1361.6	10.0	12.9	27	5	60	4
				2014–2015	during the period 2014–2015			
Estonia	8137	30.7	3.8	3.7	15	0	19	65
Latvia	5506	54.2	9.8	7.8	56	0	44	0
Lithuania	9326	32.1	3.4	3.8	44	0	56	0
Total	422427	5371	12.7	16.8	51	2	41	5

Ppm (parts per million) represents ENS as a proportional value of the consumed energy, which is calculated: ENS × 10^6 / consumption. The sum of the ENS divided according to installation may not be exactly 100 % because all the ENS is not always connected with a cause.

Figure 4.2.1 and 4.2.2 presents the progression of ENS during the period 2006–2015 in the Nordic countries and during the period 2014–2015 in the Baltic countries. 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.

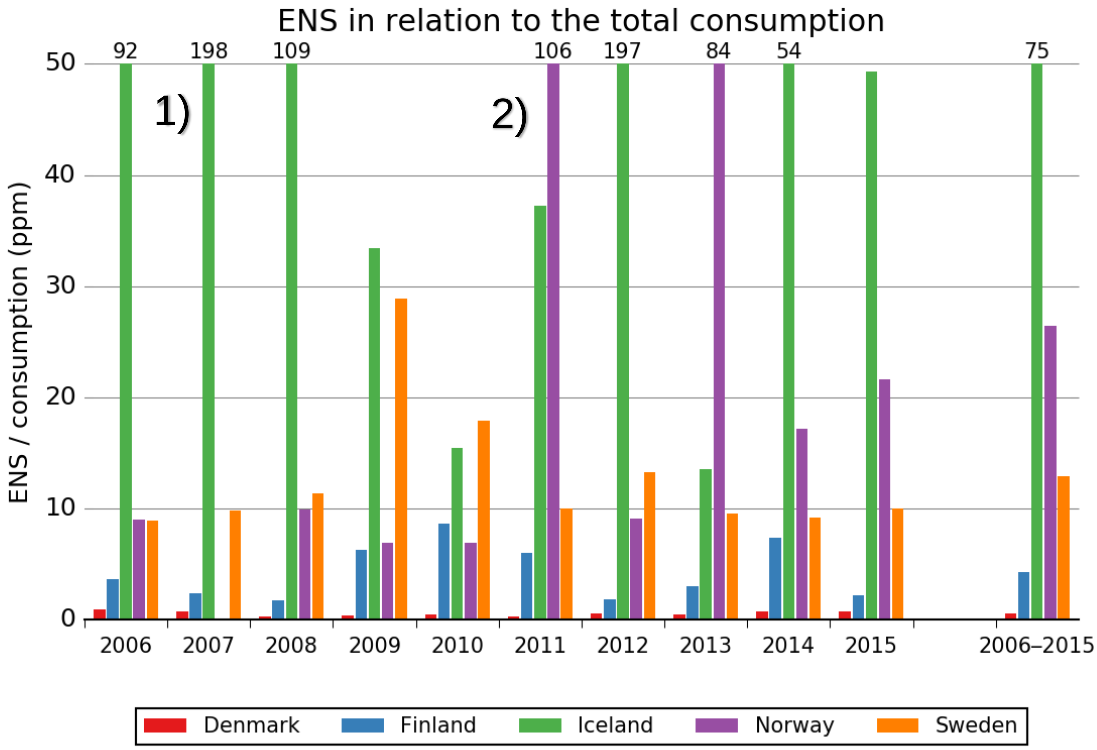

FIGURE 4.2.1 ANNUAL ENERGY NOT SUPPLIED (ENS) DIVIDED BY CONSUMPTION (PPM) IN THE NORDIC COUNTRIES FOR THE PERIOD 2006–2015

1) 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 and 2012.

2) The unusually high ENS divided by the consumption in 2011 in Norway was caused by extreme weather conditions in December (aka the storm named Dagmar).

Denmark’s low values in Figure 4.2.1 are a result of various elements such as having a meshed grid and compared to the other Nordic countries, a mild climate.

Iceland’s high values in Figure 4.2.1 are a result of power intensive industries that cause substantial amounts of ENS even during short interruptions.

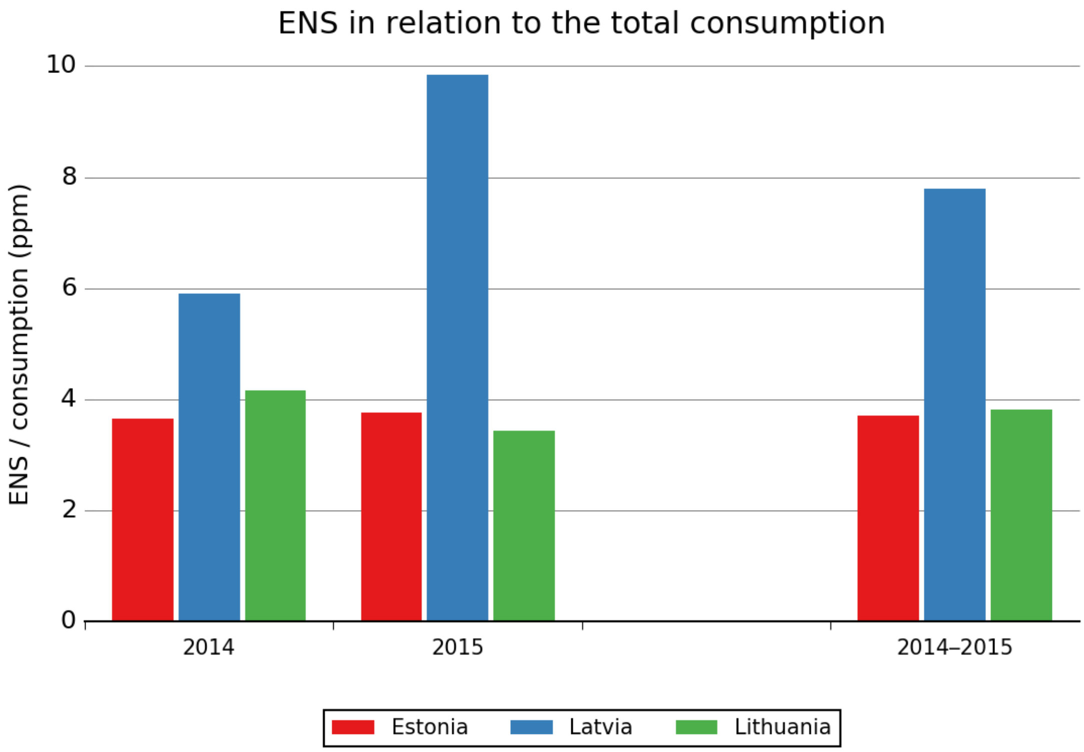

FIGURE 4.2.2 ANNUAL ENERGY NOT SUPPLIED (ENS) DIVIDED BY CONSUMPTION (PPM) IN THE BALTIC COUNTRIES FOR THE PERIOD 2014–2015

4.3 ENERGY NOT SUPPLIED (ENS) DISTRIBUTED ACCORDING TO MONTH

Figure 4.3.1 and Figure 4.3.2 present the distribution of energy not supplied according to month for the year 2015. Figure 4.3.3 presents the average for the period 2006–2015 in the Nordic countries and Figure 4.3.4 presents the average for the period 2014–2015 in the Baltic countries.

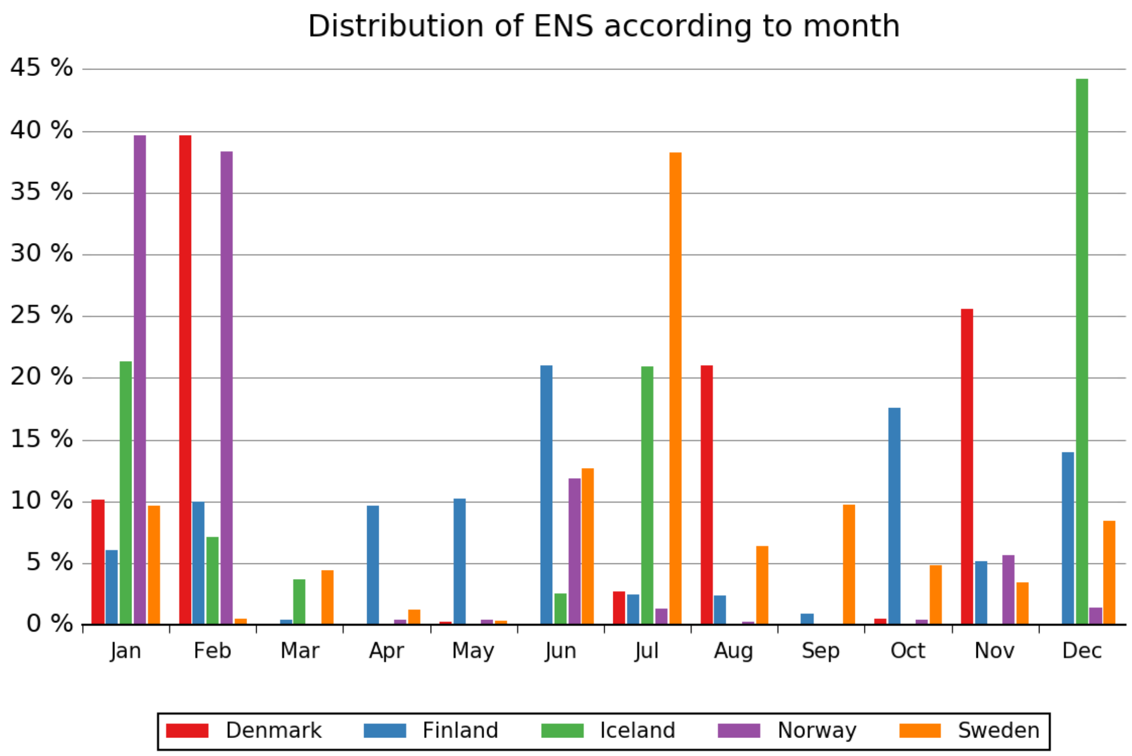

Figure 4.3.1 Percentage distribution of energy not supplied (ENS) according to month in each Nordic country in 2015

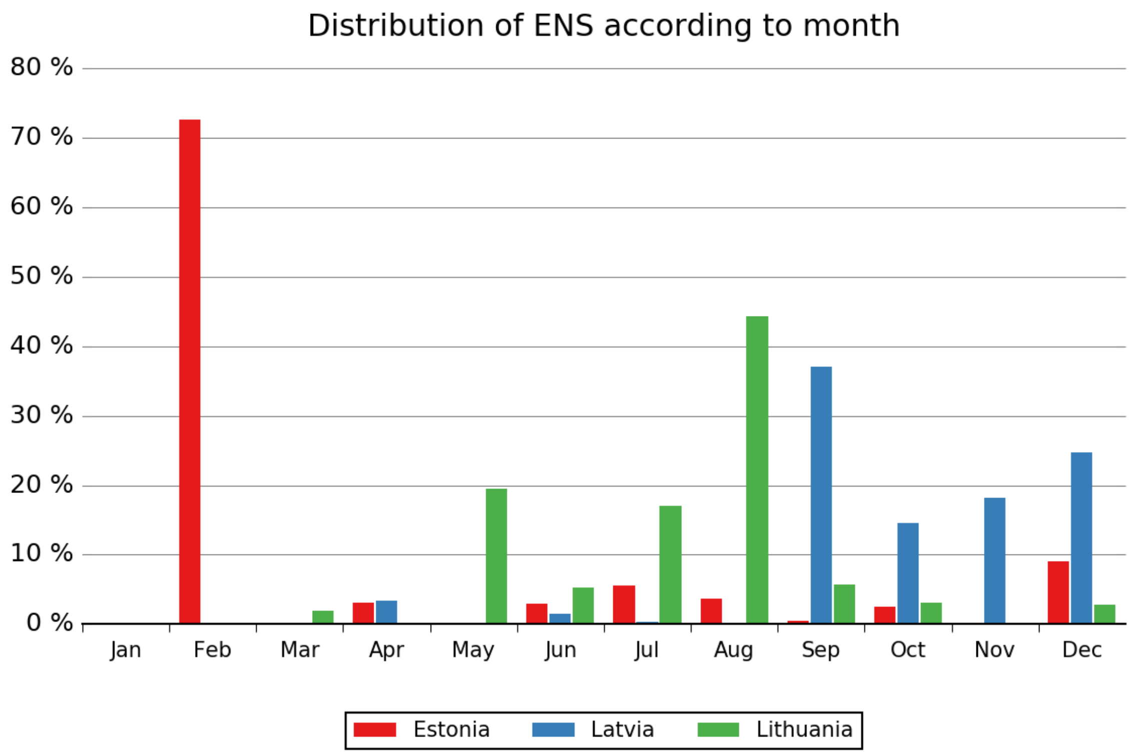

Figure 4.3.2 Percentage distribution of energy not supplied (ENS) according to month in each Baltic country in 2015

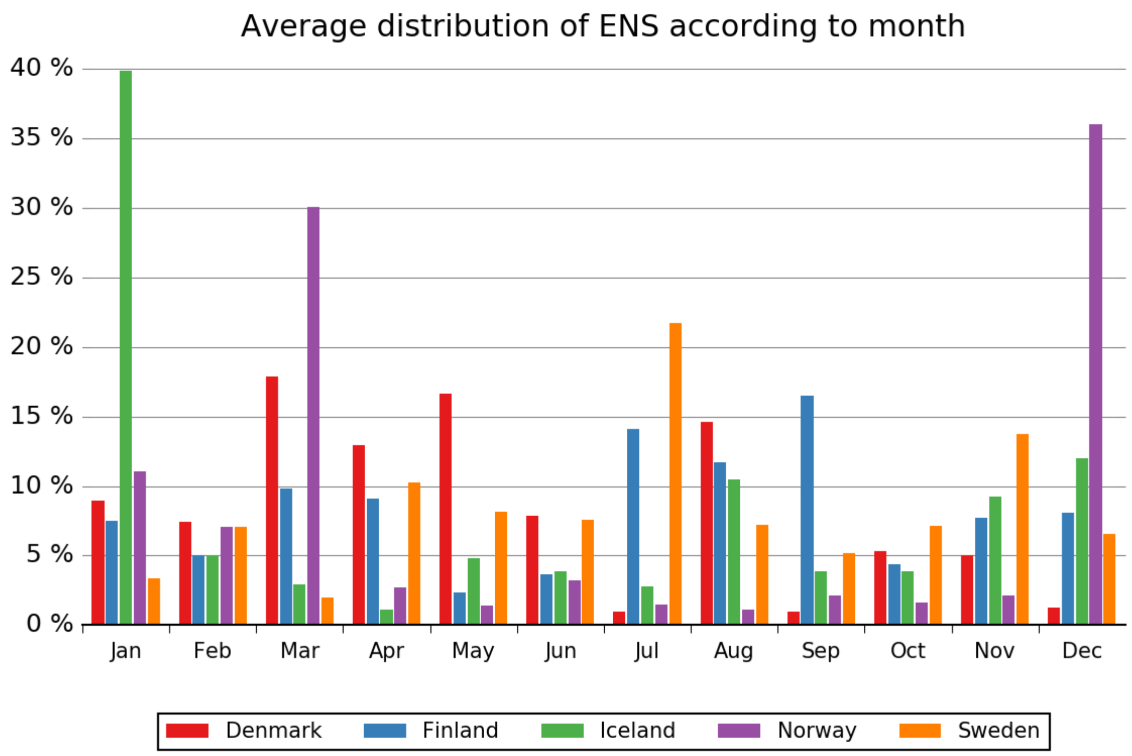

FIGURE 4.3.3 AVERAGE PERCENTAGE DISTRIBUTION OF GRID DISTURBANCES ACCORDING TO MONTH IN EACH NORDIC COUNTRY DURING THE PERIOD 2006–2015

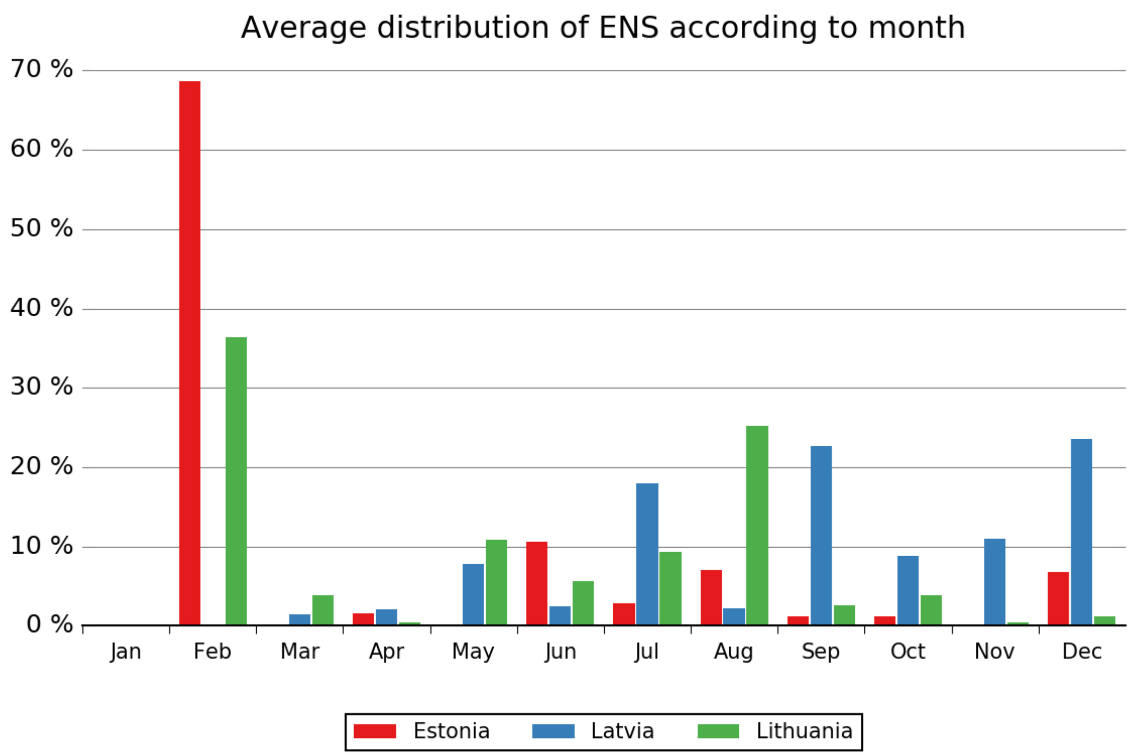

FIGURE 4.3.4 AVERAGE PERCENTAGE DISTRIBUTION OF GRID DISTURBANCES ACCORDING TO MONTH IN EACH BALTIC COUNTRY DURING THE PERIOD 2014–2015

4.4 Energy not supplied (ENS) distributed according to cause

Figure 4.4.1 and Figure 4.4.2 present the distribution of energy not supplied according to cause in 2015. Figure 4.4.3 presents the average for the period 2006–2015 in the Nordic countries and Figure 4.4.4 presents the average for the period 2014–2015 in the Baltic countries. Appendix 2 provides more details about how each country investigates line faults.

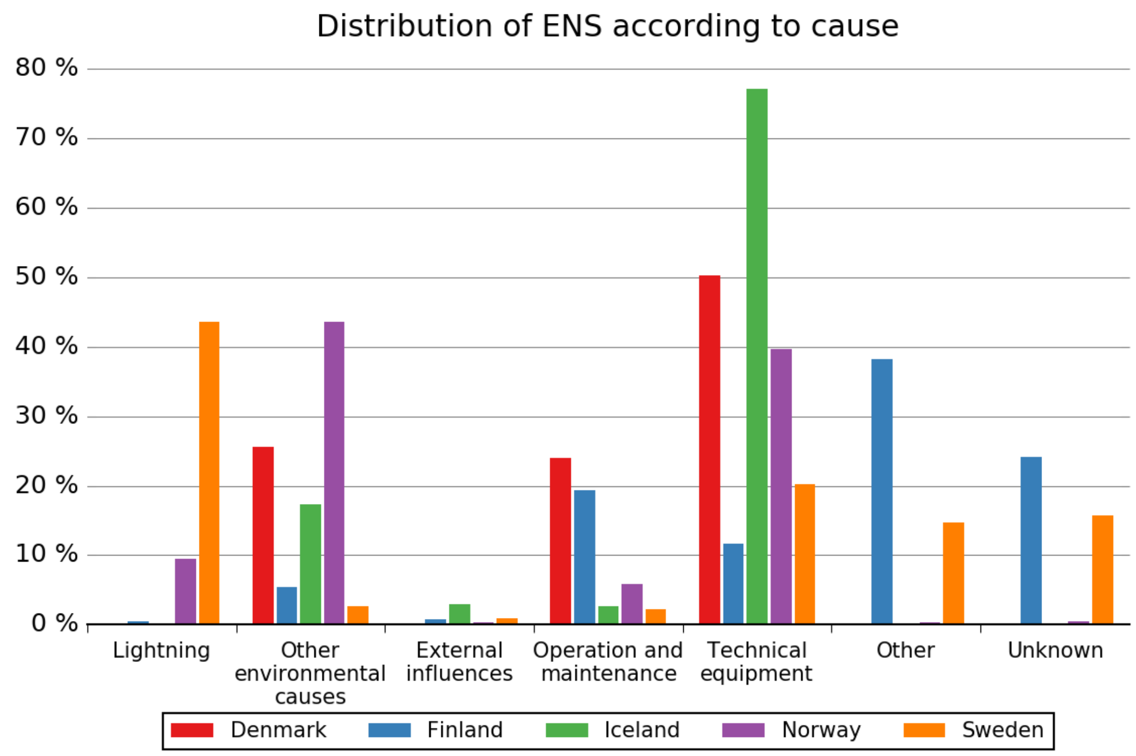

Figure 4.4.1 Percentage distribution of energy not supplied according to the cause of the primary fault in each Nordic country in 2015

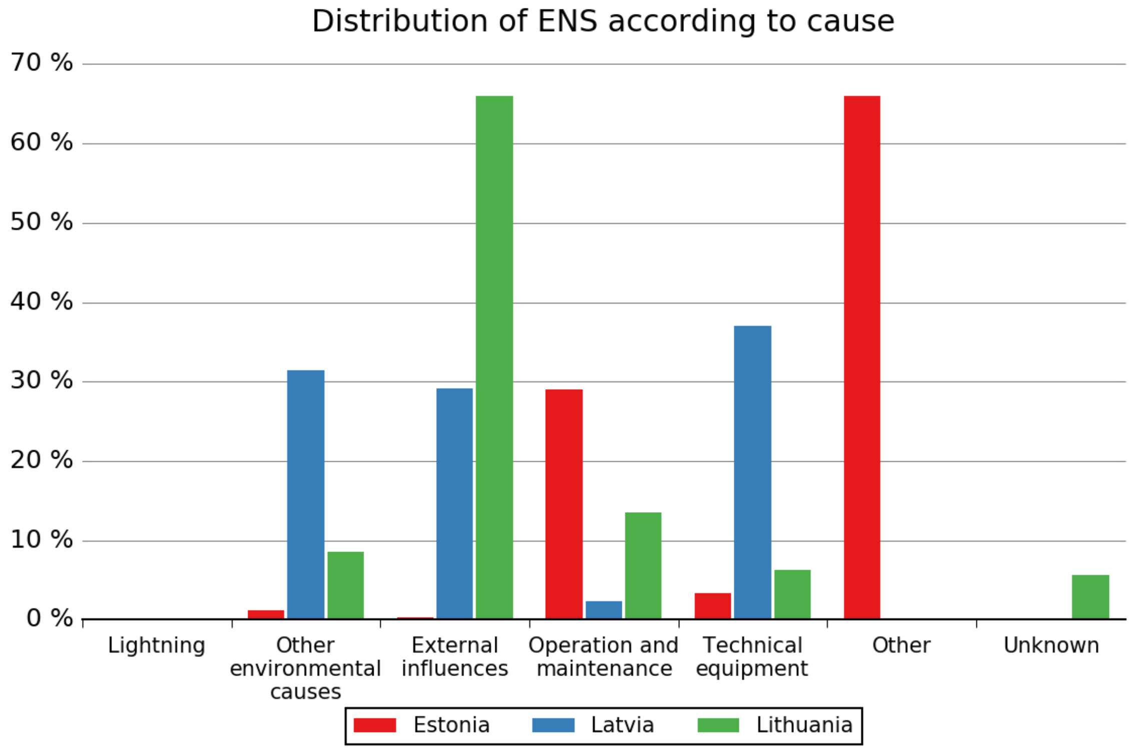

FIGURE 4.4.2 PERCENTAGE DISTRIBUTION OF ENERGY NOT SUPPLIED ACCORDING TO THE CAUSE OF THE PRIMARY FAULT IN EACH BALTIC COUNTRY IN 2015

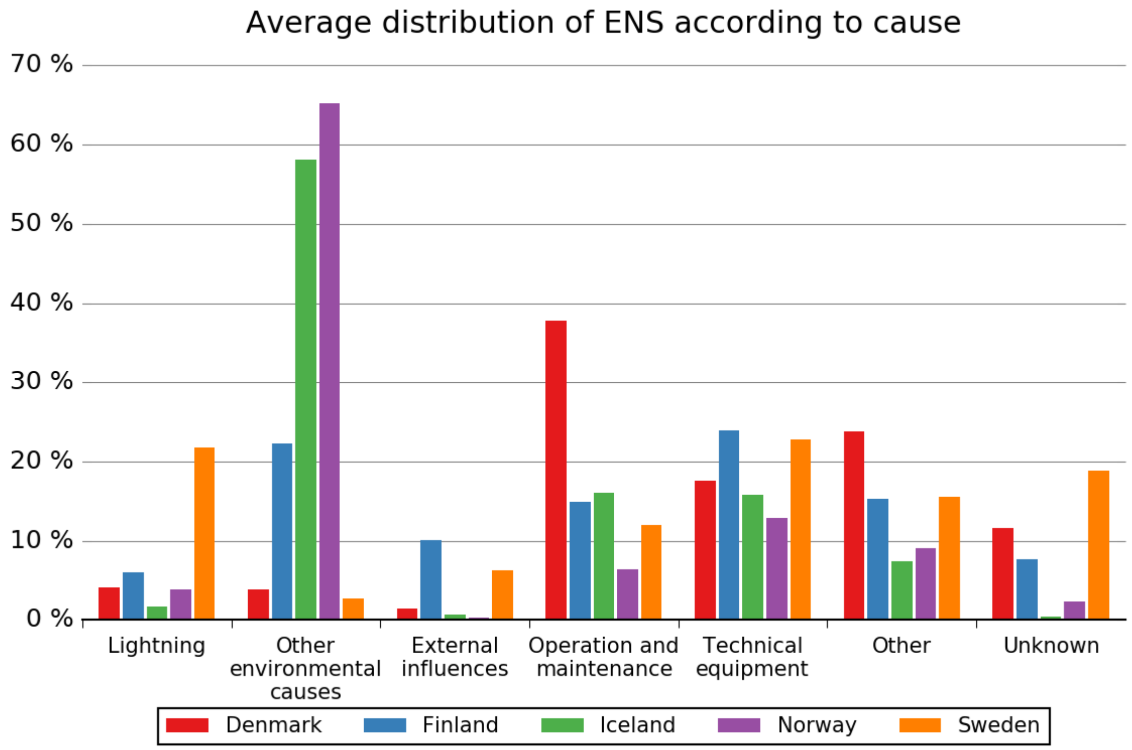

FIGURE 4.4.3 AVERAGE PERCENTAGE DISTRIBUTION OF ENS ACCORDING TO THE CAUSE OF THE PRIMARY FAULT IN EACH NORDIC COUNTRY DURING THE PERIOD 2006–2015

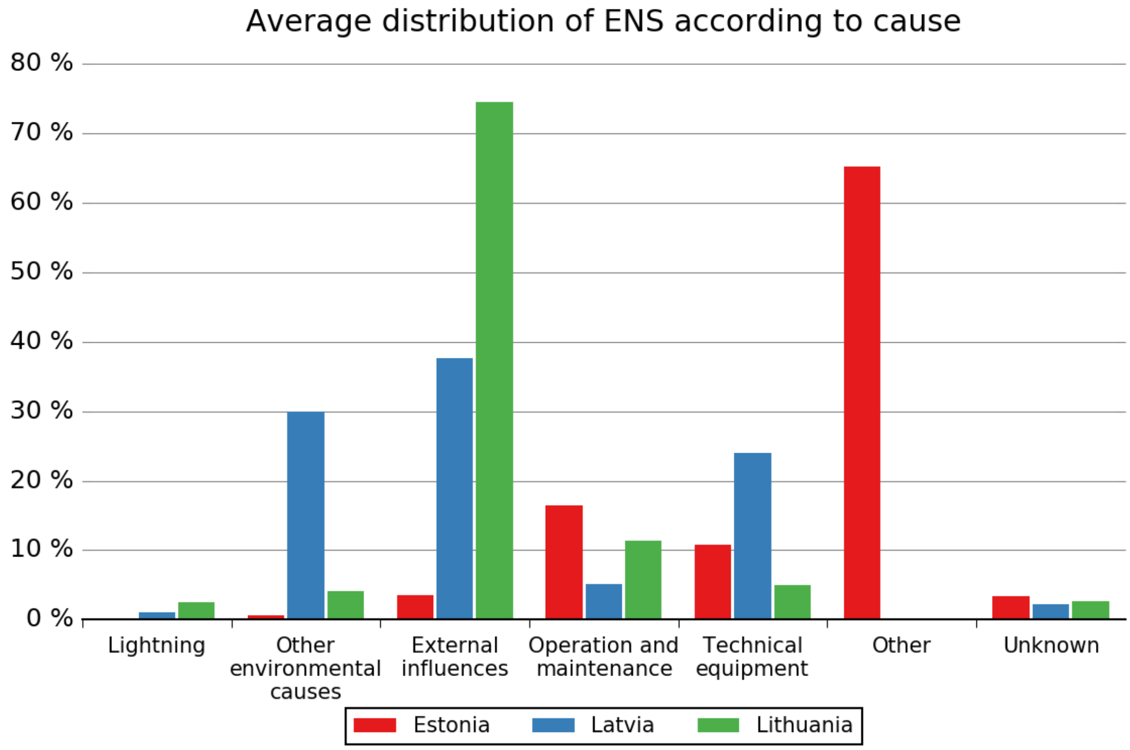

FIGURE 4.4.4 AVERAGE PERCENTAGE DISTRIBUTION OF ENS ACCORDING TO THE CAUSE OF THE PRIMARY FAULT IN EACH BALTIC COUNTRY DURING THE PERIOD 2014–2015

4.5 Energy not supplied (ENS) distributed according to component

Table 4.5.1 shows the amount of energy not supplied in 2015 and the annual average for the period 2006–2015. Table 4.5.2 and Table 4.5.3 show the distribution of energy not supplied according to component.

TABLE 4.5.1 ENERGY NOT SUPPLIED (ENS) IN EACH NORDIC AND BALTIC COUNTRY IN 2015 AND THE ANNUAL AVERAGE FOR THE PERIOD 2006–2015

Country	ENS (MWh)	
	2015	2006–2015
Denmark	26	19
Estonia[1)]	31	30
Finland	182	365
Iceland	905	1209
Latvia[1)]	54	45
Lithuania[1)]	32	36
Norway	2779	3441
Sweden[2)]	1362	1818
Total	5371	6963

1) The average for the Baltic countries is counted from 2014 because their earliest data is from 2014.

2) One Swedish regional grid delivered incomplete data in 2012. The details of the origin of the fault were not reported and therefore 750 MWh of ENS is not included from that year.

TABLE 4.5.2 PERCENTAGE DISTRIBUTION OF ENERGY NOT SUPPLIED IN TERMS OF COMPONENT IN EACH NORDIC COUNTRY

	Denmark		Finland		Iceland		Norway		Sweden		Average	
Fault location	2015	2006–2015	2015	2006–2015	2015	2006–2015	2015	2006–2015	2015	2006–2015	2015	2006–2015
Overhead line	0	4	41	62	17	28	39	71	56	27	39	51
Cable	0	0	0	0	0	1	0	2	0	5	0	2
Line faults	**0**	**4**	**41**	**63**	**17**	**29**	**39**	**72**	**56**	**32**	**40**	**53**
Power transformers	20	18	1	2	0	0	0	3	17	9	5	4
Instrument transformers	41	10	0	3	0	0	3	2	0	5	2	2
Circuit breakers	0	9	3	2	45	25	1	1	0	3	8	6
Busbar	25	10	0	2	0	4	19	3	1	2	10	3
Control equipment	3	11	2	12	3	10	36	8	3	3	21	7
Disconnectors and earth connectors	10	16	9	2	0	8	0	1	4	7	1	4
Surge arresters and spark gap	0	0	0	3	0	0	0	3	0	0	0	2
Common ancillary equipment	0	0	0	0	0	0	1	0	0	0	0	0
Other substation faults	0	0	5	3	17	3	1	6	5	30	5	11
Substation faults	**99**	**75**	**19**	**28**	**65**	**50**	**61**	**27**	**30**	**59**	**52**	**40**
Shunt capacitor	0	0	0	0	0	2	0	0	2	0	1	0
Series capacitor	0	0	10	1	0	0	0	0	0	0	0	0
Reactor	0	1	5	0	0	0	0	0	0	0	0	0
Synchronous compensator	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
Compensation faults	**0**	**1**	**16**	**1**	**0**	**2**	**0**	**0**	**2**	**0**	**1**	**1**
System fault	0	12	9	0	1	15	0	0	0	1	0	3
Faults in adjoining statistical area	0	8	15	9	18	3	0	0	11	3	7	2
Unknown	0	0	0	0	0	0	0	0	0	0	0	0
Other faults	**0**	**20**	**25**	**9**	**19**	**18**	**0**	**0**	**11**	**4**	**7**	**5**

TABLE 4.5.3 PERCENTAGE DISTRIBUTION OF ENERGY NOT SUPPLIED IN TERMS OF COMPONENT IN EACH BALTIC COUNTRY IN 2015

	Estonia		**Latvia**		**Lithuania**		**Average**	
Fault location	**2015**	**2014–2015**	**2015**	**2014–2015**	**2015**	**2014–2015**	**2015**	**2014–2015**
Overhead line	26	15	41	56	83	44	48	41
Cable	0	0	0	0	0	0	0	0
Line faults	**26**	**15**	**41**	**56**	**83**	**44**	**48**	**41**
Power transformers	0	0	0	0	0	0	0	0
Instrument transformers	0	0	0	0	0	2	0	1
Circuit breakers	0	2	0	0	1	0	0	1
Busbar	0	1	0	3	3	3	1	2
Control equipment	0	9	51	37	10	46	26	32
Disconnectors and earth connectors	2	1	7	5	0	2	4	3
Surge arresters and spark gap	0	0	0	0	0	0	0	0
Common ancillary equipment	0	0	0	0	0	0	0	0
Other substation faults	6	6	0	0	4	2	3	2
Substation faults	**8**	**19**	**59**	**44**	**17**	**56**	**34**	**41**
Shunt capacitor	0	0	0	0	0	0	0	0
Series capacitor	0	0	0	0	0	0	0	0
Reactor	0	0	0	0	0	0	0	0
Synchronous compensator	0	0	0	0	0	0	0	0
SVC and statcom	0	0	0	0	0	0	0	0
Compensation faults	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
System fault	0	0	0	0	0	0	0	0
Faults in adjoining statistical area	66	65	0	0	0	0	17	18
Unknown	0	0	0	0	0	0	0	0
Other faults	**66**	**65**	**0**	**0**	**0**	**0**	**17**	**18**

It should be noted that some countries register the total amount of energy not supplied in a disturbance in terms of the primary fault. Therefore, the data is not necessarily comparable.

5 FAULTS IN POWER SYSTEM COMPONENTS

This chapter presents the faults in power system components for the countries that have that particular component in their grid. The definitions and scope is defined in chapter 5.1.

Chapter 5.2 gives an overview of all faults registered in the component groups used in these statistics, followed by more detailed statistics relating to each specific component group. Ten-year average values have been calculated for most components. An even a longer period has been used for overhead lines and cables 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 grouped into 100–150 kV, 220–330 kV and 380–420 kV voltage levels for most of the components. Readers who need more detailed data should use the national statistics published by the national regulators.

5.1 DEFINITIONS AND SCOPE

A fault in a component implies that it is not able to perform its function properly. Faults can have many causes, for example manufacturing defects or insufficient maintenance. 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. Overhead lines, for example, normally have more faults than cables. On the other hand, cables normally have considerably longer repair times than overhead lines.

A component fault is defined as:

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 disturbance*

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"*

5.2 OVERVIEW OF THE FAULTS RELATED TO DISTURBANCES

Table 5.2.1 presents the number of faults and disturbances during 2015.

TABLE 5.2.1 NUMBER OF FAULTS AND GRID DISTURBANCES IN EACH NORDIC AND BALTIC COUNTRY IN 2015

2015	Number of faults in 2015	Number of disturbances in 2015	Fault / disturbance ratio in 2015	Fault / disturbance ratio during 2006–2015
Denmark	93	79	1.18	1.15
Estonia[1)]	221	219	1.01	1.00
Finland	476	454	1.05	1.06
Iceland	87	47	1.85	1.38
Latvia[1)]	126	112	1.13	1.11
Lithuania[1)]	151	138	1.09	1.04
Norway	485	437	1.11	1.08
Sweden	403	378	1.07	1.03

1) The average for the Baltic countries is counted from 2014 because their earliest data is from 2014.

Table 5.2.2 presents the distribution of faults and energy not supplied in terms of voltage level and country. In addition, the table shows the overhead 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 on lines and in power transformers.

TABLE 5.2.2 FAULTS IN DIFFERENT COUNTRIES IN TERMS OF VOLTAGE LEVEL IN EACH NORDIC AND BALTIC COUNTRY

Voltage	Country	Size of the grid in 2015		Number of faults		ENS (MWh)	
		Number of power transformers	Length of lines in km[2)]	2015	2006–2015	2015	2006–2015
380–420 kV	Denmark	29	1479	19	7.7	0.0	0.0
	Estonia[1)]	0	0	11	5.5	0.0	0.0
	Finland	101	4932	19	25.7	0.0	12.3
	Iceland	0	0	0	0.0	0.0	0.0
	Latvia[1)]	0	0	0	0.0	0.0	0.0
	Lithuania[1)]	0	0	0	0.0	0.0	0.0
	Norway	64	2976	116	73.1	166.9	2129.2
	Sweden	70	10568	103	113.5	189.8	35.3
220–330 kV	Denmark	5	116	3	1.0	0.0	0.0
	Estonia[1)]	23	1856	22	24.0	11.9	6.0
	Finland	46	2214	7	20.1	2.0	9.2
	Iceland	12	859	23	14.6	295.7	759.7
	Latvia[1)]	25	1395	16	17.0	0.0	0.6
	Lithuania[1)]	24	1761	16	13.5	0.0	0.0
	Norway	250	5207	153	99.8	426.5	266.2
	Sweden	105	4143	44	65.5	43.2	279.1
100–150 kV	Denmark	226	4321	58	59.2	25.4	17.6
	Estonia[1)]	218	3492	152	165.0	18.8	24.2
	Finland	1171	16489	395	375.4	154.7	329.8
	Iceland	43	1365	61	29.6	439.6	421.9
	Latvia[1)]	246	3891	93	115.0	54.2	44.3
	Lithuania[1)]	419	5070	116	131.0	32.1	35.7
	Norway	724	11199	216	184.9	2186.1	1094.2
	Sweden	823	16375	210	346.7	1119.5	1502.5

1) The average for the Baltic countries is counted from 2014 because their earliest data is from 2014.

2) The length of lines is the sum of the length of cables and overhead lines.

Table 5.2.3 and Table 5.2.4 show the number of faults classified according to the component groups used in this statistics. It should be noted that all countries do not have every type of equipment in their network. For example, static var compensators (SVCs) or STATCOM installations do not exist in every country. 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 statistics (typically from networks with voltages lower than 100 kV) but still influence statistic area.

TABLE 5.2.3 PERCENTAGE DISTRIBUTION OF FAULTS ACCORDING TO COMPONENT TYPE IN EACH NORDIC COUNTRY

	Denmark		Finland		Iceland		Norway		Sweden		Average	
Component type	**2015**	**2006–2015**	**2015**	**2006–2015**	**2015**	**2006–2015**	**2015**	**2006–2015**	**2015**	**2006–2015**	**2015**	**2006–2015**
Overhead line	32	54	77	78	64	41	53	49	54	61	60	63
Cable	8	4	1	0	0	1	1	1	1	1	1	1
Line faults	**40**	**58**	**78**	**79**	**64**	**42**	**54**	**50**	**56**	**62**	**61**	**64**
Power transformers	11	5	1	2	1	3	2	2	8	7	4	4
Instrument transformers	3	3	0	1	0	0	2	2	1	1	1	1
Circuit breakers	3	4	1	1	3	4	4	4	2	2	3	2
Busbar	2	1	0	0	0	0	2	1	1	1	1	1
Control equipment	15	15	3	9	8	20	18	19	14	7	12	11
Disconnectors and earth connectors	2	2	0	0	0	0	1	1	1	0	1	1
Surge arresters and spark gap	1	0	0	0	0	0	1	1	0	0	0	0
Common ancillary equipment	0	0	1	0	0	0	1	1	0	0	1	0
Other substation faults	5	3	1	2	1	3	7	11	2	6	3	6
Substation faults	**44**	**32**	**9**	**15**	**14**	**30**	**38**	**43**	**29**	**25**	**26**	**27**
Shunt capacitor	0	0	1	0	0	2	2	1	0	0	1	1
Series capacitor	0	0	1	1	0	0	0	0	0	3	0	1
Reactor	1	2	0	0	0	0	0	0	1	2	1	1
Synchronous compensator	1	0	0	0	0	0	0	0	0	0	0	0
SVC and statcom	1	0	0	0	1	0	6	4	2	2	3	2
Compensation faults	**3**	**2**	**2**	**2**	**1**	**3**	**8**	**6**	**4**	**7**	**5**	**5**
System fault	0	1	0	0	17	20	0	0	0	1	1	1
Faults in adjoining statistical area	13	6	11	4	3	5	0	2	11	5	7	4
Unknown	0	0	0	0	0	0	0	0	0	0	0	0
Other faults	**13**	**7**	**11**	**4**	**21**	**25**	**0**	**2**	**11**	**6**	**8**	**5**

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

TABLE 5.2.4 PERCENTAGE DISTRIBUTION OF FAULTS ACCORDING TO COMPONENT TYPE IN EACH BALTIC COUNTRY

	Estonia		Latvia		Lithuania		Average	
Component type	**2015**	**2014–2015**	**2015**	**2014–2015**	**2015**	**2014–2015**	**2015**	**2014–2015**
Overhead line	42	49	52	64	66	73	51	60
Cable	0	0	0	0	0	0	0	0
Line faults	**42**	**49**	**52**	**64**	**66**	**73**	**51**	**60**
Power transformers	6	6	6	5	0	1	4	4
Instrument transformers	3	2	1	1	0	0	1	1
Circuit breakers	8	6	4	3	5	3	6	4
Busbar	3	2	1	1	1	1	2	1
Control equipment	1	6	21	15	13	13	9	10
Disconnectors and earth connectors	7	6	2	1	1	1	4	3
Surge arresters and spark gap	0	0	0	0	1	0	0	0
Common ancillary equipment	5	2	0	0	1	2	2	1
Other substation faults	17	12	0	0	1	0	8	5
Substation faults	**49**	**41**	**35**	**27**	**22**	**21**	**37**	**31**
Shunt capacitor	0	0	0	0	0	0	0	0
Series capacitor	0	0	0	0	0	0	0	0
Reactor	1	0	1	1	0	0	1	0
Synchronous compensator	0	0	0	0	0	0	0	0
SVC and statcom	0	0	0	0	0	0	0	0
Compensation faults	**1**	**0**	**1**	**1**	**0**	**0**	**1**	**0**
System fault	0	0	0	0	0	0	0	0
Faults in adjoining statistical area	9	9	13	9	13	6	11	8
Unknown	0	0	0	0	0	0	0	0
Other faults	**9**	**9**	**13**	**9**	**13**	**6**	**11**	**8**

5.3 FAULTS ON OVERHEAD LINES

Overhead lines are a significant part of the Nordic and Baltic transmission grids. Therefore, the tables in this section show the distribution of faults in 2015 as well as the average values for the period 1996–2015. The tables also give the faults distributed by cause during the period 1996–2015. Along with the tables, the annual distribution of faults and the annual number of permanent faults during the period 2006–2015 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.

5.3.1 380–420 KV OVERHEAD LINES

Table 5.3.1 shows the line lengths, number of faults on 380–420 kV overhead lines, the causes of faults and the percentage values of 1-phase faults and permanent faults for the countries that have this voltage level. The data consists of the values for the year 2015 and for the period 1996–2015. Figure 5.3.1 presents the annual line fault values per line length during the ten-year period 2006–2015 and the average value of period 1996–2015. Figure 5.3.2 presents the annual distribution of permanent line faults during the same period. Iceland and the Baltic countries are absent from these tables and figures because they lack 380–420 kV overhead lines.

TABLE 5.3.1 380–420 KV OVERHEAD LINES FAULTS AND THE DISTRIBUTION ACCORDING TO CAUSE

Country	Lines (km)	Number of faults	Number of faults per 100 km		Lightning	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown	1-phase faults	Permanent faults
	2015	2015	2015	1996–2015	Faults divided by cause (%) during the period 1996–2015								
Denmark	1348	7	0.52	0.33	20	61	6	4	4	4	1	50	5
Finland	4932	7	0.14	0.25	71	10	2	6	2	5	5	64	10
Norway	2951	61	2.07	1.15	21	73	0	0	2	2	2	70	6
Sweden	10560	49	0.46	0.37	49	19	2	3	3	1	23	82	7
Total	19791	124	0.63	0.45	41	38	1	2	2	2	12	74	7

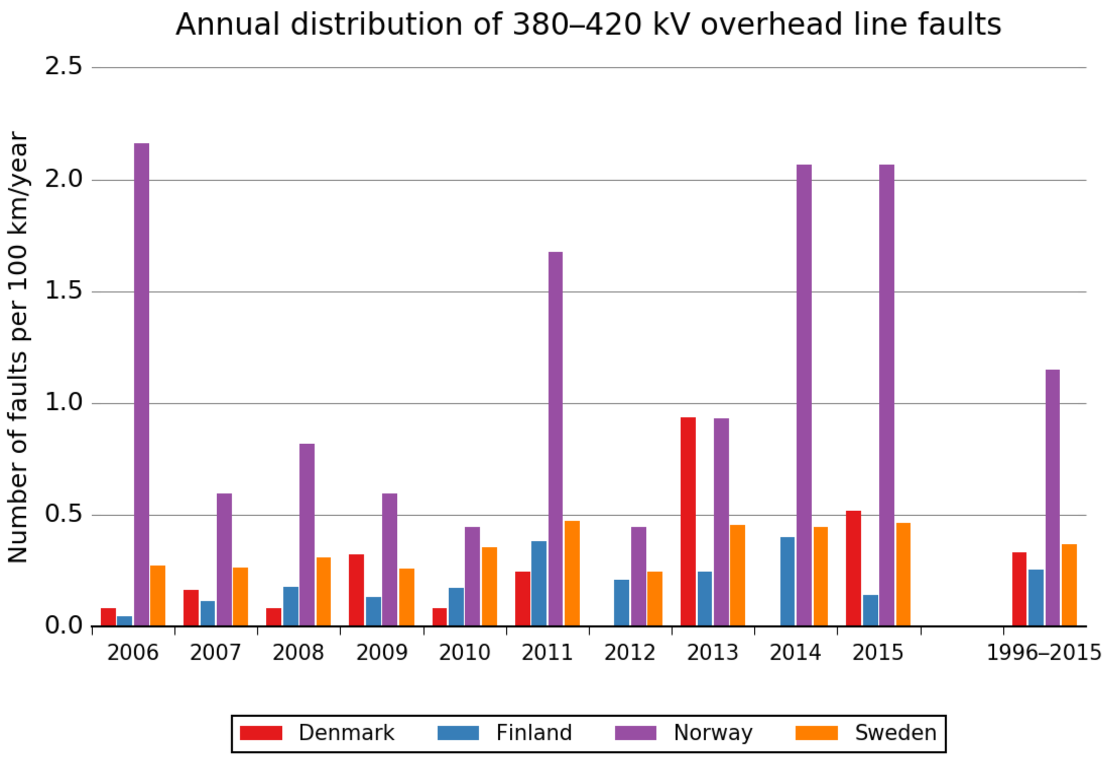

FIGURE 5.3.1 ANNUAL DISTRIBUTION OF FAULTS FOR 380–420 KV OVERHEAD LINES DURING THE PERIOD 2006–2015 AND THE AVERAGE FOR 1996–2015 IN NORDIC COUNTRIES

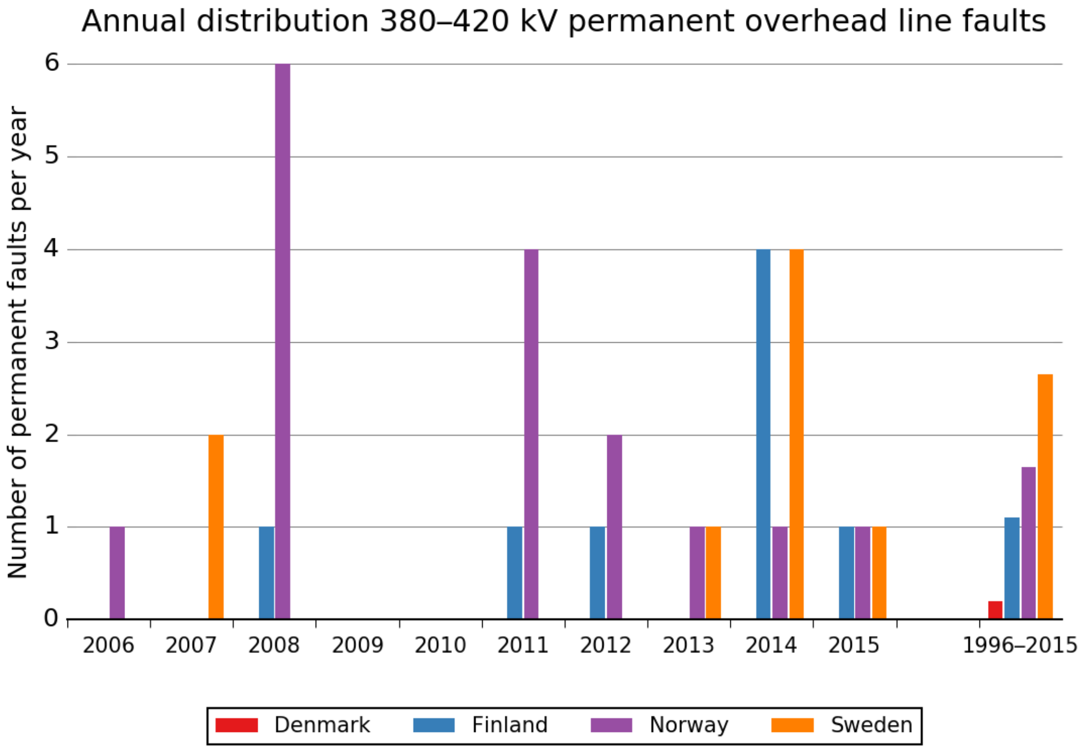

FIGURE 5.3.2 ANNUAL DISTRIBUTION OF PERMANENT FAULTS FOR 380–420 KV OVERHEAD LINES DURING THE PERIOD 1995–2015 AND THE AVERAGE FOR 1996–2015 IN NORDIC COUNTRIES

5.3.2 220–330 KV OVERHEAD LINES

Table 5.3.2 shows the line lengths, number of faults on 220–330 kV overhead lines, the causes of faults and the percentage values of 1-phase faults and permanent faults. Figure 5.3.3 presents the annual line fault values per line length during the period 2006–2015 and the average value for the period 1996–2015 in the Nordic countries. Figure 5.3.4 presents the annual line fault values per line length during the period 2014–2015 and the average in the Baltic countries. Figure 5.3.5 and Figure 5.3.6 present the annual distribution of permanent line faults during the mentioned periods in the Nordic and Baltic countries, respectively.

TABLE 5.3.2 220–330 KV OVERHEAD LINES FAULTS AND THE DISTRIBUTION ACCORDING TO CAUSE IN EACH NORDIC AND BALTIC COUNTRY

Country	Lines (km)	Number of faults	Number of faults per 100 km		Light-ning	Other environ-mental causes	Exter-nal influ-ences	Opera-tion and mainte-nance	Tech-nical equip-ment	Ot-her	Un-known	1-phase faults	Perma-nent faults
	2015	2015	2015	1996–2015	Faults divided by cause (%) during the period 1996–2015								
Denmark	56	1	1.79	0.51	40	10	20	0	0	10	20	90	0
Finland	2214	6	0.27	0.75	46	11	2	2	1	2	37	73	4
Iceland	859	12	1.40	0.40	21	66	0	0	14	0	0	38	17
Norway	5139	77	1.50	0.76	49	40	1	0	2	2	5	65	8
Sweden	4031	16	0.40	0.85	68	5	4	4	4	1	15	57	7
				2014–2015	Faults divided by cause (%) during the period 2014–2015								
Estonia	1856	14	0.75	0.57	19	24	0	19	38	0	0	62	5
Latvia	1381	6	0.43	0.65	17	11	11	17	0	0	44	72	11
Lithuania	1761	12	0.68	0.65	4	0	17	13	0	0	65	83	9
Total	17297	144	0.83	0.66	45	26	5	1	4	3	15	65	7

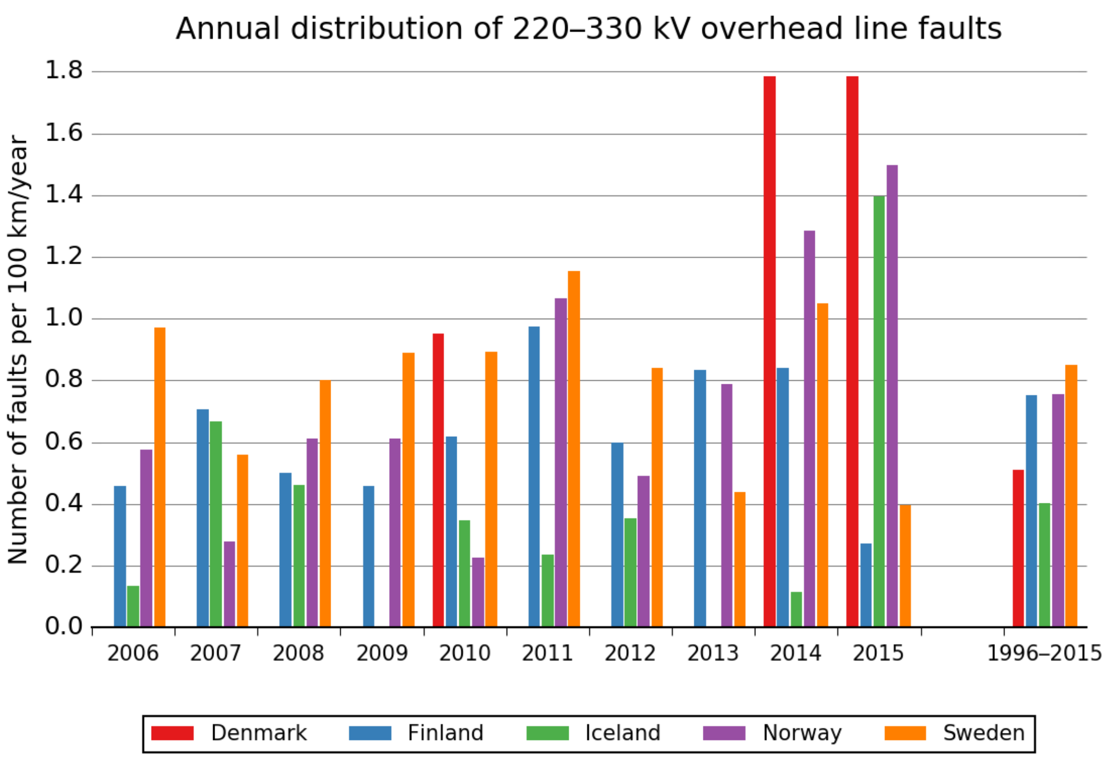

FIGURE 5.3.3 ANNUAL DISTRIBUTION OF FAULTS FOR 220–330 KV OVERHEAD LINES DURING THE PERIOD 2006–2015 AND THE AVERAGE FOR 1996–2015 IN EACH NORDIC COUNTRY

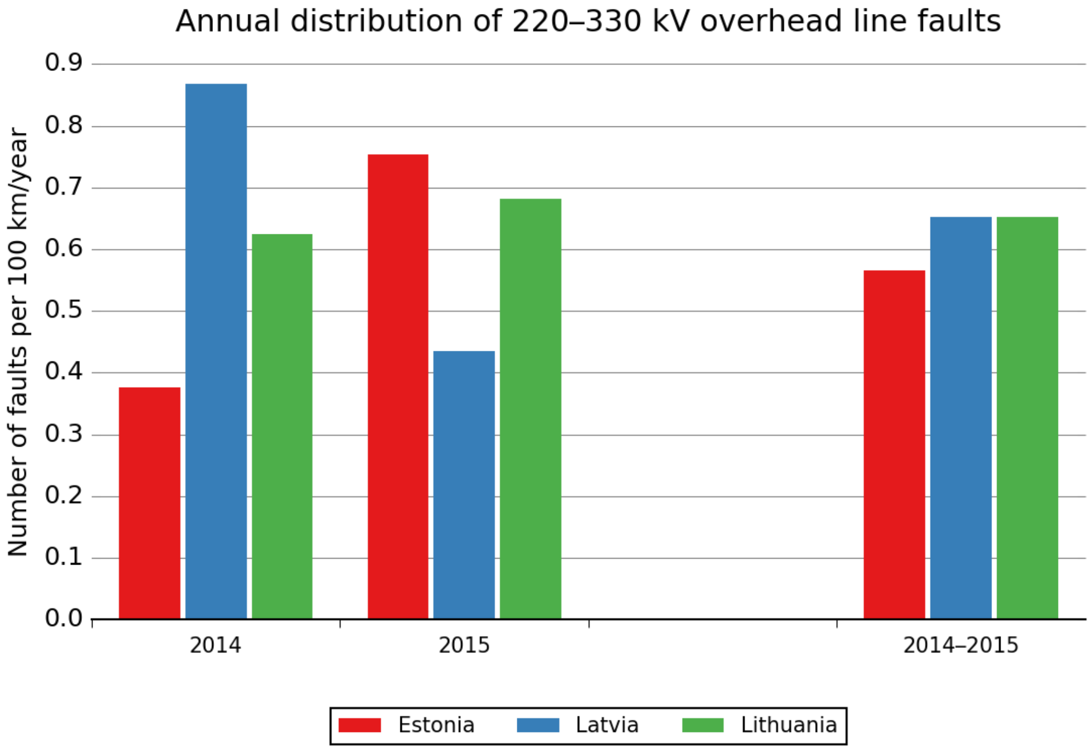

FIGURE 5.3.4 ANNUAL DISTRIBUTION OF FAULTS FOR 220–330 KV OVERHEAD LINES DURING THE PERIOD 2014–2015 AND THE AVERAGE FOR 2014–2015 IN EACH BALTIC COUNTRY

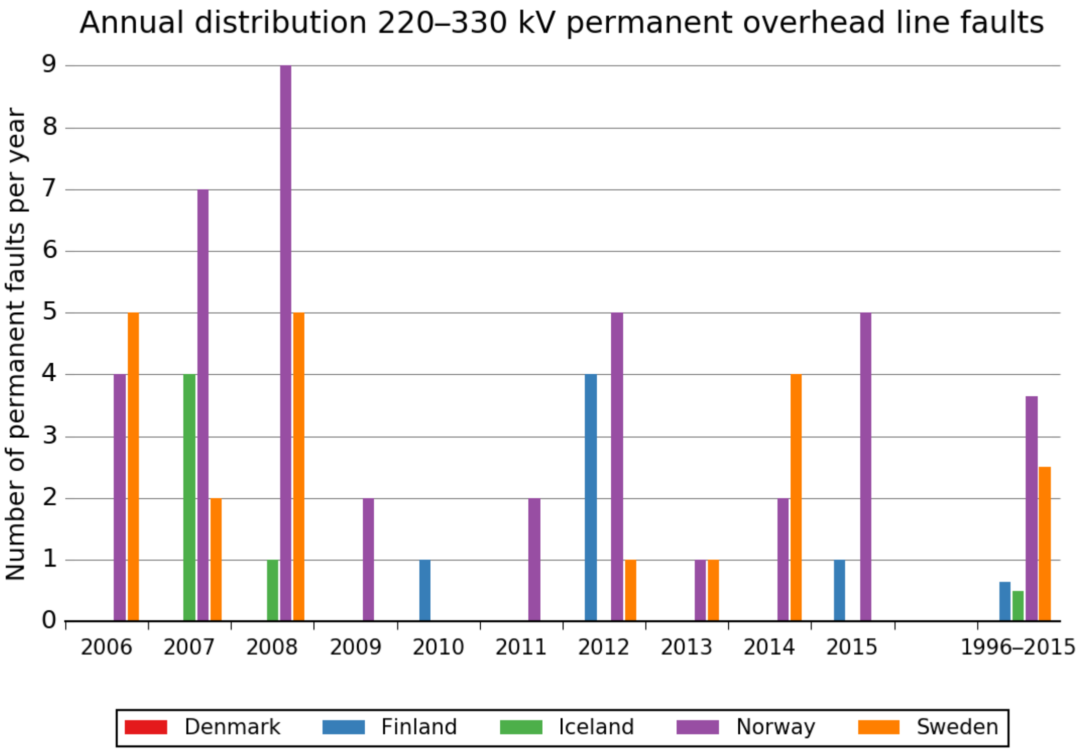

FIGURE 5.3.5 ANNUAL DISTRIBUTION OF PERMANENT FAULTS FOR 220–330 KV OVERHEAD LINES DURING THE PERIOD 2006–2015 AND THE AVERAGE FOR 1996–2015 IN EACH NORDIC COUNTRY

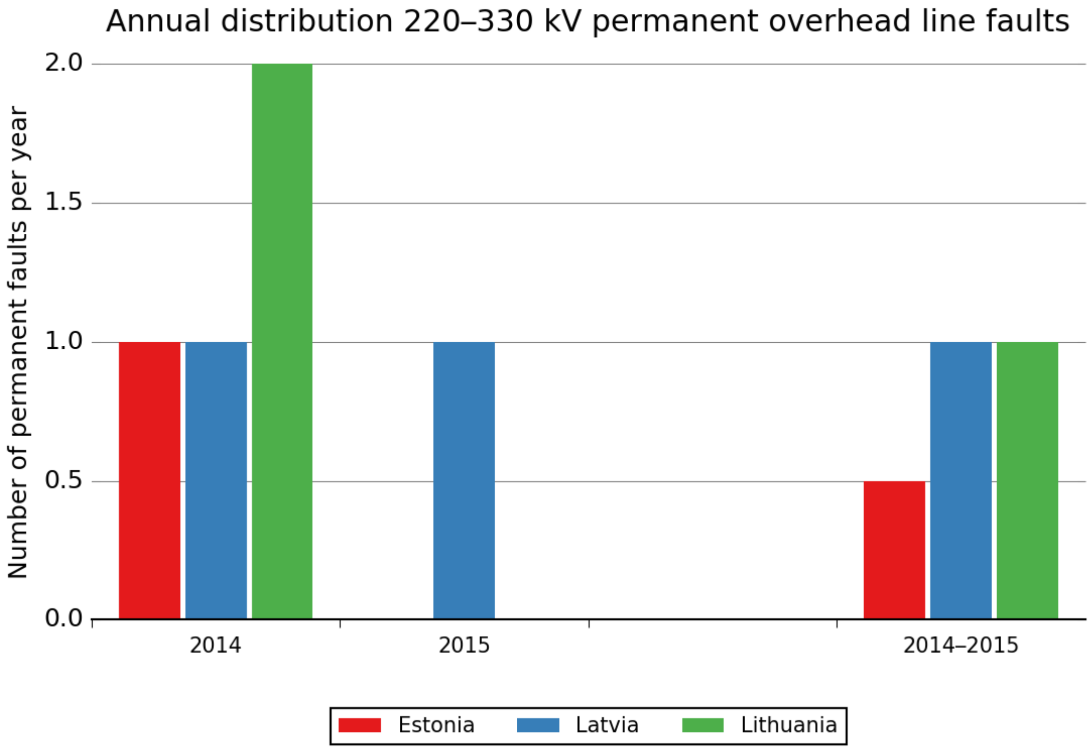

FIGURE 5.3.6 ANNUAL DISTRIBUTION OF PERMANENT FAULTS FOR 220–330 KV OVERHEAD LINES DURING THE PERIOD 2014–2015 AND THE AVERAGE FOR 2014–2015 IN EACH BALTIC COUNTRY

5.3.3 100–150 KV OVERHEAD LINES

Table 5.3.3 shows the line lengths, number of faults on 100–150 kV overhead lines, the causes of faults and the percentage values of 1-phase faults and permanent faults. Figure 5.3.7 presents the annual line fault values per line length during the period 2006–2015 and the average value for the period 1996–2015 in the Nordic countries. Figure 5.3.8 presents the annual line fault values per line length during the period 2014–2015 and the average in the Baltic countries. Figure 5.3.9 and Figure 5.3.10 presents the annual distribution of permanent line faults during the mentioned periods in the Nordic and Baltic countries, respectively.

TABLE 5.3.3 100–150 KV OVERHEAD LINES FAULTS AND THE DISTRIBUTION ACCORDING TO CAUSE IN EACH NORDIC AND BALTIC COUNTRY

Country	Lines (km)	Number of faults	Number of faults per 100 km		Lightning	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown	1-phase faults	Permanent faults
	2015	2015	2015	1996–2015	Faults divided by cause (%) during the period 1996–2015								
Denmark	3163	21	0.66	1.02	24	39	21	2	1	2	11	51	5
Finland	16245	354	2.18	2.05	36	18	1	1	0	5	38	78	4
Iceland	1249	44	3.52	1.40	3	87	3	1	6	0	1	30	9
Norway	10997	119	1.08	1.04	52	34	2	1	5	4	2	28	18
Sweden	15952	154	0.97	2.13	61	5	2	3	3	2	25	35	5
				2014–2015	Faults divided by cause (%) during the period 2014–2015								
Estonia	3428	78	2.28	2.88	19	63	5	6	7	0	0	85	16
Latvia	3821	59	1.54	2.20	15	34	30	1	1	0	19	63	38
Lithuania	4984	87	1.75	2.04	11	3	42	3	1	0	39	87	11
Total	59839	916	1.53	1.53	35	37	6	2	3	3	15	45	8

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

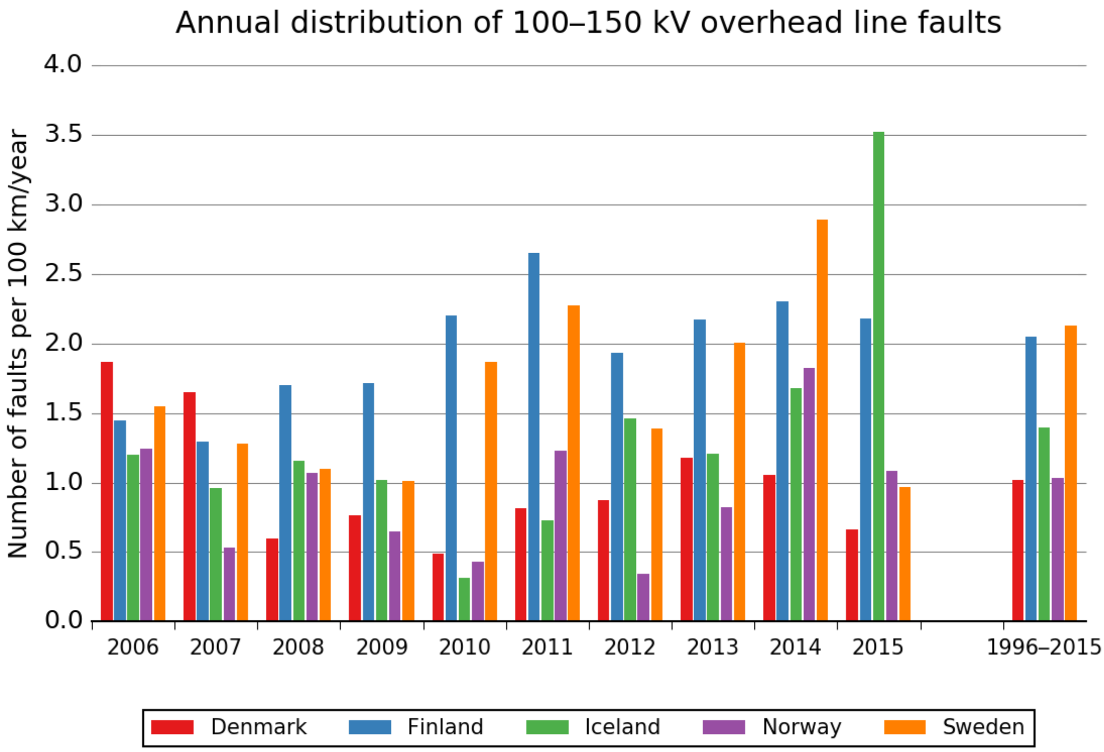

FIGURE 5.3.7 ANNUAL DISTRIBUTION OF LINE FAULTS FOR 100–150 KV OVERHEAD LINES DURING THE PERIOD 2006–2015 AND THE AVERAGE FOR 1996–2015 IN EACH NORDIC COUNTRY

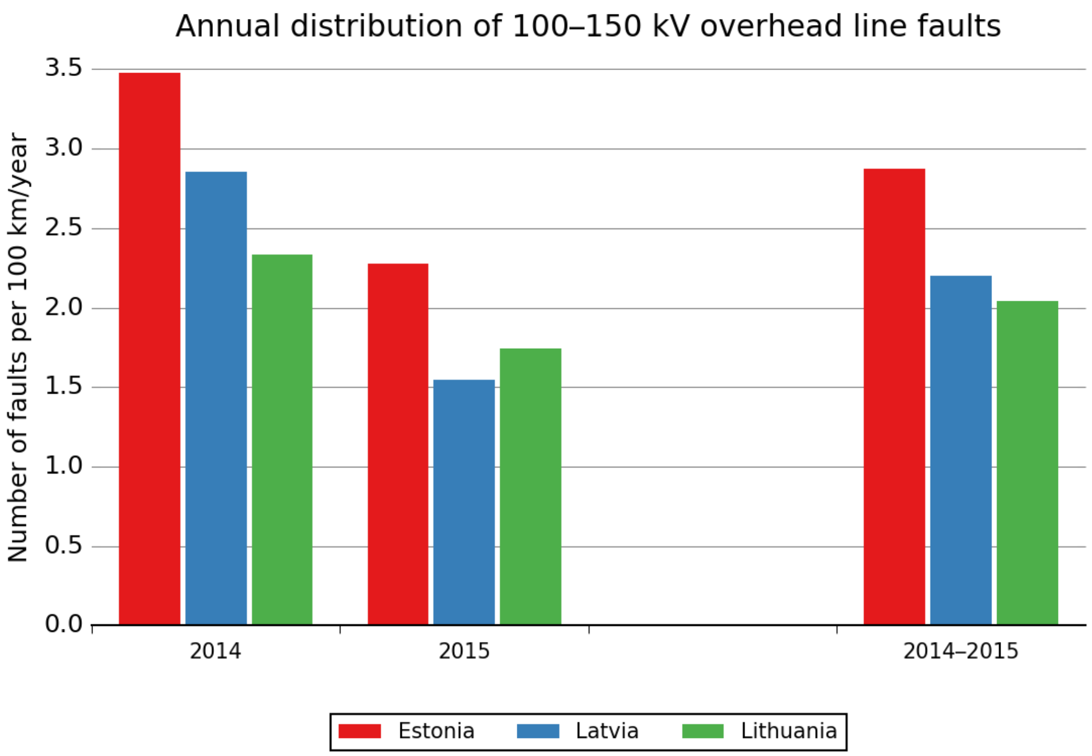

FIGURE 5.3.8 ANNUAL DISTRIBUTION OF LINE FAULTS FOR 100–150 KV OVERHEAD LINES DURING THE PERIOD 2014–2015 AND THE AVERAGE FOR 2014–2015 IN EACH BALTIC COUNTRY

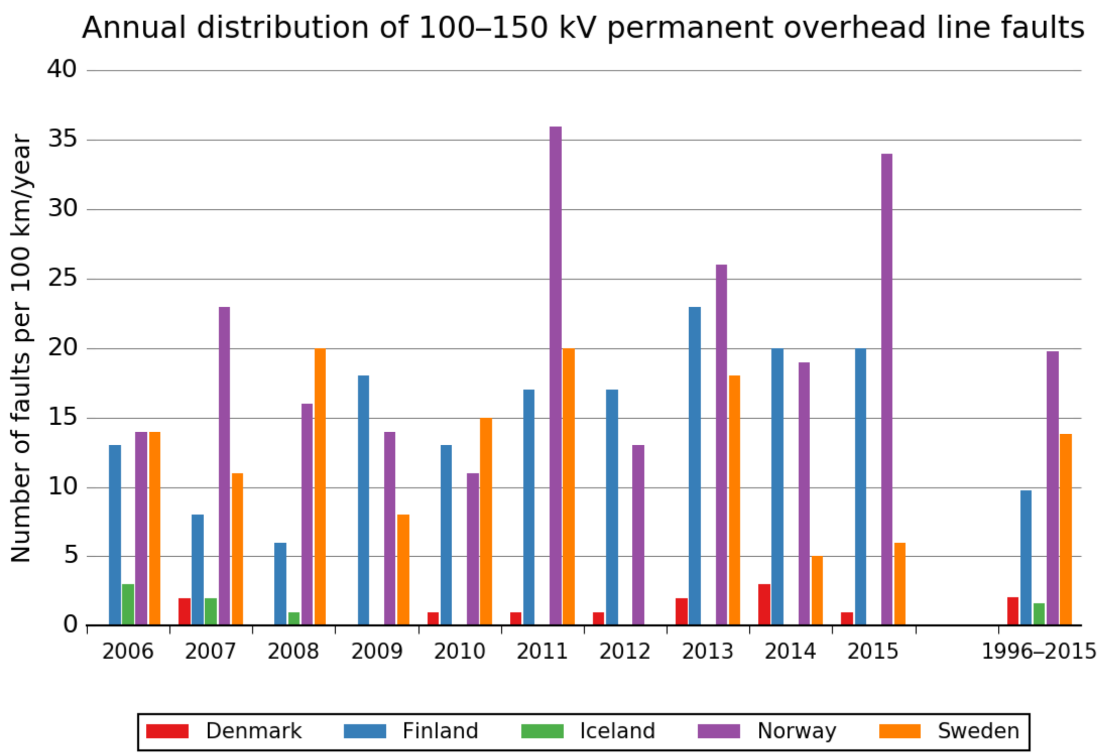

FIGURE 5.3.9 ANNUAL DISTRIBUTION OF PERMANENT LINE FAULTS FOR 100–150 KV OVERHEAD LINES DURING THE PERIOD 2006–2015 AND THE AVERAGE FOR 1996–2015 IN EACH NORDIC COUNTRY

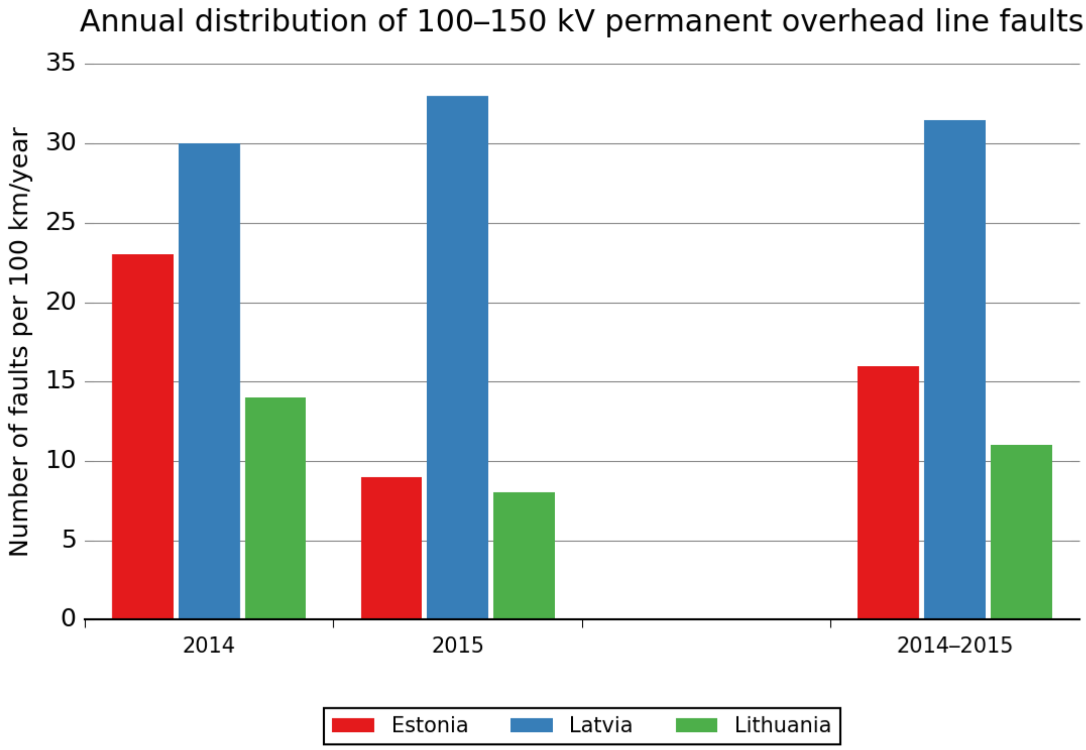

FIGURE 5.3.10 ANNUAL DISTRIBUTION OF PERMANENT LINE FAULTS FOR 100–150 KV OVERHEAD LINES DURING THE PERIOD 2014–2015 AND THE AVERAGE FOR 2014–2015 IN EACH BALTIC COUNTRY

5.3.4 OVERHEAD LINE FAULT TRENDS

Figure 5.3.11, Figure 5.3.12 and Figure 5.3.13 present trend curves of overhead line faults in the Nordic countries as of 1996 for 380–420 kV, 220–330 kV and 100–150 kV lines, respectively. The five-year average is calculated by dividing the sum of the faults by the total overhead line length for each five-year period. The trend curves are proportioned to overhead line length in order to get comparable results between countries.

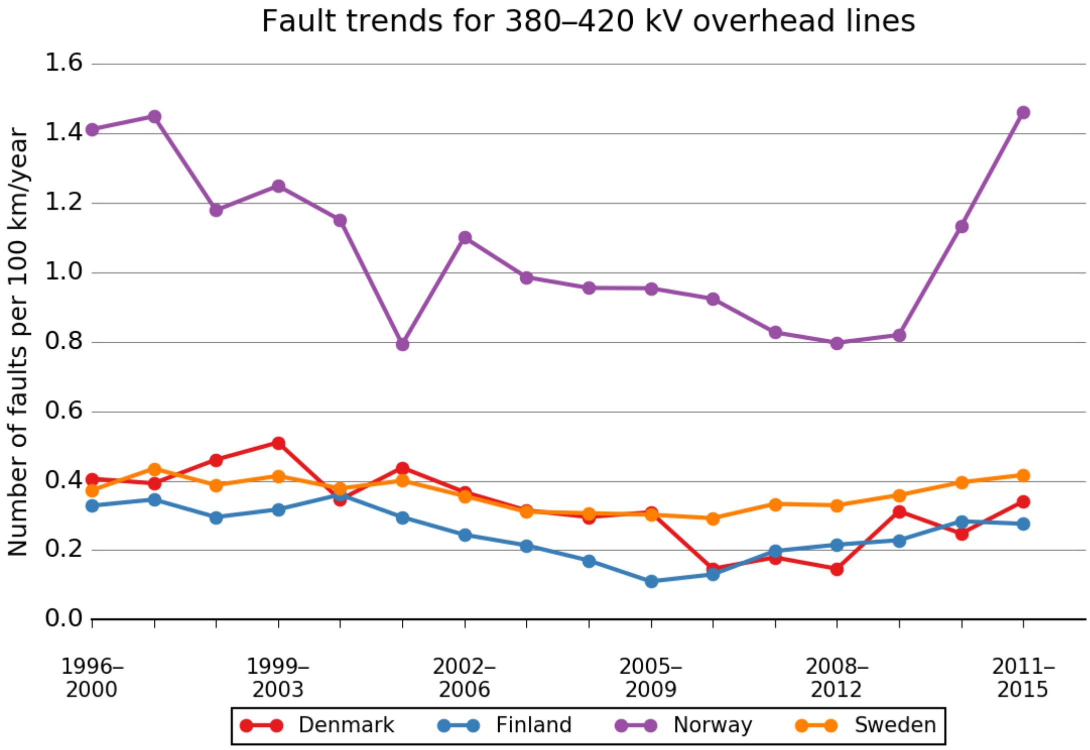

FIGURE 5.3.11 FAULT TRENDS AS FIVE-YEAR AVERAGES FOR OVERHEAD LINES AT THE VOLTAGE LEVEL 380–420 KV IN NORDIC COUNTRIES

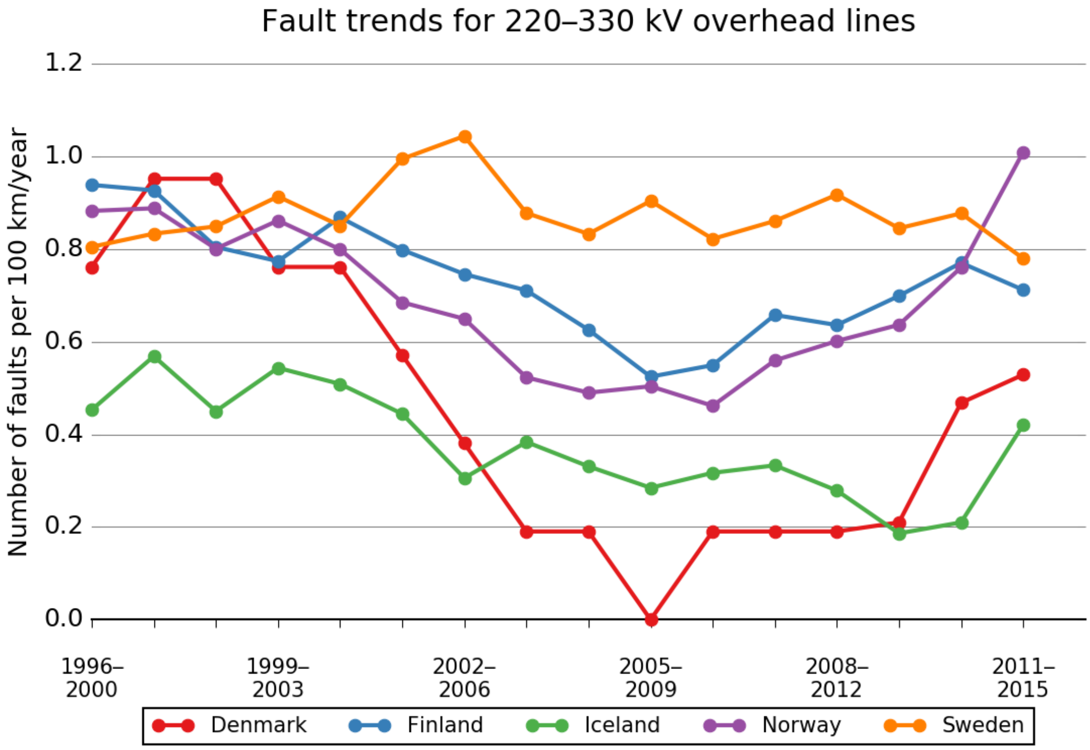

FIGURE 5.3.12 FAULT TRENDS AS FIVE-YEAR AVERAGES FOR OVERHEAD LINES AT THE VOLTAGE LEVEL 220–330 KV IN EACH NORDIC COUNTRY

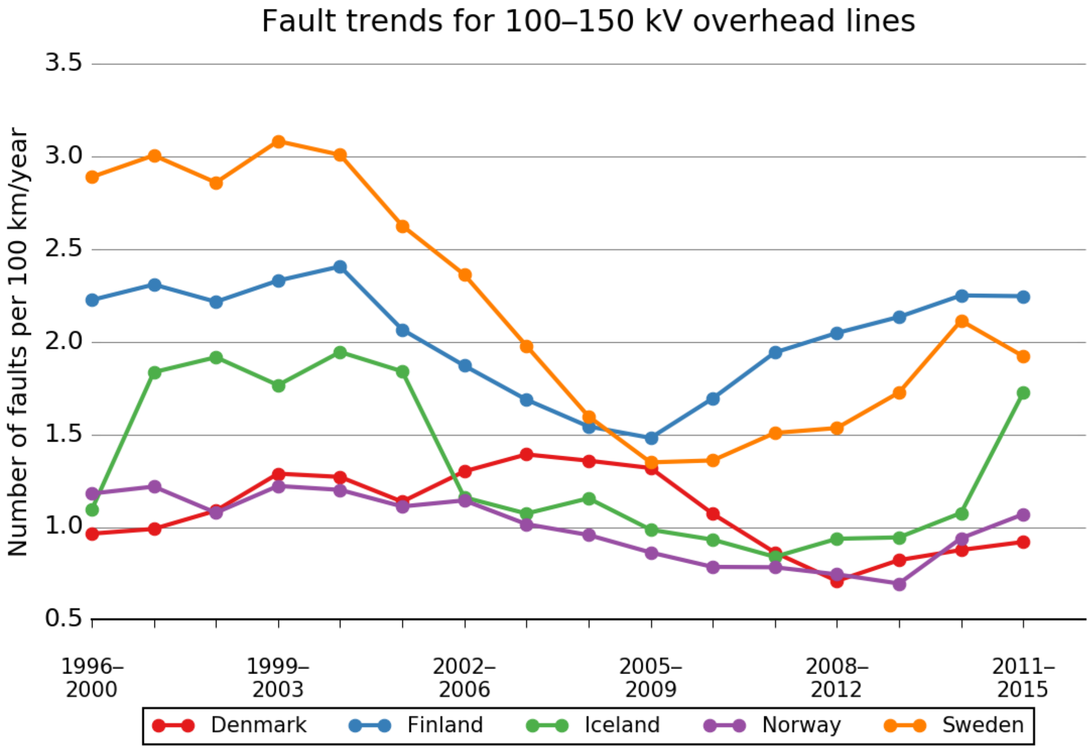

FIGURE 5.3.13 FAULT TRENDS AS FIVE-YEAR AVERAGES FOR OVERHEAD LINES AT THE VOLTAGE LEVEL 100–150 KV IN EACH NORDIC COUNTRY

5.4 FAULTS IN CABLES

Figure 5.4.1 presents the cable distributions in the Nordic countries to voltage levels in each year from 2006 to 2015.

Table 5.4.1, Table 5.4.2, and Table 5.4.3 present cable faults for the year 2015 and fault distribution at each statistical voltage level for the period 1996–2015. Figure 5.4.2 presents the annual distribution of 100–150 kV cables faults during the period 2006–2015 and the average for the period 1996–2015 in the Nordic countries only, because the Baltic countries had no faults in 100–150 kV cables during 2014–2015 with the exception of Estonia that had one fault in 2014.

Fault trends for all the voltage levels in the Nordic countries are presented in Figure 5.4.3.

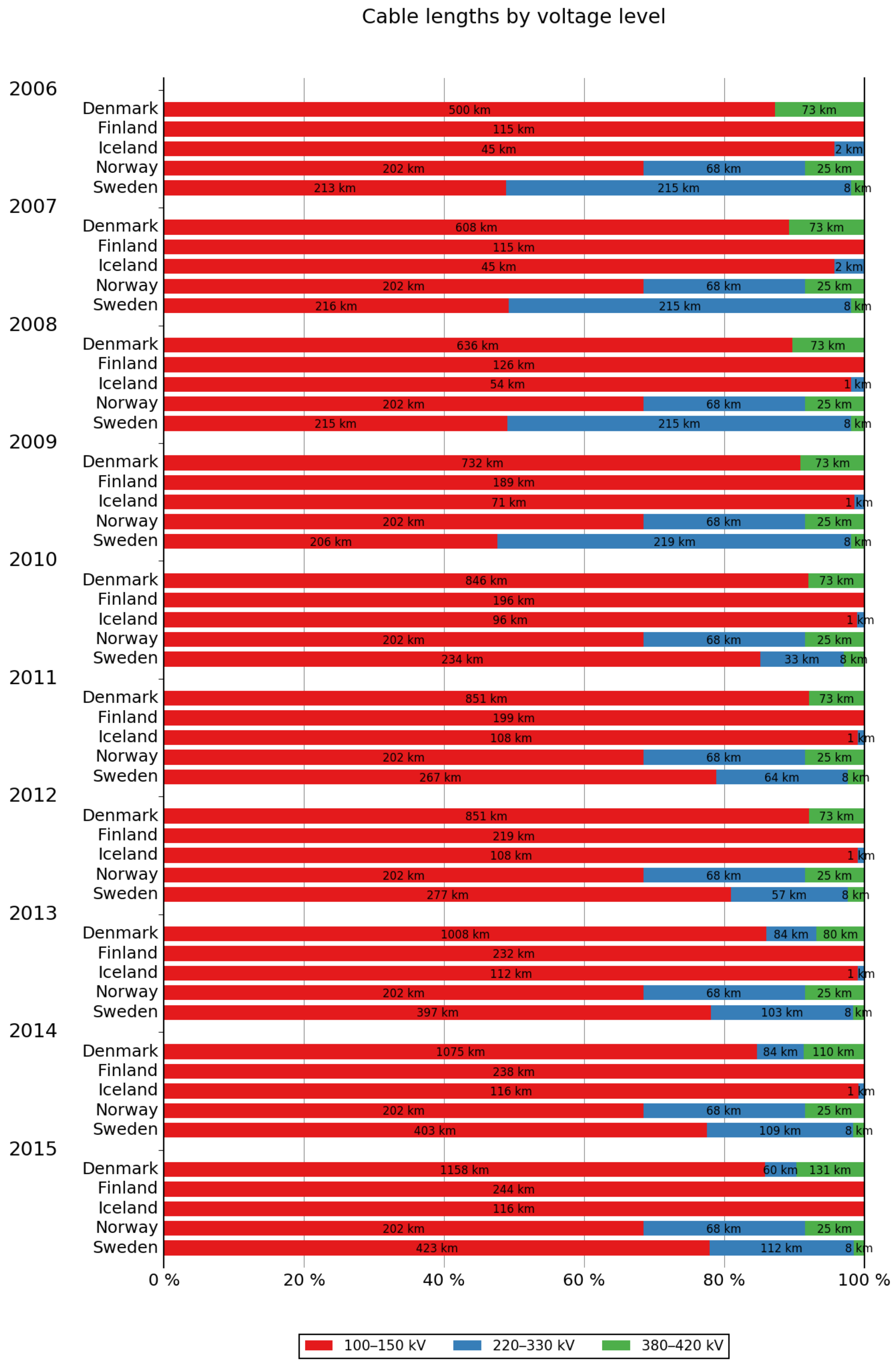

FIGURE 5.4.1 DISTRIBUTION OF CABLES LENGTHS ACCORDING TO VOLTAGE LEVEL IN EACH NORDIC COUNTRY FROM 2006 TO 2015

TABLE 5.4.1 380–420 KV CABLES FAULTS AND THE DISTRIBUTION ACCORDING TO CAUSE IN NORDIC COUNTRIES

Country	Lines (km)	Number of faults	Number of faults per 100 km		Lightning	Other environmental causes	External influence	Operation and maintenance	Technical equipment	Other	Unknown
	2015	2015	2015	1996–2015	Faults divided by cause (%) during the period 1996–2015						
Denmark	131	0	0.00	0.46	0	0	0	14	57	14	14
Norway	25	0	0.00	1.13	0	0	0	0	67	17	17
Sweden	8	0	0.00	0.00	0	0	0	0	0	0	0
Total	164	0	0.00	0.58	0	0	0	8	62	15	15

TABLE 5.4.2 DISTRIBUTION OF FAULTS ACCORDING TO CAUSE FOR 220–330 KV CABLES IN NORDIC AND BALTIC COUNTRIES

Country	Lines (km)	Number of faults	Number of faults per 100 km		Lightning	Other environmental causes	External influence	Operation and maintenance	Technical equipment	Other	Unknown
	2015	2015	2015	1996–2015	Faults divided by cause (%) during the period 1996–2015						
Denmark	60	1	1.66	0.88	0	0	0	0	100	0	0
Iceland	0	0	0.00	0.00	0	0	0	0	0	0	0
Norway	68	0	0.00	0.29	0	25	0	25	25	0	25
Sweden	112	5	4.46	1.38	5	0	0	9	82	0	5
				2014–2015	Faults divided by cause (%) during the period 2014–2015						
Latvia	14	0	0.00	0.00	0	0	0	0	0	0	0
Total	240	6	2.50	0.87	4	4	0	11	75	0	7

TABLE 5.4.3 100–150 KV CABLES FAULTS AND THE DISTRIBUTION ACCORDING TO CAUSE IN EACH NORDIC AND BALTIC COUNTRY

Country	Lines (km)	Number of faults	Number of faults per 100 km		Lightning	Other environmental causes	External influence	Operation and maintenance	Technical equipment	Other	Unknown
	2015	2015	2015	1996–2015	Faults divided by cause (%) during the period 1996–2015						
Denmark	1158	6	0.52	0.33	2	5	17	12	56	5	2
Finland	244	3	1.23	0.44	0	0	0	22	33	22	22
Iceland	116	0	0.00	0.34	0	0	0	25	75	0	0
Norway[1)]	202	4	1.98	1.68	2	9	11	11	48	15	5
Sweden	423	1	0.24	0.95	0	0	16	7	47	11	20
				2014–2015	Faults divided by cause (%) during the period 2014–2015						
Estonia	64	0	0.00	0.83	0	0	0	0	0	0	0
Latvia	70	0	0.00	0.00	0	0	0	0	0	0	0
Lithuania	86	0	0.00	0.00	0	0	0	0	0	0	0
Total	2362	14	3.97	4.58	1	5	13	11	49	12	9

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

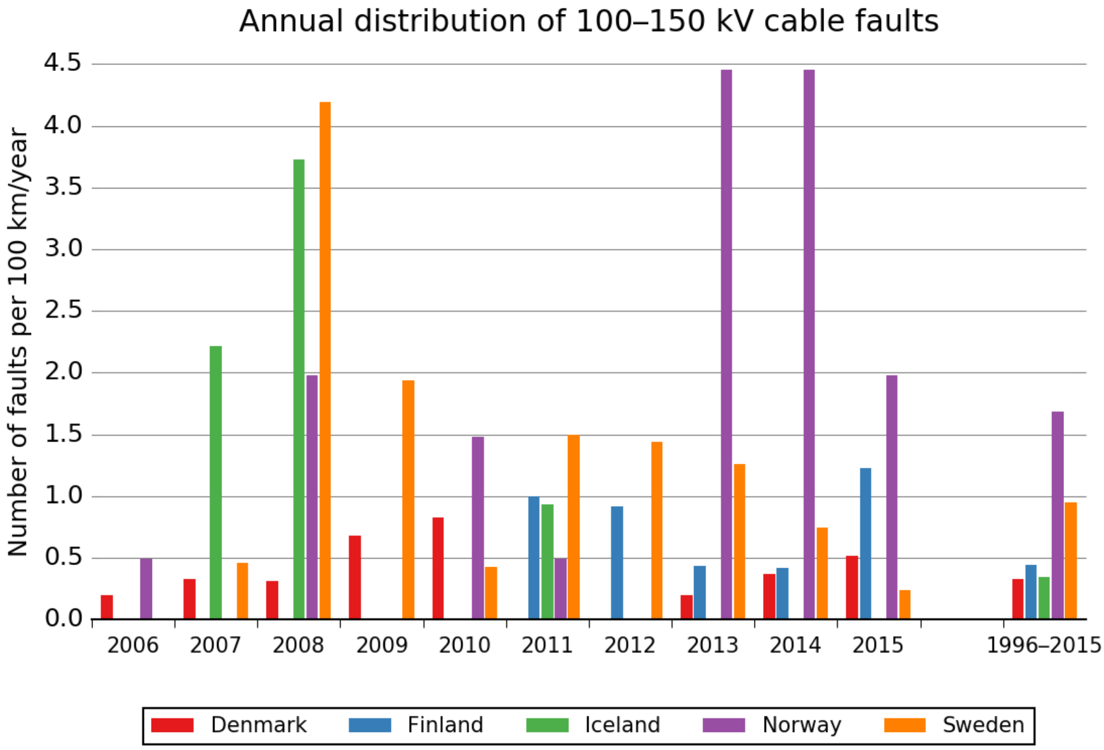

FIGURE 5.4.2 ANNUAL DISTRIBUTION OF CABLE FAULTS DURING THE PERIOD 2006–2015 AND THE AVERAGE FOR THE PERIOD 1995–2015 IN EACH NORDIC COUNTRY FOR 100–150 KV CABLES

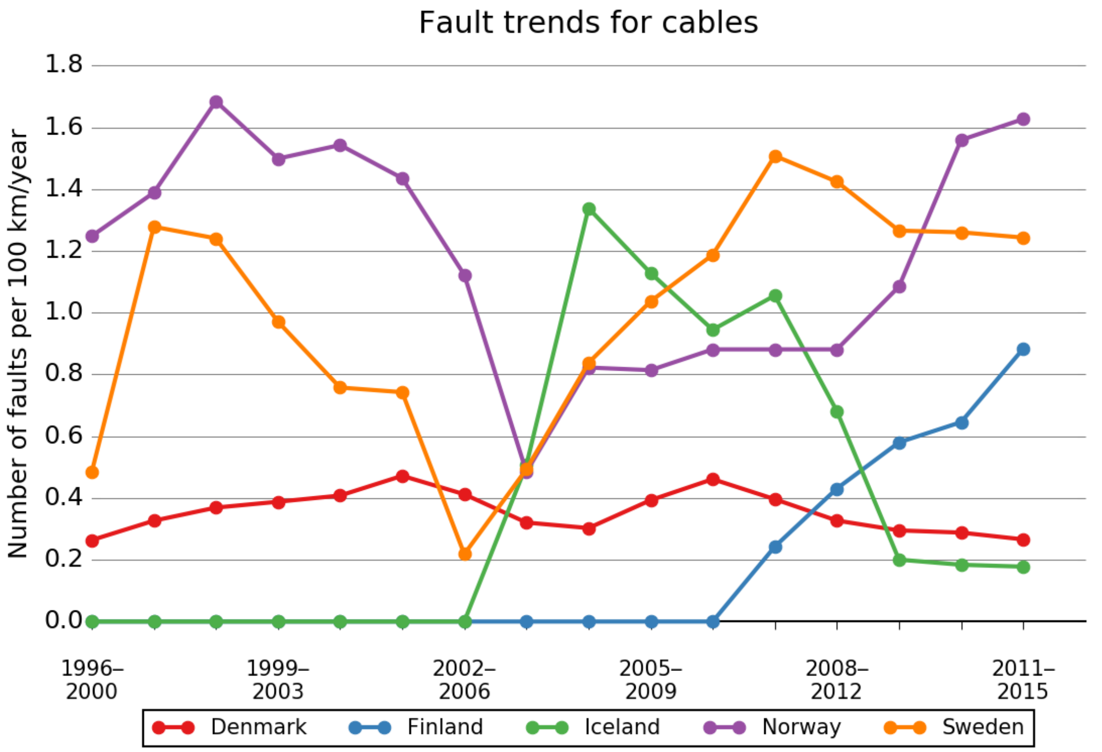

FIGURE 5.4.3 FAULT TRENDS AS FIVE-YEAR AVERAGES FOR CABLES AT ALL VOLTAGE LEVELS IN EACH NORDIC COUNTRY

The main explanation for the high values in the fault trend for Sweden during the years 2008–2012 is that there were several cable faults in 2008, as seen in Figure 5.4.2.

5.5 FAULTS IN POWER TRANSFORMERS

The tables in this section present the distribution of faults in power transformers for the year 2015 and for the period 2006–2015 at each respective voltage level. In addition, the tables present the distribution of faults according to cause during the period 2006–2015. The annual distribution of faults and the average for the period 2006–2015 for all voltage levels is presented in Figure 5.5.1, Figure 5.5.2, Figure 5.5.3, Figure 5.5.4 and Figure 5.5.5. Fault trends for the Nordic power transformers are presented in Figure 5.5.6, Figure 5.5.7 and Figure 5.5.8. For power transformers, the statistics state the rated voltage of the winding with the highest voltage, as stated in the guidelines in Section 6.2 [1].

TABLE 5.5.1 380–420 KV POWER TRANSFORMERS FAULTS AND THE DISTRIBUTION ACCORDING TO CAUSE IN NORDIC COUNTRIES

Country	Number of devices	Number of faults	Number of faults per 100 devices		Light-ning	Other environ-mental causes	External influence	Operation and mainte-nance	Technical equipment	Other	Unknown
	2015	2015	2015	2006–2015	Faults divided by cause (%) during the period 2006–2015						
Denmark	29	4	13.79	2.66	0	29	0	14	43	0	14
Finland	101	2	1.98	2.23	0	8	0	23	54	8	8
Norway	64	1	1.56	2.04	0	0	0	31	23	31	15
Sweden	70	4	5.71	3.24	16	5	0	37	11	26	5
Total	264	1	0.38	2.51	6	8	0	29	29	19	10

TABLE 5.5.2 220–330 KV POWER TRANSFORMERS FAULTS AND THE DISTRIBUTION ACCORDING TO CAUSE IN EACH NORDIC AND BALTIC COUNTRY

Country	Number of devices	Number of faults	Number of faults per 100 devices		Light-ning	Other environ-mental causes	External influence	Operation and mainte-nance	Technical equipment	Other	Unknown
	2015	2015	2015	2006–2015	Faults divided by cause during the period 2006–2015						
Denmark	5	1	20.00	3.23	0	100	0	0	0	0	0
Finland	46	0	0.00	2.28	0	0	0	50	17	17	17
Iceland	12	1	8.33	7.96	0	11	0	11	67	0	11
Norway	250	2	0.80	0.79	5	5	0	10	38	33	10
Sweden	105	3	2.86	4.72	26	0	9	15	13	11	26
				2014–2015	Faults divided by cause during the period 2014–2015						
Estonia	23	2	8.70	17.78	0	0	0	13	88	0	0
Latvia	25	2	8.00	8.00	0	0	25	25	50	0	0
Lithuania	24	0	0.00	2.13	0	0	0	100	0	0	0
Total	418	7	1.67	2.06	13	3	5	16	31	13	16

TABLE 5.5.3 100–150 KV POWER TRANSFORMERS FAULTS AND THE DISTRIBUTION ACCORDING TO CAUSE IN EACH NORDIC AND BALTIC COUNTRY

Country	Number of devices	Number of faults	Number of faults per 100 devices		Lightning	Other environmental causes	External influence	Operation and maintenance	Technical equipment	Other	Unknown
	2015	2015	2015	2006–2015	Faults divided by cause (%) during the period 2006–2015						
Denmark	226	5	2.21	1.05	4	16	0	36	24	4	16
Finland	1171	3	0.26	0.54	8	2	12	18	25	14	22
Iceland	43	0	0.00	1.12	0	40	0	40	20	0	0
Norway	724	5	0.69	0.68	10	31	4	12	20	18	4
Sweden	823	27	3.28	3.86	19	1	2	20	26	5	26
				2014–2015	Faults divided by cause (%) during the period 2014–2015						
Estonia	218	10	4.59	4.38	0	0	0	0	100	0	0
Latvia	246	6	2.44	2.44	0	0	42	33	25	0	0
Lithuania	419	0	0.00	0.24	0	0	0	0	100	0	0
Total	2987	40	1.34	1.52	14	6	4	20	28	7	20

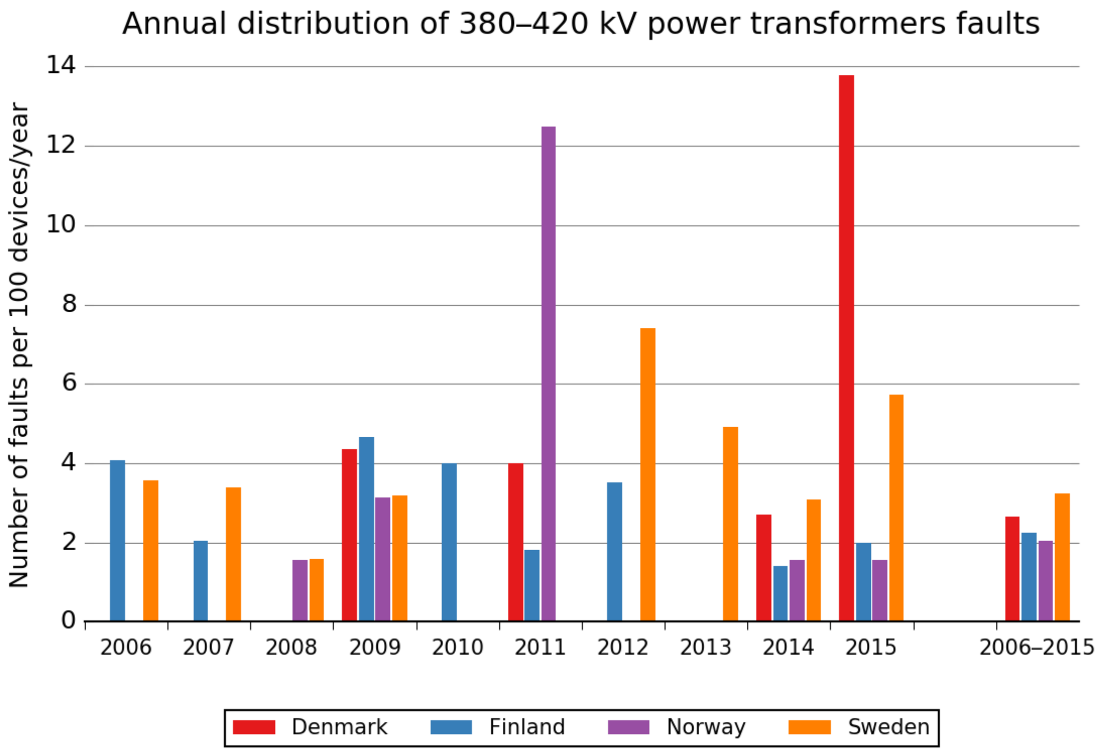

FIGURE 5.5.1 ANNUAL DISTRIBUTION OF FAULTS FOR 380–420 KV POWER TRANSFORMERS IN NORDIC COUNTRIES DURING THE PERIOD 2006–2015

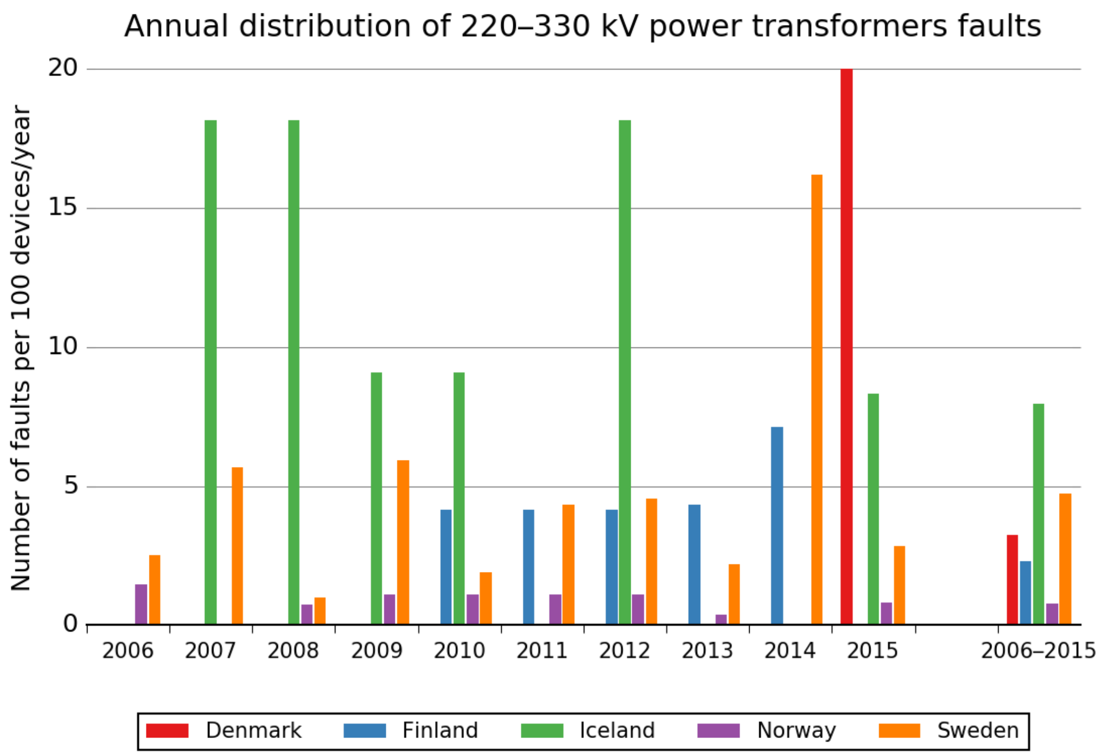

FIGURE 5.5.2 ANNUAL DISTRIBUTION OF FAULTS FOR 220–330 kV POWER TRANSFORMERS IN EACH NORDIC COUNTRY DURING THE PERIOD 2006–2015

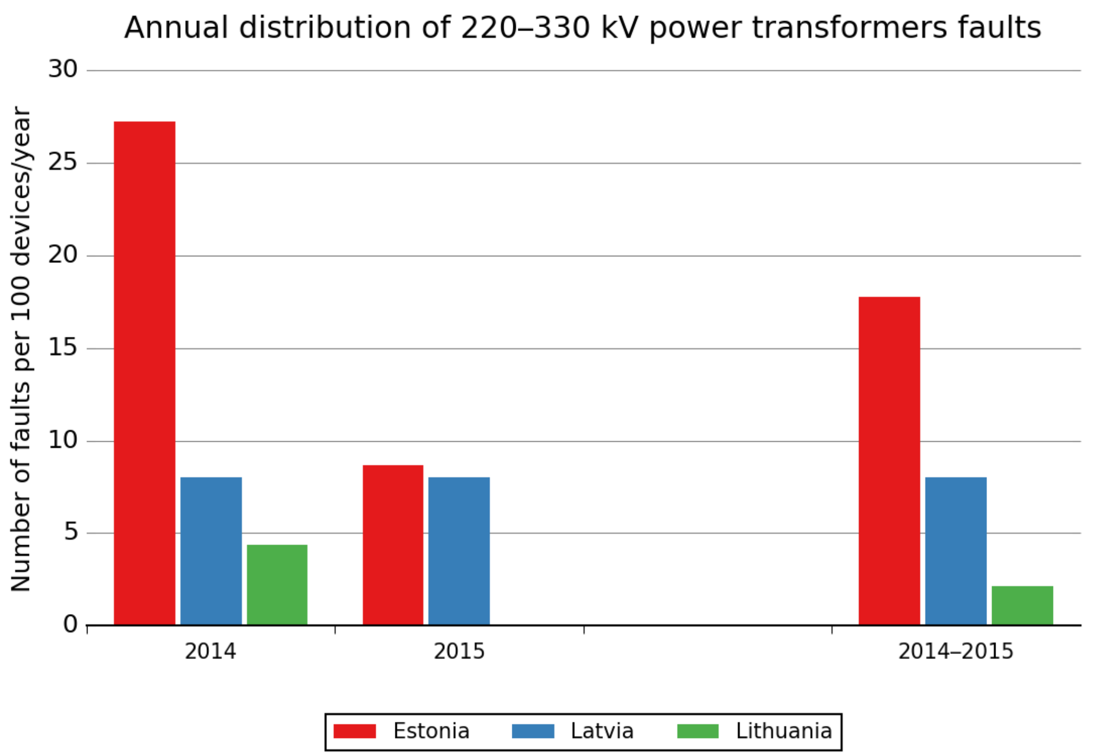

FIGURE 5.5.3 ANNUAL DISTRIBUTION OF FAULTS FOR 220–330 kV POWER TRANSFORMERS IN EACH BALTIC COUNTRY DURING THE PERIOD 2014–2015

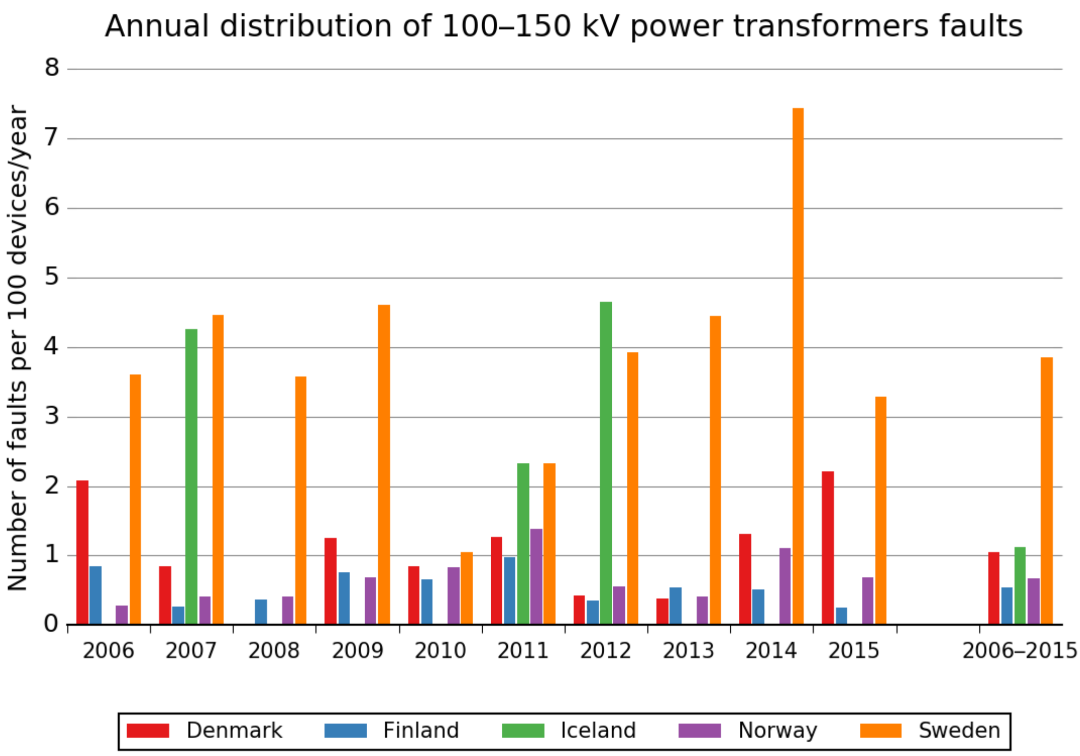

FIGURE 5.5.4 ANNUAL DISTRIBUTION OF FAULTS FOR 100–150 KV POWER TRANSFORMERS IN EACH NORDIC COUNTRY DURING THE PERIOD 2006–2015

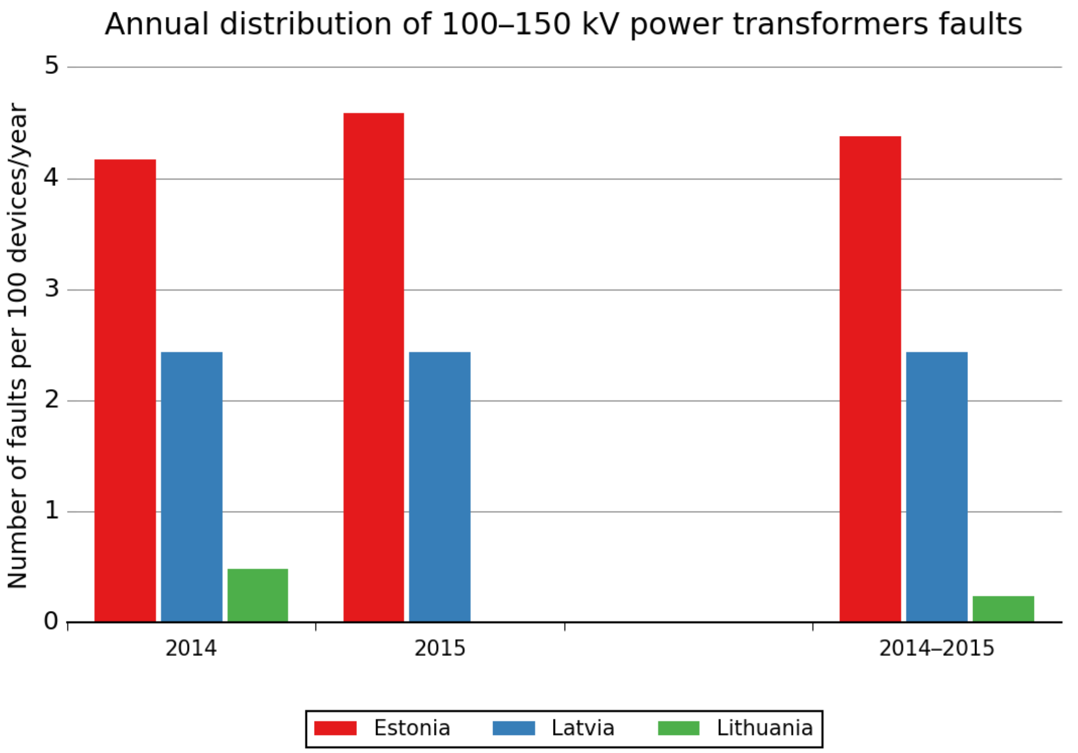

FIGURE 5.5.5 ANNUAL DISTRIBUTION OF FAULTS FOR 100–150 KV POWER TRANSFORMERS IN EACH BALTIC COUNTRY DURING THE PERIOD 2014–2015

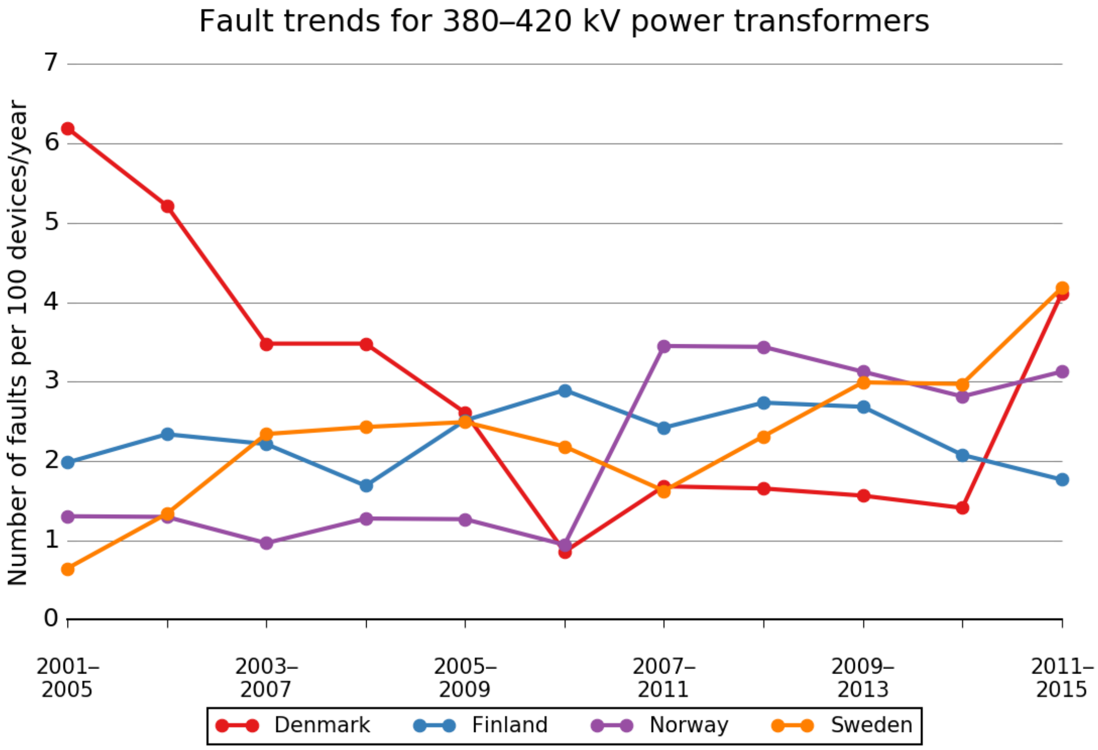

FIGURE 5.5.6 FAULT TRENDS AS FIVE-YEAR AVERAGES FOR 380–420 KV POWER TRANSFORMERS IN NORDIC COUNTRIES

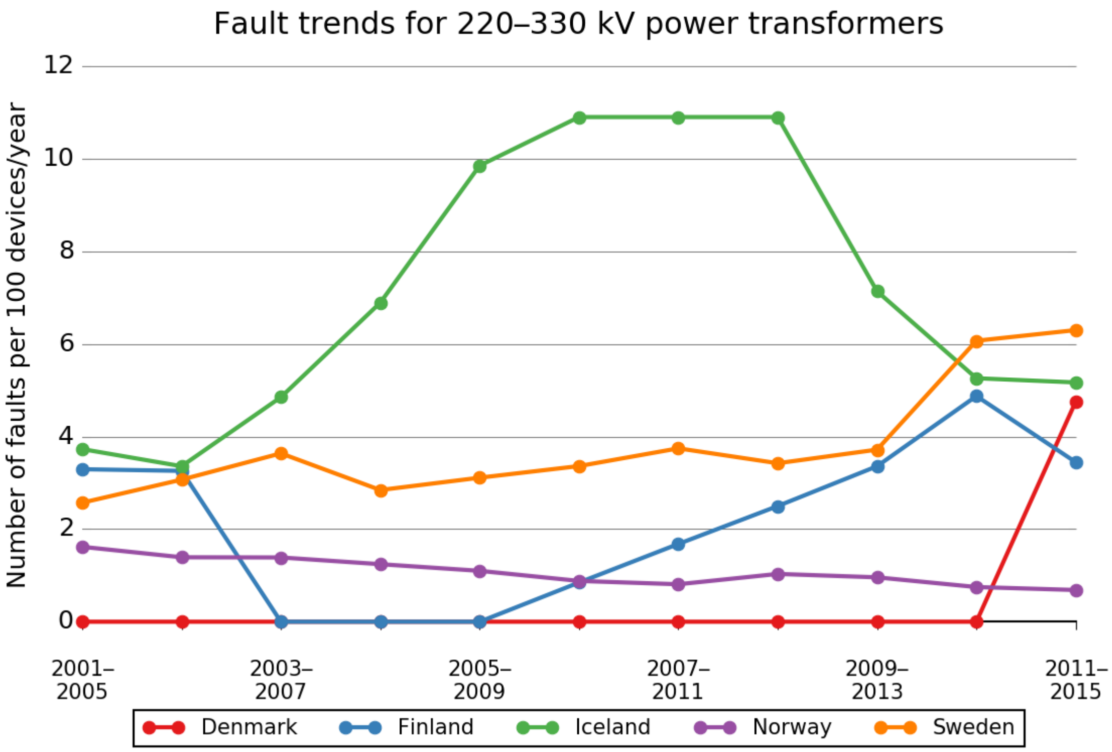

FIGURE 5.5.7 FAULT TRENDS AS FIVE-YEAR AVERAGES FOR 220–330 KV POWER TRANSFORMERS IN EACH NORDIC COUNTRY

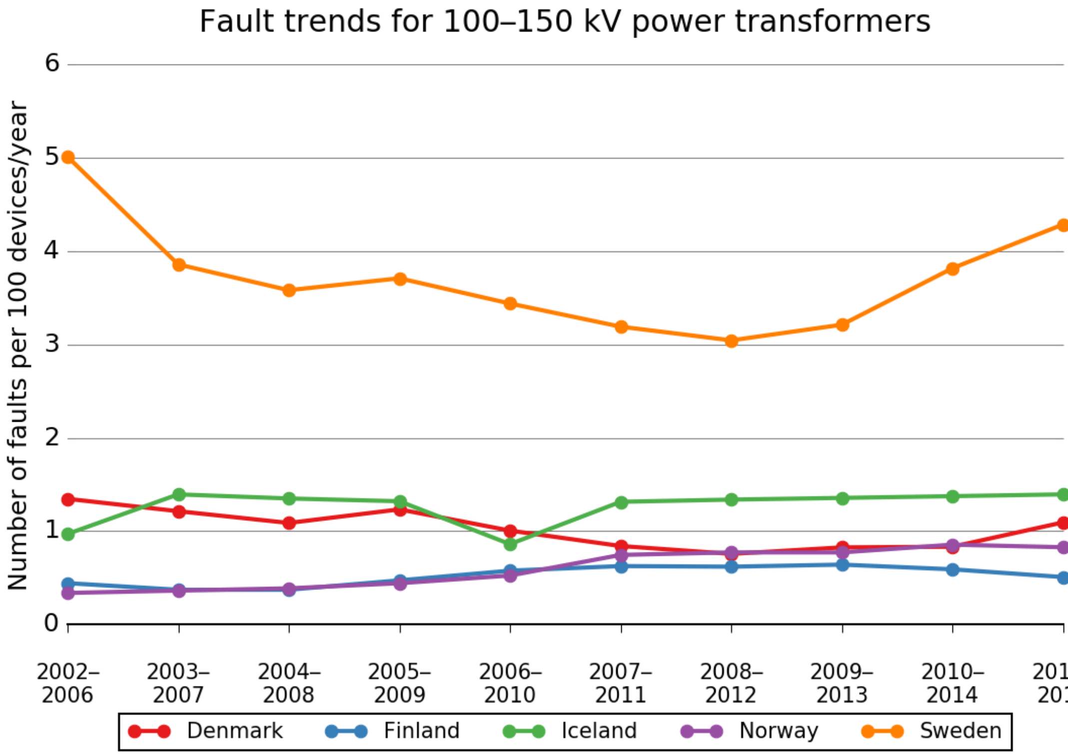

FIGURE 5.5.8 FAULT TRENDS AS FIVE-YEAR AVERAGES FOR 100–150 KV POWER TRANSFORMERS IN EACH NORDIC COUNTRY

5.6 FAULTS IN INSTRUMENT TRANSFORMERS

The tables in this section present the faults in instrument transformers for the year 2015 and for the period 2006–2015 at each statistical voltage level. In addition, the tables present the distribution of faults according to cause during that 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. The figures in this section present the fault trends for instrument transformers at each statistical voltage level in the Nordic countries.

TABLE 5.6.1 380–420 KV INSTRUMENT TRANSFORMERS FAULTS AND THE DISTRIBUTION ACCORDING TO CAUSE IN NORDIC COUNTRIES

Country	Number of devices	Number of faults	Number of faults per 100 devices		Lightning	Other environmental causes	External influence	Operation and maintenance	Technical equipment	Other	Unknown
	2015	2015	2015	2006–2015	Faults divided by cause (%) during the period 2006–2015						
Denmark	214	0	0.00	0.00	0	0	0	0	0	0	0
Finland	564	0	0.00	0.02	0	0	0	0	100	0	0
Norway	930	3	0.32	0.12	0	9	0	9	82	0	0
Sweden	1338	4	0.30	0.19	0	0	0	5	90	0	5
Total	3046	7	0.23	0.11	0	3	0	6	88	0	3

TABLE 5.6.2 220–330 KV INSTRUMENT TRANSFORMERS FAULTS AND THE DISTRIBUTION ACCORDING TO CAUSE IN EACH NORDIC AND BALTIC COUNTRY

Country	Number of devices	Number of faults	Number of faults per 100 devices		Light-ning	Other environ-mental causes	External influence	Operation and mainte-nance	Technical equipment	Other	Unknown
	2015	2015	2015	2006–2015	Faults divided by cause (%) during the period 2006–2015						
Denmark	11	0	0.00	0.86	0	0	0	0	0	0	100
Finland	161	0	0.00	0.07	0	0	0	0	100	0	0
Iceland	444	0	0.00	0.00	0	0	0	0	0	0	0
Norway	2805	5	0.18	0.07	10	0	0	30	40	10	10
Sweden	786	0	0.00	0.08	14	0	0	0	86	0	0
				2014–2015	Faults divided by cause (%) during the period 2014–2015						
Estonia	203	4	1.97	0.96	0	0	0	0	100	0	0
Latvia	200	1	0.50	0.25	0	0	0	0	100	0	0
Lithuania	225	0	0.00	0.00	0	0	0	0	0	0	0
Total	4835	10	0.21	0.08	9	0	0	18	59	6	9

TABLE 5.6.3 100–150 KV INSTRUMENT TRANSFORMERS FAULTS AND THE DISTRIBUTION ACCORDING TO CAUSE IN EACH NORDIC AND BALTIC COUNTRY

Country	Number of devices	Number of faults	Number of faults per 100 devices		Light-ning	Other environ-mental causes	External influence	Operation and mainte-nance	Technical equipment	Other	Unknown
	2015	2015	2015	2006–2015	Faults divided by cause (%) during the period 2006–2015						
Denmark	902	3	0.33	0.05	0	0	0	12	65	6	18
Finland	3746	2	0.05	0.09	9	0	0	0	61	13	17
Iceland	611	0	0.00	0.00	0	0	0	0	0	0	0
Norway	7768	4	0.05	0.05	27	0	0	11	22	32	8
Sweden	3606	0	0.00	0.07	6	0	3	13	65	0	10
				2014–2015	Faults divided by cause (%) during the period 2014–2015						
Estonia	973	2	0.21	0.16	0	0	0	0	100	0	0
Latvia	930	0	0.00	0.05	0	0	0	0	100	0	0
Lithuania	906	0	0.00	0.06	0	0	0	0	100	0	0
Total	19442	11	0.06	0.06	12	0	1	9	51	14	12

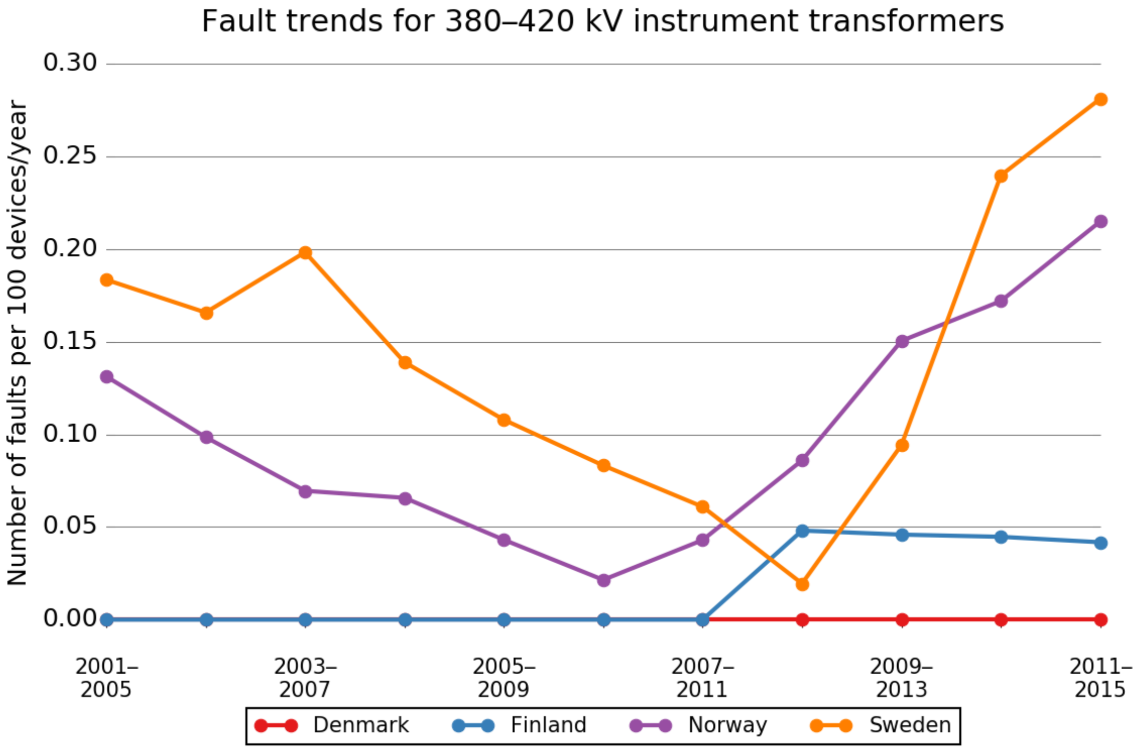

FIGURE 5.6.1 FAULT TRENDS AS FIVE-YEAR AVERAGES FOR 380–420 KV INSTRUMENT TRANSFORMERS IN NORDIC COUNTRIES

The change in the Swedish trend curve in Figure 5.6.1 is due to seven instrument transformers that exploded in 2014. All of the exploded transformers were from the same manufacturer, of the same type and were manufactured in the same year. They also exploded during the same week after a long and warm summer period.

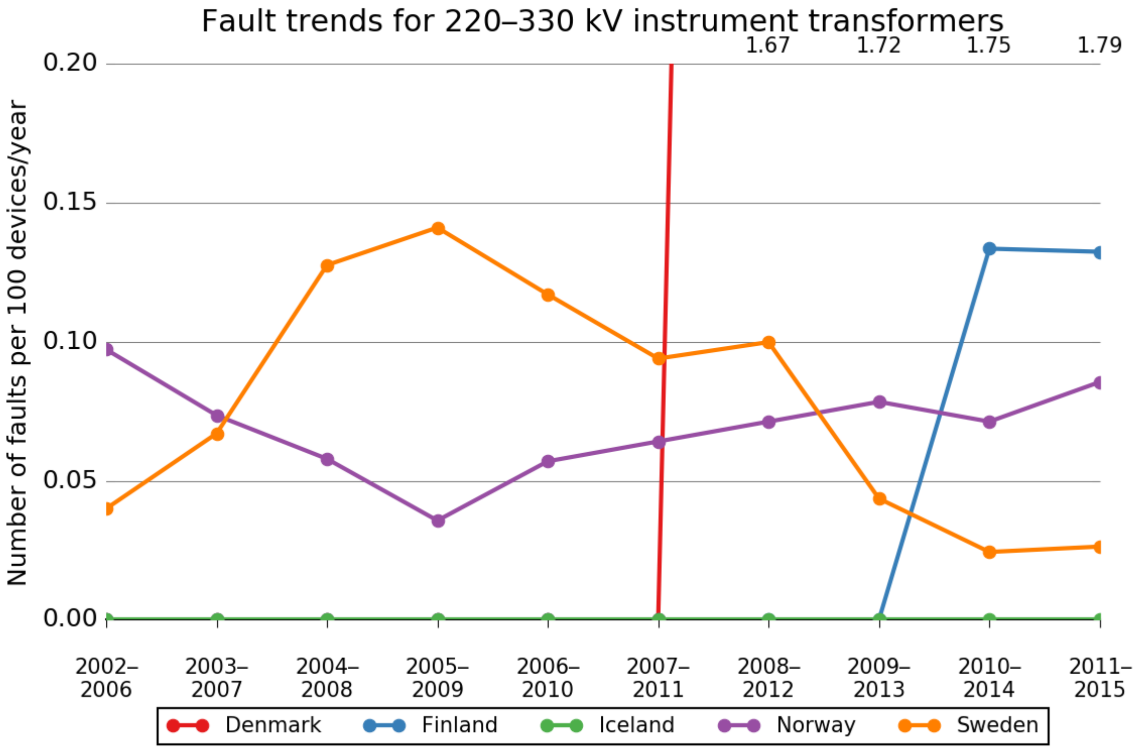

FIGURE 5.6.2 FAULT TRENDS AS FIVE-YEAR AVERAGES FOR INSTRUMENT TRANSFORMERS AT THE VOLTAGE LEVEL 220–330 KV IN EACH NORDIC COUNTRY

The high values for the Danish fault trend during 2007–2011 is caused by the transformer failures during years 2008 and 2009. Another reason is due to the fact that the number of instrument transformers is significantly smaller in Denmark than the other countries.

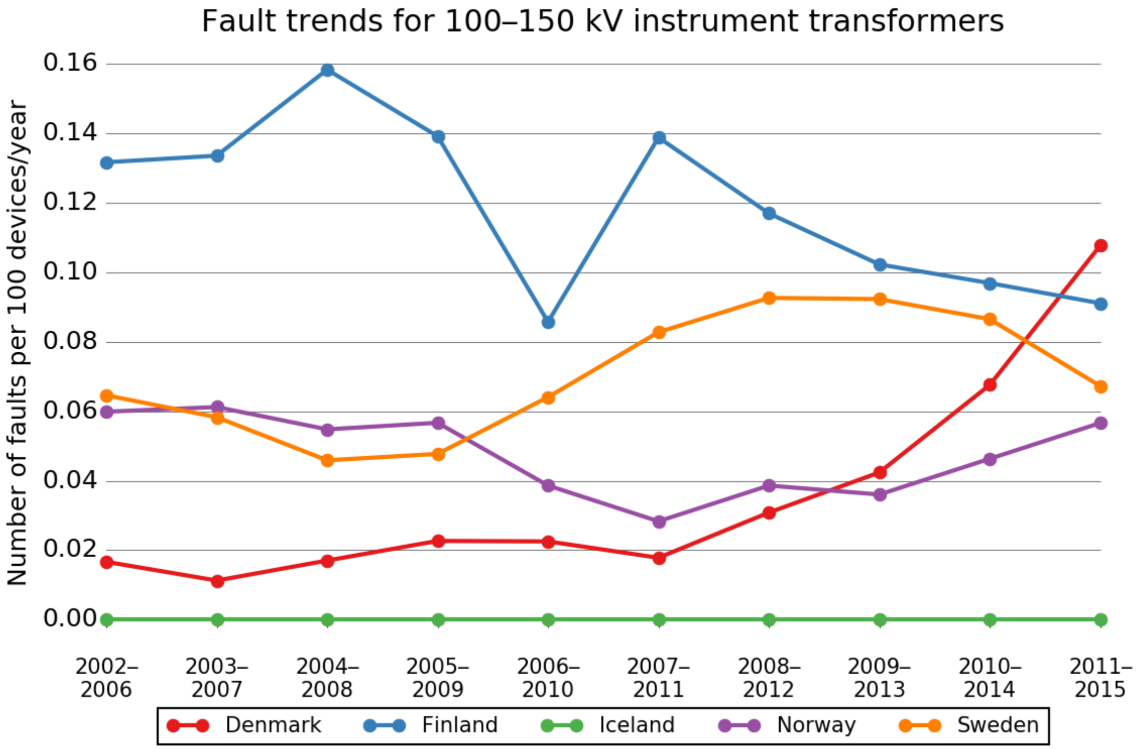

FIGURE 5.6.3 FAULT TRENDS AS FIVE-YEAR AVERAGES FOR INSTRUMENT TRANSFORMERS AT THE VOLTAGE LEVEL 100–150 KV IN EACH NORDIC COUNTRY

5.7 FAULTS IN CIRCUIT BREAKERS

The tables in this section present circuit breaker faults at each statistical voltage level for the year 2015 and for the period 2006–2015. The tables also present the distribution of faults according to cause during that period.

The figures in this section present the fault trends for circuit breakers at each statistical voltage level in the Nordic countries.

TABLE 5.7.1 380–420 KV CIRCUIT BREAKER FAULTS AND THE DISTRIBUTION ACCORDING TO CAUSE IN NORDIC COUNTRIES

Country	Number of devices	Number of faults	Number of faults per 100 devices		Light-ning	Other environ-mental causes	External influence	Operation and mainte-nance[2)]	Technical equipment	Other	Unknown
	2015	2015	2015	2006–2015	Faults divided by cause (%) during the period 2006–2015						
Denmark	214	0	0.00	0.25	0	0	0	25	50	25	0
Finland	209	0	0.00	0.37	0	0	11	0	78	11	0
Norway	287	2	0.70	0.79	0	0	0	38	48	10	5
Sweden[1)]	583	3	0.51	1.16	0	0	0	5	86	2	7
Total	1293	5	0.39	0.79	0	0	1	13	75	5	5

1) For Sweden, the breaker failures at the 380–420 kV level most often occurred in breakers that are 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.

2) One should note that a high number of operation and maintenance is because erroneous circuit breaker operations are registered as faults with operation and maintenance as the cause. These are caused by 380–420 kV shunt reactor circuit breakers, which are operated more often than other circuit breakers.

TABLE 5.7.2 220–330 KV CIRCUIT BREAKER FAULTS AND THE DISTRIBUTION ACCORDING TO CAUSE IN EACH NORDIC AND BALTIC COUNTRY

Country	Number of devices	Number of faults	Number of faults per 100 devices		Light-ning	Other environ-mental causes	External influence	Operation and mainte-nance	Technical equipment	Other	Unknown
	2015	2015	2015	2006–2015	Faults divided by cause (%) during the period 2006–2015						
Denmark	11	0	0.00	0.00	0	0	0	0	0	0	0
Finland	78	0	0.00	0.32	0	0	0	0	100	0	0
Iceland	80	1	1.25	0.78	0	17	0	17	67	0	0
Norway	734	7	0.95	0.58	0	2	2	33	48	7	7
Sweden	327	1	0.31	0.28	10	0	0	0	60	0	30
				2014–2015	Faults divided by cause (%) during the period 2014–2015						
Estonia	117	3	2.56	2.10	0	0	0	20	80	0	0
Latvia	103	0	0.00	0.00	0	0	0	0	0	0	0
Lithuania	108	1	0.93	0.47	0	0	0	0	0	0	100
Total	1558	13	0.83	0.51	1	3	1	24	55	4	10

TABLE 5.7.3 100–150 KV CIRCUIT BREAKER FAULTS AND THE DISTRIBUTION ACCORDING TO CAUSE IN EACH NORDIC AND BALTIC COUNTRY

Country	Number of devices	Number of faults	Number of faults per 100 devices		Light-ning	Other environ-mental causes	External influence	Operation and mainte-nance	Technical equipment	Other	Unknown
	2015	2015	2015	2006–2015	Faults divided by cause (%) during the period 2006–2015						
Denmark	902	3	0.33	0.36	0	0	0	46	46	4	4
Finland	2516	5	0.20	0.16	6	3	3	31	28	6	25
Iceland	176	2	1.14	0.80	0	8	8	25	58	0	0
Norway	2058	11	0.53	0.29	8	0	0	60	23	6	2
Sweden	2342	4	0.17	0.25	31	2	6	19	38	0	4
				2014–2015	Faults divided by cause (%) during the period 2014–2015						
Estonia	569	15	2.64	1.87	0	0	0	14	86	0	0
Latvia	606	5	0.83	0.66	0	0	0	0	100	0	0
Lithuania	862	6	0.70	0.51	0	0	0	38	50	0	13
Total	10031	51	0.51	0.30	10	1	2	35	41	3	6

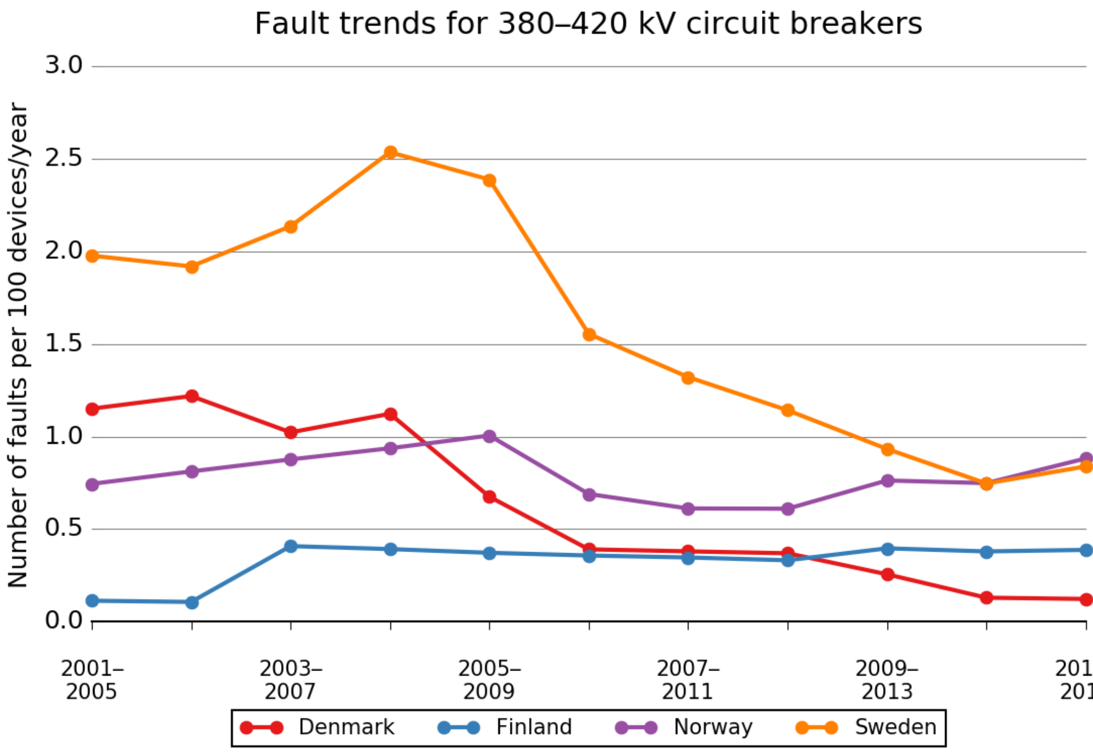

FIGURE 5.7.1 FAULT TRENDS AS FIVE-YEAR AVERAGES FOR CIRCUIT BREAKERS AT THE VOLTAGE LEVEL 380–420 KV IN NORDIC COUNTRIES

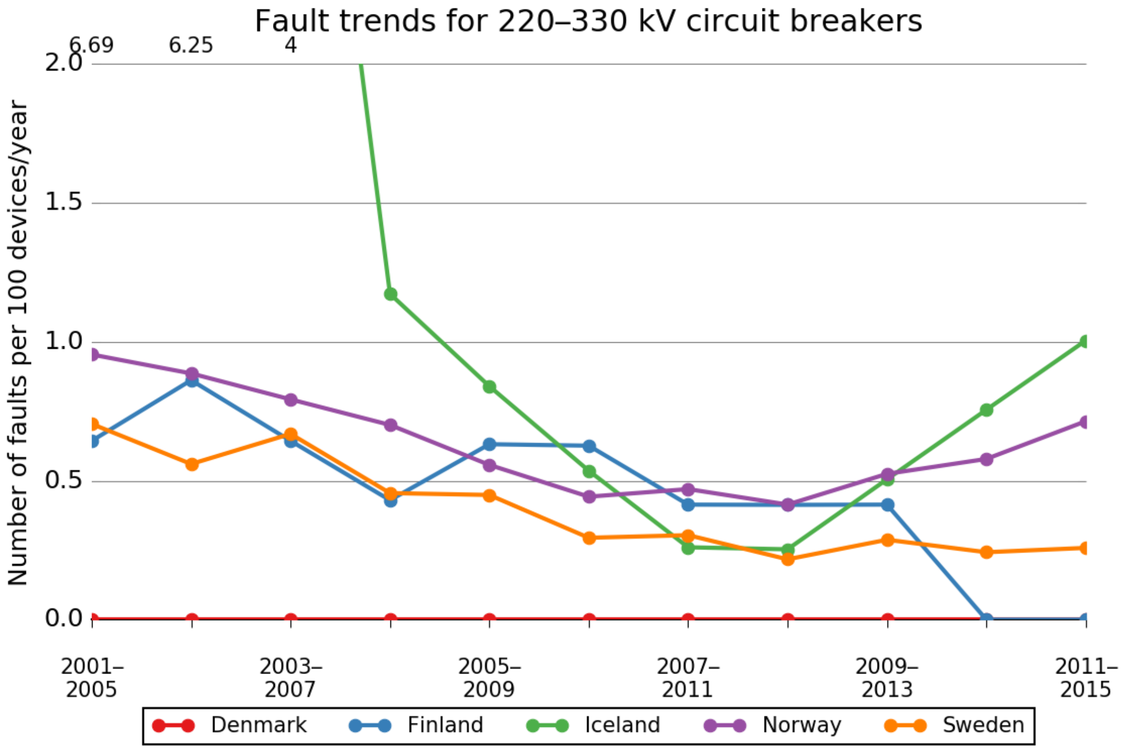

FIGURE 5.7.2 FAULT TRENDS AS FIVE-YEAR AVERAGES FOR CIRCUIT BREAKERS AT THE VOLTAGE LEVEL 220–330 KV IN NORDIC COUNTRIES

The explanation for the remarkable improvement on the fault trend of Iceland is that most of the faults on circuit breakers up to 2003 in the 220 kV network occurred at one substation. These breakers caused problems due to gas leaks and were repaired in 2003.

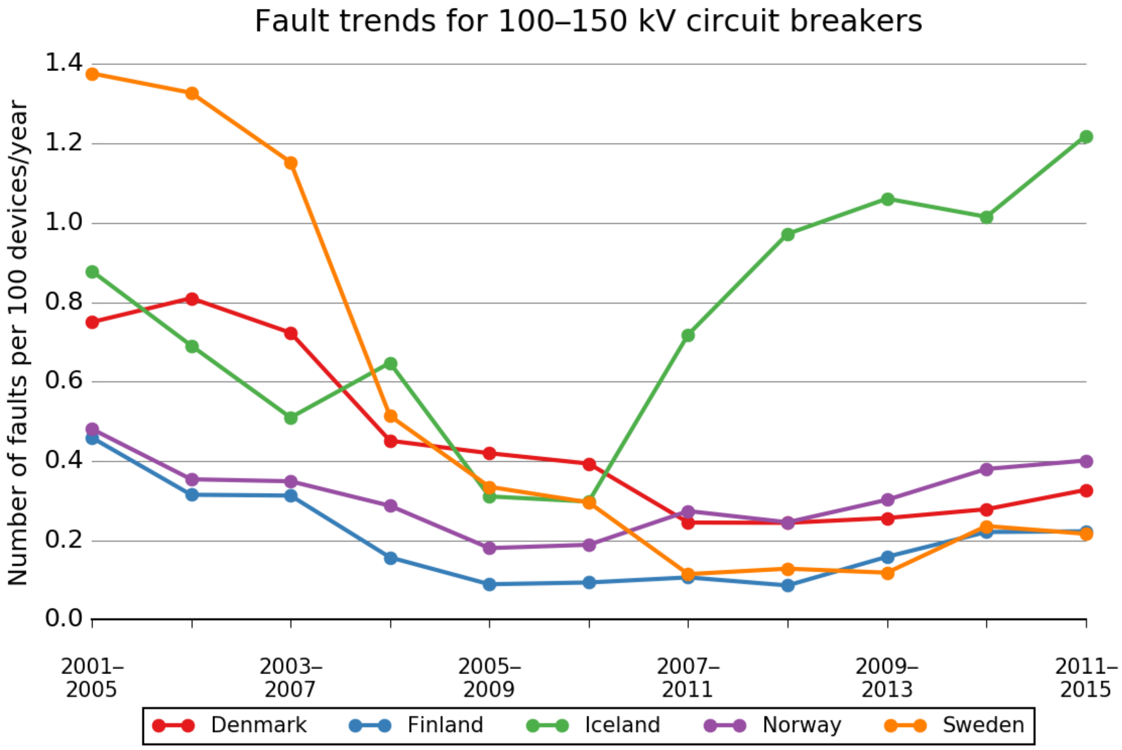

FIGURE 5.7.3 FAULT TRENDS AS FIVE-YEAR AVERAGES FOR CIRCUIT BREAKERS IN EACH NORDIC COUNTRY AT THE VOLTAGE LEVEL 100–150 KV

5.8 FAULTS IN CONTROL EQUIPMENT

The tables in this section present faults in control equipment at each statistical voltage level for the year 2015 and for the period 2006–2015. In addition, the tables present the distribution of faults according to cause during that ten-year period.

Figure 5.8.1, Figure 5.8.2, Figure 5.8.3, Figure 5.8.4 and present the annual distribution of control equipment faults at each statistical voltage level during the period 2006–2015 in the Nordic countries and at 100–150 kV and 220–330 kV during the period 2014–2015 in the Baltic countries.

For control equipment, it is important to distinguish between faults in technical equipment and faults made by human errors. Human errors include, for example, erroneous settings in an IED. In these statistics, human errors are registered under operation and maintenance, separated from the category technical equipment.

In apparatus where the control equipment is integrated, which is typical for SVCs, there is an uncertainty whether faults are registered in the control equipment or in the actual apparatus. When the control equipment is integrated in another installation, it should normally be categorised as faults in the installation and not in the control equipment. However, this definition is not yet fully applied in all countries.

TABLE 5.8.1 380–420 KV CONTROL EQUIPMENT FAULTS AND THE DISTRIBUTION ACCORDING TO CAUSE

Country	Number of devices	Number of faults	Number of faults per 100 devices		Light-ning	Other environ-mental causes	External influence	Operation and mainte-nance	Technical equipment	Other	Unknown
	2015	2015	2015	2006–2015	Faults divided by cause (%) during the period 2006–2015						
Denmark	214	1	0.47	0.82	0	8	8	25	50	8	0
Finland	209	4	1.91	3.24	0	0	0	67	21	3	10
Norway	287	15	5.23	4.14	0	2	0	48	35	6	8
Sweden	583	36	6.17	4.73	0	4	0	16	80	0	1
Total	1293	56	4.33	3.78	0	3	0	33	57	2	4

TABLE 5.8.2 220–330 KV CONTROL EQUIPMENT FAULTS AND THE DISTRIBUTION ACCORDING TO CAUSE

Country	Number of devices	Number of faults	Number of faults per 100 devices		Light-ning	Other environ-mental causes	External influence	Operation and mainte-nance	Technical equipment	Other	Unknown
	2015	2015	2015	2006–2015	Faults divided by cause (%) during the period 2006–2015						
Denmark	11	0	0.00	2.17	0	0	0	100	0	0	0
Finland	78	1	1.28	3.44	0	0	0	56	28	6	9
Iceland	80	3	3.75	4.93	0	3	0	34	47	5	0
Norway	734	34	4.63	3.25	1	2	2	38	40	7	9
Sweden	327	11	3.36	1.91	0	0	1	37	47	9	6
				2014–2015	Faults divided by cause (%) during the period 2014–2015						
Estonia	117	0	0.00	1.79	0	0	0	0	100	0	0
Latvia	103	2	1.94	3.40	0	0	0	71	29	0	0
Lithuania	108	1	0.93	0.47	0	0	0	100	0	0	0
Total	1558	52	3.34	2.93	1	1	2	39	41	7	8

TABLE 5.8.3 100–150 KV CONTROL EQUIPMENT FAULTS AND THE DISTRIBUTION ACCORDING TO CAUSE

Country	Number of devices	Number of faults	Number of faults per 100 devices		Light-ning	Other environ-mental causes	External influence	Operation and mainte-nance	Technical equipment	Other	Unknown
	2015	2015	2015	2006–2015	Faults divided by cause (%) during the period 2006–2015						
Denmark	902	13	1.44	1.19	7	7	2	46	25	9	5
Finland	2516	11	0.44	1.32	1	0	2	50	25	7	15
Iceland	176	4	2.27	3.85	0	0	0	19	72	2	0
Norway	2058	40	1.94	1.62	2	4	1	38	30	10	15
Sweden	2342	9	0.38	0.27	2	0	0	49	24	10	10
				2014–2015	Faults divided by cause (%) during the period 2014–2015						
Estonia	569	2	0.35	1.98	0	0	0	41	45	0	14
Latvia	606	24	3.96	3.14	0	0	0	50	39	5	5
Lithuania	862	18	2.09	2.40	0	0	24	34	21	0	21
Total	10031	121	1.21	1.24	2	2	2	42	30	8	13

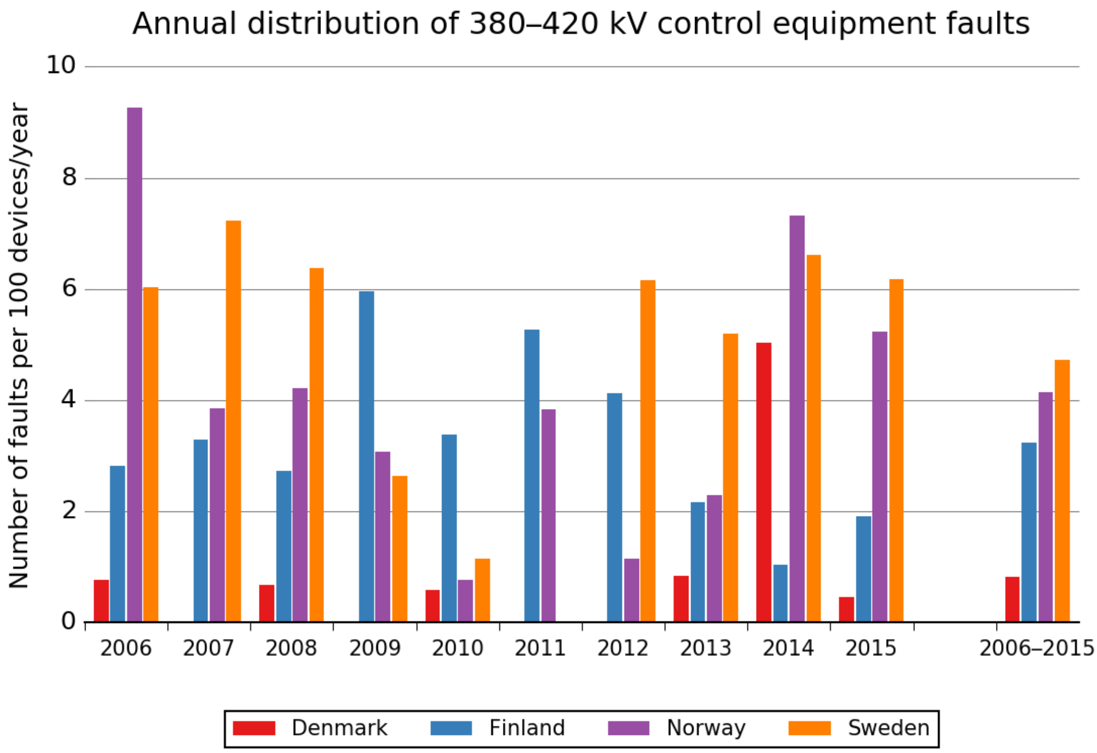

FIGURE 5.8.1 ANNUAL DISTRIBUTION OF 380–420 KV CONTROL EQUIPMENT FAULTS AND THE AVERAGE FOR THE PERIOD 2006–2015

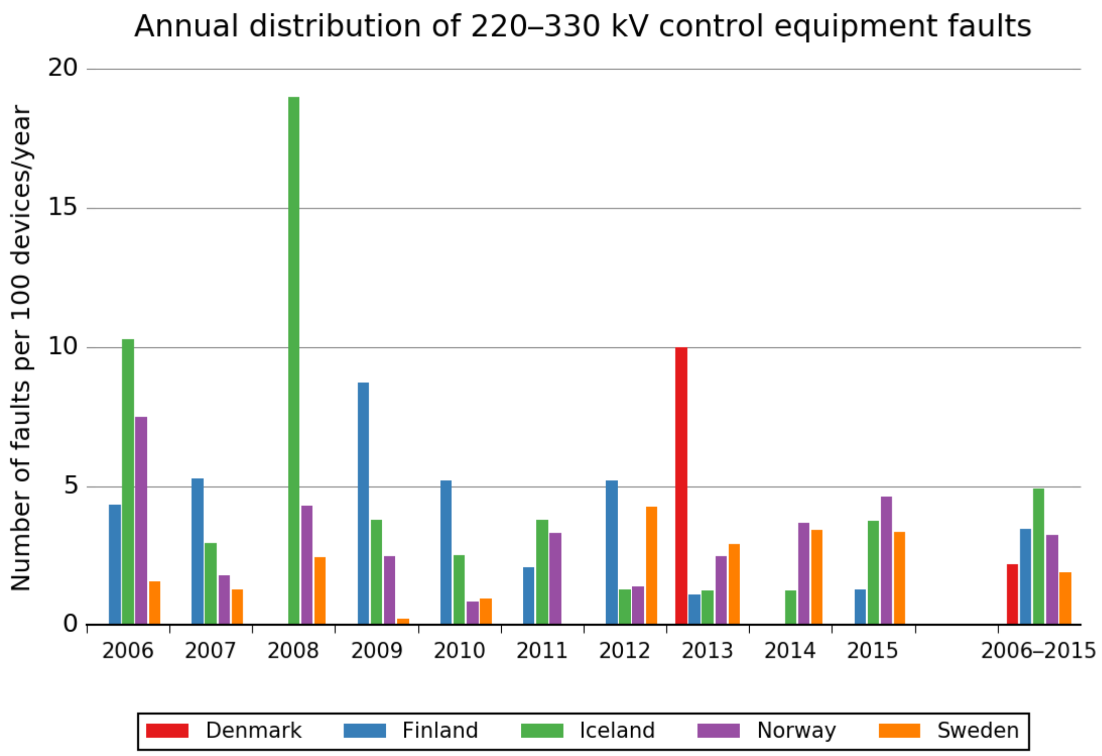

FIGURE 5.8.2 ANNUAL DISTRIBUTION OF 220–330 KV CONTROL EQUIPMENT FAULTS AND THE AVERAGE FOR THE PERIOD 2006–2015 FOR EACH NORDIC COUNTRY

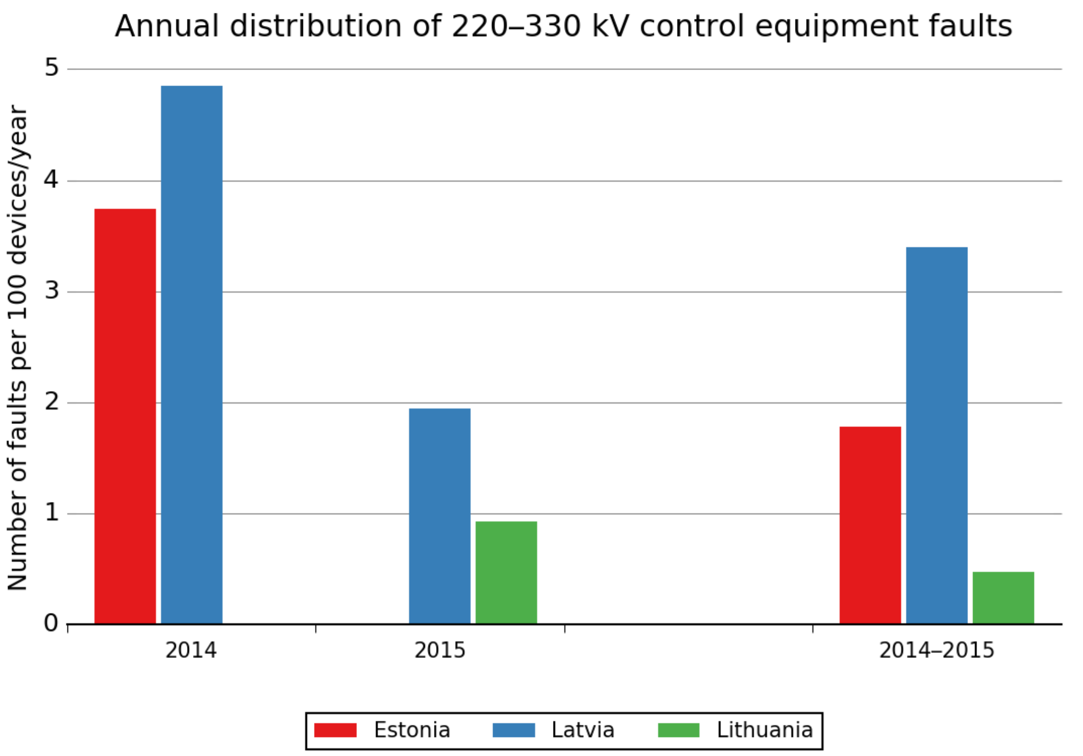

FIGURE 5.8.3 ANNUAL DISTRIBUTION OF 220–330 KV CONTROL EQUIPMENT FAULTS AND THE AVERAGE FOR THE PERIOD 2006–2015 FOR EACH BALTIC COUNTRY

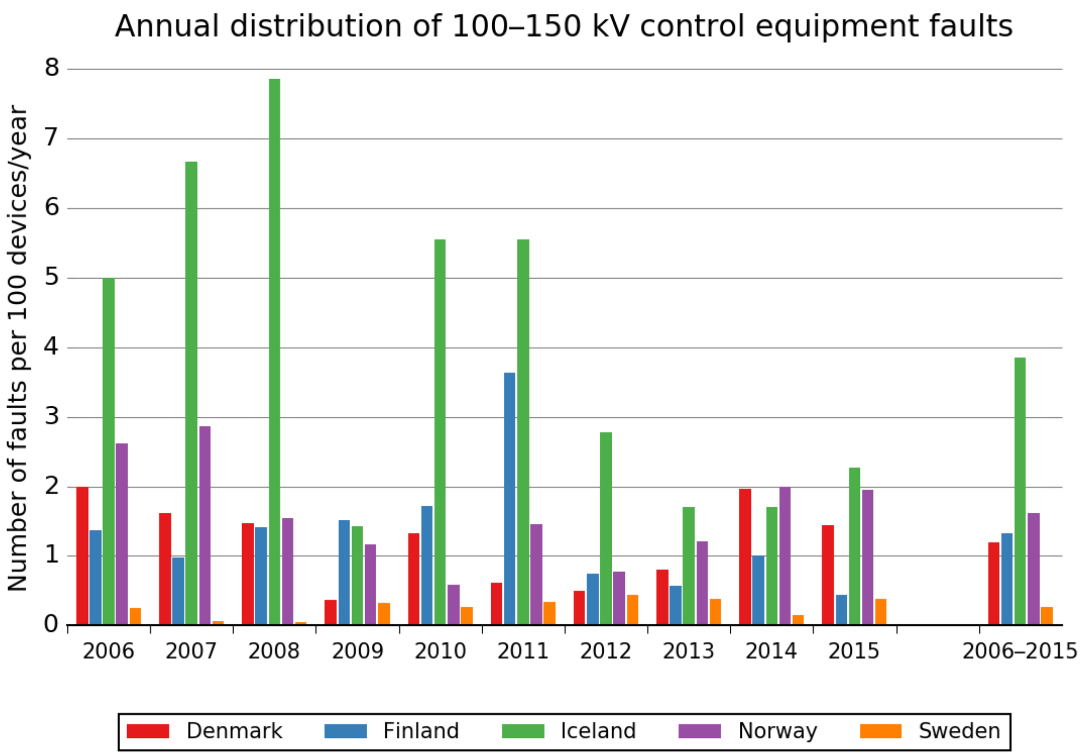

FIGURE 5.8.4 ANNUAL DISTRIBUTION OF 100–150 KV CONTROL EQUIPMENT FAULTS AND THE AVERAGE FOR THE PERIOD 2006–2015 FOR EACH NORDIC COUNTRY

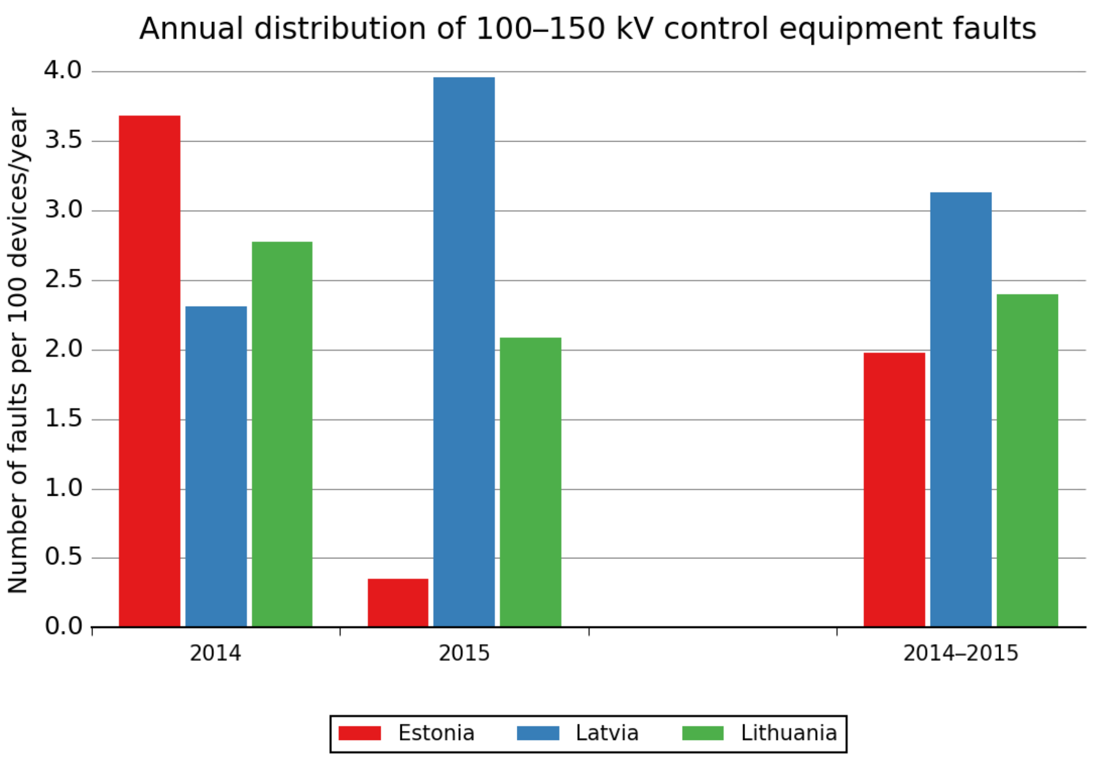

FIGURE 5.8.5 ANNUAL DISTRIBUTION OF 100–150 KV CONTROL EQUIPMENT FAULTS AND THE AVERAGE FOR THE PERIOD 2006–2015 FOR EACH BALTIC COUNTRY

5.9 FAULTS IN COMPENSATION DEVICES

For compensation devices, 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 2015 and for the period 2006–2015. In addition, the tables present the distribution of faults according to cause during the ten-year period 2006–2015.

TABLE 5.9.1 REACTOR FAULTS AND THE DISTRIBUTION ACCORDING TO CAUSE

Country	Number of devices	Number of faults	Number of faults per 100 devices		Light-ning	Other environ-mental causes	External influence	Operation and mainte-nance	Technical equipment	Other	Unknown
	2015	2015	2015	2006–2015	Faults divided by cause (%) during the period 2006–2015						
Denmark	76	1	1.32	3.30	0	0	0	36	36	0	27
Finland	70	1	1.43	0.31	0	0	0	50	50	0	0
Norway	36	1	2.78	3.61	0	8	0	38	31	23	0
Sweden	78	5	6.41	11.51	0	30	1	11	29	26	4
				2014–2015	Faults divided by cause (%) during the period 2014–2015						
Estonia	26	2	7.69	4.26	0	0	0	0	100	0	0
Latvia	16	1	6.25	6.25	0	0	0	0	100	0	0
Lithuania	11	0	0.00	0.00	0	0	0	0	0	0	0
Total	313	11	3.51	5.15	0	23	1	17	33	22	5

In Finland, reactors compensating the reactive power of 380–420 kV lines are connected to the 20 kV tertiary winding of the 380–420/100–150/20 kV power transformers.

TABLE 5.9.2 SERIES CAPACITOR FAULTS AND THE DISTRIBUTION ACCORDING TO CAUSE

Country	Number of devices	Number of faults	Number of faults per 100 devices		Light-ning	Other environ-mental causes	External influence	Operation and mainte-nance	Technical equipment	Other	Unknown
	2015	2015	2015	2006–2015	Faults divided by cause (%) during the period 2006–2015						
Finland	10	3	30.00	54.12	0	4	7	9	48	0	33
Iceland	0	0	0.00	0.00	0	0	0	0	0	0	0
Norway	3	0	0.00	3.33	0	100	0	0	0	0	0
Sweden	8	1	12.50	138.79	0	1	0	0	14	81	7
Total	21	4	19.05	86.31	0	2	1	2	21	63	13

TABLE 5.9.3 SHUNT CAPACITOR FAULTS AND THE DISTRIBUTION ACCORDING TO CAUSE

Country	Number of devices	Number of faults	Number of faults per 100 devices		Light-ning	Other environ-mental causes	External influence	Operation and mainte-nance	Technical equipment	Other	Unknown
	2015	2015	2015	2006–2015	Faults divided by cause (%) during the period 2006–2015						
Denmark	25	0	0.00	1.20	0	0	100	0	0	0	0
Finland	109	6	5.50	4.06	0	9	45	5	32	5	5
Iceland	13	0	0.00	9.35	0	20	10	0	70	0	0
Norway	194	8	4.12	1.65	3	6	0	13	69	6	3
Sweden	189	2	1.06	1.02	0	18	6	0	53	6	18
				2014–2015	Faults divided by cause (%) during the period 2014–2015						
Estonia	14	0	0.00	0.00	0	0	0	0	0	0	0
Latvia	2	0	0.00	0.00	0	0	0	0	0	0	0
Lithuania	2	0	0.00	0.00	0	0	0	0	0	0	0
Total	530	16	3.02	1.86	1	11	17	6	54	5	6

TABLE 5.9.4 SVC FAULTS AND THE DISTRIBUTION ACCORDING TO CAUSE

Country	Number of devices	Number of faults	Number of faults per 100 devices		Light-ning	Other environ-mental causes	External influence	Operation and mainte-nance	Technical equipment	Other	Unknown
	2015	2015	2015	2006–2015	Faults divided by cause (%) during the period 2006–2015						
Denmark	1	1	100.0	20.0	0	50	0	0	50	0	0
Finland	5	0	0.0	13.3	0	0	0	50	50	0	0
Iceland	2	1	50.0	16.7	0	100	0	0	0	0	0
Norway	15	30	200.0	90.7	1	1	0	3	73	17	5
Sweden	3	7	233.3	300.0	1	8	2	14	61	4	10
Total	26	39	150.0	110.4	1	4	1	8	68	12	7

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 MULTIPLE FAULTS

This chapter presents the multiple faults that have occurred in the main grids. The definition of multiple faults and the scope of this chapter are presented in Chapter 6.1.

Chapter 6.2 gives an overview of multiple faults and the relation of multiple faults and disturbances. The following chapters present energy not supplied according to cause and voltage levels.

This chapter and the data it contains is new to this report and has thereby only data from 2015. Unfortunately, Sweden was not able to provide reliable data for their 100–150 kV network. For 2015, Sweden can only provide multiple fault data for 220kV-300kV and 380kV-420kV. This should be kept in mind when comparing data with Sweden in all graphs/tables on chapter 6.

6.1 DEFINITIONS AND SCOPE

A multiple fault situation occurs when a disturbance has more than one fault. Multiple fault situations are rarer than single fault situations but have a tendency to cause more ENS. This is partly because the main grids are designed to withstand single fault situations without degrading the performance.

The scope of this chapter is the same as the scope of disturbances, which are presented in Chapter 3.

6.2 OVERVIEW OF DISTURBANCES RELATED TO MULTIPLE FAULTS

Table 6.2.1 presents the number of disturbances, the number of disturbances with multiple faults and the ratio between the number of disturbances with multiple faults and the total number of disturbances in 2015. As can be seen, the number of disturbances with multiple faults is significantly smaller than the number of disturbances.

TABLE 6.2.1 THE NUMBER OF DISTURBANCES, THE NUMBER OF DISTURBANCES WITH MULTIPLE FAULTS AND THEIR RATION IN 2015

2015	Number of all disturbances in 2015	Number of multiple fault disturbances in 2015	Percentage (%) of disturbances due to multiple fault situations in 2015	Number of disturbances with ENS in 2015	Number of multiple fault disturbances divided by number of disturbances with ENS in 2015
Denmark	79	13	16	7	1.86
Estonia	219	2	1	21	0.10
Finland	454	16	4	70	0.23
Iceland	47	16	34	29	0.55
Latvia	112	13	12	18	0.72
Lithuania	138	13	9	19	0.68
Norway	437	37	8	86	0.43
Sweden	378	12	3	122	0.10
Total	1864	122	7	372	0.33

6.3 MULTIPLE FAULT SITUATIONS DISTRIBUTED ACCORDING TO CAUSE

Figure 6.3.1 and Figure 6.3.2 present the percentage distribution of multiple fault situations according to cause in 2015.

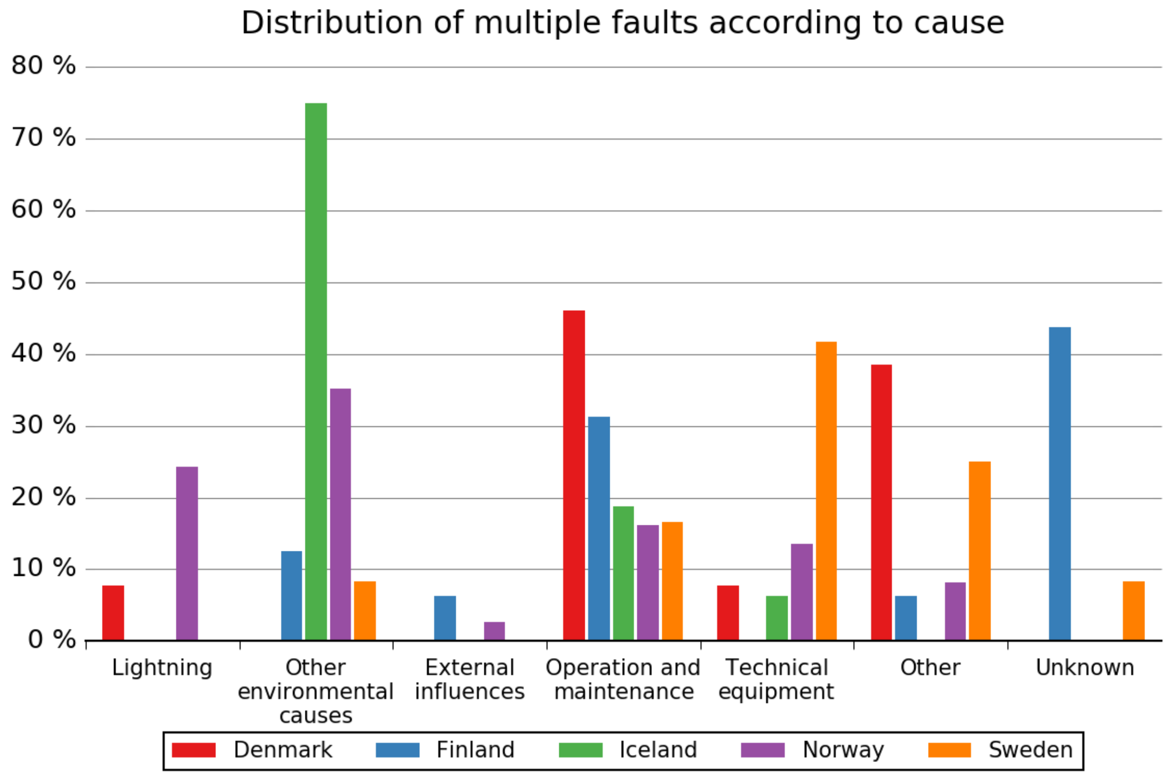

FIGURE 6.3.1 PERCENTAGE DISTRIBUTION OF MULTIPLE FAULT SITUATIONS ACCORDING TO CAUSE IN THE NORDIC COUNTRIES IN 2015

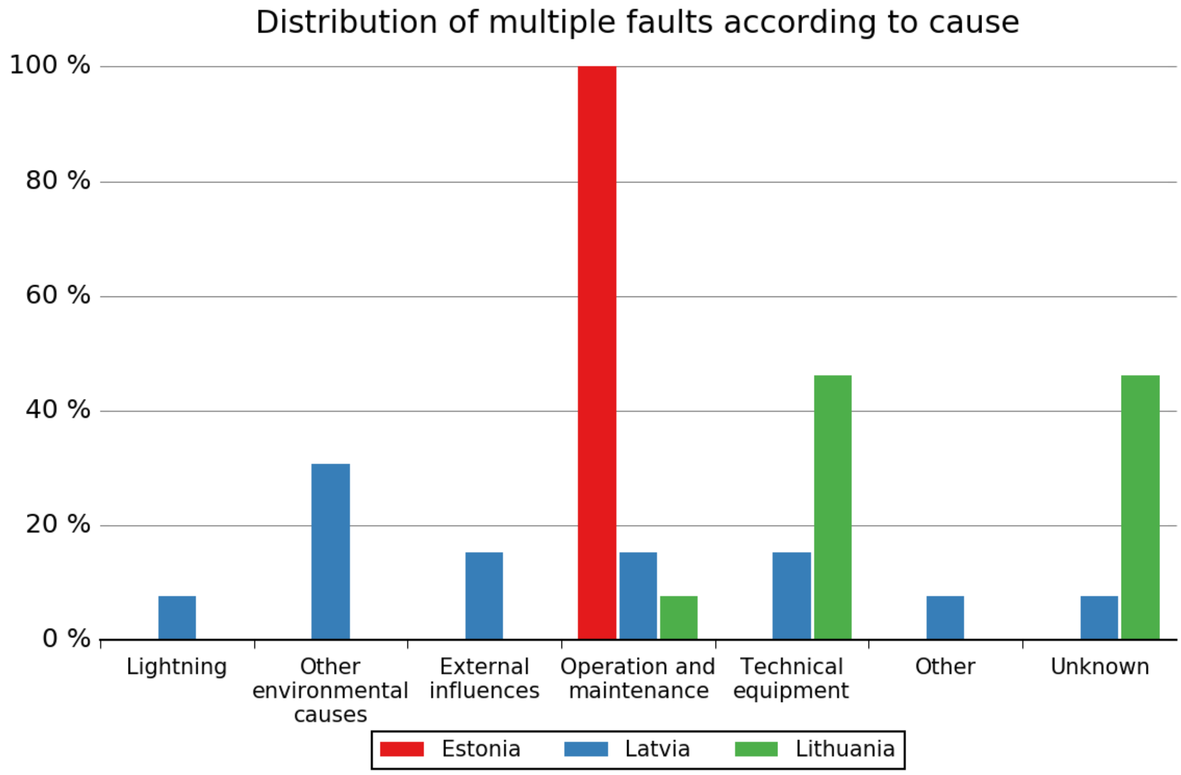

FIGURE 6.3.2 PERCENTAGE DISTRIBUTION OF MULTIPLE FAULT SITUATIONS ACCORDING TO CAUSE IN THE BALTIC COUNTRIES IN 2015

6.4 MULTIPLE FAULT SITUATIONS DISTRIBUTED ACCORDING TO VOLTAGE LEVEL

Figure 6.4.1 presents the percentage distribution of multiple fault situations according to voltage level in 2015.

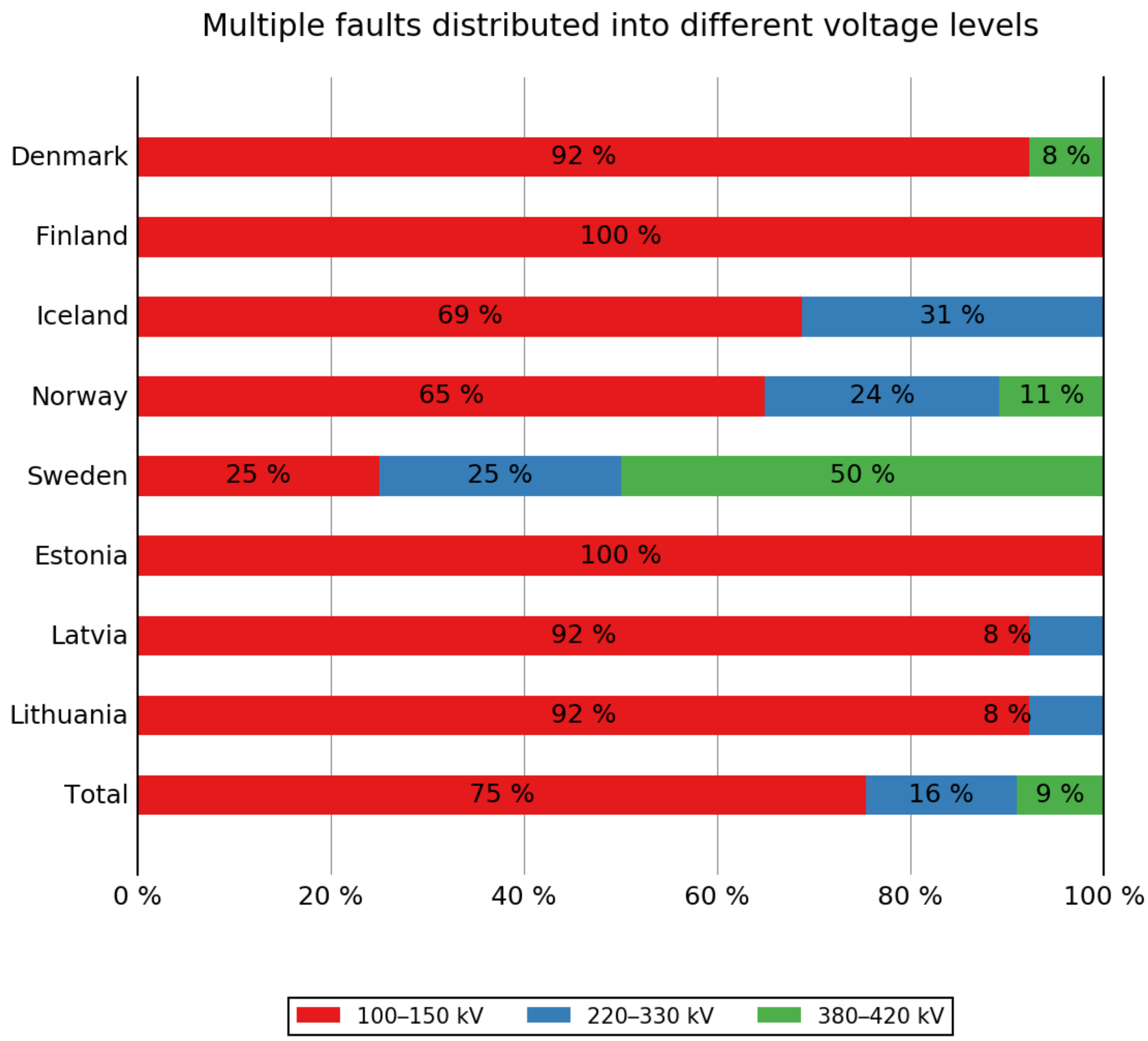

FIGURE 6.4.1 PERCENTAGE DISTRIBUTION OF MULTIPLE FAULT SITUATIONS IN THE NORDIC AND BALTIC COUNTRIES IN 2015

6.5 ENERGY NOT SUPPLIED DISTRIBUTED ACCORDING TO CAUSE

Table 6.5.1 presents how all ENS due to multiple faults is distributed according to cause.

TABLE 6.5.1 PERCENTAGE DISTRIBUTION OF ALL ENS DUE TO MULTIPLE FAULTS ACCORDING TO CAUSE IN 2015

2015	ENS in 2015 (MWh)	ENS due to multiple faults in 2015 (MWh)	Percentage (%) of ENS due to multiple faults in 2015	Percentage (%) distribution of ENS due to multiple faults according to cause in 2015							
				Light-ning	Other environ-mental causes	External influ-ences	Opera-tion and mainte-nance	Tech-nical equip-ment	Ot-her	Un-known	Single faults
Denmark	25	1	3	0	0	0	3	0	0	0	97
Estonia	31	2	6	0	0	0	6	0	0	0	94
Finland	176	3	2	0	0	0	1	0	0	0	98
Iceland	735	209	28	0	6	0	3	20	0	0	72
Latvia	54	31	57	0	18	3	1	36	0	0	43
Lithuania	32	2	6	0	0	0	0	6	0	0	94
Norway	2779	1796	65	9	16	0	4	35	0	0	35
Sweden	1353	0	0	0	0	0	0	0	0	0	100
Total	5185	2043	39	5	9	0	3	22	0	0	61

Table 6.5.2 presents how much of the ENS caused by a specific cause was due to a multiple fault situation. For example, if 100 MWh of all ENS was caused by external influences and 30 MWh of that was caused by multiple fault situations, the column for external influences would read 30 %.

TABLE 6.5.2 PERCENTAGE OF THE CAUSE SPECIFIC ENS DUE TO DISTURBANCES WITH MULTIPLE FAULTS ACCORDING TO CAUSE IN 2015

2015	Percentage (%) of the cause specific ENS due to disturbances with multiple faults according to cause in 2015						
	Lightning	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Denmark	0	0	0	12	0	0	0
Estonia	0	0	0	19	0	0	0
Finland	0	7	0	6	0	0	0
Iceland	0	36	0	100	25	0	0
Latvia	0	57	9	36	97	0	0
Lithuania	0	0	0	0	97	0	0
Norway	94	36	0	76	89	53	0
Sweden	0	0	0	0	0	0	0
Total	29	35	2	56	57	2	0

6.6 ENERGY NOT SUPPLIED DISTRIBUTED ACCORDING TO VOLTAGE LEVEL

Table 6.6.1 presents how all ENS due to multiple faults is distributed according to voltage level.

TABLE 6.6.1 PERCENTAGE DISTRIBUTION OF ENS DUE TO MULTIPLE FAULTS ACCORDING TO VOLTAGE LEVEL IN 2015

2015	ENS in 2015 (MWh)	ENS due to multiple faults in 2015 (MWh)	Percentage (%) of ENS due to multiple faults in 2015	Percentage (%) distribution of ENS due to multiple faults according to voltage level in 2015			
				100–150 kV	220–330 kV	380–420 kV	Single faults
Denmark	25	1	3	3	0	0	97
Estonia	31	2	6	6	0	0	94
Finland	176	3	2	2	0	0	98
Iceland	735	209	28	9	20	0	72
Latvia	54	31	57	57	0	0	43
Lithuania	32	2	6	6	0	0	94
Norway	2779	1796	65	52	12	0	35
Sweden	1353	0	0	0	0	0	100
Total	5185	2043	39	30	9	0	61

For example, if 100 MWh of all ENS was caused in the 220–330 kV grid and 30 MWh of that was caused by multiple fault situations, the 220–330 kV column would read 30 %.

TABLE 6.6.2 PERCENTAGE OF THE TOTAL VOLTAGE LEVEL SPECIFIC ENS DUE TO DISTURBANCES WITH MULTIPLE FAULTS ACCORDING TO VOLTAGE LEVEL IN 2015

2015	Percentage (%) of the total voltage level specific ENS due to disturbances with multiple faults according to voltage level in 2015		
	100–150 kV	220–330 kV	380–420 kV
Denmark	3	0	0
Estonia	9	0	0
Finland	2	0	0
Iceland	15	49	0
Latvia	57	0	0
Lithuania	6	0	0
Norway	67	79	0
Sweden	0	0	0
Total	39	62	0

7 REFERENCES

[1] Nordel, “Guidelines for the Classification of Grid Disturbances,” 2009. [Online]. Available: http://www.entsoe.eu/index.php?id=63. [Accessed 19 October 2015].

[2] ENTSO-E, ”The ENTSO-E Interconnected System Grid Map,” [Online]. Available: https://www.entsoe.eu/publications/order-maps-and-publications/electronic-grid-maps/Pages/default.aspx. [Haettu 19 October 2015].

[3] The Energy Concern’s National League, The Norwegian Water Supply and Energy Department, Statnett and Sintef Energy Research, “Definisjoner knyttet til feil og avbrudd i det elektriske kraftsystemet – Versjon 2 (In English: Definitions in relation to faults and outages in the electrical power system – Version 2),” 2001. [Online]. Available: https://www.sintef.no/globalassets/project/kile/definisjoner.pdf. [Accessed 19 October 2015].

[4] IEC 50(191-05-01), *International Electrotechnical Vocabulary, Dependability and Quality of Service. Note that the IEC standard 50-191 Dependability and quatlity of service is canceled on 27 April 2015. Since the statistics have been prepared by using this defintion,* it is used as a reference.

[5] IEEE, *Standard Terms for Reporting and Analyzing Outage Occurrence and Outage States of Electrical Transmission Facilities,* IEEE Std 859-1987, 1988. DOI: 10.1109/IEEESTD.1988.86288, p. 11.

Appendix 1 The calculation of energy not supplied

Every country calculates their energy not supplied (ENS) is various ways. This chapter describes how the calculations are done.

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 connection points 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 Estonia, ENS calculation is based on interruption time for the end user. When the outage duration is less than two hours, ENS is calculated by cut-off power (measured straight before the outage) multiplied by the interruption time. When the outage duration is more than two hours, the load data of previous or next day shall be taken into account and ENS is calculated according to these load profiles.

In Iceland, ENS is computed according to the delivery from the transmission grid. It 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 and Baltic 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 Latvia, the ENS is linked to the end user. This means that ENS is not counted as long as the end user receives energy through the distribution grid. Note that the distribution grid is 100 % dependent of the TSO supply due to undeveloped energy generation. The amount of ENS is calculated by multiplying the load before the outage occurred with the duration of the outage.

In Lithuania energy not delivered (END) is treated as the ENS. The END of the transmission grid is calculated at the point of supply of the end customer. The point of supply means the low voltage side of the 110/35/10 kV or 110/10 kV transformer at the low voltage customer connection point. If an outage is in a radial 110 kV connection, END is calculated by the distribution system operator (DSO), who considers the possibility to supply energy from the other 35 kV or 10 kV voltage substations. The DSO then uses the average load before the outage and its duration in the calculations. All events with the energy not supplied shall be investigated together with the DSO or Significant User directly connected to 110 kV network. Both parties shall agree and confirm the amounts of not supplied energy.

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 power is often not registered, some companies use the rated power of the point of supply multiplied by the outage duration.

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Appendix 2 Policies for examining the cause for line faults

This appendix is added in order to explain the effort put into finding the most probable cause of each disturbance.

In Denmark, the quality of data from disturbance recorders and other information that has been gathered is not always good enough to pinpoint the cause of the disturbance. In this case it leads to a cause stated as unknown. This is mainly the case on the sub-transmission level as Energinet.dk does not have full access to disturbance recorders and event lists due to the fact that Energinet.dk does not fully own the 100–150 kV network. It is also a fact that every line fault is not inspected, which may lead to a cause stated as unknown.

In Finland, Fingrid Oyj has changed the classification policy of faults in July 2011. More effort is put to clarify causes. Even if the cause is not 100 % certain but if the expert opinion is that the cause was lightning, the reported cause will be lightning. Therefore, the number of unknown faults has decreased.

In Estonia, the causes of line faults are found by inspections or by some identifying or highly probable signs. Fault location is usually categorised as it is measured by disturbance recorders although the accuracy may vary a lot. The 110 kV lines have many trips with a successful automatic reclosing at nights during summer months. The reasons were examined and it was found out that stork contamination on insulators causes these flashovers. In these cases, the fault sites are not always inspected. Elering has an access to lightning detection system, which allows identifying the line faults caused by lightning. If there are no signs referring to a certain cause, the reason for a fault is unknown.

In Iceland, disturbances in Landsnet‘s transmission system are classified into two categories: sudden disturbances in the transmission network and sudden disturbances in other systems. Every month the listings for interference are analysed by the staff of system operation and corrections are made to the data if needed. In 2015, Landsnet started to hold meetings three times a year, with representatives from the asset management and maintenance department to review the registration of interference and corrections made if the cause was something else than what was originally reported. This also leads to a better understanding how disturbances are listed in the disturbance database for these parties.

In Latvia, disturbance recorders, relay protection systems, on-sight inspections and information from witnesses are used to find the cause of a disturbance. If there is enough evidence for a fault cause, a disturbance will be counted as known. Unfortunately, there are many cases (for example lightning, other environmental causes or external influences), where it is difficult to find the right cause. In those cases, we use our experience to pinpoint the most probable cause and mark it as such.

In Lithuania, disturbances in the transmission system are mainly classified into two categories: disturbances that affected the consumers (Significant users and the DSO) connected to the transmission network and disturbances that did not. All disturbances are investigated according to the internal investigation procedures of Litgrid. To detect line faults, TSO analyses the data from disturbance recorders, relay protection terminals and the post-inspection of the line. Litgrid does not have access to the data of the lightning detection system.

In Norway, primarily for these statistics, the reporting TSO needs to distinguish between six fault categories and unknown. Norway has at least a single sided distance to a fault on most lines on this reporting level and all line faults are inspected. The fault categories external influence (people), operation and maintenance (people), technical equipment and other will normally be detected during the disturbance and the post-inspection of the line. To distinguish between the remaining two categories lightning and other environmental faults, Statnett uses waveform analysis on fault records, the lightning detection system and weather information to sort out the lightning. If the weather was good and no other category is suitable, unknown is used.

In Sweden, data from disturbance recorders and other gathered information is not enough to pinpoint the cause of the disturbance in many cases. Svenska kraftnät does not have full access to raw data from the lightning detection system and if a successful reclosing has taken place Svenska kraftnät prefers to declare the cause unknown instead of lightning, which may be the most probable cause.

Appendix 3 Contact persons in the Nordic and Baltic countries

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Appendix 4 Contact persons for the distribution network statistics

ENTSO-E Regional Group Nordic provides no statistics for distribution networks (voltage voltages lower than 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 and Baltic countries, which are listed below:

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