European Network of
Transmission System Operators
for Electricity

NORDIC AND BALTIC GRID DISTURBANCE STATISTICS 2016

16.11.2017

REGIONAL GROUP NORDIC

Table of Contents

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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 2016. Transmission System Operators providing the statistical data are *Energinet* 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.

The report is made according to the Guidelines for Classification of Grid Disturbances above 100 kV [1], which is published by ENTSO-E, and includes the faults causing disturbances in the 100–420 kV grids.

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 2016.
- Chapter 3 presents the disturbances and focuses on the analysis and allocation of the causes of disturbances. The distribution of disturbances during the year 2016 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.
- Chapter 5 presents the faults in different components. A summary of all the faults is followed by the presentation of more detailed statistics.
- Chapter 6 presents multiple faults and their relations to single fault situations.

1.2 History of the report

The Nordic and Baltic Grid Disturbance Statistics were first published in 1996 by Nordel[1] in Swedish and with the name *Driftstörningsstatistik* (Eng. Fault statistics) and only comprised the Nordic countries. In 2007, the statistics were translated to English and the name became *Nordic Grid Disturbance Statistics*. In 2014, the Baltic countries joined the report and the report changed its name to *Nordic and Baltic Grid Disturbance Statistics*, which is also the name of the report today.

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

Figure 1.2.1 The Nordic and Baltic main grids [2]

1.3 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.

1.4 Voltage levels in the Nordic and Baltic networks

Table 1.4.1 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 per the table.

Table 1.4.1 Nominal voltage levels (U_N) in the respective statistical voltages and the percentage of the grid at the respective nominal voltage level (P)

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

1.5 The Scope and limitations of the statistics

Table 1.5.1 presents the coverage of the statistics in each country. The percentage of the grid is estimated per the length of lines included in the statistics material divided by the actual length of lines in the grid.

Table 1.5.1 Percentage of national networks included in the statistics

	Voltage level		
Country	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 %	100 %
Norway	100 %	100 %	100 %
Sweden	100 %	100 %	100 %

1) Percentage for Finland is reduced because some regional grid owners did not deliver data.

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

Although the statistics are built upon common guidelines [1], there are slight differences in the interpretations between different countries and companies. However, these differences are considered to have a minor impact on the statistical material. Nevertheless, readers should – partly because of these differences, but also because of the different maintenance and general policies in each company – use the appropriate published average values. Values concerning control equipment and unspecified faults or causes should be used with wider margins than other values

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.

1.6 Available data in the report

Most charts and tables include data for the period 2007–2016. In some cases, where older data has been available, even longer periods have been used. However, all the participating TSOs have not reported data for the whole period 2007–2016. In these cases, the tables and figures show all the available data. In this report, Latvia and Lithuania have reported for the period 2012–2016.

Therefore, the ten-year average values for Latvia and Lithuania are calculated from the years 2012–2016 and the trend curves for the Baltic countries use a three-year period instead of a five-year period.

2 Summary

2.1 Overview of the Nordic and Baltic countries

In 2016, the energy not supplied (ENS) due to faults in the Nordic main grid reached 3.5 GWh and 153 MWh in the Baltic main grids. Totally, there was 3.7 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 2007–2016 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 2016. In addition, the summaries present the most important issues in 2016 referred by each Transmission System Operator.

2.2 Summary of Denmark

In Denmark, the energy not supplied in 2016 reached 45 MWh (ten-year average 20 MWh). There were 51 grid disturbances (ten-year average 58) and 13 of them caused ENS. On average, 8 disturbances per year caused ENS in 2009–2016.

In 2016, 85 % of ENS was caused by substation faults and 14 % by overhead line faults. The most significant reasons for ENS were operation and maintenance (48 %) and other environmental causes (28 %). Most of the disturbances were caused by external influences (24 %) and operation and maintenance (22 %).

The three most substantial disturbances in 2016 were the following:

- An earth fault in a 132 kV station was caused when a busbar disconnector broke during switching and fell on another busbar. The disturbance was age-related and was probably caused by frost. The incident happened in February, lasted for 26 minutes and caused 9.7 MWh of ENS..
- A 150 kV station in the north-western part of Jutland disconnected during a storm called “Urd” because of salt on the isolators. The incident lasted for 24 minutes and caused 8.0 MWh of ENS.
- The disconnector of a busbar broke in a 150 kV station broke during switching. The disturbance was age-relate, lasted for 10 minutes and caused 6.5 MWh of ENS.

2.3 Summary of Estonia

In Estonia, the energy not supplied in 2016 reached 102 MWh (ten-year average 54). The number of grid disturbances was 145 (ten-year average 222) and 36 of them caused ENS. On average, 29 disturbances per year caused ENS in 2009–2016.

In 2016, 43 % of ENS was caused by substation faults and 34 % by faults in an adjoining statistical area. The most significant reasons for ENS were technical equipment (34 %) and other (34 %). Most of the disturbances were caused by technical equipment (32 %) and operation and maintenance (18 %).

The three most substantial disturbances in 2016 were the following:

- A tree fell on a transmission line 18 June and caused an earth fault. Furthermore, one line was being maintained, which resulted in ENS for two 110 kV substations.
- The differential protection of two 110 kV parallel transformers worked wrongly and tripped the transformers on 25 August. The issue was fixed and normal operation could continue

- A short circuit on a dead-ended line, along with a circuit break failure, outed half of the feeding substation Aidu on 8 October.

2.4 Summary of Finland

In Finland, the energy not supplied in 2016 reached 255 MWh (ten-year average 361 MWh). The number of grid disturbances was 413 (ten-year average 433) and 71 of them caused ENS. On average, 79 disturbances per year caused ENS in 2009–2016.

In 2016, 66 % of ENS was caused substation faults and 34 % by overhead line faults. The most significant reasons for ENS were lightning (30 %) and technical equipment (25 %). Most of the disturbances were caused by other environmental causes and occurred during the summer months.

The three most substantial disturbances in 2016 were the following:

- A 1-phase permanent earth fault on a current transformer in a 110 kV substation tripped 110 kV transmission lines. The incident happened on 25.12.2016 and caused 47.5 MWh of ENS.
- A 110 kV transmission line tower fell and caused a multiphase permanent fault, which in turn tripped 110 kV transmission lines. The incident happened on 9.6.2016 and caused 37.2 MWh of ENS.
- The automatic reclosing of a 110 kV main transformer did not work during a 220 kV transmission line disturbance. The incident happened on 2.8.2016 and caused 35.8 MWh of ENS.

2.5 Summary of Iceland

In Iceland, the energy not supplied in 2016 reached 154 MWh (ten-year average 1133 MWh). The number of disturbances was 44 (ten-year average 35) and 18 of them caused ENS. On average, 15 disturbances per year caused ENS in 2009–2016. All disturbances were in the 132 and 220 kV systems.

In 2016, 54 % of ENS was caused by overhead line faults and 39 % by other faults. The most significant reasons for ENS were other (39 %) and lightning (27 %). Most of the disturbances were caused by technical equipment (32 %) and other environmental causes (30 %).

Even if the amount of grid disturbances were above the ten-year average, the amount of ENS was dramatically lower than the ten-year average of total ENS. This is a result of Landsnet introducing a new smart grid solution for the transmission network, which focuses on selective preventive splits and outages along with fast ramping of load in the transmission network based on WACS (wide area control schemes). The results for the first year is dramatic reduction of ENS.

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

- A high demand customer tripped 15 June and affected the relay protection scheme. This resulted in a system split and load shedding at other high demand customers and caused 80 MWh of ENS.
- A 220 kV transmission line BU3 tripped 15 November due to lightning. The incident left wo power intensive users some curtailable users without power and caused 42 MWh of ENS.
- A 132 kV transmission line tripped 19 June because of a tree growing on to it. This caused power fluctuations, which in turn resulted in automatic load shedding at high demand customers. Furthermore, the relay protection scheme split the system. The incident caused 6 MWh of ENS.

2.6 Summary of Latvia

In Latvia, the energy not supplied in 2016 reached 23 MWh (five-year average 38 MWh). The number of grid disturbances was 124 (five-year average 134) and 12 of them caused ENS. On average, 17 disturbances per year caused ENS in 2012–2016.

In 2016, 83 % of ENS was caused by substation faults 17 % overhead line faults. The most significant reasons for ENS were other (52 %) and external influences (24 %). Most of the disturbances were caused by external influences (24 %) and unknown causes (23 %) that occurred almost only on overhead lines.

The most substantial disturbance in 2016 was due to a short circuit in the DSO grid. Furthermore, the control equipment of a feeding transformer malfunctioned because of erroneous settings and fast reservation was impossible due to planned outage of the second transformer. This incident was a multiple fault situation and caused 52 % of the ENS in 2016.

2.7 Summary of Lithuania

In Lithuania, the energy not supplied in 2016 reached 28 MWh (five-year average 34 MWh). The number of grid disturbances was 137 (five-year average 169) and 11 of them caused ENS. On average, 20 disturbances per year caused ENS in 2012–2016.

In 2016, 99 % of ENS was caused by overhead line faults and 1 % by substation faults. The most significant reasons for ENS were other environmental causes (80 %) and external influences (19 %). Most of the disturbances were caused by unknown causes (37 %), external influences (17 %) and other causes (15 %).

The most substantial disturbance in 2016 was due to a storm that fell trees on an overhead line during summer and caused a permanent two-phase earth fault. Furthermore, the overhead line was in radial feeding mode because of maintenance work elsewhere and resulted therefore in one town disconnecting from the grid. Later investigation concluded that the disturbance was caused by environmental influences and resulted in 12 MWh of ENS, or about 42 % of the total ENS in 2016.

2.8 Summary of Norway

In Norway, the energy not supplied in 2016 reached 1162 MWh (ten-year average 3448 MWh). The number of grid disturbances was 261 (ten-year average 293) and 79 of them caused ENS. On average, 92 disturbances per year caused ENS in 2009–2016.

In 2016, 86 % of ENS was caused by substation faults and 12 % by overhead line faults. The most significant causes for ENS were technical equipment (53 %) and other environmental causes (22 %). More than half of the ENS occurred in July and the rest occurred during the winter months. Most of the disturbances were caused by other environmental causes (39 %) and lightning (16 %).

The three most severe disturbances in 2016 were the following:

- A 132 kV earthling switch was accidentally connected and resulted in a total outage of both busbars at the Aluminum plant in Oevre Aardal. Furthermore, the generators in Holsbu and Tyin tripped. Nevertheless, the busbars in Aardalstangen and Fortun disconnected correctly with distance protection relays. The total ENS was 541 MWh and the Aluminum plant was fully supplied within four hours.
- A 420/132 kV Transformer 2 in Viklandet tripped correctly due to a short circuit on 132 kV side bushing (the Transformer started to burn). Parallel transformer took the load. 420kV SVC

tripped due to loss off supply for cooling from T2. This resulted in over voltage tripping on two gas-pumping compressors with 120 MW load, 80 MW industrial load and 100 MW hydro generation. The fire was extinguished around midnight.

- Sylling-Tegneby 420 kV Sea-cable: Tripped due damage on cable with saltwater intrusion. This resulted in permanent decreased capacity between Norway and Sweden until cable was changed the 12 October.

2.9 Summary of Sweden

In Sweden, the energy not supplied in 2016 reached 1924 MWh (ten-year average 1880 MWh). The number of grid disturbances was 461 (ten-year average 526) and 178 of them caused ENS. On average, 156 disturbances per year caused ENS in 2007–2016.

In 2016, 51 % of ENS was caused by overhead line faults and 31 % were caused by substation faults. The most significant reasons for ENS were unknown (27 %), external influences (23 %) and lightning (20 %). A lot of disturbances were classified with unknown cause, these were probably caused by lightning, but it could not be verified. Most of them occurred during the summer months. Most of the disturbances were caused by unknown causes (34 %) and lightning (22 %).

The most severe incidents in Sweden in 2016 were the following:

- A transformer exploded due to overvoltage during a training session for a black start test. This was caused by an automatic rebuilding scheme left active, which in turn produced the high voltages in the station.
- An end consumer drove accidentally a rig into the feeding line of one regional grid. This caused an outage on the 132 kV side that lasted for 5.5 hours. This disturbance stood for over 400 MWh, which was more than half of the ENS in their grid.
- Most of the ENS in Sweden, approximately 900 MWh, was caused by lightning or unknown. Since many of the unknown faults are expected to be unverified lightning, it can be noted that the Swedish consumers have primarily been affected by lightning faults on the 130 kV grid during 2016.

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 2016, together with the development of the number of disturbances over the ten-year period 2007–2016. 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 2007–2016

The number of disturbances during the year 2016 in the Nordic and Baltic main grids was 1636 and the combined ten-year average in the Nordic countries and Estonia and five-year average in the Baltic countries was 415. 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 2016 and the annual average for the period 2007–2016 for the complete 100–420 kV grids. Figure 3.1.1 shows the development of the number of disturbances during the period 2007–2016.

Table 3.1.1 The number of grid disturbances in 2016 and the annual average

	Disturbances		Disturbances causing ENS	
	Number	Average	Number	Average
Country	2016	2007–2016	2016	2009–2016 2)
Denmark	51	58	13	8
Estonia	145	222	36	29
Finland	413	433	71	79
Iceland	44	35	18	15
Latvia 1)	124	144	12	17
Lithuania 1)	137	169	11	20
Norway	261	293	79	92
Sweden	461	526	178	156
Nordic & Baltic	1636	1879	418	415

1) The average values of Latvia and Lithuania use the period 2012–2016.

2) The time period is 2009–2016 because every country does not have complete data before 2009.

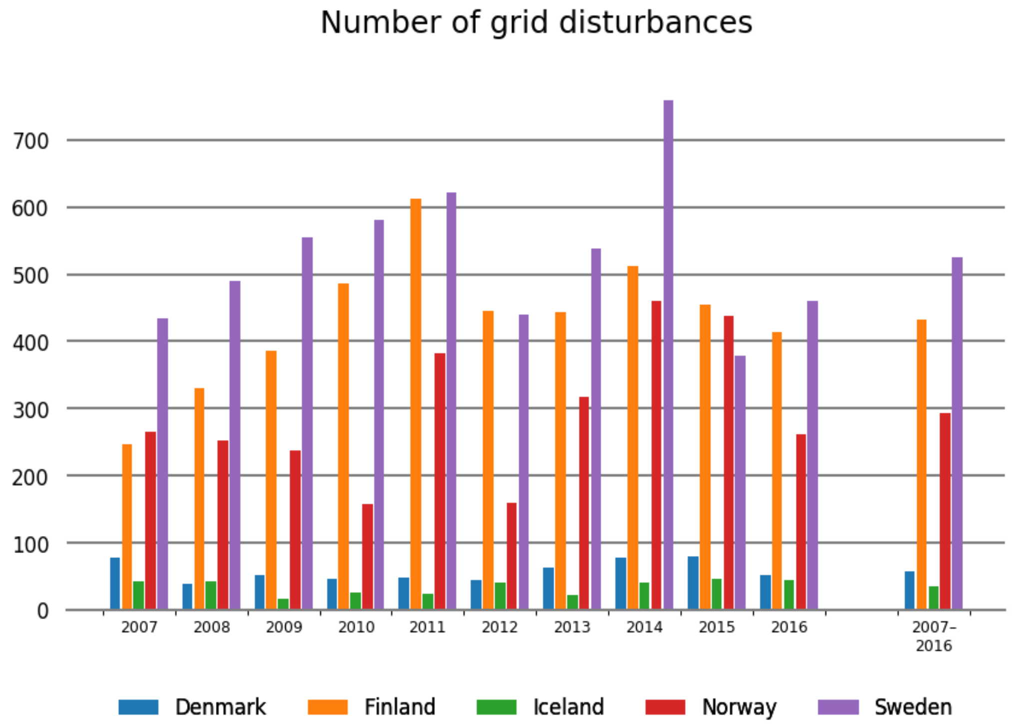

Figure 3.1.1 The annual number of grid disturbances and the average in each Nordic country for the period 2007–2016

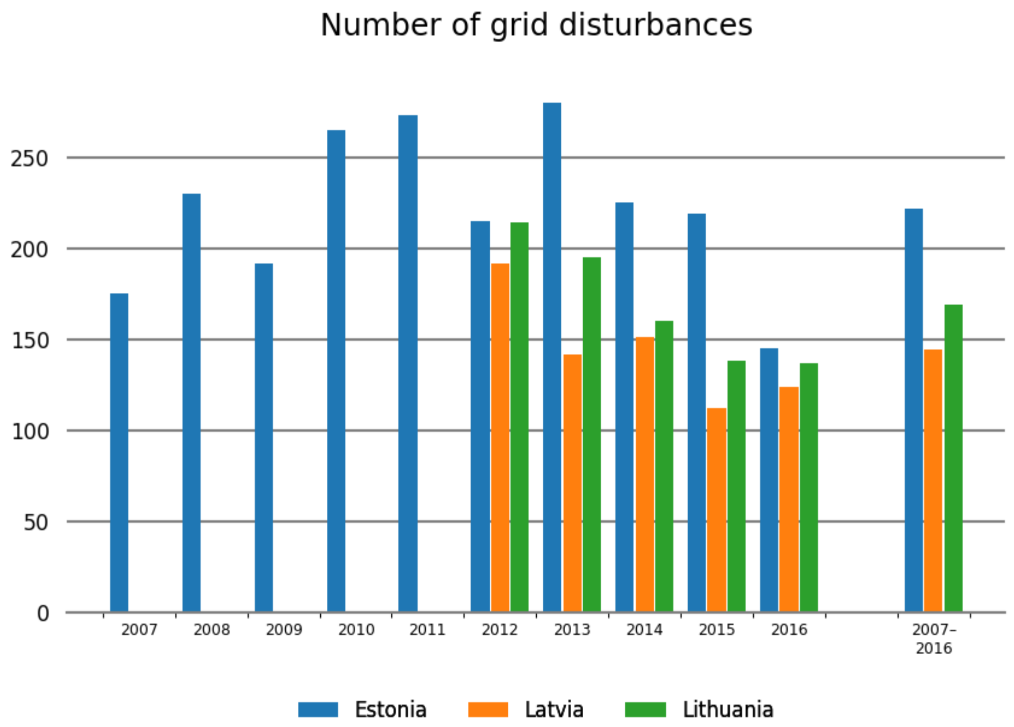

Figure 3.1.2 The annual number of grid disturbances and the average for Estonia for the period 2007–2016 and for Latvia and Lithuania for the period 2012–2016

3.2 Disturbances distributed per month

Figure 3.2.1 and 3.2.2 presents the percentage distribution of grid disturbances for all voltage levels per month in the Nordic and Baltic countries, respectively. Figure 3.2.3 presents the respective average values for the period 2007–2016 in the Nordic countries and Figure 3.2.4 presents the average values for the period 2012–2016 in the Baltic countries.

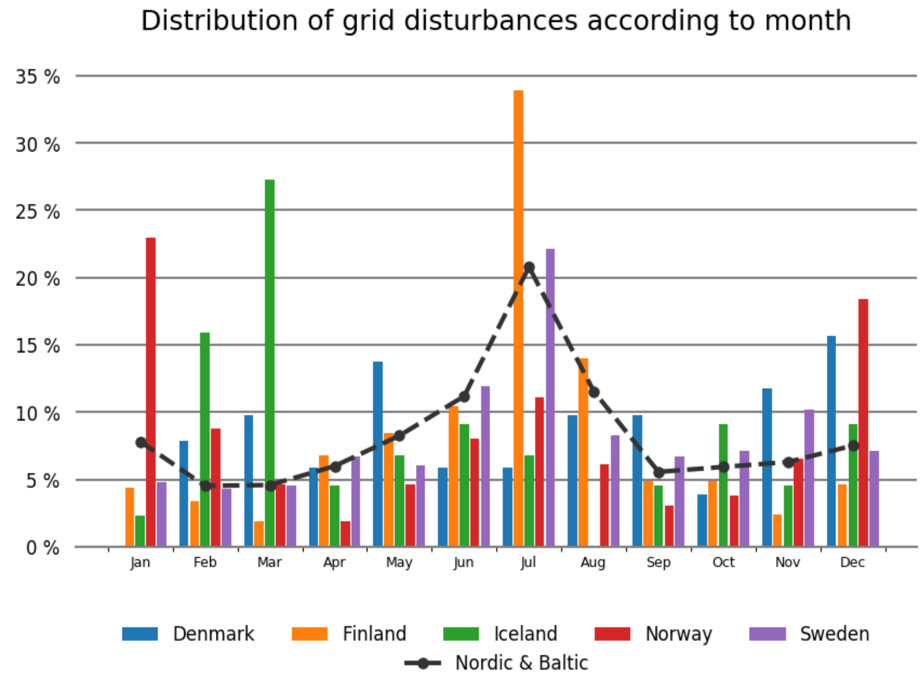

Figure 3.2.1 Percentage distribution of grid disturbances per month in each Nordic country in 2016

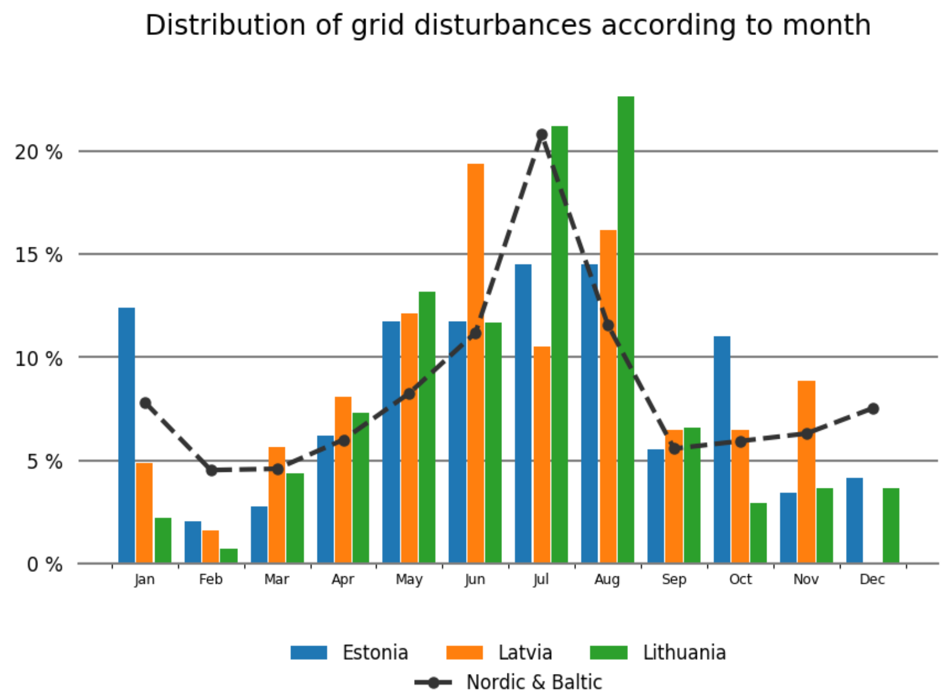

Figure 3.2.2 Percentage distribution of grid disturbances per month in each Baltic country in 2016

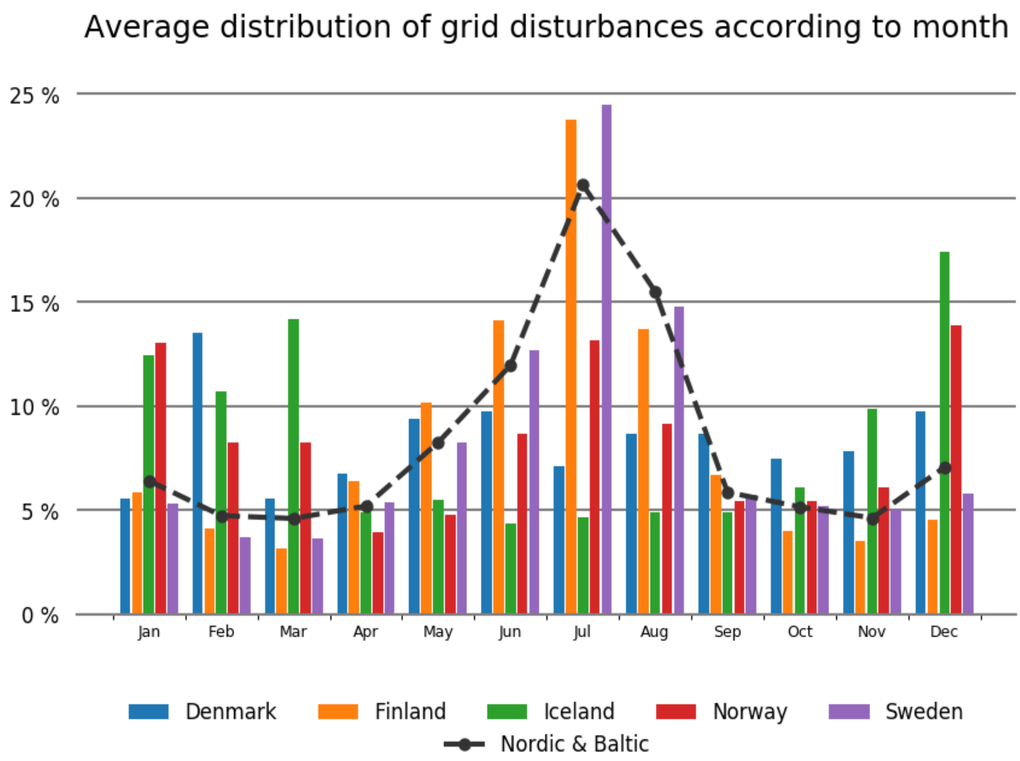

Figure 3.2.3 Average percentage distribution of grid disturbances per month in each Nordic country for the period 2007–2016

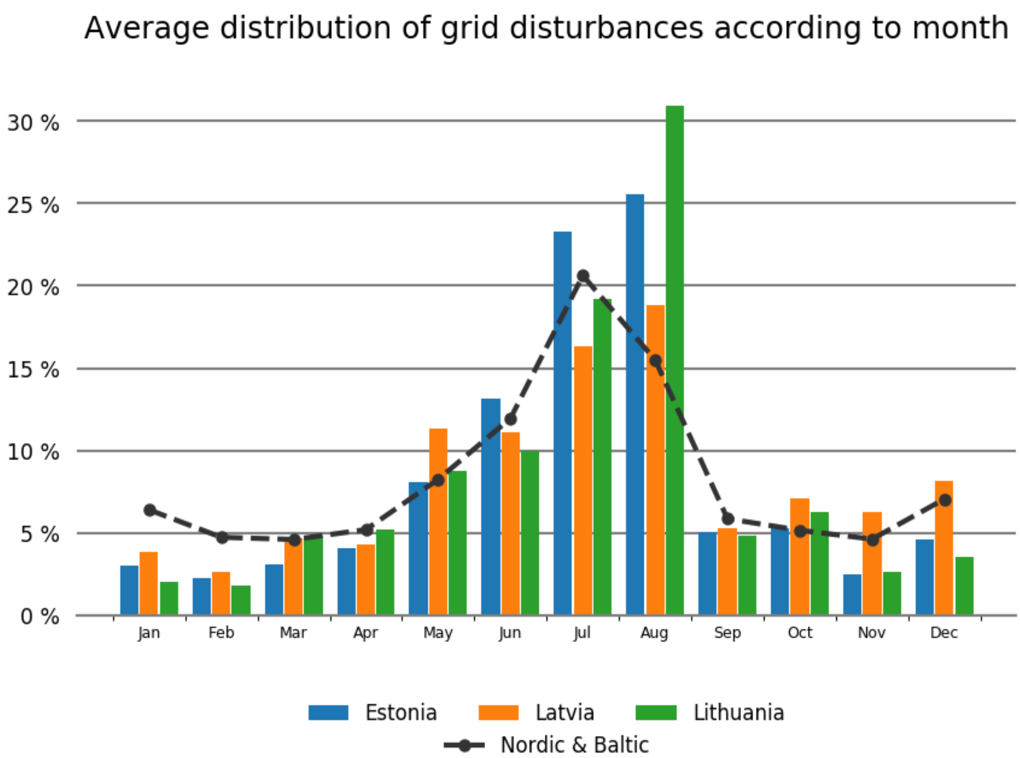

Figure 3.2.4 Average percentage distribution of grid disturbances per month for Estonia during 2007–2016 and for Latvia and Lithuania during 2012–2016

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 2016

Country	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Denmark	0	4	5	3	7	3	3	5	5	2	6	8
Estonia	18	3	4	9	17	17	21	21	8	16	5	6
Finland	18	14	8	28	35	43	140	58	20	20	10	19
Iceland	1	7	12	2	3	4	3	0	2	4	2	4
Latvia	6	2	7	10	15	24	13	20	8	8	11	0
Lithuania	3	1	6	10	18	16	29	31	9	4	5	5
Norway	60	23	12	5	12	21	29	16	8	10	17	48
Sweden	22	20	21	31	28	55	102	38	31	33	47	33
Nordic & Baltic	128	74	75	98	135	183	340	189	91	97	103	123

Table 3.2.2 Average number of grid disturbances per month during the years 2007–2016.

Country	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Denmark	4	8	4	4	5	6	4	5	5	4	5	6
Estonia	7	5	7	9	18	29	52	57	11	12	6	10
Finland	25	18	14	28	44	61	103	59	29	17	15	20
Iceland	4	4	5	2	2	2	2	2	2	2	3	6
Latvia[1)]	6	4	7	6	16	16	24	27	8	10	9	12
Lithuania[1)]	3	3	8	9	15	17	32	52	8	11	4	6
Norway	38	24	24	12	14	25	39	27	16	16	18	41
Sweden	28	20	19	28	43	67	129	78	30	27	27	31
Nordic & Baltic	115	85	87	97	158	222	383	307	109	99	87	131

1) The average values of Latvia and Lithuania use the period 2012–2016.

3.3 Disturbances distributed per 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 4.2.9 in the HVAC Guidelines [1]. This report uses seven different options for fault causes and list the primary cause of the event as the starting point.

Each country in these statistics has its own detailed way of gathering data per 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.

Figure 3.3.1 and Figure 3.3.2 present disturbances for all voltage levels in terms of the primary fault for the year 2016. Figure 3.3.5 presents the average values for the period 2007–2016 in the Nordic countries and Figure 3.3.6 presents the average values for the period 2012–2016 in the Baltic countries.

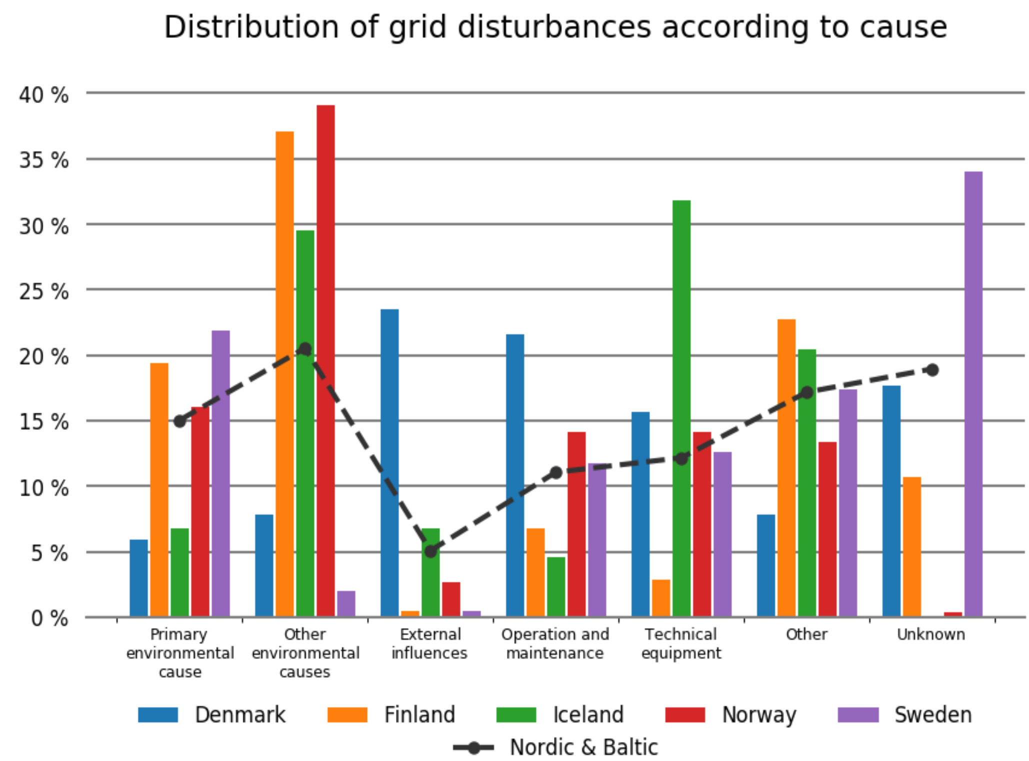

Figure 3.3.1 Percentage distribution of grid disturbances per cause in each Nordic country in 2016

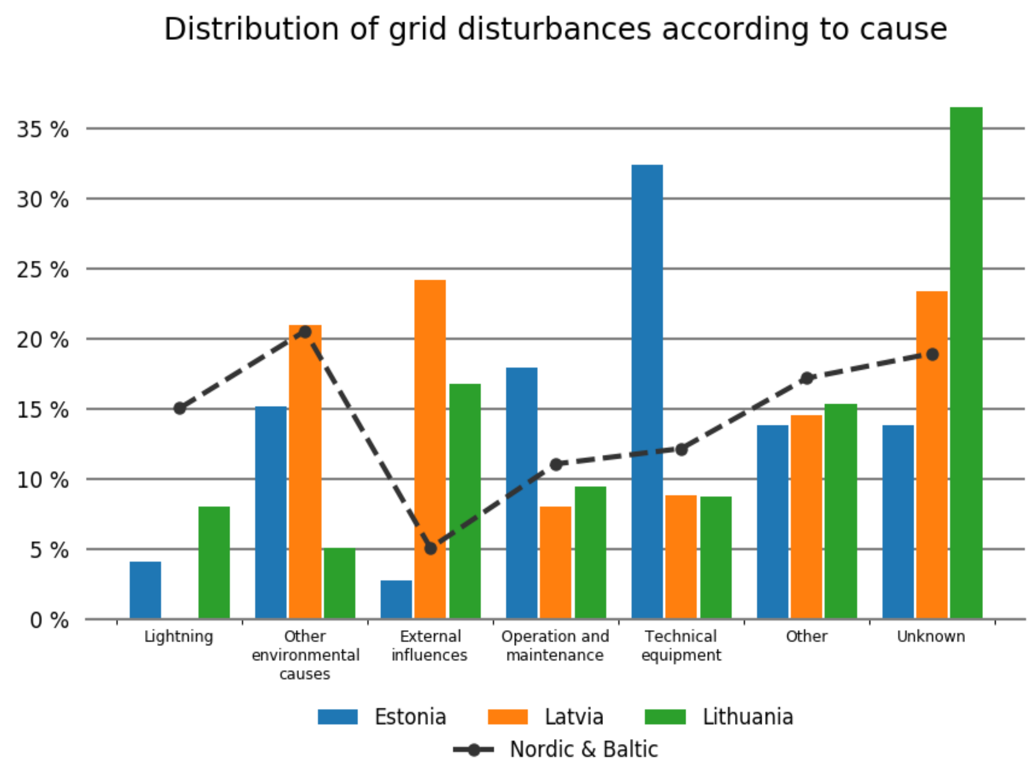

Figure 3.3.2 Percentage distribution of grid disturbances per cause in each Baltic country in 2016

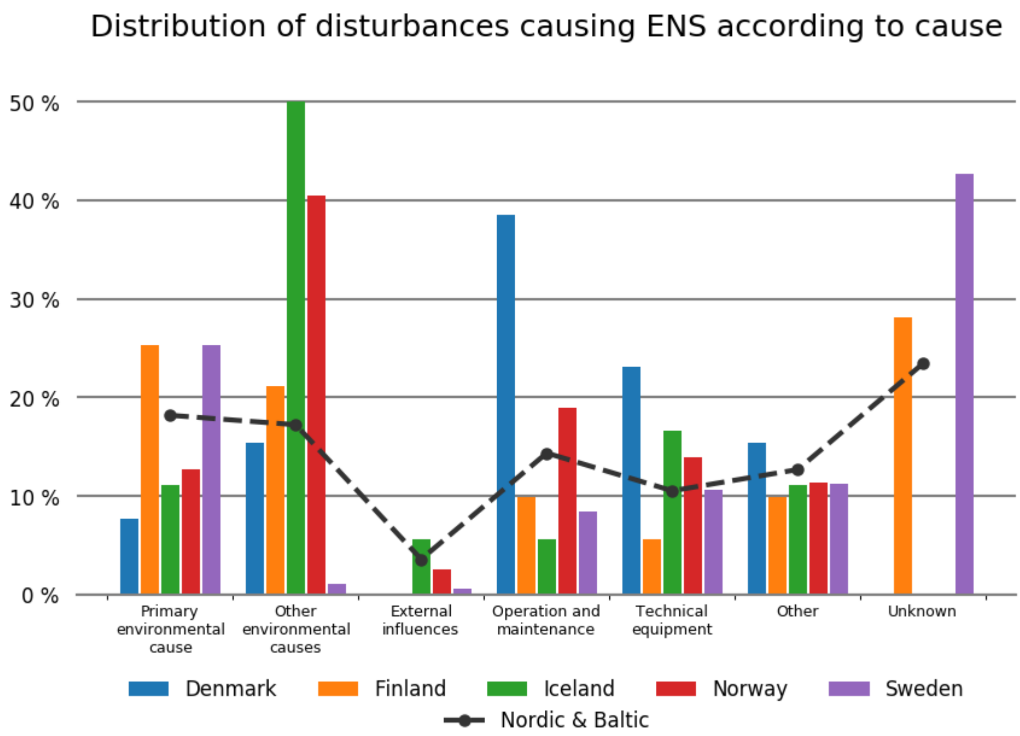

Figure 3.3.3 Percentage distribution of grid disturbances causing ENS per cause in each Nordic country in 2016

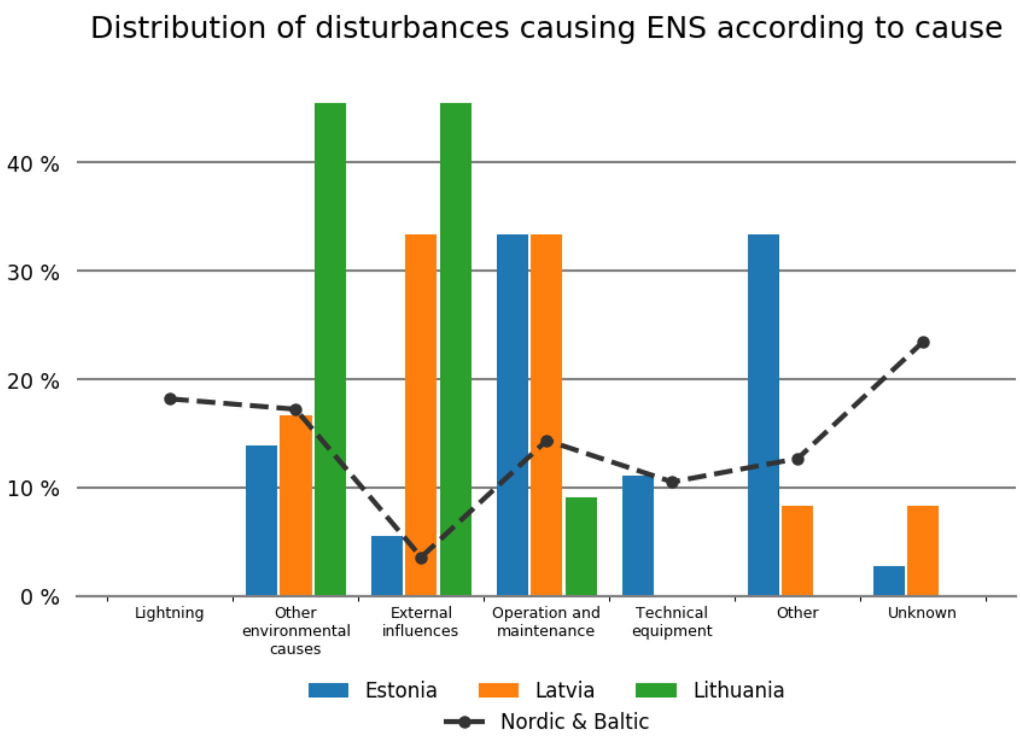

Figure 3.3.4 Percentage distribution of grid disturbances causing ENS per cause in each Baltic country in 2016

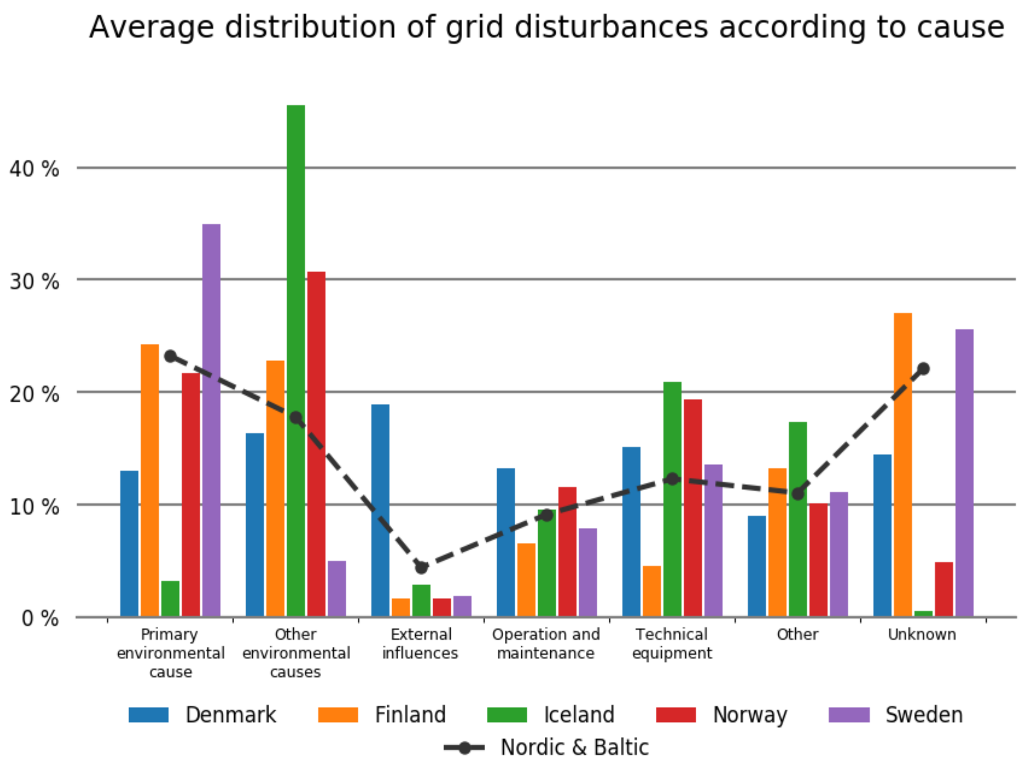

Figure 3.3.5 Average percentage distribution of grid disturbances per cause in each Nordic country for the period 2007–2016

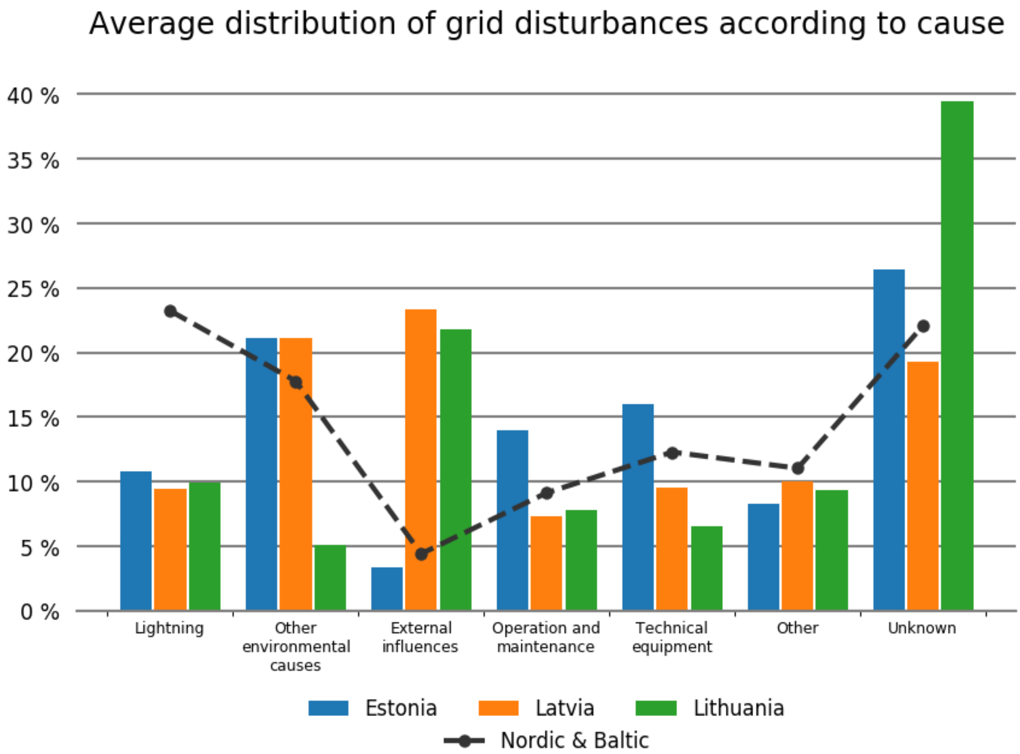

Figure 3.3.6 Average percentage distribution of grid disturbances per cause for Estonia during 2007–2016 and for Latvia and Lithuania during 2012–2016

Many disturbances caused by unknown reasons 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].*

4.1 Overview of energy not supplied (ENS)

Table 4.1.1 shows the amount of energy not supplied in 2016 and the annual average for the period 2007–2016. It should be noted that this table includes ENS caused by faults outside the statistical area of each country. Therefore, the amount of ENS in Table 4.1.1 may be higher than in the rest of the tables in this report.

Table 4.1.1 Energy not supplied (ENS) in each Nordic and Baltic country in 2016 and the annual average for the period 2007–2016

	ENS (MWh)	
Country	2016	2007–2016
Denmark	44.7	19.9
Estonia 1)	101.9	54.1
Finland	254.8	360.6
Iceland	154.4	1133.2
Latvia 1)	23.1	91.0
Lithuania 1)	28.1	34.2
Norway	1161.7	3447.7
Sweden 2)	1924.1	1880.1
Nordic and Baltic	3692.8	7021.0

1) The average values of Latvia and Lithuania use the period 2012–2016.

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.

4.2 Energy not supplied distributed per voltage level

Table 4.2.1 shows the amount of energy not supplied and its distribution per voltage level.

Table 4.2.1 Energy not supplied (ENS) per the voltage level of the primary fault

Country	ENS (MWh) 2016	Average ENS (MWh) 2007–2016	100–150 kV	220–330 kV	380–420 kV	Other 2)
			Average ENS (%) divided into different voltage levels, 2007–2016			
Denmark	45	19.8	94	0	0	6
Estonia	102	179.3	84	1	0	15
Finland	255	348.6	93	3	4	1
Iceland	154	1105.6	33	67	0	0
Latvia 1)	23	91.0	100	0	0	0
Lithuania 1)	28	34.2	96	4	0	0
Norway	1162	3512.9	33	7	60	0
Sweden	1924	1810.9	81	15	3	1
Nordic & Baltic	3693	7102	50	18	31	1

1) The average values of Latvia and Lithuania use the period 2012–2016.

2) 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 4.2.1 presents the energy not supplied per the different voltage levels for the year 2016 and Figure 4.2.2 summarises the energy not supplied per the different voltage levels for the period 2007–2016 in the Nordic countries and Estonia and for the period 2012–2016 for Latvia and Lithuania. A voltage level refers to the primary fault of the respective disturbance.

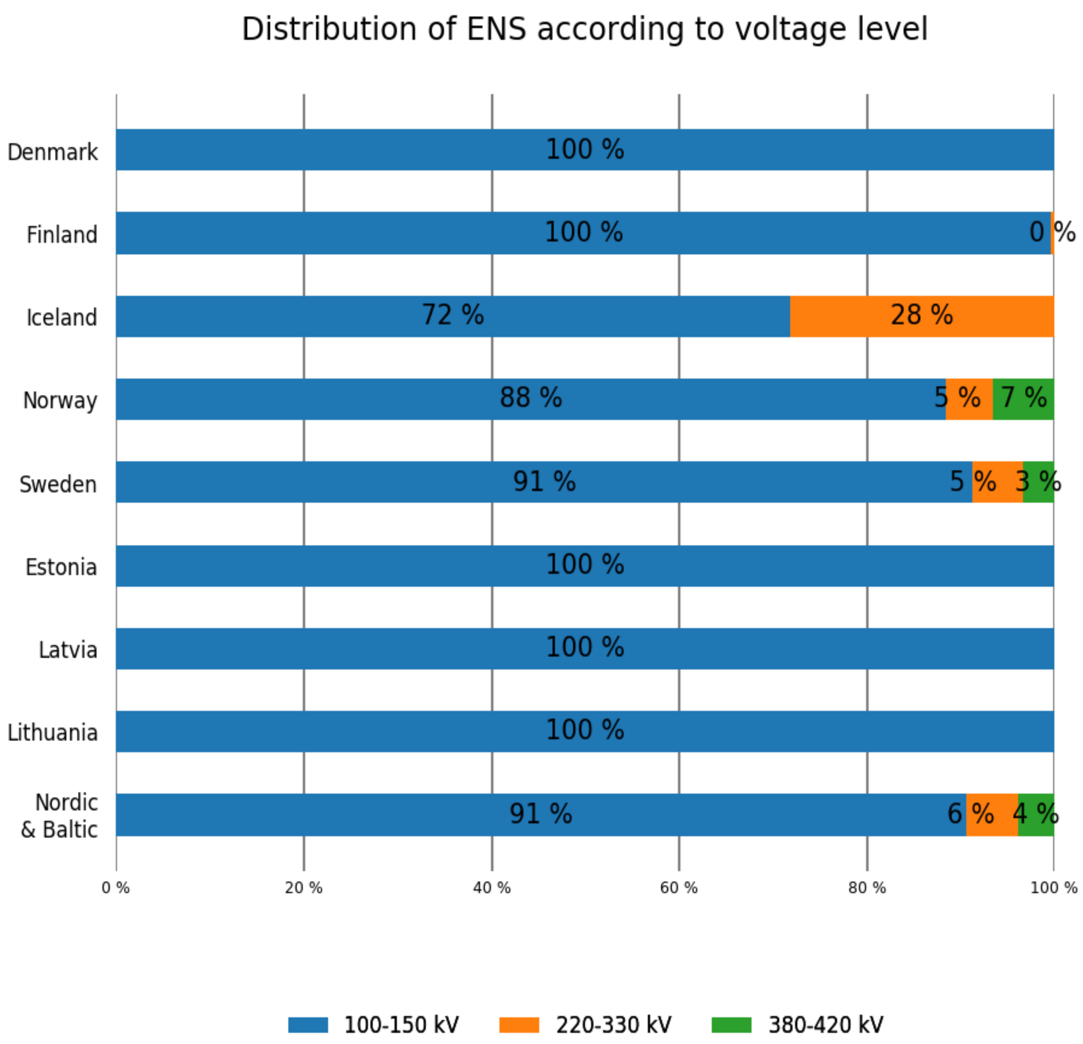

Figure 4.2.1 Percentage distribution of energy not supplied (ENS) in terms of the voltage level of the primary fault in 2016

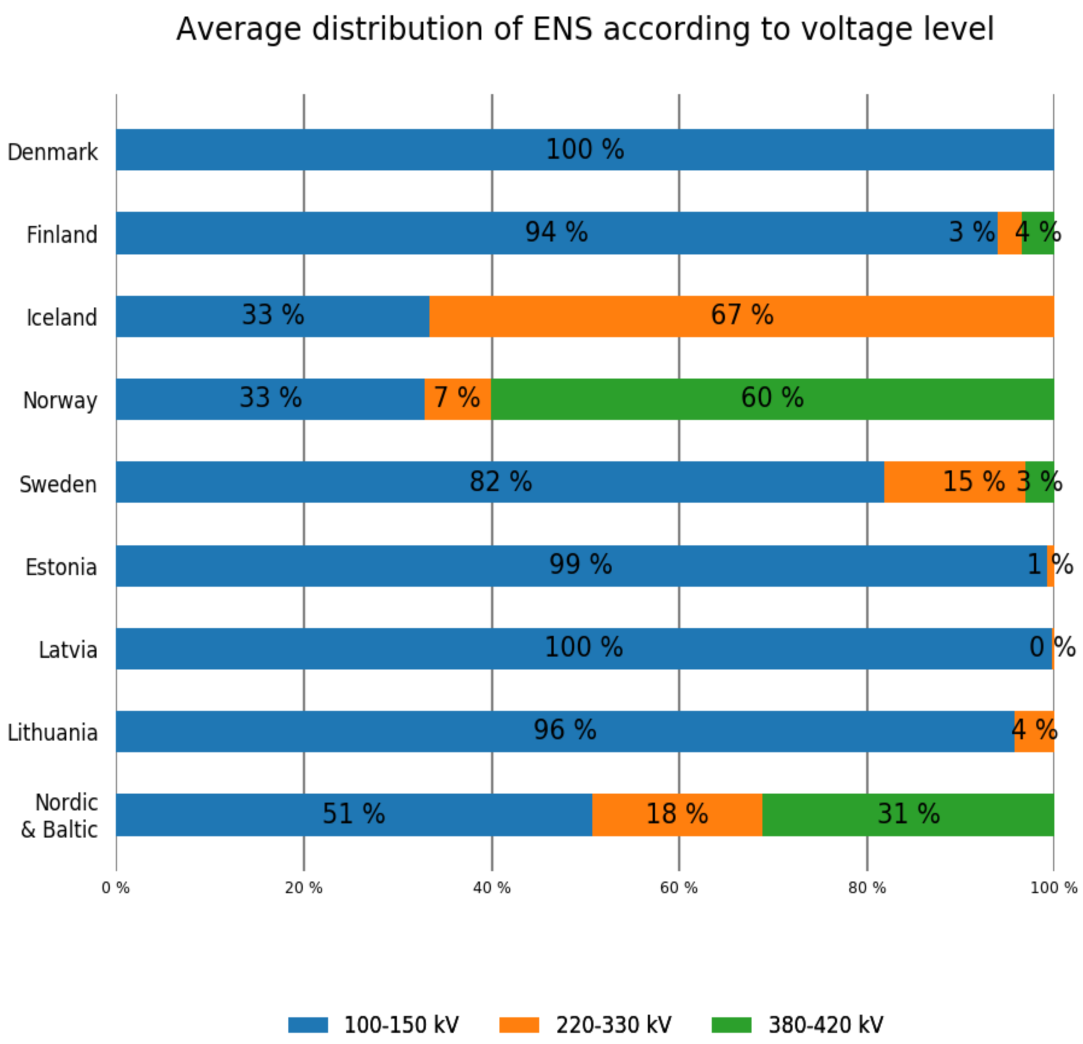

Figure 4.2.2 Percentage distribution of Energy not supplied in terms of the voltage level of the primary fault during the period 2007–2016 for the Nordic countries and Estonia and for the period 2012–2016 for Latvia and Lithuania

4.3 Energy not supplied (ENS) and total consumption

Table 4.3.1 shows the energy not supplied in relation to the total consumption of energy in each respective country and its distribution per installation.

Table 4.3.1 Energy not supplied (ENS) and its distribution per installation

Country	Consumption (GWh)	ENS (MWh)	ENS / consumption (ppm)		Overhead lines	Cable	Station	Other
	2016	2016	2016	2007–2016	ENS (%) divided per installation during the period 2007–2016			
Denmark	33987	44.7	1.3	0.6	4	0	88	8
Estonia	8385	101.9	12.2	6.7	20	0	34	45
Finland	85100	254.8	3.0	4.2	61	0	30	9
Iceland	17744	154.4	8.7	67.3	26	1	54	20
Latvia[1)]	7505	23.1	3.1	13.2	70	0	30	0
Lithuania[1)]	10468	28.1	2.7	3.4	67	1	33	0
Norway	132332	1161.7	8.8	26.3	69	2	29	0
Sweden	139800	1924.1	13.8	13.4	28	5	58	4
Nordic & Baltic	435321	3693	8.5	16.6	50	2	41	5

1) The average values of Latvia and Lithuania use the period 2012–2016.

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 per installation may not be exactly 100 % because all the ENS is not always connected with a cause.

Figure 4.3.1 and 4.2.2 presents the progression of ENS in relation to the consumption during the period 2007–2016 in the Nordic countries and Estonia and during the period 2012–2016 in Latvia and Lithuania. One should note that there is a considerable difference from year to year depending on occasional events, such as storms. These events have a significant effect on each country's yearly statistics.

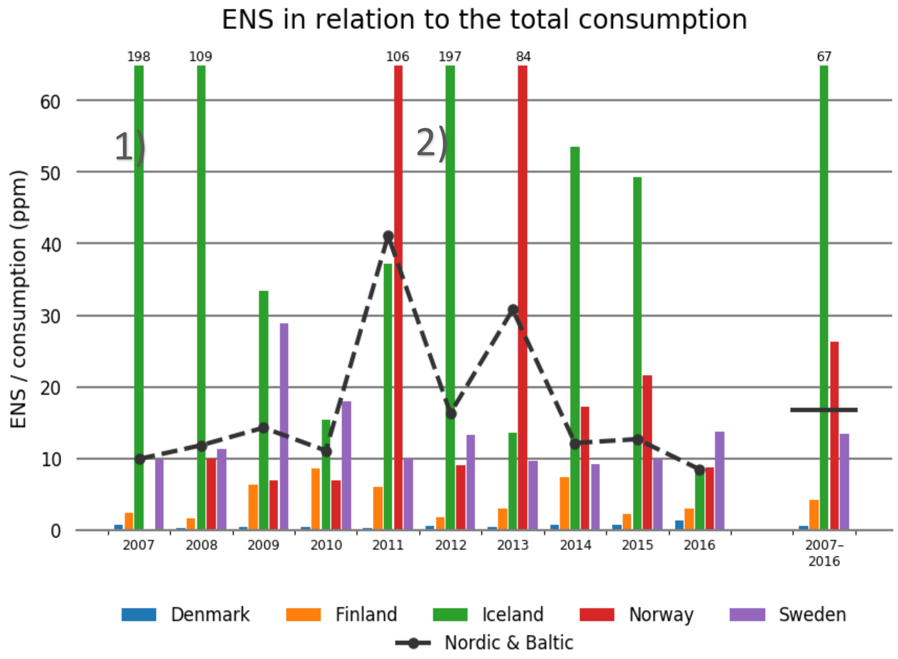

Figure 4.3.1 Annual energy not supplied (ENS) divided by consumption (ppm) in the Nordic countries for the period 2007–2016

[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 4.3.1 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 4.3.1 are a result of power intensive industries that cause substantial amounts of ENS even during short interruptions.

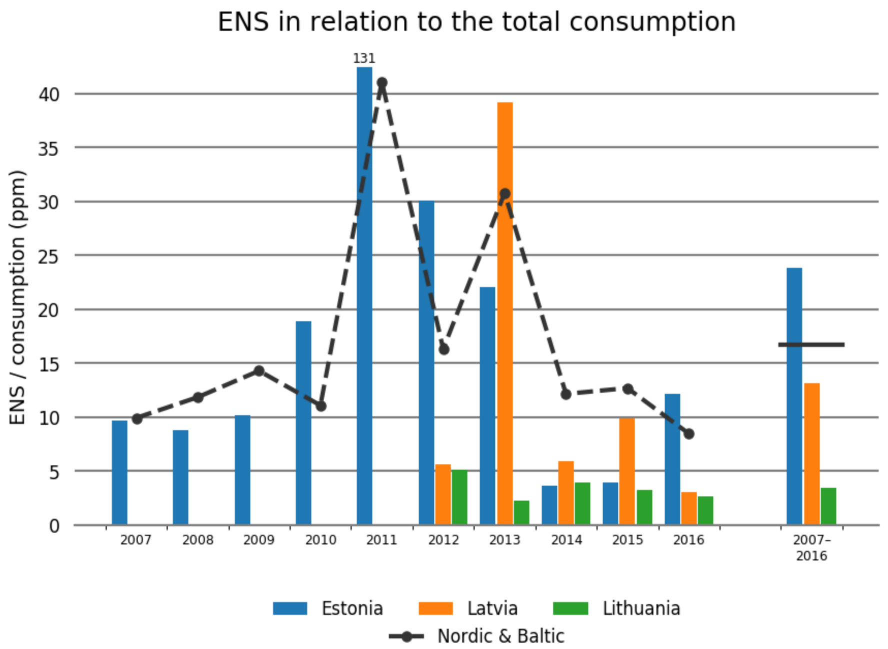

Figure 4.3.2 Annual energy not supplied (ENS) divided by consumption (ppm) for Estonia during 2007–2016 and for Latvia and Lithuania during 2012–2016

4.4 Energy not supplied (ENS) distributed per month

Figure 4.4.1 and Figure 4.4.2 present the distribution of energy not supplied per month for the year 2016. Figure 4.3.3 presents the average for the period 2007–2016 in the Nordic countries and Figure 4.4.4 presents the average for the period 2012–2016 in the Baltic countries.

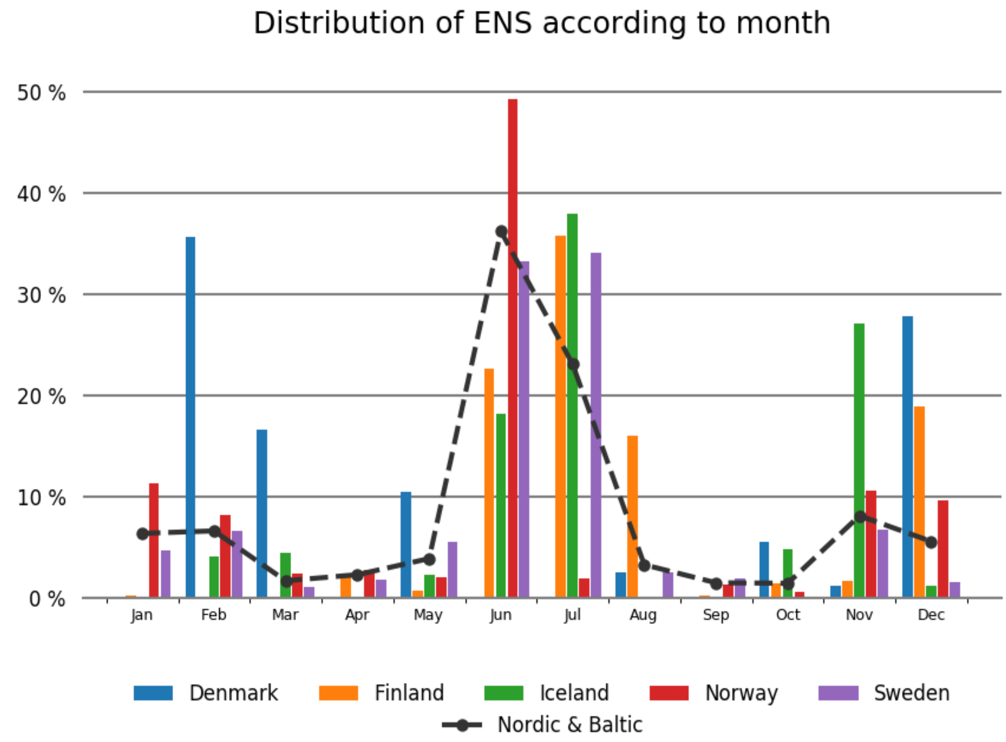

Figure 4.4.1 Percentage distribution of energy not supplied (ENS) per month in each Nordic country in 2016

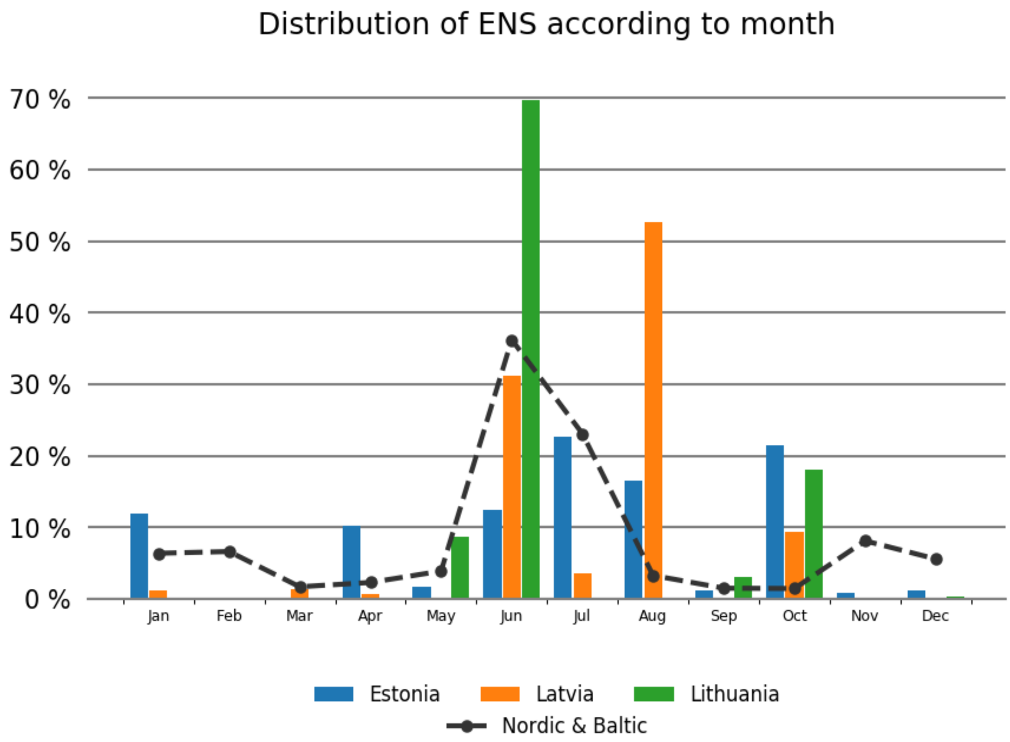

Figure 4.4.2 Percentage distribution of energy not supplied (ENS) per month in each Baltic country in 2016

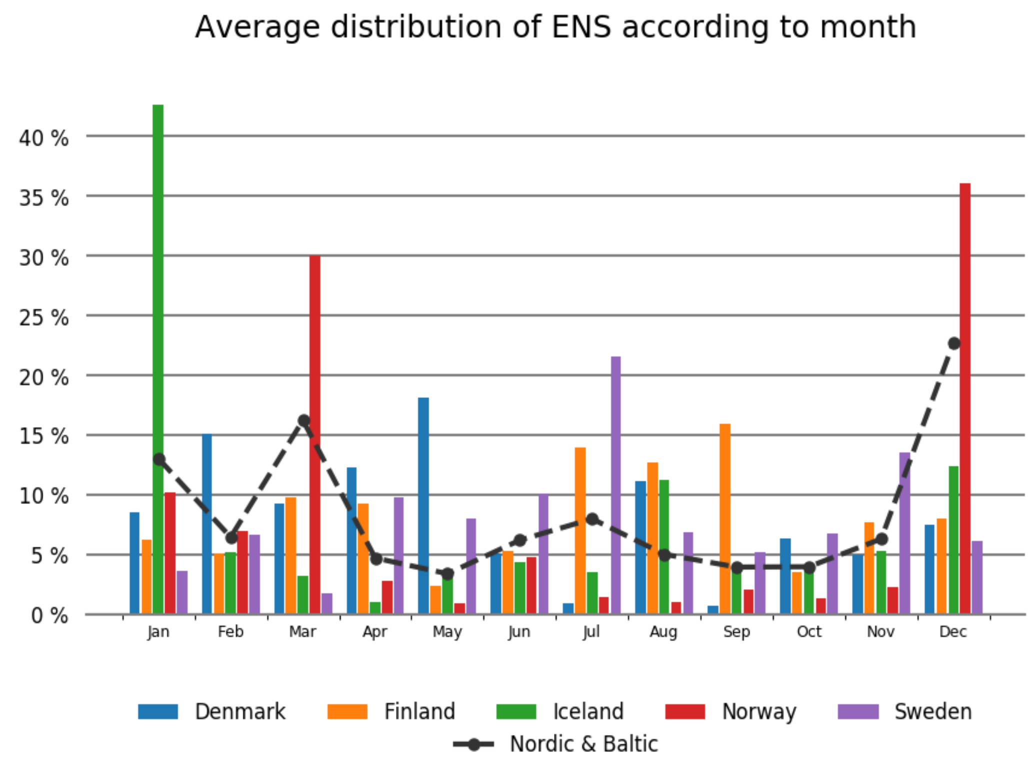

Figure 4.4.3 Average percentage distribution of grid disturbances per month in each Nordic country during the period 2007–2016

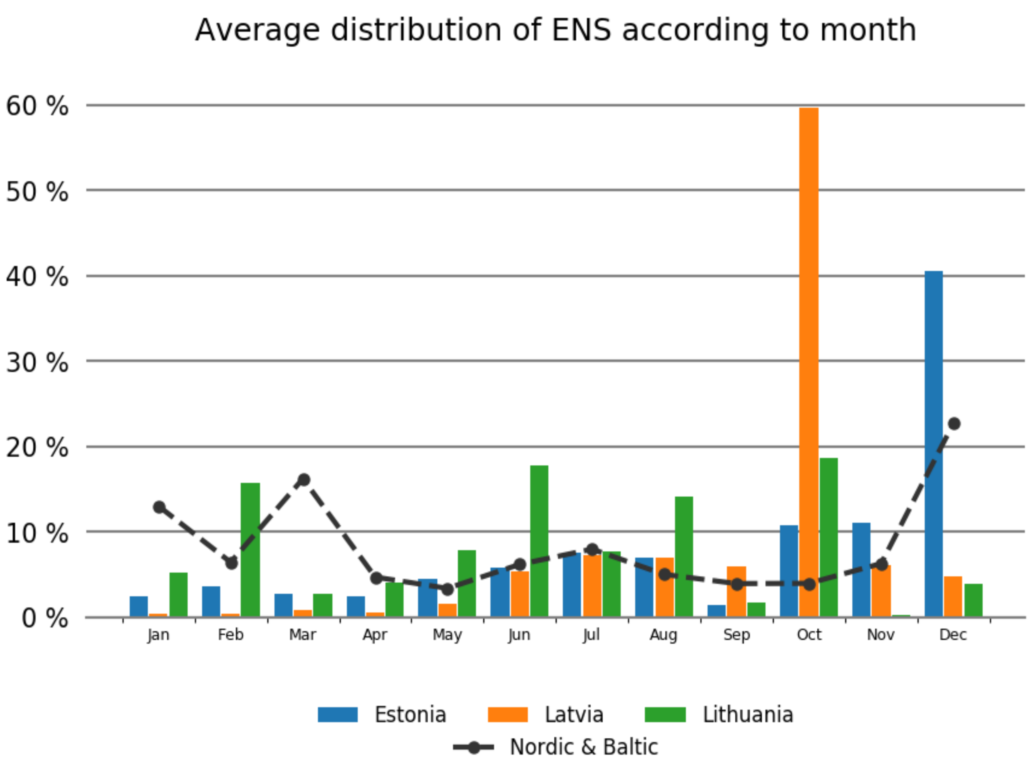

Figure 4.4.4 Average percentage distribution of grid disturbances per month for Estonia during 2007–2016 and for Latvia and Lithuania during 2012–2016

4.5 Energy not supplied (ENS) distributed per cause

Figure 4.5.1 and

Figure 4.5.2 present the distribution of energy not supplied per cause in 2016. Figure 4.4.3 presents the average for the period 2007–2016 in the Nordic countries and Figure 4.5.4 presents the average for the period 2012–2016 in the Baltic countries. Appendix 2 provides more details about how each country investigates line faults.

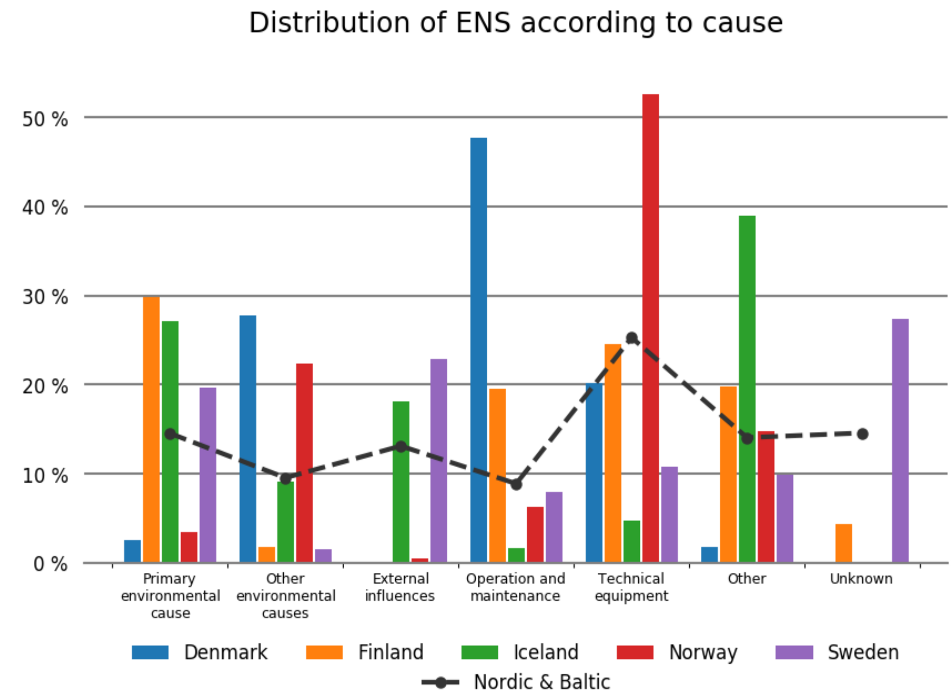

Figure 4.5.1 Percentage distribution of energy not supplied per the cause of the primary fault in each Nordic country in 2016

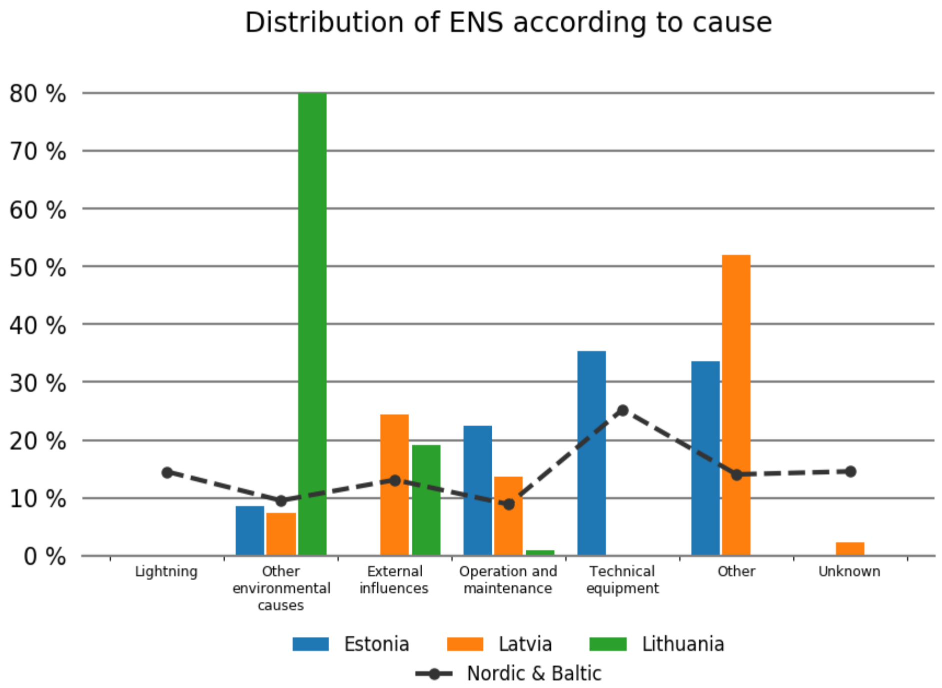

Figure 4.5.2 Percentage distribution of energy not supplied per the cause of the primary fault in each Baltic country in 2016

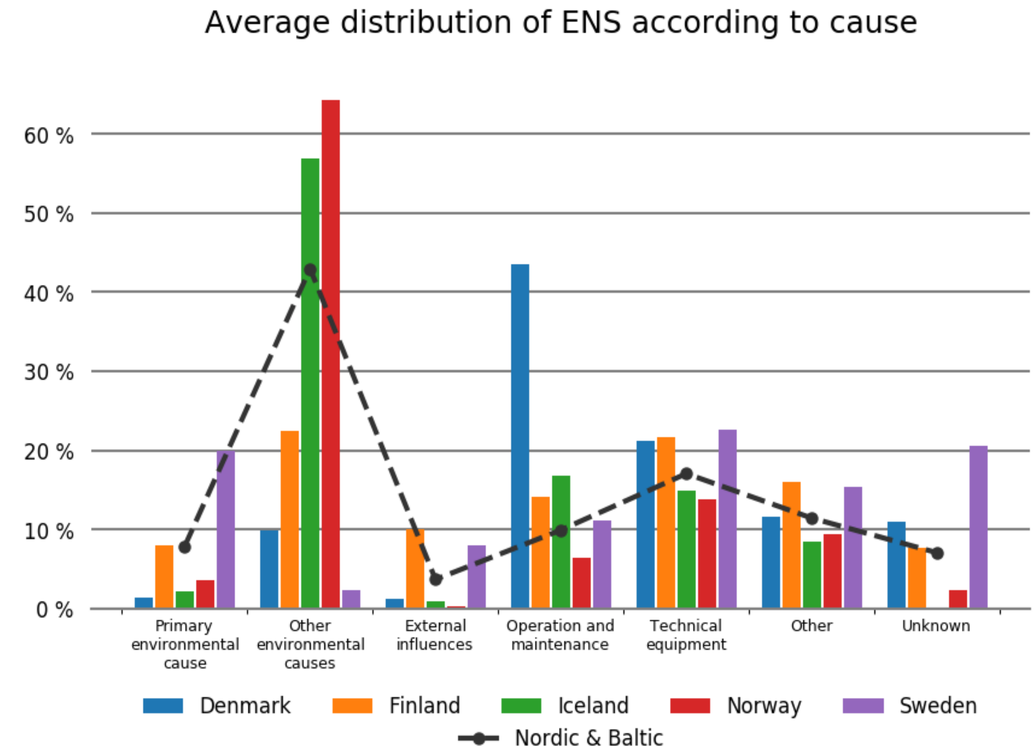

Figure 4.5.3 Average percentage distribution of ENS per the cause of the primary fault in each Nordic country during the period 2007–2016

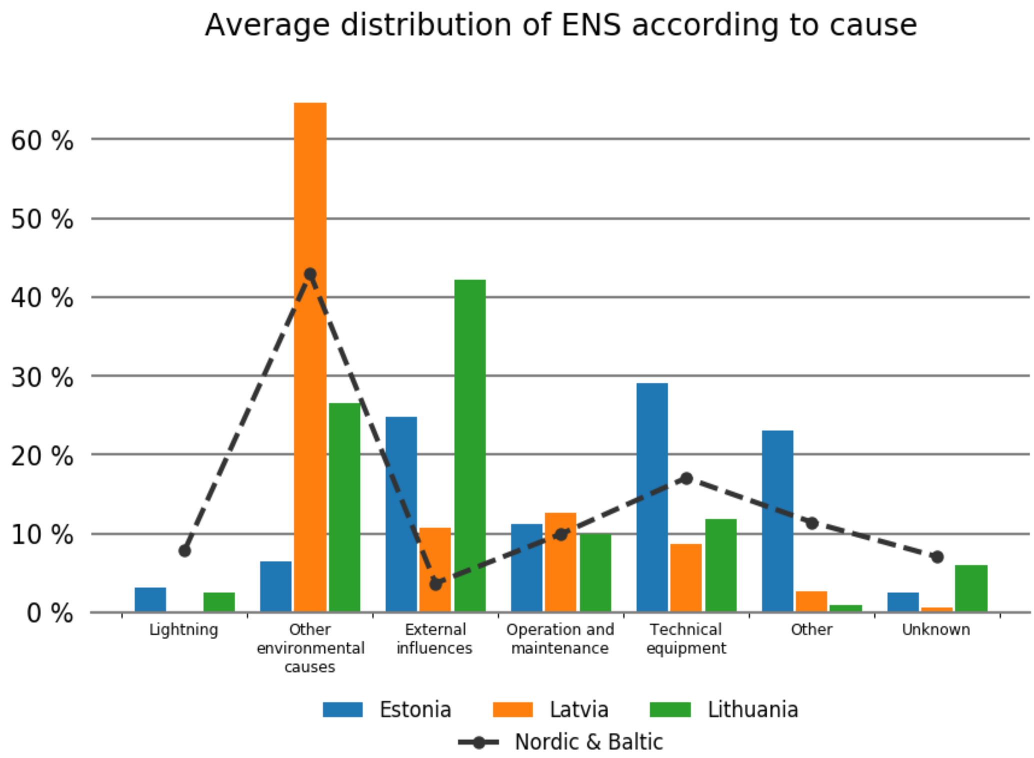

Figure 4.5.4 Average percentage distribution of ENS per the cause of the primary fault for Estonia during 2007–2016 and for Latvia and Lithuania during 2012–2016

4.6 Energy not supplied (ENS) distributed per component

Table 4.6.1 and Table 4.6.2 show the distribution of energy not supplied per component.

Table 4.6.1 Percentage distribution of energy not supplied in terms of component in each Nordic country

	Denmark		Finland		Iceland		Norway		Sweden		Average	
Fault location	**2016**	**2007–2016**	**2016**	**2007–2016**	**2016**	**2007–2016**	**2016**	**2007–2016**	**2016**	**2007–2016**	**2016**	**2007–2016**
Overhead line	14	4	34	61	54	26	12	69	51	28	37	50
Cable	0	0	0	0	0	1	2	2	4	5	3	3
Line faults	**14**	**4**	**34**	**62**	**54**	**26**	**14**	**71**	**55**	**33**	**40**	**53**
Power transformers	14	18	27	3	2	0	1	3	3	8	4	4
Instrument transformers	0	9	19	4	0	0	8	2	4	5	6	3
Circuit breakers	0	9	6	2	0	27	1	1	1	3	1	6
Busbar	56	22	0	1	0	4	0	3	1	2	1	3
Control equipment	0	10	15	13	5	8	20	8	19	4	18	7
Disconnectors and earth connectors	15	18	0	2	0	9	47	2	0	6	16	5
Surge arresters and spark gap	0	0	0	2	0	0	0	3	0	0	0	2
Common ancillary equipment	0	0	0	0	0	0	0	0	2	0	1	0
Other substation faults	0	0	0	2	0	3	9	6	0	29	3	12
Substation faults	**85**	**87**	**66**	**29**	**6**	**52**	**86**	**29**	**31**	**58**	**51**	**41**
Shunt capacitor	0	0	0	0	0	2	0	0	4	1	2	1
Series capacitor	0	0	0	1	0	0	0	0	0	0	0	0
Reactor	0	1	0	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**	**0**	**1**	**0**	**2**	**0**	**0**	**4**	**1**	**2**	**1**
System fault	0	0	0	0	0	16	0	0	0	1	0	3
Faults in adjoining statistical area	1	8	0	8	39	4	0	0	9	4	7	2
Unknown	0	0	0	0	0	0	0	0	0	0	0	0
Other faults	**1**	**8**	**0**	**9**	**39**	**20**	**0**	**0**	**9**	**4**	**7**	**5**

Table 4.6.2 Percentage distribution of energy not supplied in terms of component in each Baltic country in 2016

	Estonia		Latvia		Lithuania		Average	
Fault location	**2016**	**2007–2016**	**2016**	**2012–2016**	**2016**	**2012–2016**	**2016**	**2012–2016**
Overhead line	23	32	17	70	99	66	36	52
Cable	0	0	0	0	0	1	0	0
Line faults	**23**	**32**	**17**	**70**	**99**	**67**	**36**	**52**
Power transformers	0	2	20	4	0	3	3	3
Instrument transformers	7	1	0	0	0	1	4	1
Circuit breakers	21	4	0	0	0	3	14	3
Busbar	0	2	0	4	0	2	0	2
Control equipment	15	4	63	20	0	22	20	13
Disconnectors and earth connectors	0	0	0	1	1	2	0	1
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	0	11	0	0	0	1	0	5
Substation faults	**43**	**25**	**83**	**30**	**1**	**33**	**42**	**28**
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	34	43	0	0	0	0	22	20
Unknown	0	0	0	0	0	0	0	0
Other faults	**34**	**43**	**0**	**0**	**0**	**0**	**22**	**20**

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 faults according to power system components. Furthermore, it should be noted that the grid in every country contains a different set of components. 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 [3].

The scope of the statistics, per 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 2016.

Table 5.2.1 Number of faults and grid disturbances in each Nordic and Baltic country in 2016

Country	Number of faults in 2016	Number of disturbances in 2016	Fault / disturbance ratio in 2016	Fault / disturbance ratio during 2007–2016
Denmark	53	51	1.04	1.14
Estonia	149	145	1.03	1.01
Finland	433	413	1.05	1.05
Iceland	49	44	1.11	1.37
Latvia[1)]	139	124	1.12	1.08
Lithuania[1)]	151	137	1.10	1.06
Norway	293	261	1.12	1.17
Sweden	469	461	1.02	1.03
Nordic & Baltic	1736	1636	1.06	1.07

1) The average values of Latvia and Lithuania use the period 2012–2016.

Table 5.2.2, Table 5.2.3 and Table 5.2.4 present the distribution of faults and energy not supplied in terms of voltage level and country. In addition, the tables show 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 and ENS in the 380–420 kV grid in each Nordic and Baltic country for 2016 and the average for 2007–2016

	Size of the grid in 2016		Number of faults		ENS (MWh)	
Country	Number of power transformers	Length of 380–420 kV lines in km[2)]	2016	2007–2016	2016	2007–2016
Denmark	30	1566	6	7.5	0.0	0.0
Estonia	0	0	0	0.0	0.0	0.0
Finland	62	6086	22	26.7	0.0	12.3
Iceland	0	0	0	0.0	0.0	0.0
Latvia	0	0	0	0.0	0.0	0.0
Lithuania[1)]	0	102	2	2.0	0.0	0.0
Norway	100	3291	68	70.3	76.1	2105.6
Sweden	78	10579	96	108.3	65.1	55.5
Nordic & Baltic	270	21624	194	214.8	141.2	2173.3

1) Lithuania started maintaining their 380–420 kV grid in 2012.

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

Table 5.2.3 Faults and ENS in the 220–330 kV grid in each Nordic and Baltic country for 2016 and the average for 2007–2016

	Size of the grid in 2016		Number of faults		ENS (MWh)	
Country	Number of power transformers	Length of 220–330 kV lines in km 2)	2016	2007–2016	2016	2007–2016
Denmark	8	229	0	1.1	0.0	0.0
Estonia	23	1856	28	29.0	0.0	4.0
Finland	36	2447	25	21.0	1.0	8.8
Iceland	12	858	9	14.0	43.5	736.8
Latvia 1)	25	1395	23	17.0	0.0	0.2
Lithuania 1)	24	1761	27	20.8	0.0	1.8
Norway	266	5453 h	64	94.3	58.9	248.2
Sweden	78	4073	70	62.0	103.5	270.0
Nordic & Baltic	472	18071	246	259.3	206.9	1269.8

1) The average values of Latvia and Lithuania use the period 2012–2016.

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

Table 5.2.4 Faults and ENS in the 100–150 kV grid in each Nordic and Baltic country for 2016 and the average for 2007–2016

	Size of the grid in 2016		faults		ENS (MWh)	
Country	Number of power transformers	Length of 100–150 kV lines in km 2)	2016	2007–2016	2016	2007–2016
Denmark	228	4361	45	52.5	44.7	18.6
Estonia	218	3493	100	143.3	101.9	50.1
Finland	1167	17724	386	389.3	253.9	325.6
Iceland	43	1371	31	30.0	110.9	368.8
Latvia 1)	246	3891	98	123.4	23.1	90.8
Lithuania 1)	416	5070	103	142.2	28.1	32.8
Norway	913	11158	161	180.0	1026.6	1150.5
Sweden	930	17884	265	346.7	1755.5	1502.5
Nordic & Baltic	4161	64952	1189	1407.4	3344.7	3539.7

1) The average values of Latvia and Lithuania use the period 2012–2016.

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

Table 5.2.5 and Table 5.2.6 show the number of faults classified per the component groups used in these 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 the statistical area.

Table 5.2.5 Percentage distribution of faults per component type in each Nordic country

	Denmark		Finland		Iceland		Norway		Sweden		Average	
Component type	**2016**	**2007–2016**	**2016**	**2007–2016**	**2016**	**2007–2016**	**2016**	**2007–2016**	**2016**	**2007–2016**	**2016**	**2007–2016**
Overhead line	43	52	87	79	43	42	50	50	51	60	62	62
Cable	4	5	0	0	0	1	1	1	2	1	1	1
Line faults	**47**	**58**	**87**	**80**	**43**	**42**	**52**	**51**	**52**	**61**	**63**	**63**
Power transformers	9	5	2	2	8	4	1	2	4	6	3	4
Instrument transformers	0	2	0	1	0	0	3	2	2	1	1	1
Circuit breakers	0	4	1	1	4	4	4	4	3	2	2	2
Busbar	13	2	0	0	0	0	1	1	1	1	1	1
Control equipment[1)]	13	15	6	9	20	19	21	18	16	8	14	11
Disconnectors and earth connectors	2	2	0	0	0	0	2	2	0	0	0	1
Surge arresters and spark gap	0	0	1	0	0	0	1	1	1	0	1	0
Common ancillary equipment	0	0	0	0	0	0	0	1	1	0	1	0
Other substation faults	6	3	1	2	0	3	12	12	0	6	3	6
Substation faults	**43**	**33**	**11**	**15**	**33**	**30**	**44**	**43**	**29**	**25**	**27**	**26**
Shunt capacitor	0	0	0	0	4	2	1	1	1	0	1	1
Series capacitor	0	0	2	1	0	0	0	0	3	3	2	2
Reactor	2	1	0	0	0	0	0	0	2	2	1	1
Synchronous compensator	2	0	0	0	0	0	1	0	0	0	0	0
SVC and statcom	2	0	0	0	2	0	3	4	4	2	2	2
Compensation faults	**6**	**2**	**2**	**2**	**6**	**3**	**5**	**6**	**11**	**8**	**6**	**5**
System fault	0	0	0	0	0	18	0	0	0	1	0	1
Faults in adjoining statistical area	4	7	0	4	18	7	0	0	8	5	4	4
Unknown	0	0	0	0	0	0	0	0	0	0	0	0
Other faults	**4**	**7**	**0**	**4**	**18**	**24**	**0**	**0**	**8**	**6**	**4**	**4**

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

Table 5.2.6 Percentage distribution of faults per component type in each Baltic country

	Estonia		Latvia		Lithuania		Average	
Component type	**2016**	**2007–2016**	**2016**	**2012–2016**	**2016**	**2012–2016**	**2016**	**2012–2016**
Overhead line	43	59	58	66	64	72	55	65
Cable	1	0	1	0	0	0	0	0
Line faults	**44**	**59**	**58**	**66**	**64**	**72**	**55**	**65**
Power transformers	6	5	6	5	0	1	4	4
Instrument transformers	3	1	1	0	2	1	2	1
Circuit breakers	9	4	3	2	5	5	6	4
Busbar	6	3	1	1	1	2	3	2
Control equipment[1)]	12	4	14	14	11	9	12	8
Disconnectors and earth connectors	5	3	2	1	3	1	3	2
Surge arresters and spark gap	0	0	0	0	0	0	0	0
Common ancillary equipment	0	1	1	0	3	1	1	1
Other substation faults	1	9	1	0	0	0	0	4
Substation faults	**42**	**30**	**27**	**24**	**24**	**20**	**31**	**25**
Shunt capacitor	0	0	0	0	0	0	0	0
Series capacitor	0	0	0	0	0	0	0	0
Reactor	1	1	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**	**1**	**1**	**1**	**0**	**0**	**1**	**0**
System fault	0	0	0	0	0	0	0	0
Faults in adjoining statistical area	14	10	13	9	13	8	13	9
Unknown	0	0	0	0	0	0	0	0
Other faults	**14**	**10**	**13**	**9**	**13**	**8**	**13**	**9**

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

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 2016 as well as the average values for the period 1996–2016. The tables also give the faults distributed by cause during the period 1996–2016. Along with the tables, the annual distribution of faults and the annual number of permanent faults during the period 2007–2016 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 2016 and for the period 2007–2016. Figure 5.3.1 presents the annual line fault values per line length during the ten-year period 2007–2016 and the average value of period 2007–2016. Figure 5.3.2 presents the annual distribution of permanent line faults during the same period.

Table 5.3.1 380–420 kV overhead lines faults and the distribution per cause

			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
Country	Lines (km) in 2016	Number of faults in 2016	2016	1996–2016	Faults divided by cause (%) during the period 1996–2016								
Denmark	1419	2 0	0.14	0.32	20	60	6	5	4	4	2	49	6
Estonia[1)]	0	0 0	0.00	0.00	0	0	0	0	0	0	0	0	0
Finland	6086	7 0	0.12	0.25	71	10	2	6	2	4	5	64	10
Iceland	0	0 0	0.00	0.00	0	0	0	0	0	0	0	0	0
Latvia	0	0 0	0.00	0.00	0	0	0	0	0	0	0	0	0
Lithuania[2)]	102	2 0	1.96	1.96	100	0	0	0	0	0	0	100	0
Norway	3266	30 0	0.92	1.14	22	72	0	0	1	2	2	69	6
Sweden	10564	25 0	0.24	0.36	50	18	2	3	3	1	23	82	7
Nordic & Baltic	21437	66	0.31	0.44	41	38	1	2	2	2	12	73	7

1) The average values for Estonia use the period 2007–2016.

2) Lithuania started maintaining their 380–420 kV grid in 2012.

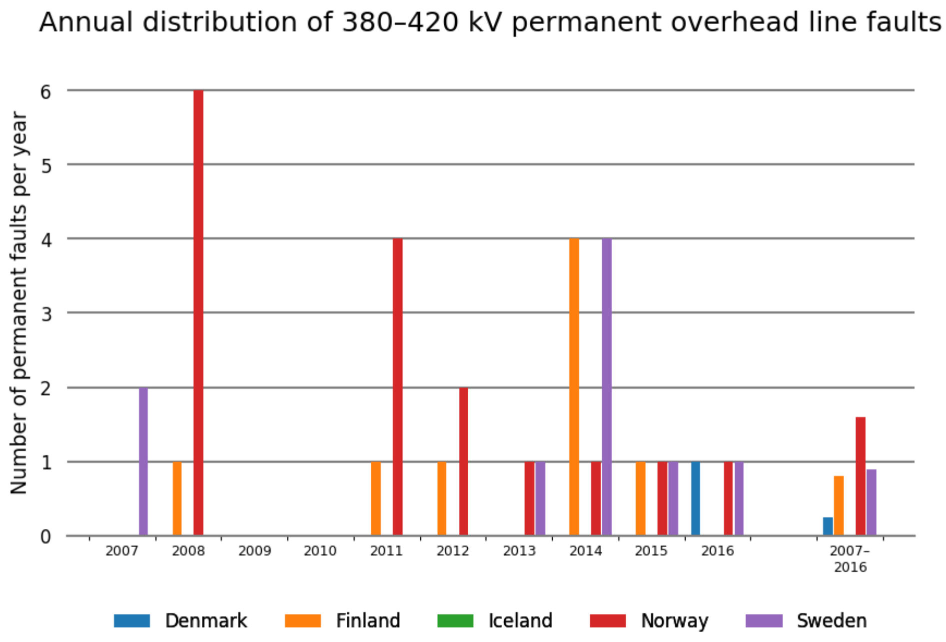

Figure 5.3.1 Annual distribution of faults for 380–420 kV overhead lines during the period 2007–2016 and the average for 2007–2016 in Nordic countries

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 5.3.2 presents the annual line fault values per line length during the period 2007–2016 and the average value for the period 2007–2016 in the Nordic countries. Figure 5.3.3 presents the annual line fault values per line length during the period 2012–2016 and the average in the Baltic countries. Figure 5.3.4 and Figure 5.3.5 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 per cause in each Nordic and Baltic country

			Number of faults per 100 km		Lightning	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown	1-phase faults	Permanent faults
Country	Lines (km) in 2016	Number of faults in 2016	2016	1996–2016	Faults divided by cause (%) during the period 1996–2016								
Denmark	64	0	0.00	0.50	40	10	20	0	0	10	20	90	0
Estonia[1)]	1856	10	0.54	0.87	17	15	8	29	11	0	21	42	41
Finland	2447	20	0.82	0.76	45	13	2	2	1	3	35	72	4
Iceland	857	2	0.23	0.39	22	63	0	0	15	0	0	37	17
Latvia[2)]	1381	13	0.94	0.75	13	10	23	10	4	0	40	87	15
Lithuania[2)]	1761	15	0.85	0.85	5	12	12	4	4	0	62	89	15
Norway	5355	40	0.75	0.76	48	42	1	0	2	2	4	65	9
Sweden	4007	25	0.62	0.84	67	5	3	4	4	1	16	58	7
Nordic & Baltic	17728	125	0.71	0.77	49	22	3	4	3	2	17	63	10

1) The average values for Estonia use the period 2007–2016.

2) The average values of Latvia and Lithuania use the period 2012–2016.

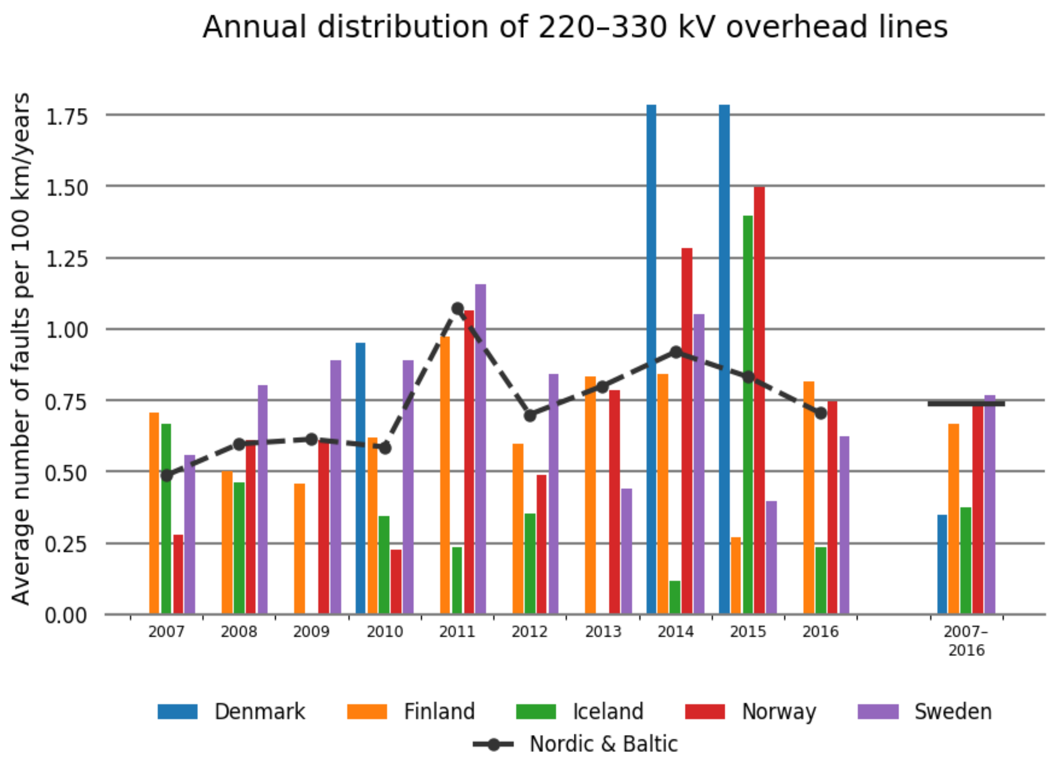

Figure 5.3.2 Annual distribution of faults for 220–330 kV overhead lines during the period 2007–2016 and the average for 2007–2016 in each Nordic country

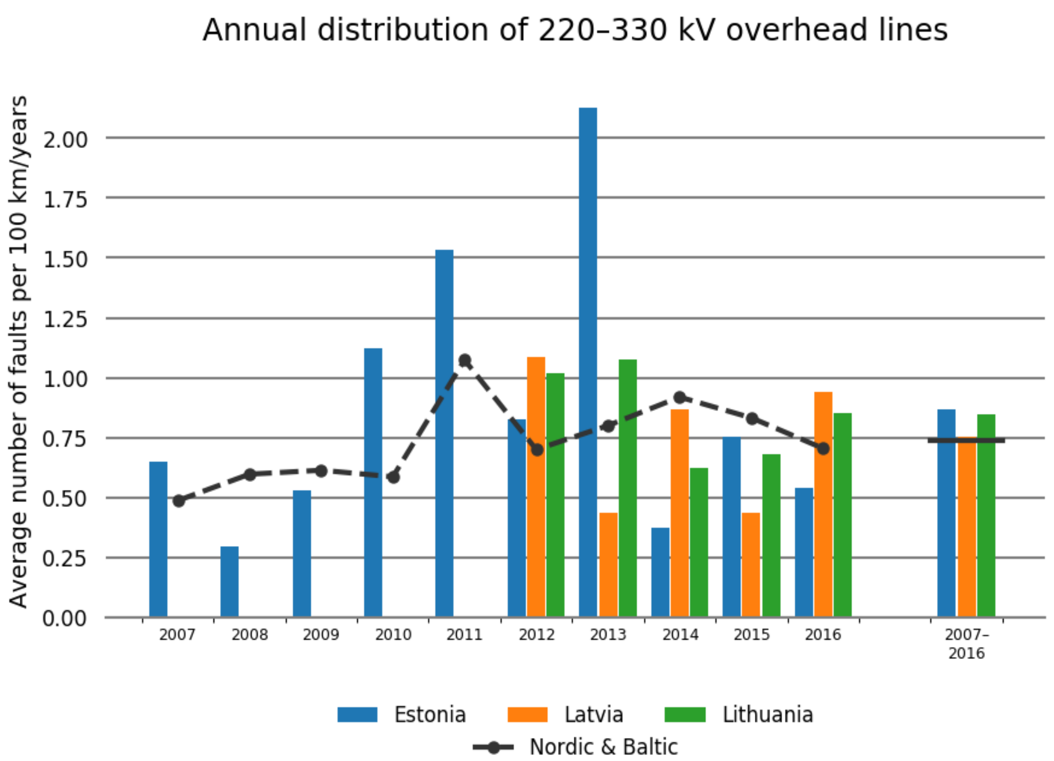

Figure 5.3.3 Annual distribution of faults for 220–330 kV overhead lines during the period 2007–2016 and the average for Estonia during 2007–2016 and for Latvia and Lithuania during 2012–2016

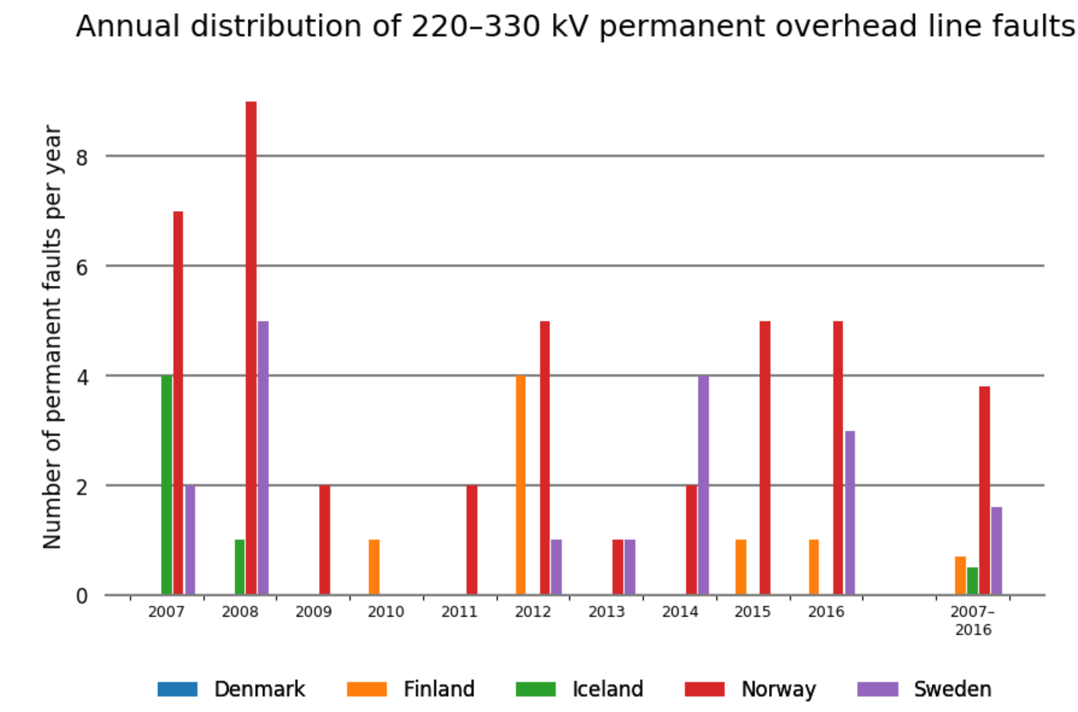

Figure 5.3.4 Annual distribution of permanent faults for 220–330 kV overhead lines during the period 2007–2016 and the average for 2007–2016 in each Nordic country

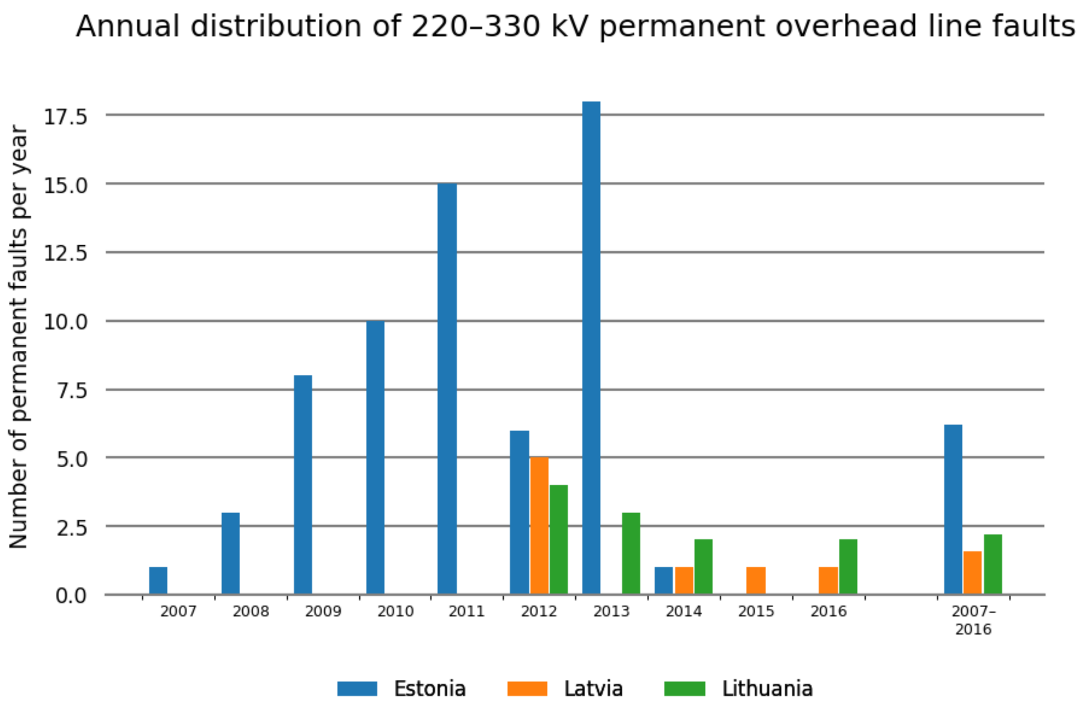

Figure 5.3.5 Annual distribution of permanent faults for 220–330 kV overhead lines during the period 2007–2016 and the average for Estonia during 2007–2016 and for Latvia and Lithuania during 2012–2016

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 5.3.6 presents the annual line fault values per line length during the period 2007–2016 and the average value for the period 2007–2016 in the Nordic countries. Figure 5.3.7 presents the annual line fault values per line length during the period 2012–2016 and the average in the Baltic countries. Figure 5.3.8 and Figure 5.3.9 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 per cause in each Nordic and Baltic country

			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
Country	Lines (km) in 2016	Number of faults in 2016	2016	1996–2016	Faults divided by cause (%) during the period 1996–2016								
Denmark	3067	21	0.68	1.01	23	38	22	3	1	2	11	52	5
Estonia[1)]	3429	54	1.57	4.17	15	29	4	9	6	0	37	35	14
Finland	17464	349	2.00	2.05	35	19	1	1	0	6	36	78	4
Iceland	1248	19	1.52	1.40	4	86	4	1	6	0	1	29	9
Latvia[2)]	3821	67	1.75	2.42	13	32	29	1	1	0	24	75	36
Lithuania[2)]	4980	79	1.59	2.28	13	6	28	1	3	1	48	88	16
Norway[3)]	10736	77	0.72	1.02	51	35	2	1	5	4	1	28	19
Sweden	17474	187	1.07	2.06	60	5	2	3	3	2	26	35	5
Nordic & Baltic	62219	853	1.37	1.80	41	19	5	2	2	3	26	51	8

1) The average values for Estonia use the period 2007–2016.

2) The average values of Latvia and Lithuania use the period 2012–2016.

3) The Norwegian grid includes a resonant earthed system, which contributes to the low number of single-phase earth faults in Norway.

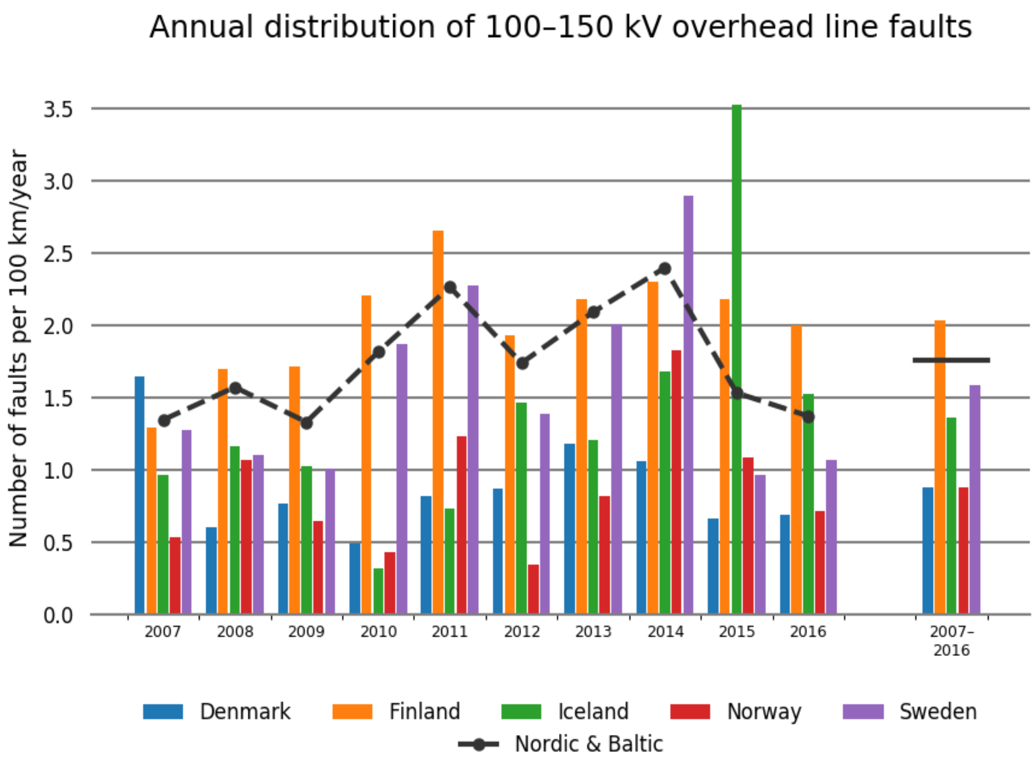

Figure 5.3.6 Annual distribution of line faults for 100–150 kV overhead lines during the period 2007–2016 and the average for 2007–2016 in each Nordic country

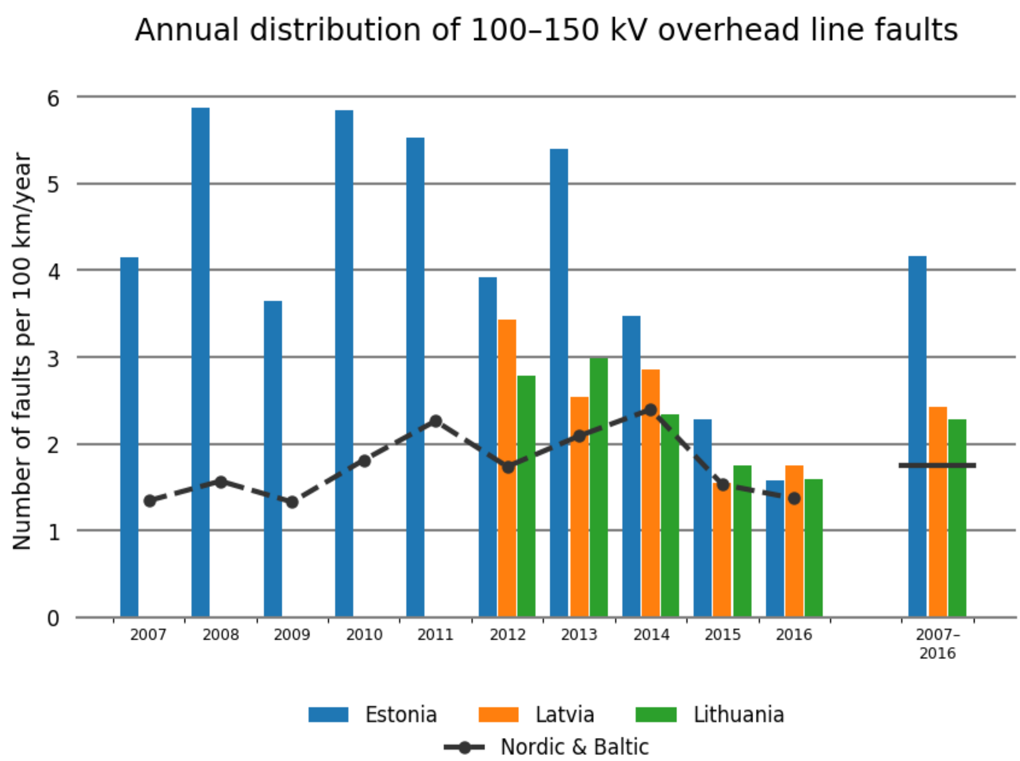

Figure 5.3.7 Annual distribution of line faults for 100–150 kV overhead lines during the period 2007–2016 and the average for Estonia during 2007–2016 and for Latvia and Lithuania during 2012–2016

Annual distribution of 100–150 kV permanent overhead line faults

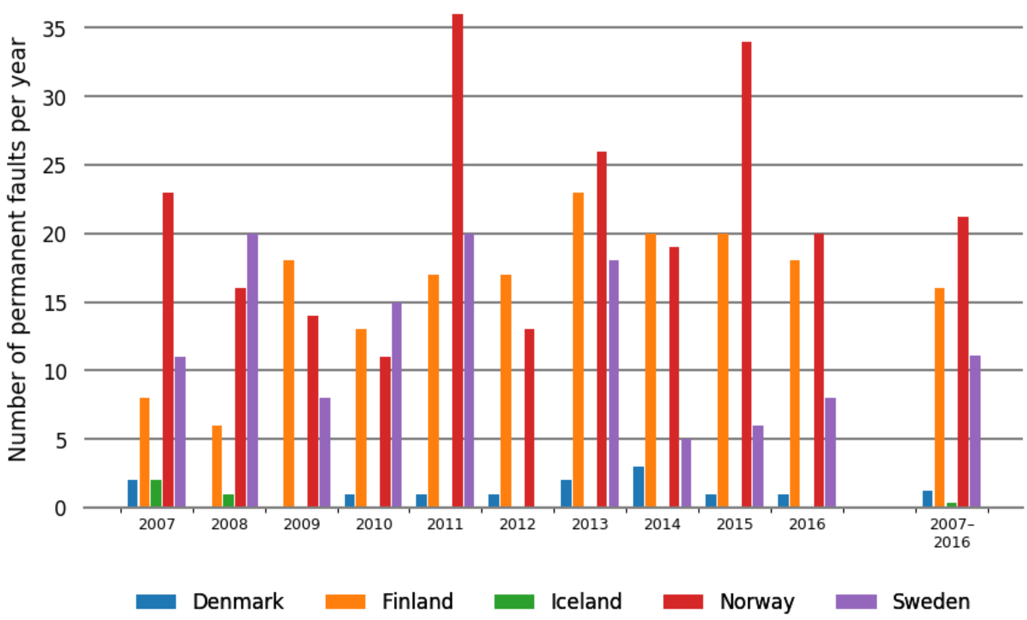

Figure 5.3.8 Annual distribution of permanent faults for 100–150 kV overhead lines during the period 2007–2016 and the average for 2007–2016 in each Nordic country

Annual distribution of 100–150 kV permanent overhead line faults

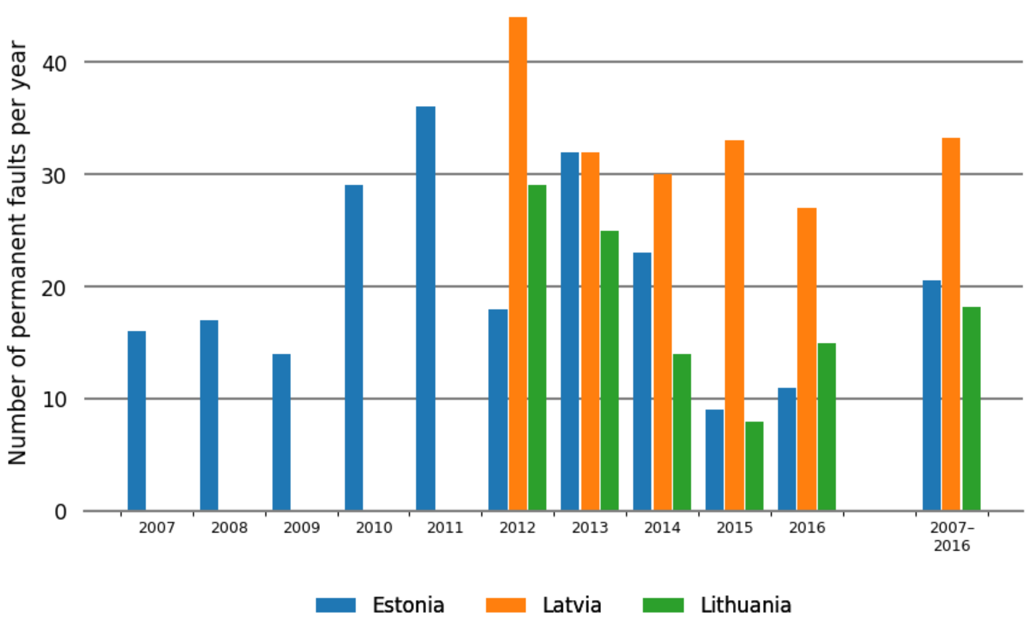

Figure 5.3.9 Annual distribution of permanent faults for 100–150 kV overhead lines during the period 2007–2016 and the average for Estonia during 2007–2016 and for Latvia and Lithuania during 2012–2016

5.3.4 Overhead Line fault trends

The figures in this chapter present trend curves for overhead line faults in the Nordic and Baltic countries 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 three-year average is calculated similarly, but for each three-year period. The trend curves are proportioned to overhead line length in order to get comparable results between countries.

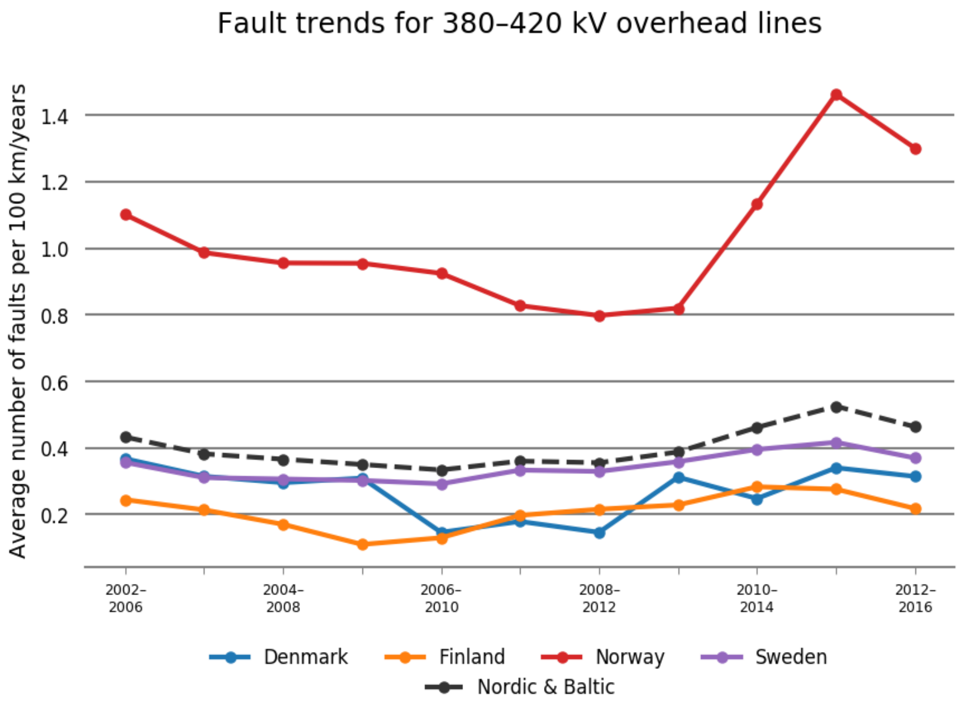

Figure 5.3.10 Fault trends as five-year averages for overhead lines at the voltage level 380–420 kV in Nordic countries

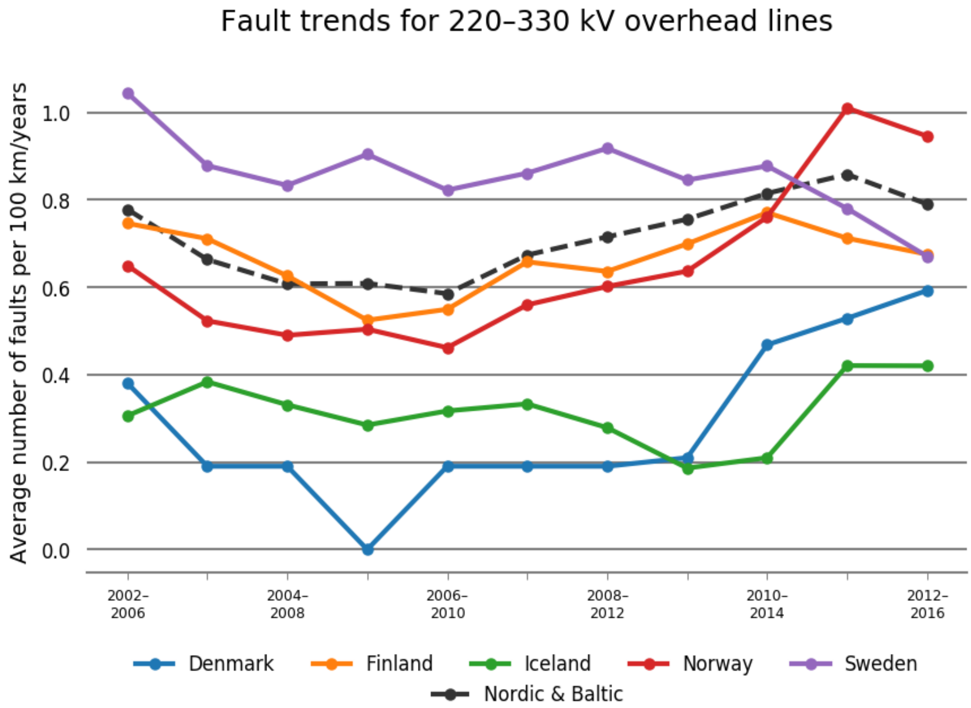

Figure 5.3.11 Fault trends as five-year averages for overhead lines at the voltage level 220–330 kV in each Nordic country

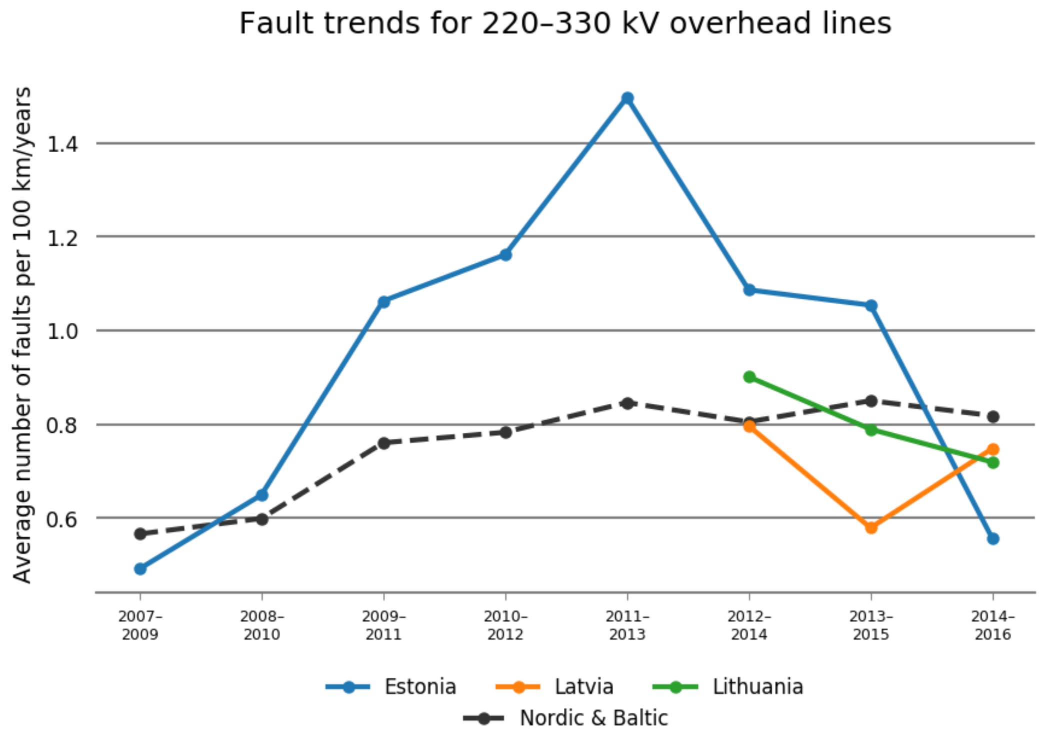

Figure 5.3.12 Fault trends as three-year averages for overhead lines at the voltage level 220–330 kV in each Baltic country. Estonia has reported data since 2007 and Latvia and Lithuania have reported data since 2012.

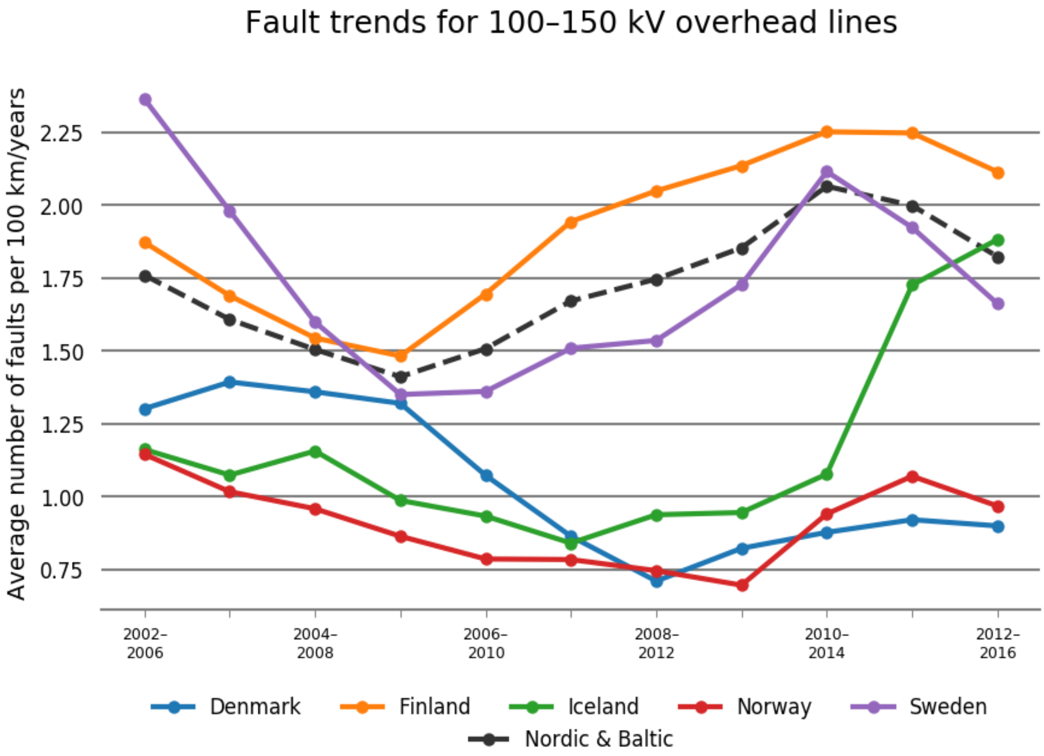

Figure 5.3.13 Fault trends as five-year averages for overhead lines at the voltage level 100–150 kV in each Nordic country

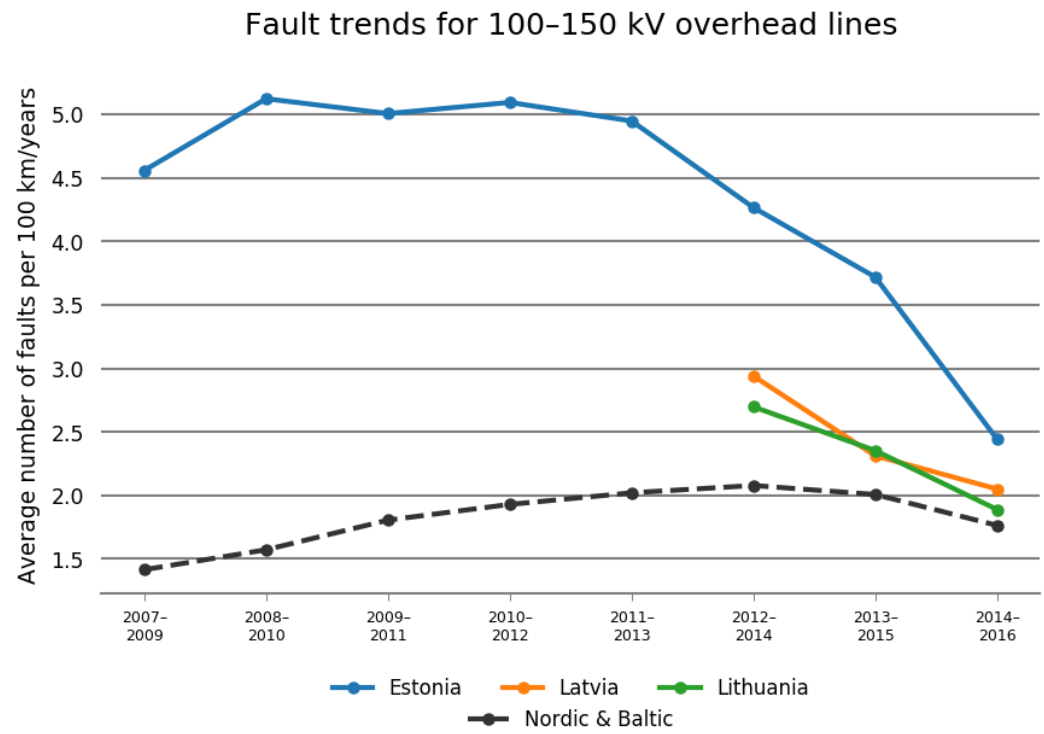

Figure 5.3.14 Fault trends as three-year averages for overhead lines at the voltage level 100–150 kV in each Baltic country. Estonia has reported data since 2007 and Latvia and Lithuania have reported data since 2012.

5.4 Faults in cables

Table 5.4.1, Table 5.4.2, and Table 5.4.3 present cable faults for the year 2016 and fault distribution at each statistical voltage level for the period 1996–2016.

Figure 5.4.1 presents the annual distribution of 100–150 kV cables faults during the period 2007–2016 and the average for the period 2007–2016 in the Nordic countries only, because the Baltic countries had no faults in 100–150 kV cables during 2012–2016 except for 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 and Figure 5.4.4.

Table 5.4.1 380–420 kV cables faults and the distribution per cause in Nordic countries

	Lines (km)	Number of faults	Number of faults per 100 km		Lightning	Other environmental causes	External influence	Operation and maintenance	Technical equipment	Other	Unknown
Country	2016	2016	2016	1996–2016	Faults divided by cause (%) during the period 1996–2016						
Denmark	147	0	0.00	0.42	0	0	0	14	57	14	14
Estonia[1)]	0	0	0.00	0.00	0	0	0	0	0	0	0
Finland	0	0	0.00	0.00	0	0	0	0	100	0	0
Iceland	0	0	0.00	0.00	0	0	0	0	0	0	0
Latvia[2)]	0	0	0.00	0.00	0	0	0	0	0	0	0
Lithuania[2)]	0	0	0.00	0.00	0	0	0	0	0	0	0
Norway	25	1	4.00	1.26	0	0	0	0	71	14	14
Sweden	15	0	0.00	0.00	0	0	0	0	0	0	0
Nordic & Baltic	186	1	0.54	0.62	0	0	0	7	67	13	13

1) The average values for Estonia use the period 2007–2016.

2) The average values of Latvia and Lithuania use the period 2012–2016.

Table 5.4.2 Distribution of faults per cause for 220–330 kV cables in Nordic and Baltic countries

	Lines (km)	Number of faults	Number of faults per 100 km		Lightning	Other environmental causes	External influence	Operation and maintenance	Technical equipment	Other	Unknown
Country	2016	2016	2016	1996–2016	Faults divided by cause (%) during the period 1996–2016						
Denmark	164	0	0.00	0.51	0	0	0	0	100	0	0
Estonia[1)]	0	0	0.00	0.00	0	0	0	0	0	0	0
Finland	0	0	0.00	0.00	0	0	0	0	0	0	0
Iceland	1	0	0.00	0.00	0	0	0	0	0	0	0
Latvia[2)]	14	0	0.00	0.00	0	0	0	0	0	0	0
Lithuania[2)]	0	0	0.00	0.00	0	0	0	0	0	0	0
Norway	98	0	0.00	0.27	0	25	0	25	25	0	25
Sweden	66	0	0.00	1.32	5	0	0	9	82	0	5
Nordic & Baltic	343	0	0.00	0.77	4	4	0	11	75	0	7

1) The average values for Estonia use the period 2007–2016.

2) The average values of Latvia and Lithuania use the period 2012–2016.

Table 5.4.3 100–150 kV cables faults and the distribution per cause in each Nordic and Baltic country

Country	Lines (km) 2016	Number of faults 2016	Number of faults per 100 km 2016	Number of faults per 100 km 1996–2016	Light-ning	Other environ-mental causes	External influence	Operation and mainte-nance	Technical equipment	Other	Un-known
					Faults divided by cause (%) during the period 1996–2016						
Denmark	1293.5	2	0.15	0.31	2	5	16	12	56	5	5
Estonia[1)]	64.0	1	1.56	0.78	0	0	25	0	0	0	0
Finland	260.5	0	0.00	0.39	0	0	0	22	33	22	22
Iceland	122.8	0	0.00	0.31	0	0	0	25	75	0	0
Latvia[2)]	70.0	1	1.43	0.29	0	0	0	0	100	0	0
Lithuania[2)]	90.0	0	0.00	0.29	0	0	0	0	0	0	0
Norway[3)]	422.0	3	0.71	1.59	1	10	10	12	47	15	4
Sweden	410.1	8	1.95	1.03	4	0	13	9	40	9	25
Nordic & Baltic	2732.9	15.0	0.55	0.66	2	5	12	11	46	10	11

1) The average values for Estonia use the period 2007–2016.

2) The average values of Latvia and Lithuania use the period 2012–2016.

3) Cables in Norway include cables in resonant earthed grids.

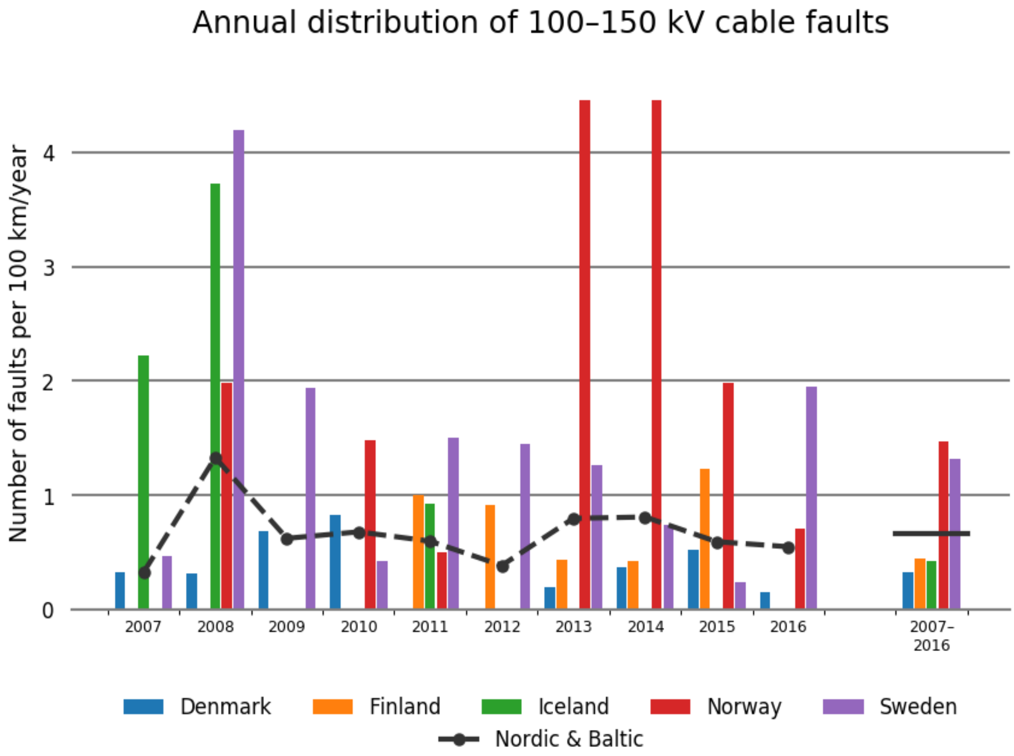

Figure 5.4.1 Annual distribution of 100–150 kV cable faults during the period 2007–2016 and the average for the period 2007–2016 in each Nordic country

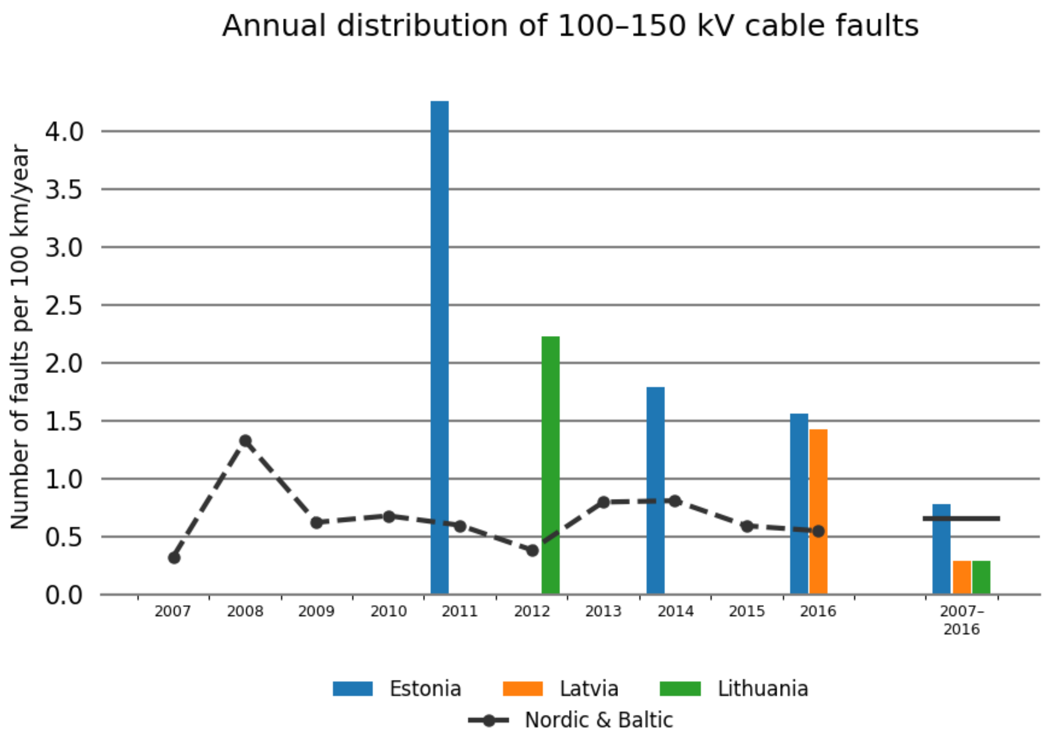

Figure 5.4.2 Annual distribution of 100–150 kV cable faults during the period 2007–2016 and the average for Estonia during 2007–2016 and for Latvia and Lithuania during 2012–2016

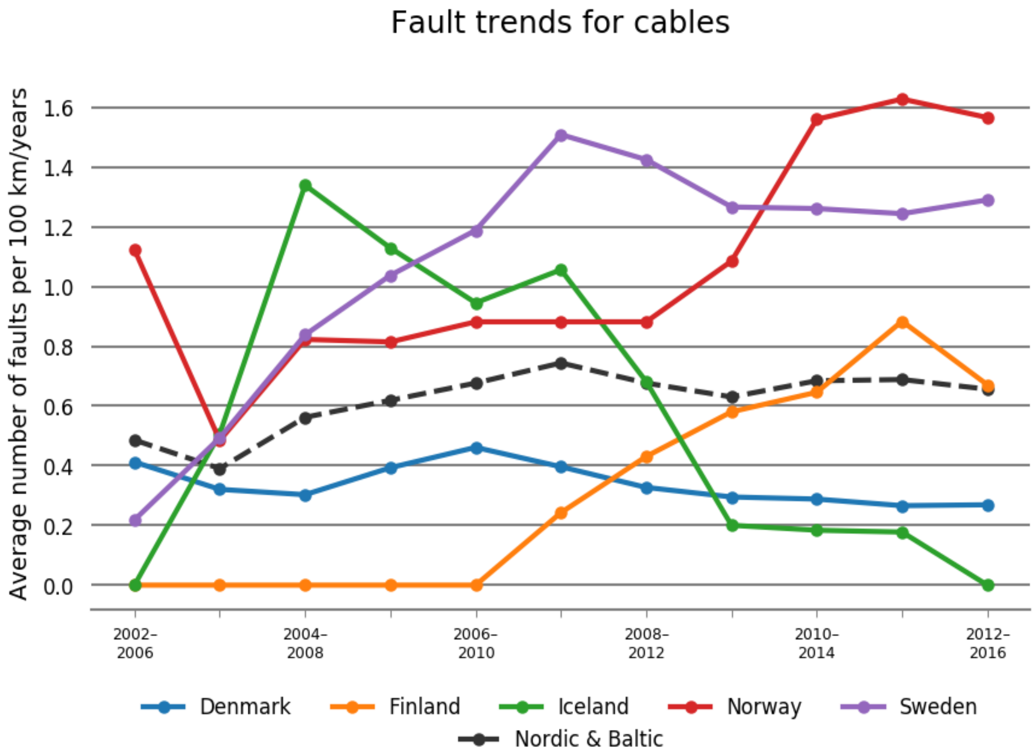

Figure 5.4.3 Fault trends as five-year averages for cables at all voltage levels in each Nordic country

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 5.4.1.

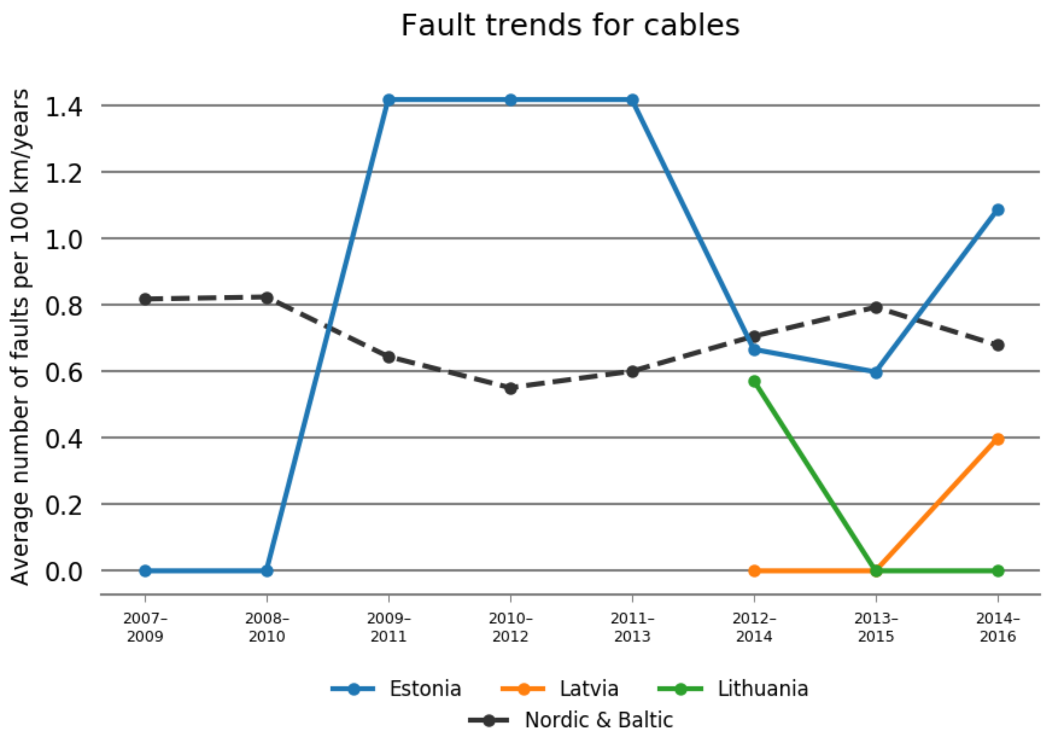

Figure 5.4.4 Fault trends as three-year averages for cables at all voltage levels in each Baltic country. Estonia has reported data since 2007 and Latvia and Lithuania have reported data since 2012.

5.5 Faults in power transformers

The tables in this section present the distribution of faults in power transformers for the year 2016 and for the period 2007–2016 at each respective voltage level. In addition, the tables present the distribution of faults per cause during the period 2007–2016.

The annual distribution of faults and the average for the period 2007–2016 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 and Baltic power transformers are presented in Figure 5.5.6, Figure 5.5.7, Figure 5.5.8, Figure 5.5.9 and Figure 5.5.10. 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 per cause in the Nordic and Baltic countries

Country	Number of devices in 2016	Number of faults in 2016	Number of faults per 100 devices 2016	Number of faults per 100 devices 2007–2016	Lightning	Other environmental causes	External influence	Operation and maintenance	Technical equipment	Other	Unknown
					Faults divided by cause (%) during the period 2007–2016						
Denmark	30	0	0.00	2.59	0	29	0	14	43	0	14
Estonia	0	0	0.00	0.00	0	0	0	0	0	0	0
Finland	62	1	1.61	2.02	0	8	0	33	42	8	8
Iceland	0	0	0.00	0.00	0	0	0	0	0	0	0
Latvia[1)]	0	0	0.00	0.00	0	0	0	0	0	0	0
Lithuania[1)]	0	0	0.00	0.00	0	0	0	0	0	0	0
Norway	100	1	1.00	2.07	0	0	0	36	21	29	14
Sweden	78	4	5.13	3.46	14	5	0	27	9	23	23
Nordic & Baltic	270	6	2.22	2.53	5	7	0	29	24	18	16

1) The average values of Latvia and Lithuania use the period 2012–2016.

Table 5.5.2 220–330 kV power transformers faults and the distribution per cause in each Nordic and Baltic country

Country	Number of devices in 2016	Number of faults in 2016	Number of faults per 100 devices 2016	Number of faults per 100 devices 2007–2016	Lightning	Other environmental causes	External influence	Operation and maintenance	Technical equipment	Other	Unknown
					Faults divided by cause (%) during the period 2007–2016						
Denmark	8	0	0.00	2.70	0	100	0	0	0	0	0
Estonia	23	0	0.00	8.56	0	5	0	32	63	0	0
Finland	36	1	2.78	2.54	0	0	0	57	14	14	14
Iceland	12	2	16.67	9.65	0	9	0	9	73	0	9
Latvia[1)]	25	3	12.00	7.20	0	0	11	33	56	0	0
Lithuania[1)]	24	0	0.00	5.13	0	0	0	50	17	0	33
Norway	266	0	0.00	0.64	6	6	0	12	24	41	12
Sweden	78	1	1.28	4.72	20	0	9	18	13	11	27
Nordic & Baltic	472	7	1.48	3.50	9	3	4	23	32	11	16

1) The average values of Latvia and Lithuania use the period 2012–2016.

Table 5.5.3 100–150 kV power transformers faults and the distribution per cause in each Nordic and Baltic country

Country	Number of devices in 2016	Number of faults in 2016	Number of faults per 100 devices 2016	Number of faults per 100 devices 2007–2016	Lightning	Other environmental causes	External influence	Operation and maintenance	Technical equipment	Other	Unknown
					Faults divided by cause (%) during the period 2007–2016						
Denmark	228	5	2.19	1.06	4	20	0	28	32	8	8
Estonia	218	9	4.13	2.59	2	4	2	25	66	0	2
Finland	1167	5	0.43	0.51	12	2	12	16	25	14	20
Iceland	43	2	4.65	1.58	0	29	0	43	29	0	0
Latvia[1)]	246	5	2.03	2.60	0	0	38	25	34	0	3
Lithuania[1)]	416	0	0.00	0.16	0	0	0	0	100	0	0
Norway	913	3	0.33	0.67	10	32	4	12	20	18	4
Sweden	930	14	1.51	3.59	19	2	2	21	26	3	27
Nordic & Baltic	4161	43	1.03	1.51	13	6	5	21	31	5	18

1) The average values of Latvia and Lithuania use the period 2012–2016.

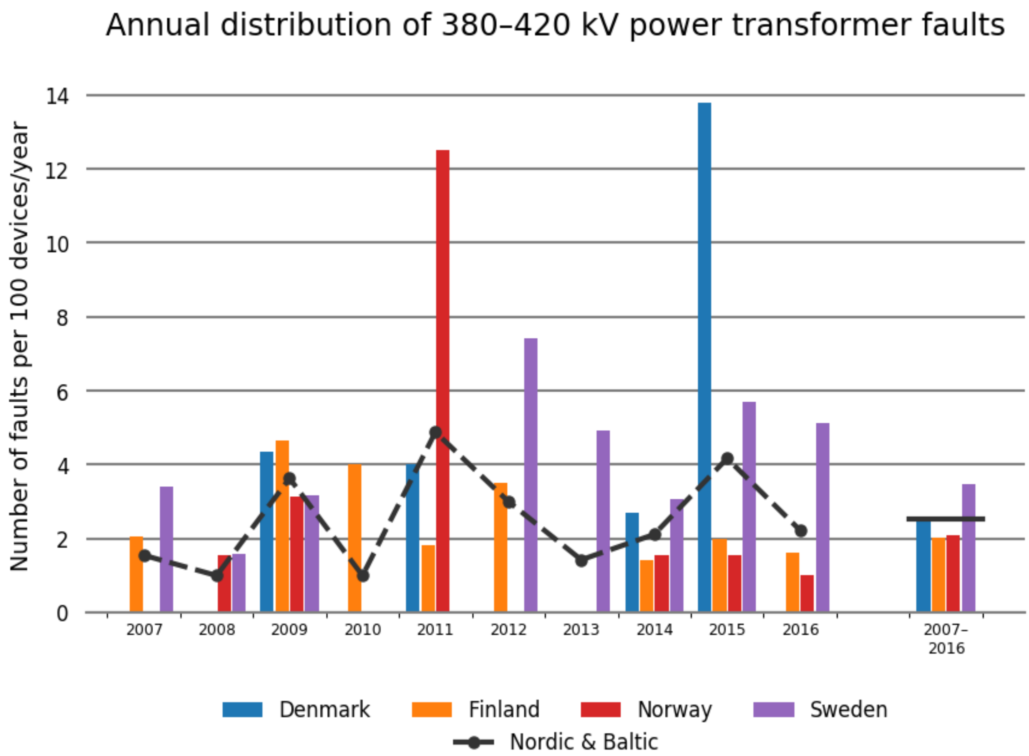

Figure 5.5.1 Annual distribution of faults for 380–420 kV power transformers in Nordic countries during the period 2007–2016

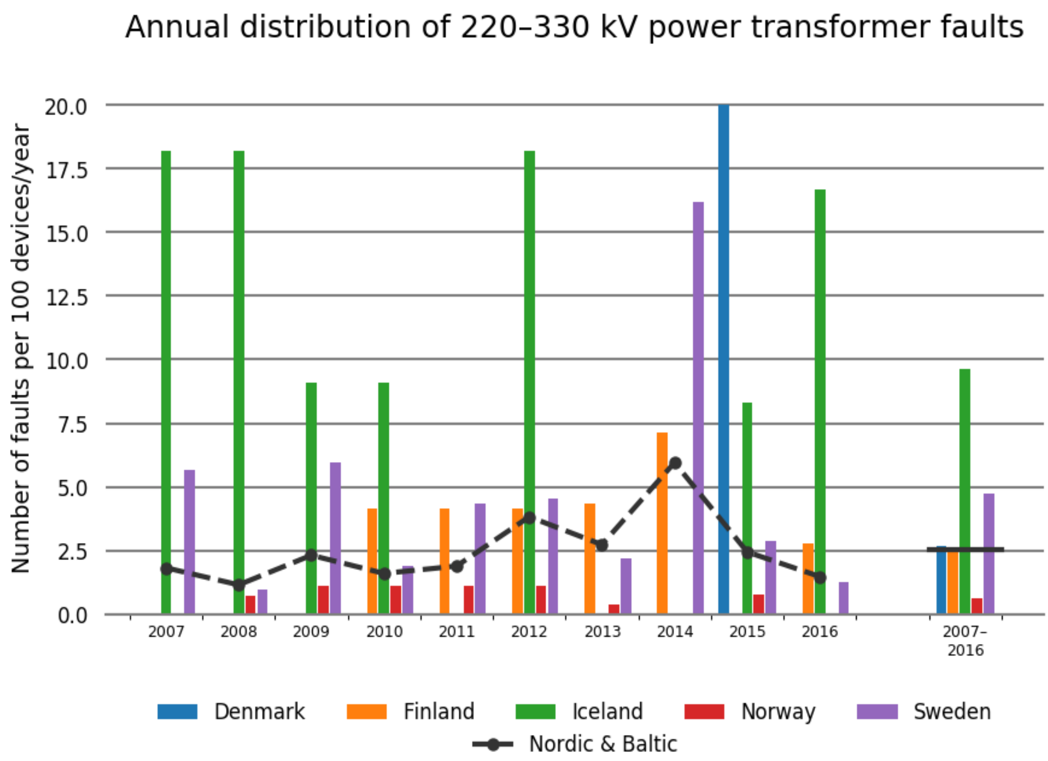

Figure 5.5.2 Annual distribution of faults for 220–330 kV power transformers in each Nordic country during the period 2007–2016

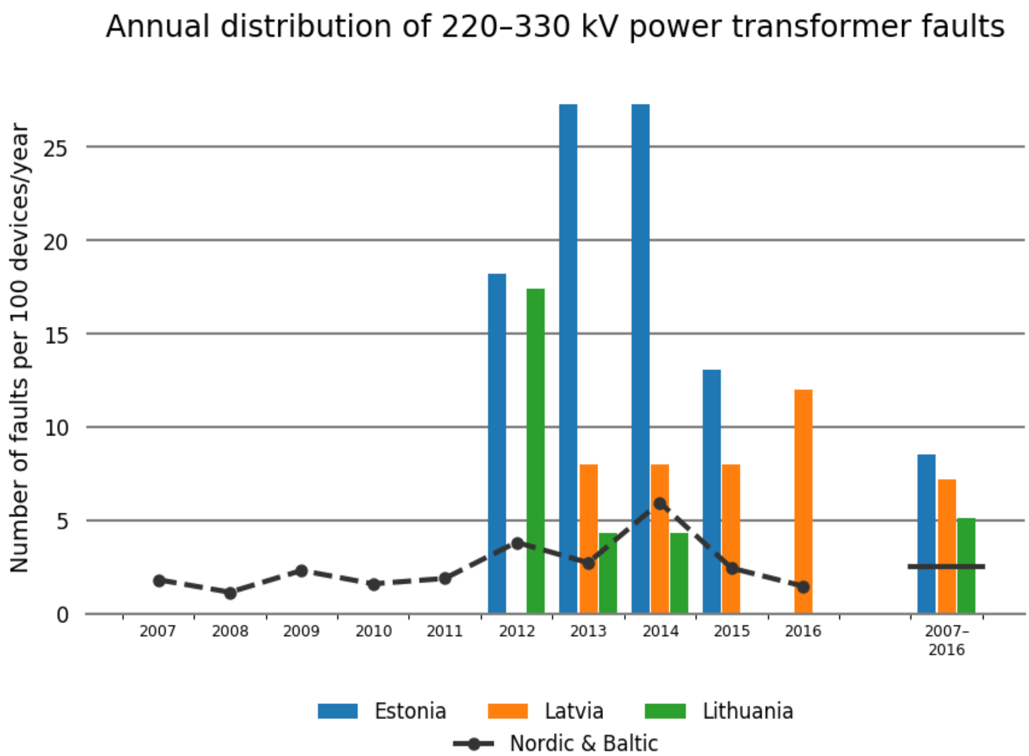

Figure 5.5.3 Annual distribution of faults for 220–330 kV power transformers and the average for Estonia during 2007–2016 and for Latvia and Lithuania during 2012–2016

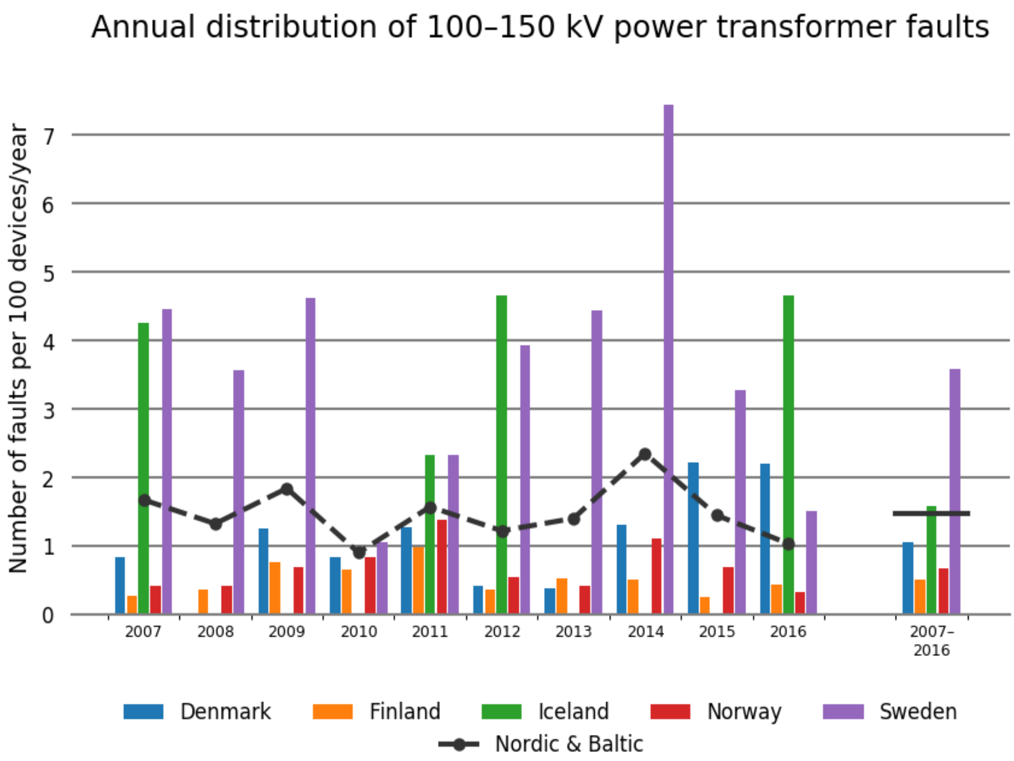

Figure 5.5.4 Annual distribution of faults for 100–150 kV power transformers in each Nordic country during the period 2007–2016

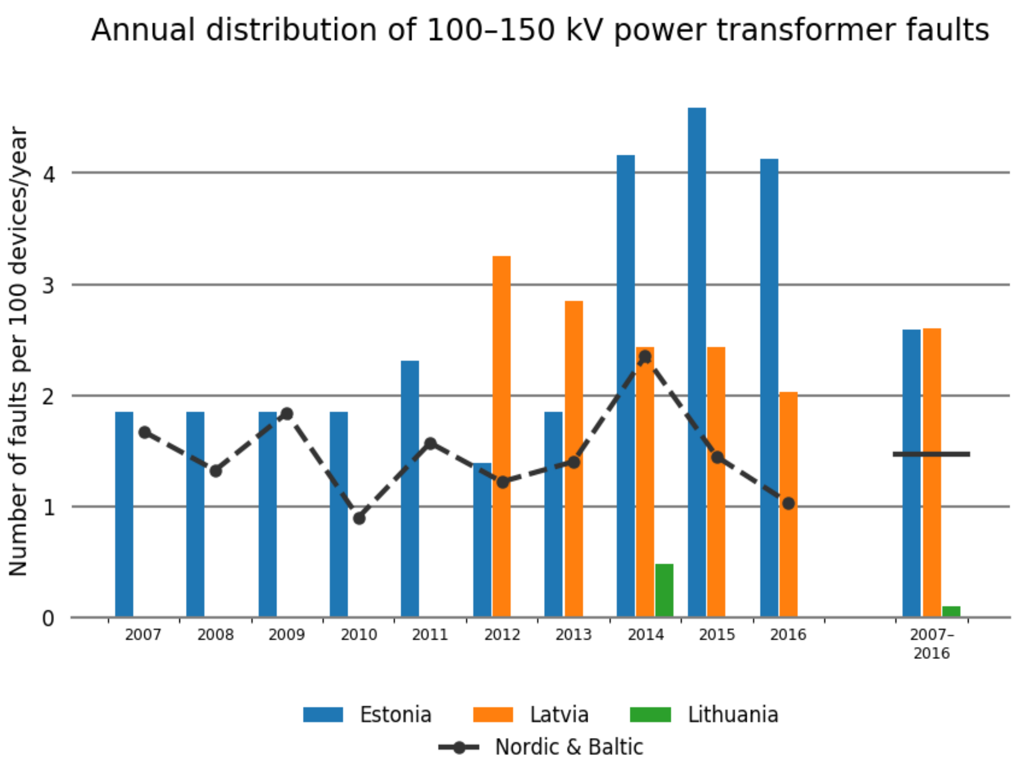

Figure 5.5.5 Annual distribution of faults for 100–150 kV power transformers and the average for Estonia during 2007–2016 and for Latvia and Lithuania during 2012–2016

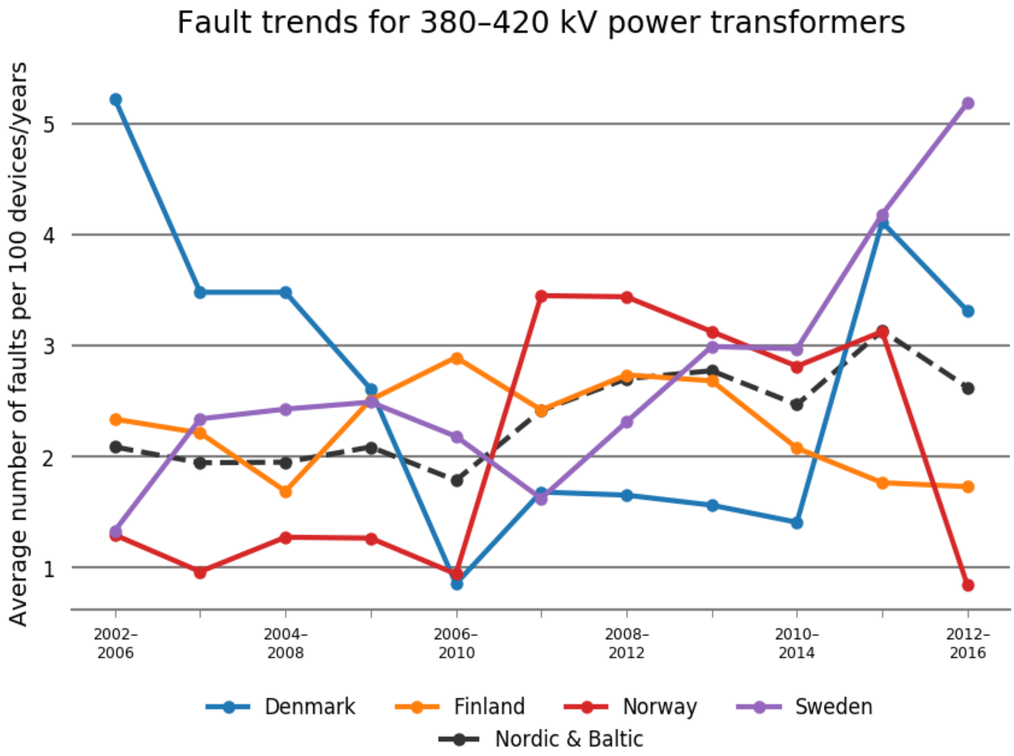

Figure 5.5.6 Fault trends as five-year averages for 380–420 kV power transformers in Nordic countries

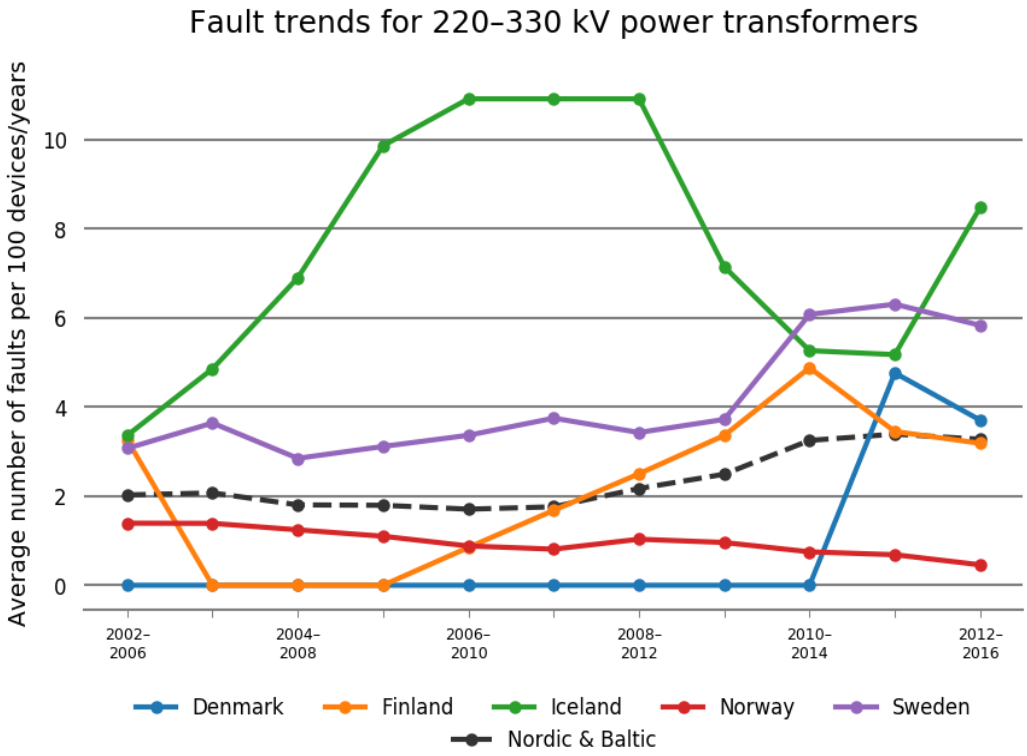

Figure 5.5.7 Fault trends as five-year averages for 220–330 kV power transformers in each Nordic country

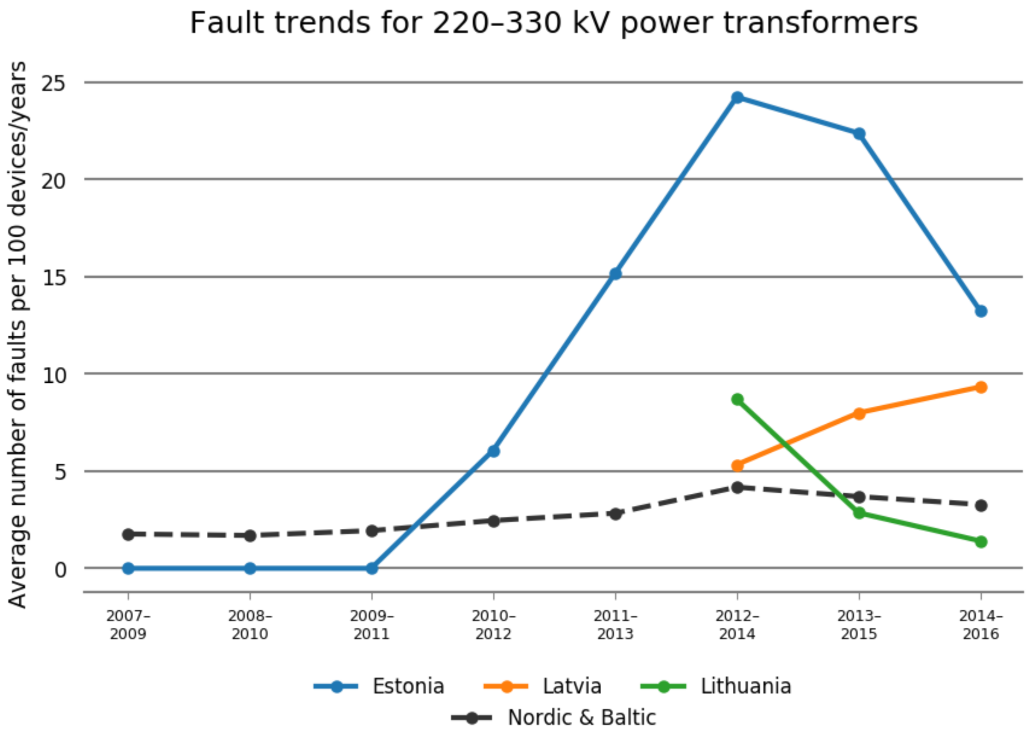

Figure 5.5.8 Fault trends as three-year averages for 220–330 kV power transformers in each Baltic country. Estonia has reported data since 2007 and Latvia and Lithuania have reported data since 2012.

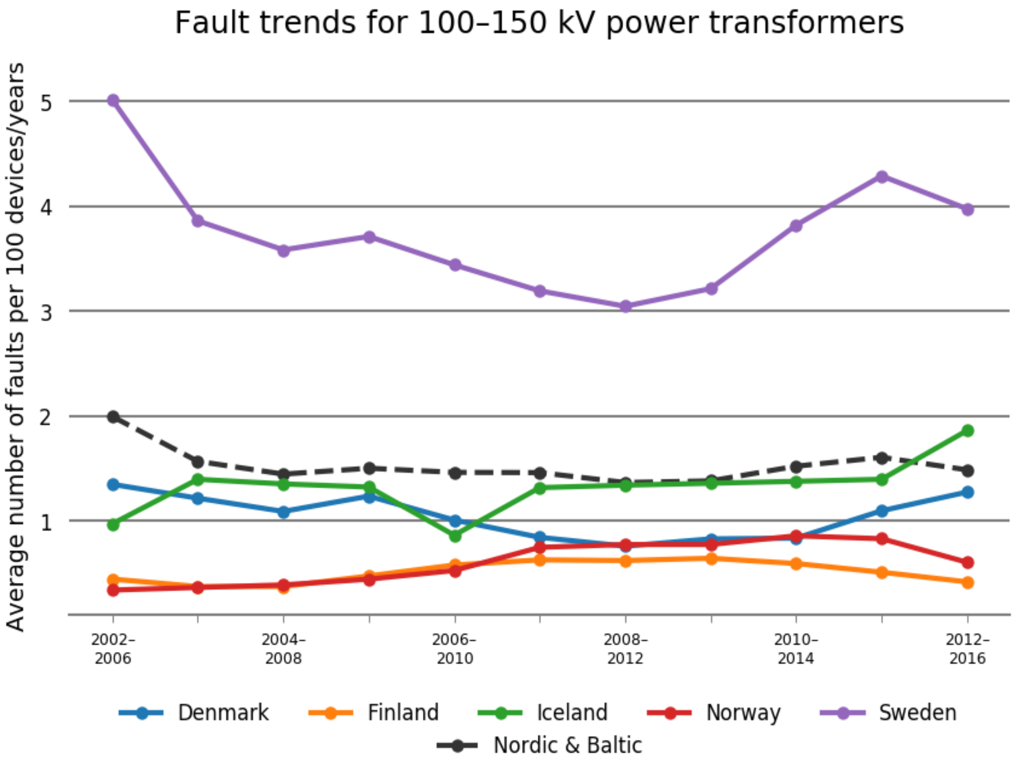

Figure 5.5.9 Fault trends as five-year averages for 100–150 kV power transformers in each Nordic country

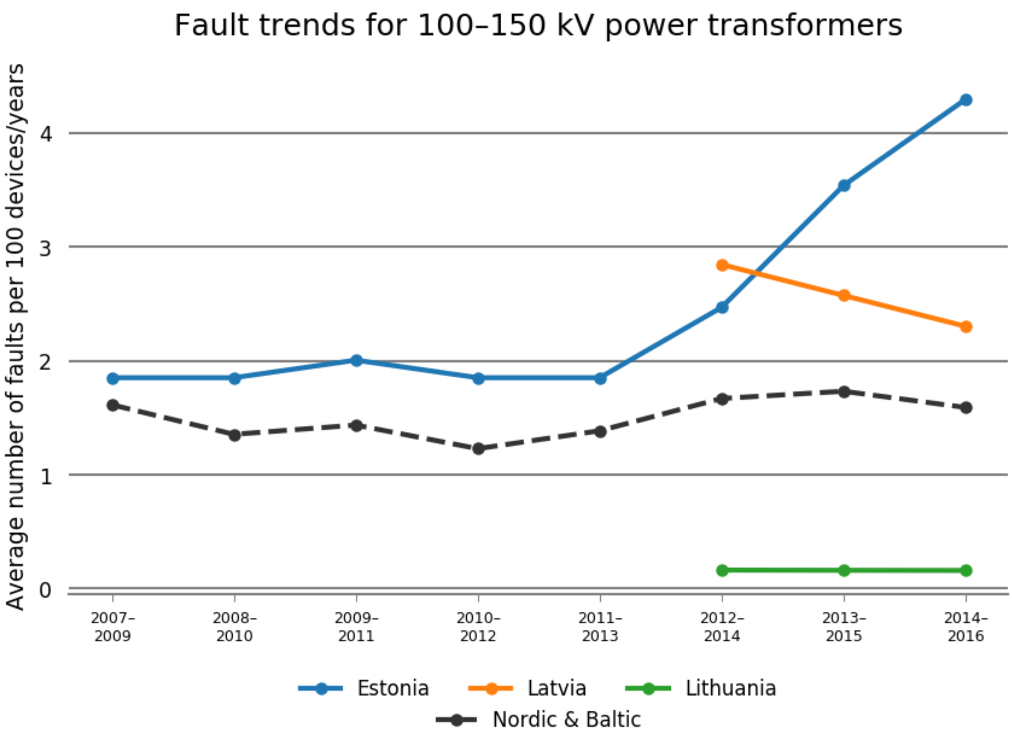

Figure 5.5.10 Fault trends as three-year averages for 100–150 kV power transformers in each Baltic country. Estonia has reported data since 2007 and Latvia and Lithuania have reported data since 2012.

5.6 Faults in instrument transformers

The tables in this section present the faults in instrument transformers for the year 2016 and for the period 2007–2016 at each statistical voltage level. In addition, the tables present the distribution of faults per 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 and Baltic countries.

Table 5.6.1 380–420 kV instrument transformers faults and the distribution per cause in Nordic countries

	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	Un-known
Country	2016	2016	2016	2007–2016	Faults divided by cause (%) during the period 2007–2016						
Denmark	224	0	0.00	0.00	0	0	0	0	0	0	0
Estonia	0	0	0.00	0.00	0	0	0	0	0	0	0
Finland	570	0	0.00	0.02	0	0	0	0	100	0	0
Iceland	0	0	0.00	0.00	0	0	0	0	0	0	0
Latvia[1)]	0	0	0.00	0.00	0	0	0	0	0	0	0
Lithuania[1)]	9	0	0.00	0.00	0	0	0	0	0	0	0
Norway	930	2	0.22	0.14	0	8	0	15	77	0	0
Sweden	1439	1	0.07	0.18	0	0	0	5	90	0	5
Nordic & Baltic	3172	3	0.09	0.12	0	3	0	9	85	0	3

1) The average values of Latvia and Lithuania use the period 2012–2016.

Table 5.6.2 220–330 kV instrument transformers faults and the distribution per cause in each Nordic and Baltic 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	Un-known
Country	2016	2016	2016	2007–2016	Faults divided by cause (%) during the period 2007–2016						
Denmark	17	0	0.00	0.83	0	0	0	0	0	0	100
Estonia	203	1	0.49	0.24	0	0	0	0	100	0	0
Finland	137	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
Latvia[1)]	200	0	0.00	0.10	0	0	0	0	100	0	0
Lithuania[1)]	235	0	0.00	0.00	0	0	0	0	0	0	0
Norway	2805	1	0.04	0.07	11	0	0	32	37	11	11
Sweden	835	0	0.00	0.07	17	0	0	0	83	0	0
Nordic & Baltic	4876	2	0.04	0.07	9	0	0	18	58	6	9

1) The average values of Latvia and Lithuania use the period 2012–2016.

Table 5.6.3 100–150 kV instrument transformers faults and the distribution per cause in each Nordic and Baltic country

Country	Number of devices 2016	Number of faults 2016	Number of faults per 100 devices 2016	Number of faults per 100 devices 2007–2016	Lightning	Other environmental causes	External influence	Operation and maintenance	Technical equipment	Other	Unknown
					Faults divided by cause (%) during the period 2007–2016						
Denmark	910	0	0.00	0.05	0	0	0	7	73	7	13
Estonia	973	3	0.31	0.08	0	0	0	14	86	0	0
Finland	3781	1	0.03	0.08	9	0	0	0	65	9	17
Iceland	611	0	0.00	0.00	0	0	0	0	0	0	0
Latvia[1)]	930	1	0.11	0.04	0	0	0	0	100	0	0
Lithuania[1)]	1092	3	0.27	0.08	0	0	0	0	100	0	0
Norway	7768	5	0.06	0.05	24	3	0	14	22	30	8
Sweden	4816	7	0.15	0.08	3	0	3	14	69	0	9
Nordic & Baltic	20881	20	0.10	0.06	10	1	1	10	57	11	10

1) The average values of Latvia and Lithuania use the period 2012–2016.

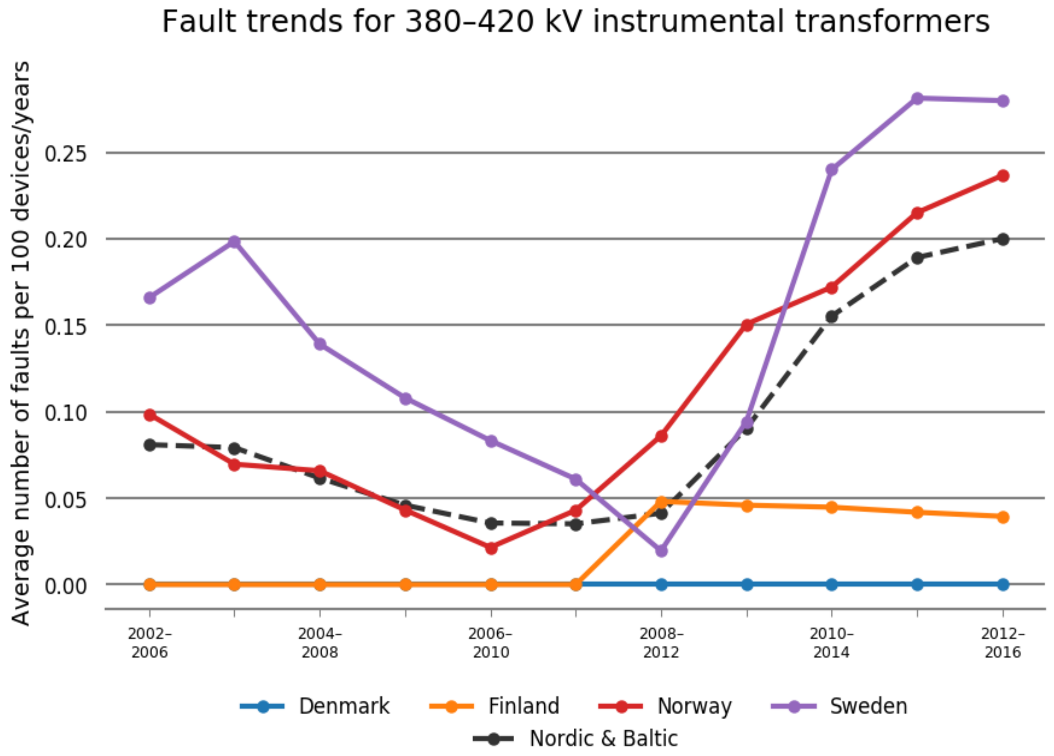

Figure 5.6.1 Fault trends as five-year averages for 380–420 kV instrument transformers in Nordic countries

The change in the Swedish trend curve in Figure 5.6.1 is due to seven instrument transformers that exploded in 2014. All 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.

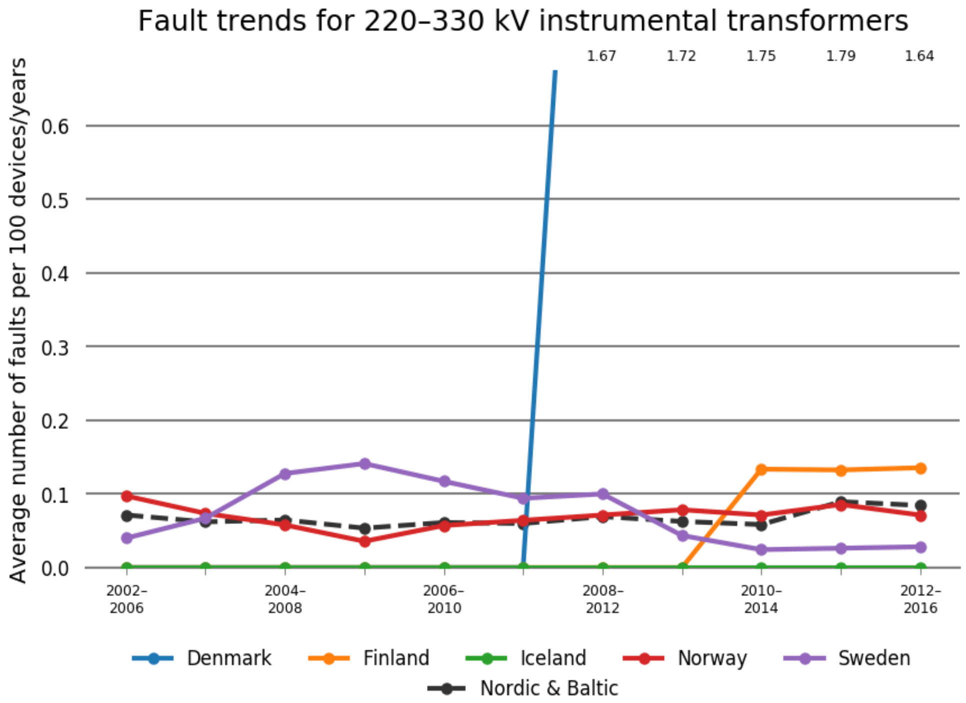

Figure 5.6.2 Fault trends as five-year averages for instrument transformers at the voltage level 220–330 kV in each Nordic country

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.

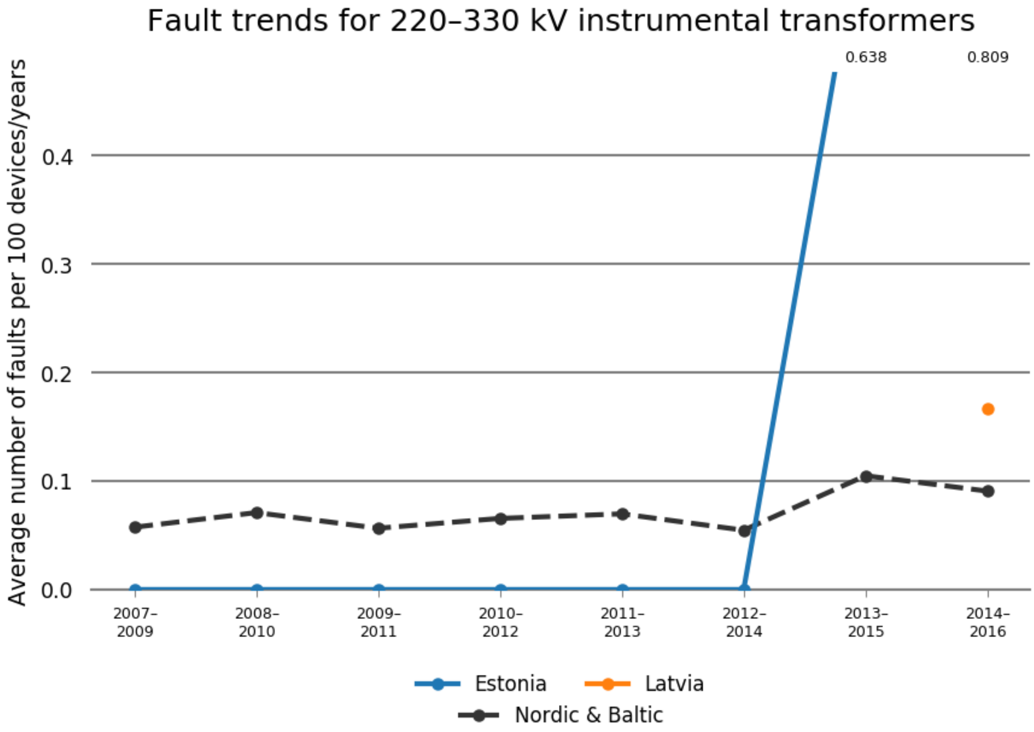

Figure 5.6.3 Fault trends as three-year averages for instrument transformers at the voltage level 220–330 kV in each Baltic country. Estonia has reported data since 2007 and Latvia and Lithuania have reported data since 2012.

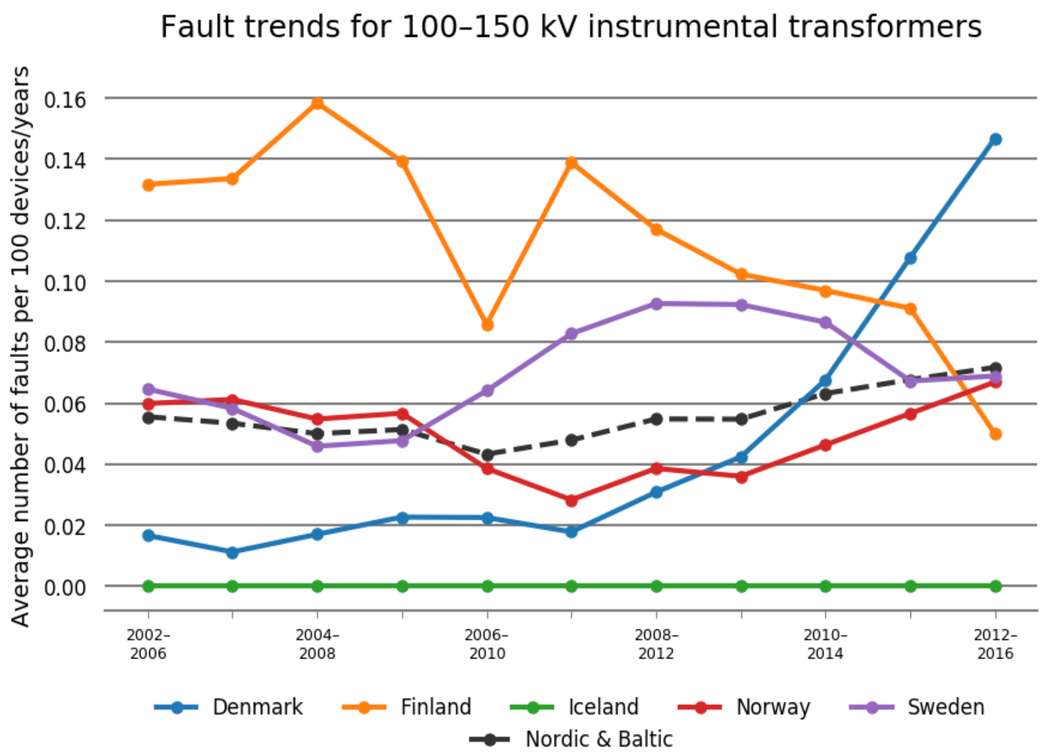

Figure 5.6.4 Fault trends as five-year averages for instrument transformers at the voltage level 100–150 kV in each Nordic country

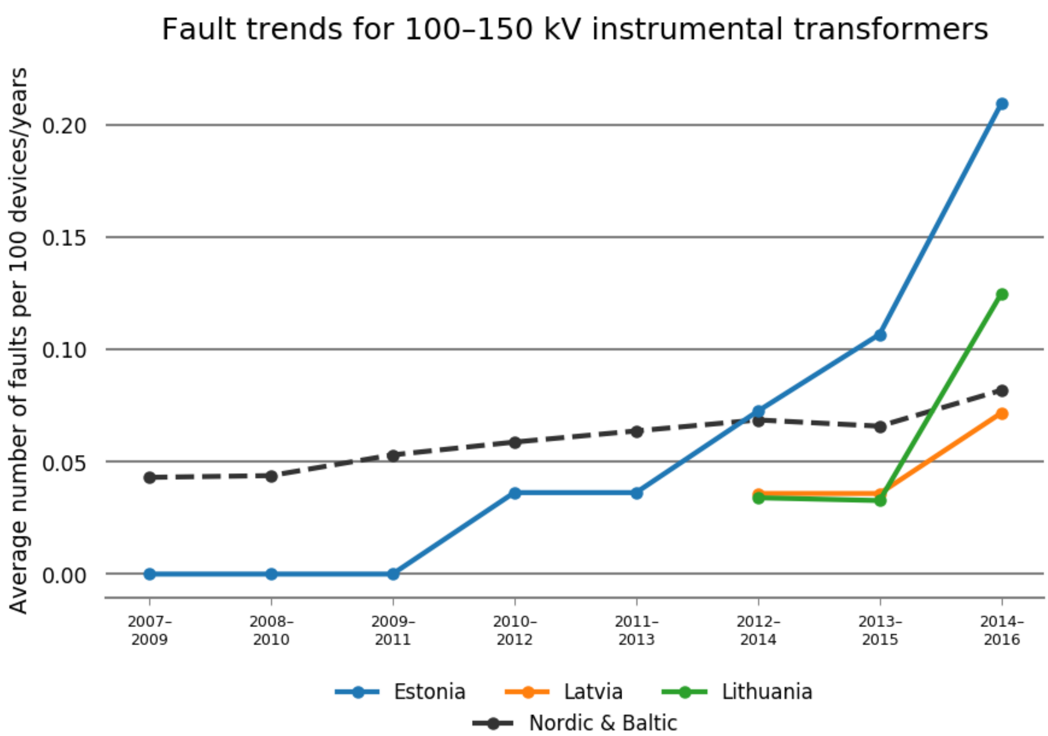

Figure 5.6.5 Fault trends as three-year averages for instrument transformers at the voltage level 100–150 kV in each Baltic country. Estonia has reported data since 2007 and Latvia and Lithuania have reported data since 2012.

5.7 Faults in circuit breakers

The tables in this section present circuit breaker faults at each statistical voltage level for the year 2016 and for the period 2007–2016. The tables also present the distribution of faults per cause during that period.

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

Table 5.7.1 380–420 kV circuit breaker faults and the distribution per cause in Nordic countries

	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	Un-known
Country	2016	2016	2016	2007–2016	Faults divided by cause (%) during the period 2007–2016						
Denmark	224	0	0.00	0.18	0	0	0	33	67	0	0
Estonia	0	0	0.00	0.00	0	0	0	0	0	0	0
Finland	334	0	0.00	0.32	0	0	0	0	88	13	0
Iceland	0	0	0.00	0.00	0	0	0	0	0	0	0
Latvia	0	0	0.00	0.00	0	0	0	0	0	0	0
Lithuania[1)]	5	0	0.00	0.00	0	0	0	0	0	0	0
Norway	453	0	0.00	0.66	0	0	0	42	42	11	5
Sweden[2)]	602	6	1.00	1.08	0	0	0	5	86	2	7
Nordic & Baltic	1618	6	0.37	0.70	0	0	0	14	76	5	6

1) Lithuania started operating its first 380–420 kV circuit breakers in 2016

2) 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.

Table 5.7.2 220–330 kV circuit breaker faults and the distribution per cause in each Nordic and Baltic 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	Un-known
Country	2016	2016	2016	2007–2016	Faults divided by cause (%) during the period 2007–2016						
Denmark	17	0	0.00	0.00	0	0	0	0	0	0	0
Estonia	117	9	7.69	1.16	0	0	0	7	64	0	29
Finland	74	0	0.00	0.22	0	0	0	0	100	0	0
Iceland	80	1	1.25	0.77	0	17	0	17	67	0	0
Latvia[1)]	103	0	0.00	0.00	0	0	0	0	0	0	0
Lithuania[1)]	111	1	0.90	0.80	0	0	0	25	0	25	50
Norway	730	3	0.41	0.54	0	3	3	44	36	8	8
Sweden	272	3	1.10	0.38	8	0	0	8	62	0	23
Nordic & Baltic	1504	17	1.13	0.53	1	3	1	27	47	5	15

1) The average values of Latvia and Lithuania use the period 2012–2016.

Table 5.7.3 100–150 kV circuit breaker faults and the distribution per cause in each Nordic and Baltic country

Country	Number of devices 2016	Number of faults 2016	Number of faults per 100 devices 2016	Number of faults per 100 devices 2007–2016	Lightning	Other environmental causes	External influence	Operation and maintenance	Technical equipment	Other	Unknown
					Faults divided by cause (%) during the period 2007–2016						
Denmark	910	0	0.00	0.28	0	0	0	36	55	5	5
Estonia	569	5	0.88	0.77	2	0	0	7	91	0	0
Finland	2575	3	0.12	0.16	5	3	3	32	29	5	24
Iceland	176	1	0.57	0.84	0	8	8	23	62	0	0
Latvia[1)]	606	4	0.66	0.46	0	0	0	7	93	0	0
Lithuania[1)]	852	7	0.82	1.02	2	0	5	35	33	5	21
Norway	2491	8	0.32	0.32	7	1	3	57	20	9	1
Sweden	2627	5	0.19	0.18	25	3	3	19	42	0	8
Nordic & Baltic	10806	33	0.31	0.32	6	1	3	32	45	4	8

1) The average values of Latvia and Lithuania use the period 2012–2016.

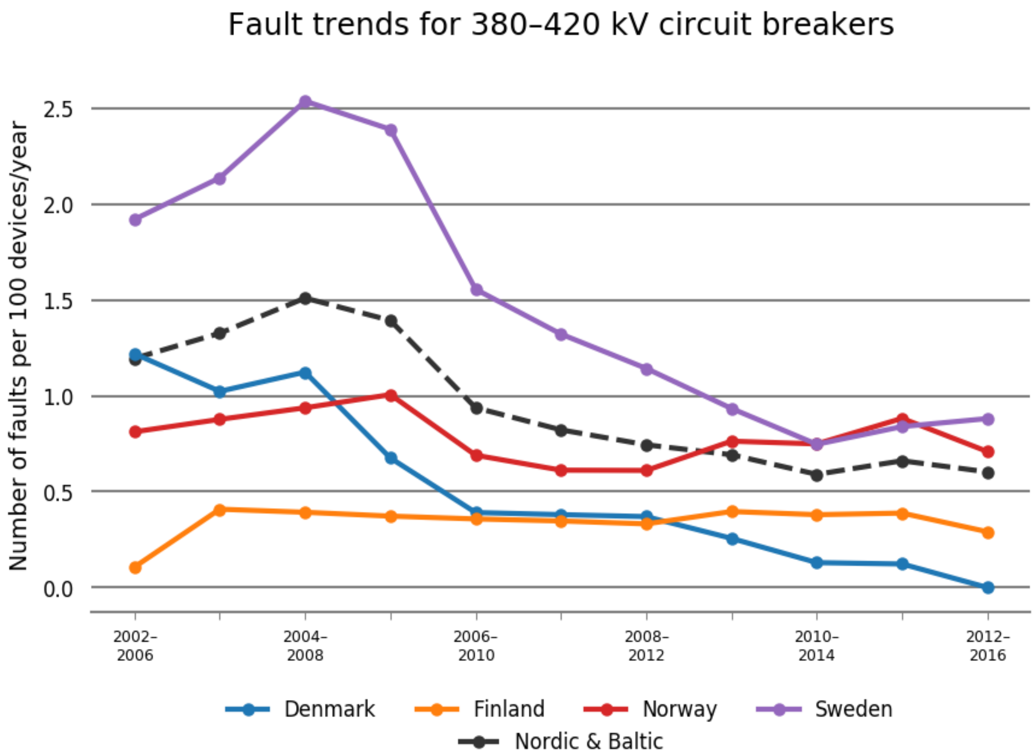

Figure 5.7.1 Fault trends as five-year averages for circuit breakers at the voltage level 380–420 kV in Nordic countries

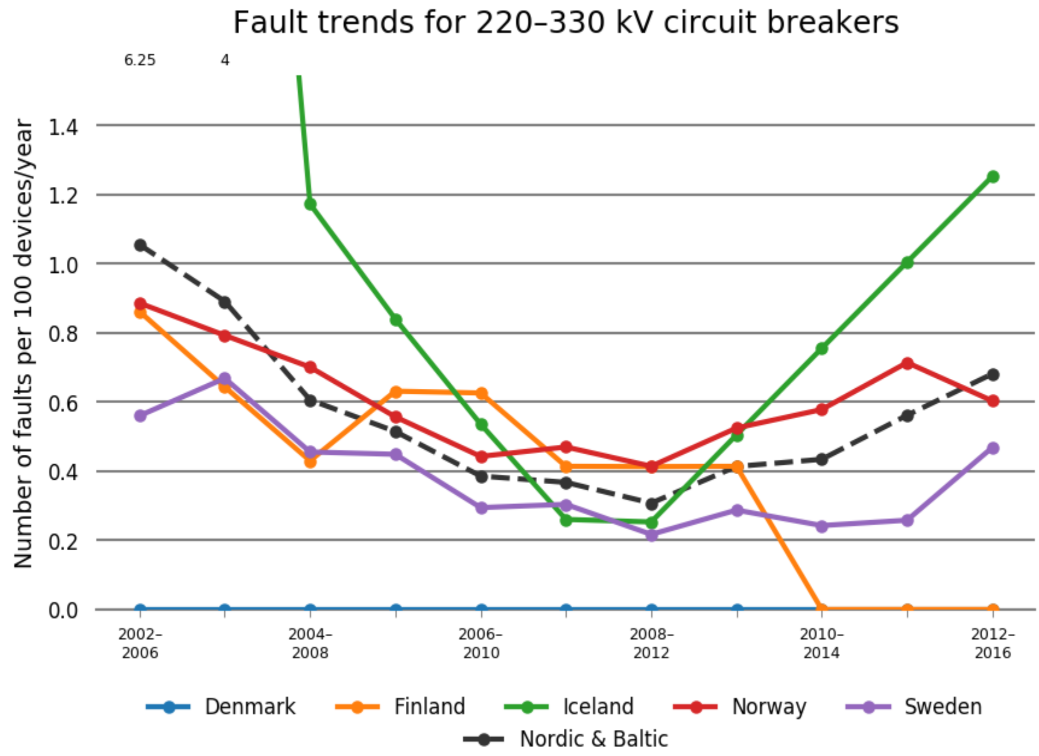

Figure 5.7.2 Fault trends as five-year averages for circuit breakers at the voltage level 220–330 kV in Nordic countries

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.

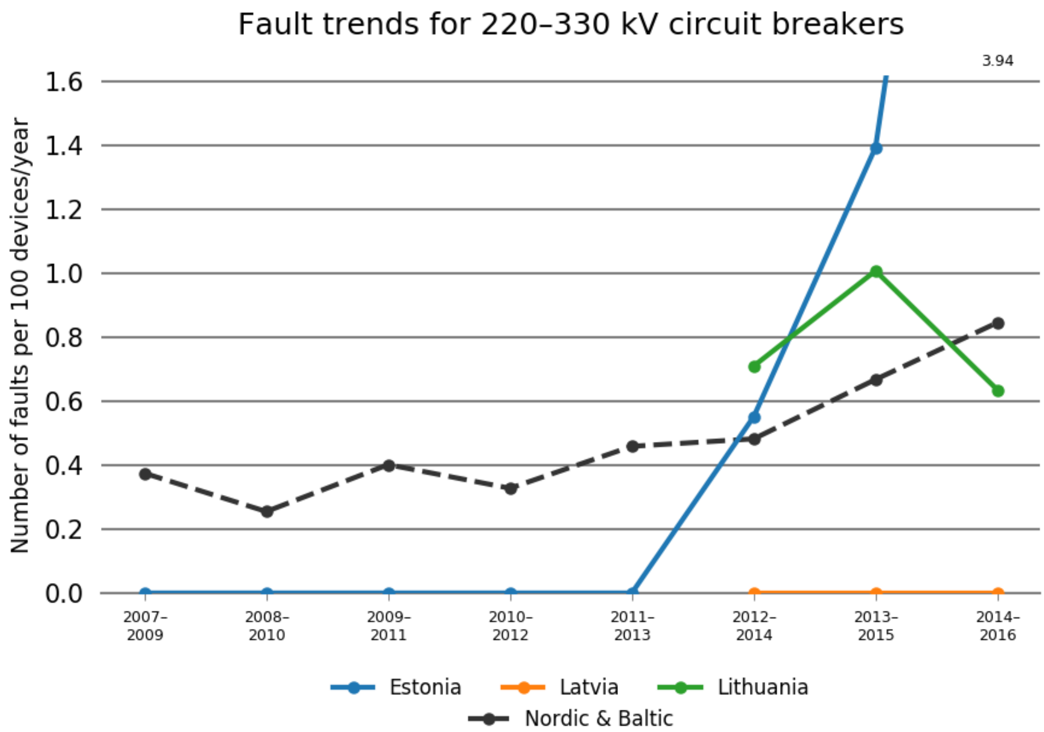

Figure 5.7.3 Fault trends as three-year averages for circuit breakers at the voltage level 220–330 kV in each Baltic country. Estonia has reported data since 2007 and Latvia and Lithuania have reported data since 2012.

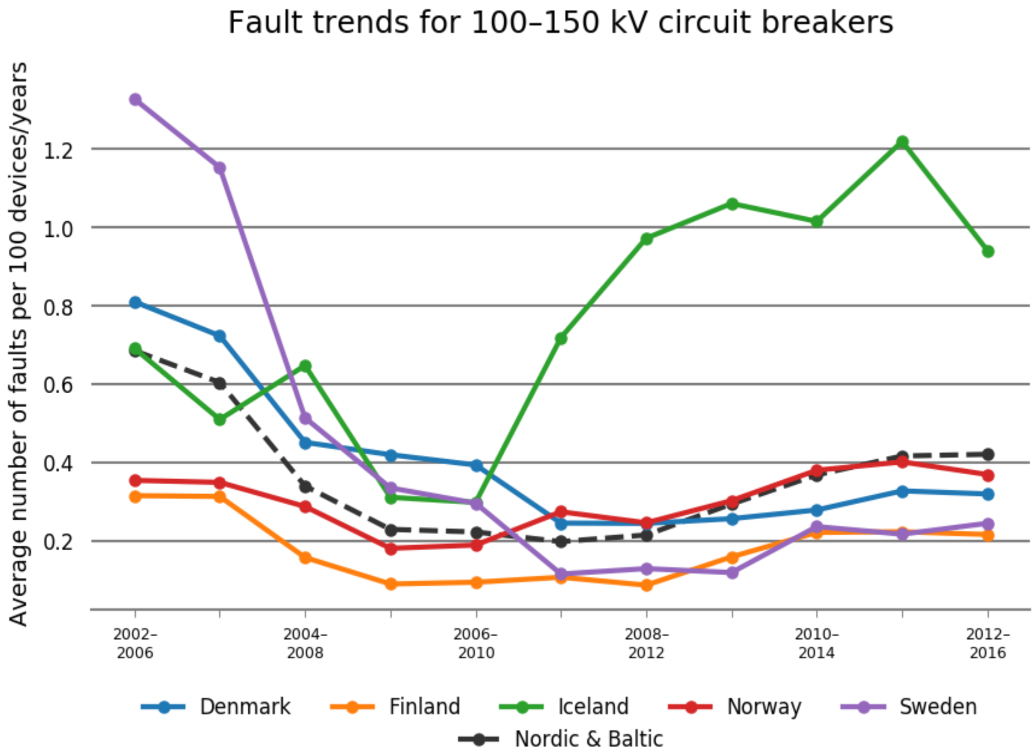

Figure 5.7.4 Fault trends as five-year averages for circuit breakers at the voltage level 100–150 kV in each Nordic country

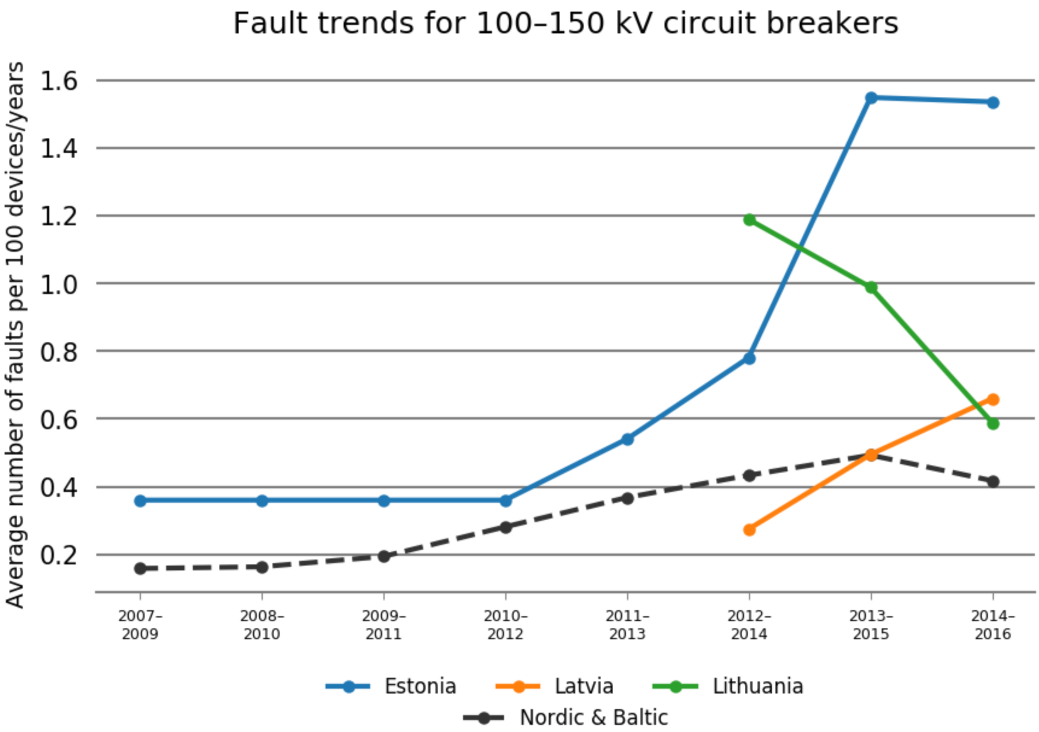

Figure 5.7.5 Fault trends as three-year averages for circuit breakers at the voltage level 100–150 kV in each Baltic country. Estonia has reported data since 2007 and Latvia and Lithuania have reported data since 2012.

5.8 Faults in control equipment

The tables in this section present faults in control equipment at each statistical voltage level for the year 2016 and for the period 2007–2016. In addition, the tables present the distribution of faults per cause during that ten-year period.

Figure 5.8.1, Figure 5.8.2, Figure 5.8.3, Figure 5.8.4 and Figure 5.8.5 present the annual distribution of control equipment faults at each statistical voltage level during the period 2007–2016 in the Nordic countries and at 100–150 kV and 220–330 kV during the period 2007–2016 for Estonia and the period 2012–2016 for Latvia and Lithuania.

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 per cause

	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
Country	2016	2016	2016	2007–2016	Faults divided by cause (%) during the period 2007–2016						
Denmark	224	2	0.89	0.83	0	8	8	38	38	8	0
Estonia	0	0	0.00	0.00	0	0	0	0	0	0	0
Finland	334	5	1.50	3.05	0	0	0	68	19	3	10
Iceland	0	0	0.00	0.00	0	0	0	0	0	0	0
Latvia[1)]	0	0	0.00	0.00	0	0	0	0	0	0	0
Lithuania[1)]	5	0	0.00	0.00	0	0	0	0	0	0	0
Norway	453	21	4.64	3.75	0	2	1	46	39	7	6
Sweden	602	22	3.65	4.51	0	6	0	19	74	0	1
Nordic & Baltic	1618	50	3.09	3.55	0	4	0	35	54	2	4

1) The average values of Latvia and Lithuania use the period 2012–2016.

Table 5.8.2 220–330 kV control equipment faults and the distribution per cause

	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
Country	2016	2016	2016	2007–2016	Faults divided by cause (%) during the period 2007–2016						
Denmark	17	0	0.00	1.64	0	0	0	100	0	0	0
Estonia	117	2	1.71	1.08	0	0	0	17	83	0	0
Finland	74	3	4.05	3.40	0	0	0	58	26	6	10
Iceland	80	3	3.75	4.34	0	3	0	29	50	6	0
Latvia[1)]	103	4	3.88	2.91	0	7	0	73	13	0	7
Lithuania[1)]	111	6	5.41	1.80	0	0	0	67	0	0	33
Norway	730	12	1.64	2.66	2	3	4	42	36	9	5
Sweden	272	23	8.46	2.47	0	0	1	46	41	5	7
Nordic & Baltic	1504	53	3.52	2.67	1	2	2	45	36	7	6

1) The average values of Latvia and Lithuania use the period 2012–2016.

Table 5.8.3 100–150 kV control equipment faults and the distribution per cause

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
	2016	2016	2016	2007–2016	Faults divided by cause (%) during the period 2007–2016						
Denmark	910	5	0.55	1.03	2	7	4	42	31	7	6
Estonia	569	16	2.81	1.52	0	0	0	43	50	0	7
Finland	2575	19	0.74	1.26	1	0	2	52	23	8	15
Iceland	176	7	3.98	3.78	0	0	0	19	72	2	0
Latvia[1)]	606	15	2.48	3.04	0	0	1	46	45	2	7
Lithuania[1)]	852	10	1.17	1.58	0	0	13	34	18	7	27
Norway	2491	28	1.12	1.46	3	4	1	42	27	12	11
Sweden	2627	30	1.14	0.39	1	0	0	39	29	9	19
Nordic & Baltic	10806	130	1.20	1.22	1	2	2	43	31	8	12

1) The average values of Latvia and Lithuania use the period 2012–2016.

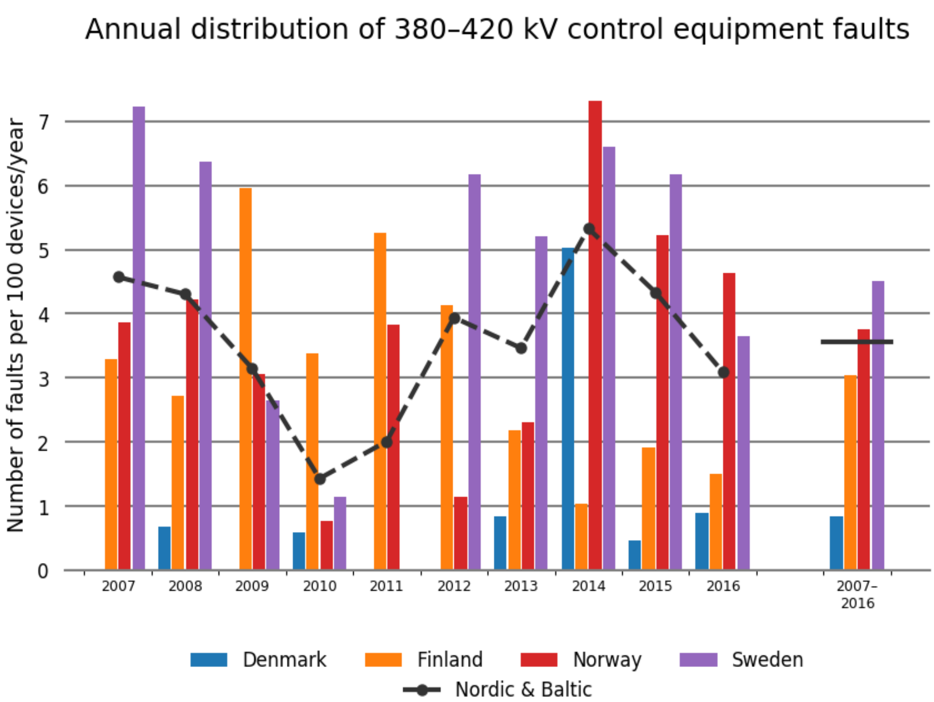

Figure 5.8.1 Annual distribution of 380–420 kV control equipment faults and the average for the period 2007–2016

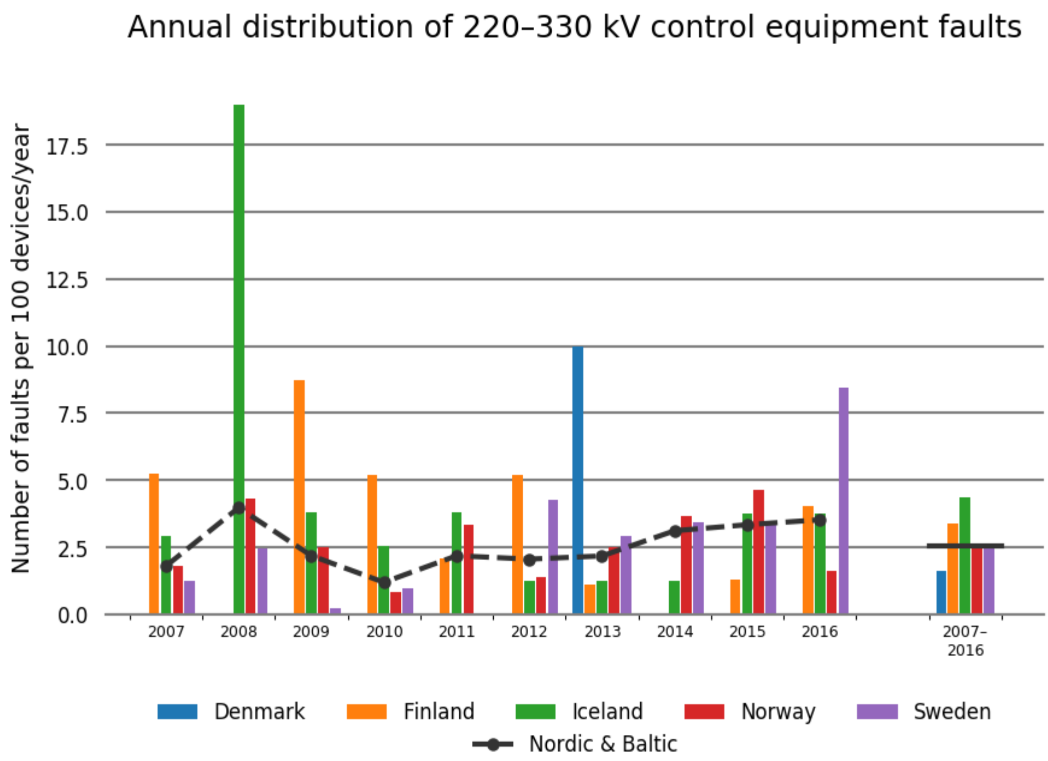

Figure 5.8.2 Annual distribution of 220–330 kV control equipment faults and the average for the period 2007–2016 for each Nordic country

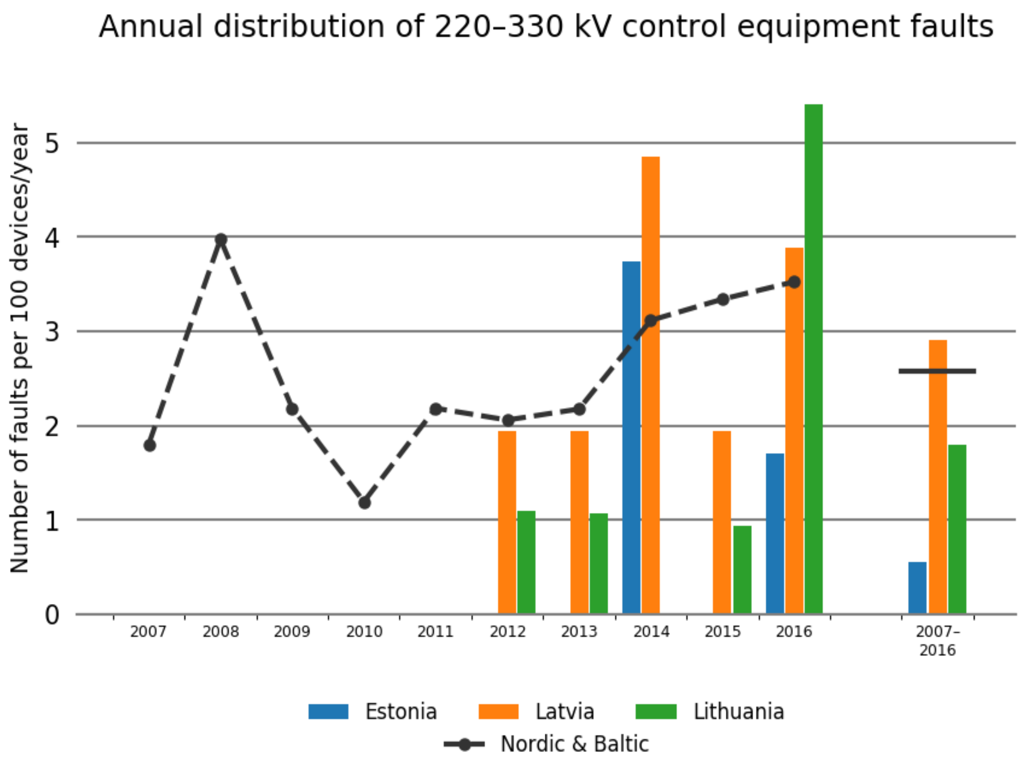

Figure 5.8.3 Annual distribution of 220–330 kV control equipment faults and the average for Estonia during 2007–2016 and for Latvia and Lithuania during 2012–2016

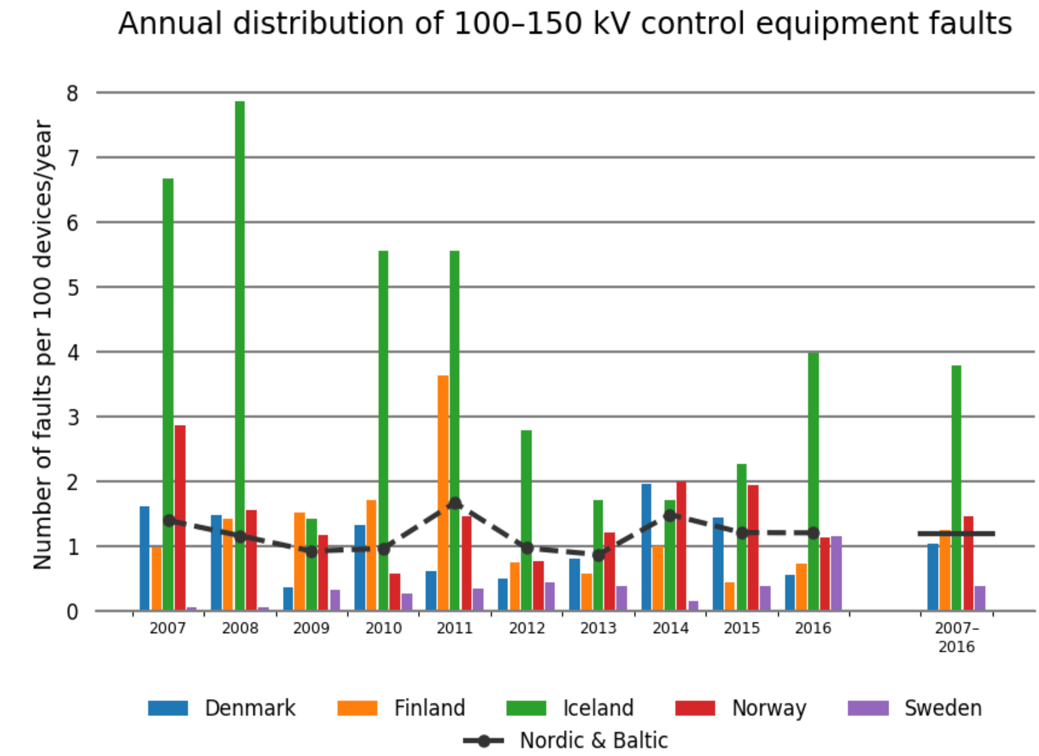

Figure 5.8.4 Annual distribution of 100–150 kV control equipment faults and the average for the period 2007–2016 for each Nordic country

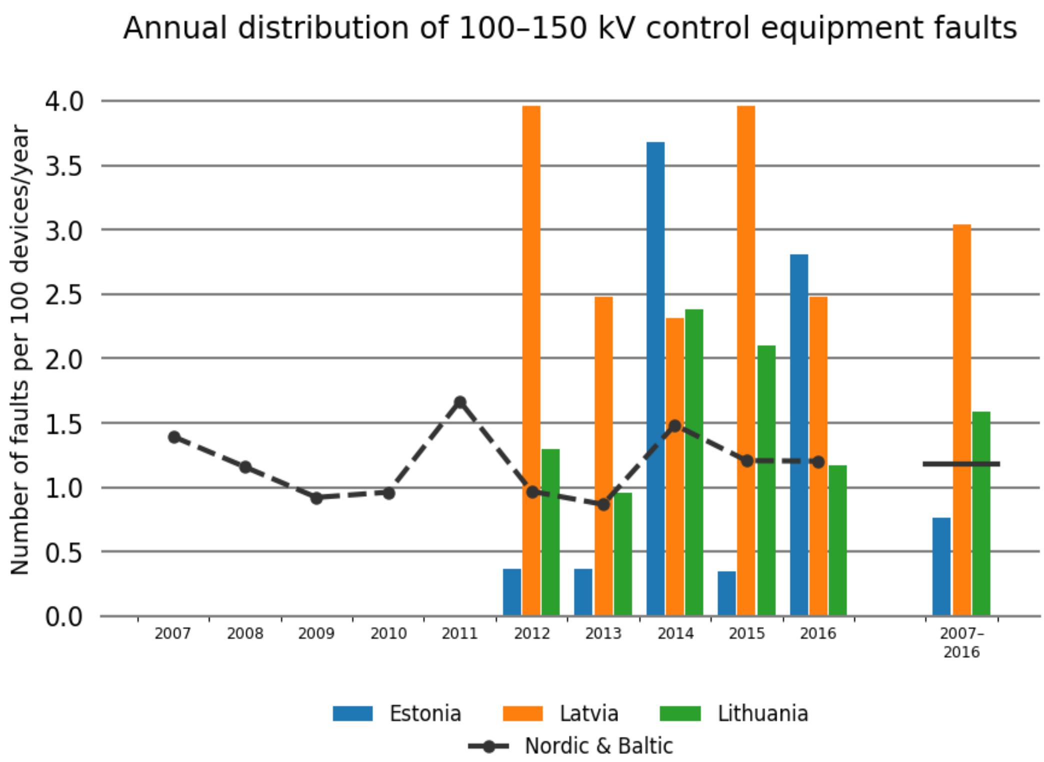

Figure 5.8.5 Annual distribution of 100–150 kV control equipment faults and the average for Estonia during 2007–2016 and for Latvia and Lithuania during 2012–2016

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 2016 and for the period 2007–2016. In addition, the tables present the distribution of faults per cause during the ten-year period 2007–2016.

Table 5.9.1 Reactor faults and the distribution per cause

	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	Un-known
Country	2016	2016	2016	2007–2016	Faults divided by cause (%) during the period 2007–2016						
Denmark	88	1	1.14	2.28	0	0	0	33	56	0	11
Estonia	26	1	3.85	9.59	0	0	0	14	43	0	43
Finland	96	0	0.00	0.29	0	0	0	50	50	0	0
Iceland	0	0	0.00	0.00	0	0	0	0	0	0	0
Latvia[1)]	16	2	12.50	5.00	0	0	0	0	100	0	0
Lithuania[1)]	2	0	0.00	0.00	0	0	0	0	0	0	0
Norway	36	1	2.78	2.78	0	10	0	40	10	40	0
Sweden	78	10	12.82	11.74	0	26	1	9	29	31	5
Nordic & Baltic	342	15	4.39	5.00	0	20	1	15	33	26	7

1) The average values of Latvia and Lithuania use the period 2012–2016.

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 per cause

	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	Un-known
Country	2016	2016	2016	2007–2016	Faults divided by cause (%) during the period 2007–2016						
Denmark	0	0	0.0	0.0	0	0	0	0	0	0	0
Estonia	0	0	0.0	0.0	0	0	0	0	0	0	0
Finland	11	8	72.7	59.6	0	8	6	11	47	0	28
Iceland	1	0	0.0	10.0	0	100	0	0	0	0	0
Latvia	0	0	0.0	0.0	0	0	0	0	0	0	0
Lithuania	0	0	0.0	0.0	0	0	0	0	0	0	0
Norway	3	0	0.0	3.3	0	100	0	0	0	0	0
Sweden	8	16	200.0	152.7	0	1	0	0	13	82	6
Nordic & Baltic	23	24	104.3	93.8	0	3	1	3	21	62	12

Table 5.9.3 Shunt capacitor faults and the distribution per cause

Country	Number of devices 2016	Number of faults 2016	Number of faults per 100 devices 2016	Number of faults per 100 devices 2007–2016	Light-ning	Other environ-mental causes	External influence	Operation and mainte-nance	Technical equipment	Other	Un-known
					Faults divided by cause (%) during the period 2007–2016						
Denmark	25	0	0.00	0.56	0	0	100	0	0	0	0
Estonia	14	0	0.00	0.00	0	0	0	0	0	0	0
Finland	41	0	0.00	3.23	0	11	33	6	39	6	6
Iceland	13	2	15.38	9.91	0	18	9	0	73	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
Norway[1)]	194	2	1.03	1.55	3	7	0	13	63	10	3
Sweden	214	5	2.34	1.16	0	10	5	0	48	5	33
Nordic & Baltic	505	9	1.78	1.71	1	10	11	6	54	6	11

1) The average values of Latvia and Lithuania use the period 2012–2016.

Table 5.9.4 SVC faults and the distribution per cause

Country	Number of devices 2016	Number of faults 2016	Number of faults per 100 devices 2016	Number of faults per 100 devices 2007–2016	Light-ning	Other environ-mental causes	External influence	Operation and mainte-nance	Technical equipment	Other	Un-known
					Faults divided by cause (%) during the period 2007–2016						
Denmark	1	1	100.0	40.0	0	33	0	0	33	0	33
Estonia	0	0	0.0	0.0	0	0	0	0	0	0	0
Finland	5	1	20.0	20.0	0	0	33	33	33	0	0
Iceland	2	1	50.0	50.0	0	50	0	0	50	0	0
Latvia[1)]	0	0	0.0	0.0	0	0	0	0	0	0	0
Lithuania[1)]	11	0	0.0	9.5	0	0	0	0	0	0	0
Norway	25	9	36.0	2.5	1	1	0	4	74	17	4
Sweden	3	18	600.0	13.3	1	6	1	13	63	7	10
Nordic & Baltic	47	30	63.8	1.5	1	4	1	8	68	12	7

1) The average values of Latvia and Lithuania use the period 2012–2016.

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 the distribution of single and multiple fault situations along with the energy not supplied per cause and voltage levels.

This chapter and the data it contains is new to this report and has thereby only data from 2016. Historical data can be presented after there is enough accumulated data of multiple fault situations.

6.1 Definitions and scope

A multiple fault situation occurs when a disturbance has more than one fault [1]. Multiple fault situations are rarer than single fault situations but tend 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, disturbances causing ENS and multiple fault situations in 2016. Furthermore, it presents also the ENS caused by disturbances and multiple fault situations separately.

As can be seen, the number of disturbances with multiple fault situations is significantly smaller than the number of disturbances.

Table 6.2.1 The number of disturbances, disturbances causing ENS and multiple faults situations and the amount of ENS in 2016

2016	Disturbances	Disturbances with ENS	ENS (MWh)	Multiple fault situations	Multiple fault ENS (MWh)
Denmark	51	13	44.7	2	0.0
Estonia	145	36	101.9	4	24.9
Finland	413	71	254.8	17	7.1
Iceland	44	18	154.4	5	0.0
Latvia	124	12	23.1	14	14.4
Lithuania	137	11	28.1	13	2.3
Norway	261	79	1161.7	30	157.3
Sweden	461	178	1924.1	8	3.6
Nordic & Baltic	1636	418	3692.8	93	209.5

6.3 Multiple fault situations distributed per cause

Figure 6.3.1 and Figure 6.3.2 present the percentage distribution of multiple fault situations per cause in 2016.

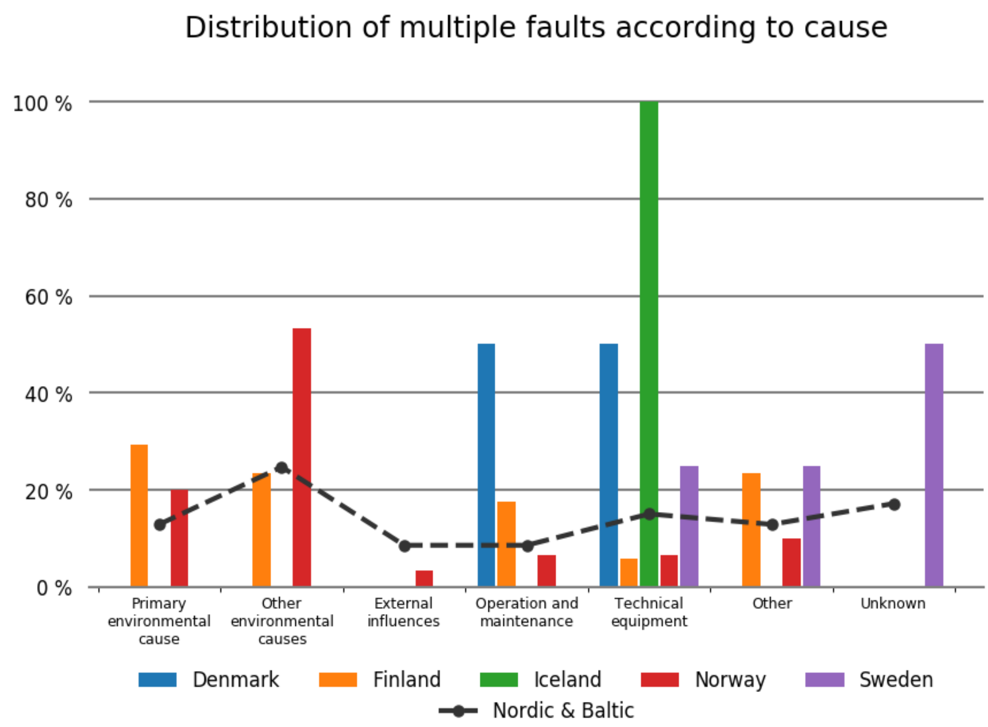

Figure 6.3.1 Percentage distribution of multiple fault situations per cause in the Nordic countries in 2016

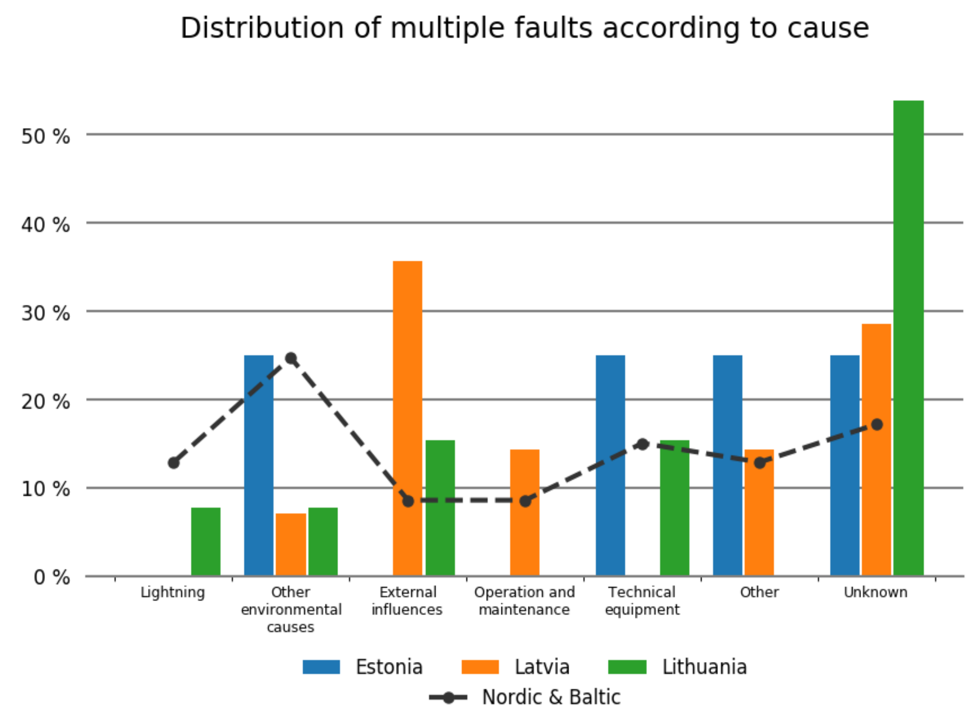

Figure 6.3.2 Percentage distribution of multiple fault situations per cause in the Baltic countries in 2016

6.4 Multiple fault situations distributed per voltage level

Figure 6.4.1 presents the percentage distribution of multiple fault situations per voltage level in 2016.

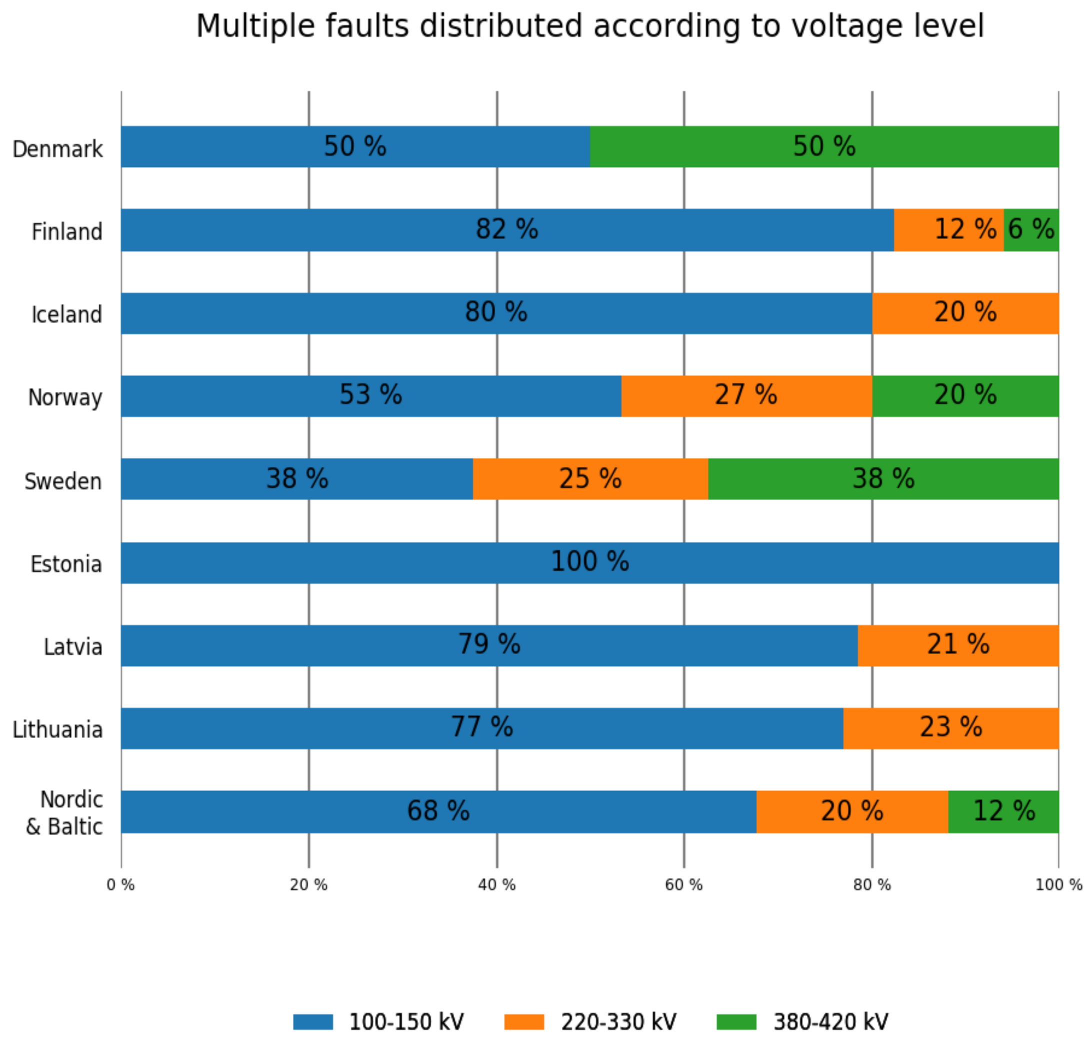

Figure 6.4.1 Percentage distribution of multiple fault situations in the Nordic and Baltic countries in 2016

6.5 Energy not supplied distributed per cause

Table 6.5.1 presents how ENS due to single fault situations is distributed per cause. The amount of ENS due to single fault situations is calculated by subtracting the amount of ENS due to multiple fault situations from the total ENS.

Table 6.5.1 Percentage distribution of all ENS due to single fault situations per cause in 2016

		Percentage (%) distribution of ENS due to single fault situations per cause in 2016						
2016	Single fault ENS (MWh)	Lightning	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Denmark	44.7	3	28	0	48	20	2	0
Estonia	77.1	0	11	0	30	36	23	0
Finland	247.8	30	2	0	19	25	19	5
Iceland	154.4	27	9	18	2	5	39	0
Latvia	8.7	0	20	53	27	0	0	0
Lithuania	25.8	0	78	21	1	0	0	0
Norway	1004.4	3	17	1	7	61	11	0
Sweden	1920.5	20	1	23	8	11	10	27
Nordic & Baltic	3483.2	15	7	14	9	27	12	15

Table 6.5.2 presents how all ENS due to multiple faults is distributed per cause.

Table 6.5.2 Percentage distribution of all ENS due to multiple fault situations per cause in 2016

		Percentage (%) distribution of ENS due to multiple fault situations per cause						
2016	Multiple fault ENS (MWh)	Lightning	Other environmental causes	External influences	Operation and maintenance	Technical equipment	Other	Unknown
Denmark	0.0	0	0	0	0	0	0	0
Estonia	24.9	0	0	0	0	32	68	0
Finland	7.1	13	1	0	39	0	46	0
Iceland	0.0	0	0	0	0	0	0	0
Latvia	14.4	0	0	7	5	0	84	4
Lithuania	2.3	0	100	0	0	0	0	0
Norway	157.3	4	57	0	3	0	36	0
Sweden	3.6	0	0	0	0	0	0	100
Nordic & Baltic	209.5	3	44	1	4	4	42	2

Table 6.5.3 presents how much of the ENS due to a specific cause was due to multiple fault situations. 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 6.5.3 Percentage of the cause specific ENS due to disturbances with multiple faults per cause in 2016

	Percentage (%) of the cause specific ENS caused by multiple fault situations						
2016	Light-ning	Other environ-mental causes	External influences	Operation and mainte-nance	Technical equipment	Other	Un-known
Denmark	0	0	0	0	0	0	0
Estonia	0	0	0	0	22	49	0
Finland	1	2	0	6	0	6	0
Iceland	0	0	0	0	0	0	0
Latvia	0	0	19	24	0	100	100
Lithuania	0	10	0	0	0	0	0
Norway	15	35	0	6	0	33	0
Sweden	0	0	0	0	0	0	1
Nordic & Baltic	1	26	0	2	1	17	1

6.6 Energy not supplied distributed per voltage level

Table 6.6.1 presents how ENS due to single fault situations is distributed per voltage level. The amount of ENS due to single fault situations is calculated by subtracting the amount of ENS due to multiple fault situations from the total ENS.

Table 6.6.1 Percentage distribution of ENS due to single fault situations per voltage level in 2016

		Percentage (%) distribution of ENS due to single fault situations per voltage level		
2016	Single fault ENS (MWh)	100–150 kV	220–330 kV	380–420 kV
Denmark	44.7	100	0	0
Estonia	77.1	100	0	0
Finland	247.8	100	0	0
Iceland	154.4	72	28	0
Latvia	8.7	100	0	0
Lithuania	25.8	100	0	0
Norway	1004.4	92	6	2
Sweden	1920.5	91	5	3
Nordic & Baltic	3483.2	92	6	2

Table 6.6.2 presents how ENS due to multiple fault situations is distributed per voltage level.

Table 6.6.2 Percentage distribution of ENS due to multiple fault situations per voltage level in 2016

2016	Multiple fault ENS (MWh)	Percentage (%) distribution of ENS due to multiple fault situations per voltage level		
		100–150 kV	220–330 kV	380–420 kV
Denmark	0.0	0	0	0
Estonia	24.9	100	0	0
Finland	7.1	100	0	0
Iceland	0.0	0	0	0
Latvia	14.4	100	0	0
Lithuania	2.3	100	0	0
Norway	157.3	63	0	36
Sweden	3.6	100	0	0
Nordic & Baltic	209.5	72	0	27

Table 6.6.3 presents how much of the ENS caused on a specific voltage level was due to multiple fault situations. 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 6.6.3 Percentage of the total voltage level specific ENS due to disturbances with multiple faults per voltage level in 2016

2016	Percentage (%) of the voltage level specific ENS caused by multiple fault situations		
	100–150 kV	220–330 kV	380–420 kV
Denmark	0	0	0
Estonia	24	0	0
Finland	3	0	0
Iceland	0	0	0
Latvia	62	0	0
Lithuania	8	0	0
Norway	10	1	75
Sweden	0	0	0
Nordic & Baltic	5	0	41

7 References

[1] DISTAC, “Guidelines for the Classification of Grid Disturbances above 100 kV,” 13 April 2017. [Online]. Available: https://www.entsoe.eu/Documents/Publications/SOC/Nordic/HVAC_guidelines_2017_04_13.pdf. [Accessed 13 October 2017].

[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. [Accessed 20 May 2017].

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

[4] 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) in their own way. This appendix 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, which is 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 per these load profiles.

In Iceland, ENS is computed per 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 per 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 rarely registered, some companies multiply the rated power at the point of supply by the outage duration.

Appendix 2 POLICIES FOR EXAMINING THE CAUSE FOR LINE FAULTS

This appendix is added to explain the effort each TSO puts 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. 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 changed the classification policy of faults in July 2011 and more effort is put into clarifying causes. Even if the cause is not 100 % certain, but if the expert opinion is that the cause is for example lightning, the reported cause will be lightning. Additionally, the category other environmental cause is used more often. 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 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 2016, 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 per 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

Denmark:	Energinet Tonne Kjærsvej 65, DK-7000 Fredericia, Denmark
	Anders Bratløv Tel. +45 51 38 01 31 E-mail: anv@energinet.dk
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	Markku Piironen Tel. +358 30 395 4172, Mobile +358 40 351 1718 E-mail: markku.piironen@fingrid.fi
Estonia:	Elering AS Kadaka tee 42, Tallinn, Estonia
	Irene Puusaar Tel. +372 508 4372 E-mail: irene.puusaar@elering.ee
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Production of the report:	Hillner Consulting
	Henrik Hillner Tel. +358 41 505 7004 E-mail: henrik.hillner@hillner.fi

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:

Denmark:	Danish Energy Association R&D Rosenørns Allé 9, DK-1970 Frederiksberg Louise Carina Jensen Tel. +45 35 300 775 E-mail: LCJ@danskenergi.dk
Finland:	Energiateollisuus ry, Finnish Energy Industries P.O. Box 100, FI-00101 Helsinki Visiting address: Fredrikinkatu 51-53 B, 5th floor Taina Wilhelms Tel. +358 9 5305 2115 E-mail: taina.wilhelms@energia.fi
Estonia:	OÜ Elektrilevi Kadaka tee 63, Tallinn Taivo Tonne Tel. +372 5078921 E-mail: Taivo.Tonne@elektrilevi.ee
Iceland:	Samorka Sudurlandsbraut 48, IS-108 Reykjavík Sigurdur Ágústsson Tel. +354 588 4430 E-mail: sa@samorka.is
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Appendix 5 FAULT TRENDS ACCORDING TO FAULT CAUSES

This appendix contains trend curves and annual faults that show the percentage distribution of either other environmental causes or faults due to operation and maintenance. The purpose of these figures is to give the reader a sense how one specific cause has contributed to the fault statistics historically.

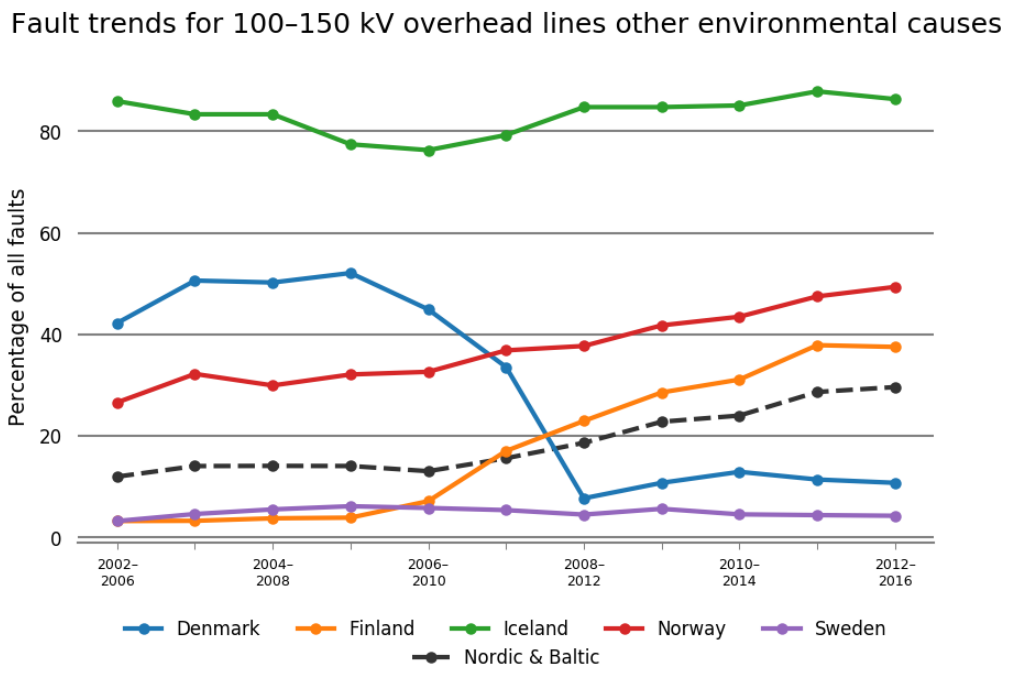

Figure 6.6.1 Fault trends as five-year averages for 100–150 kV other environmental causes for each Nordic country

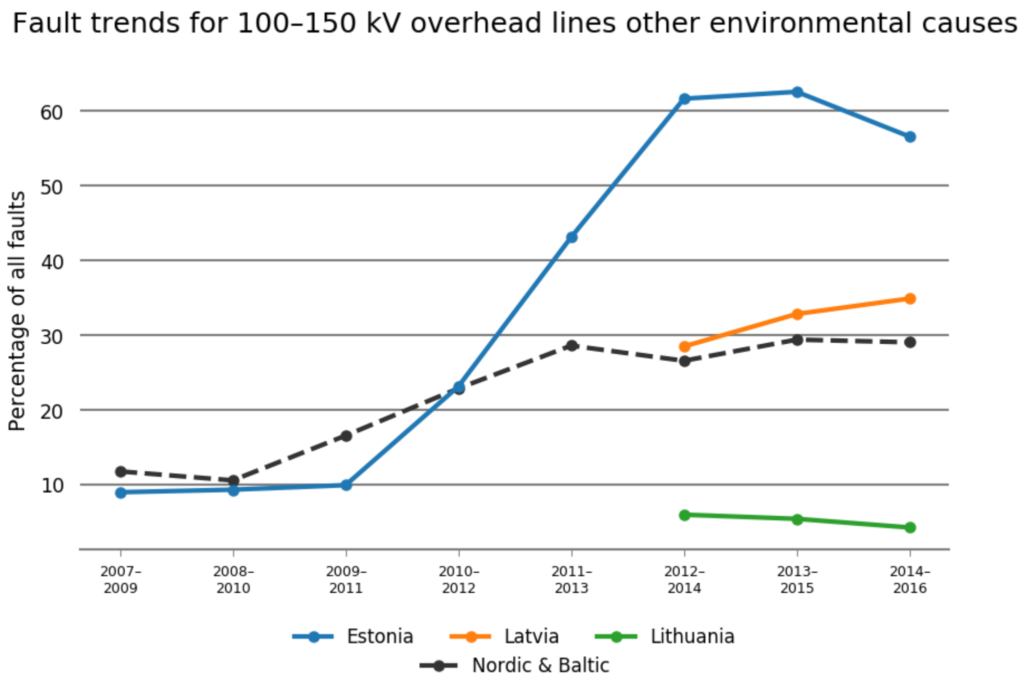

Figure 6.6.2 Fault trends as three-year averages for 100–150 kV other environmental causes for each Baltic country. Estonia has reported data since 2007 and Latvia and Lithuania have reported data since 2012.

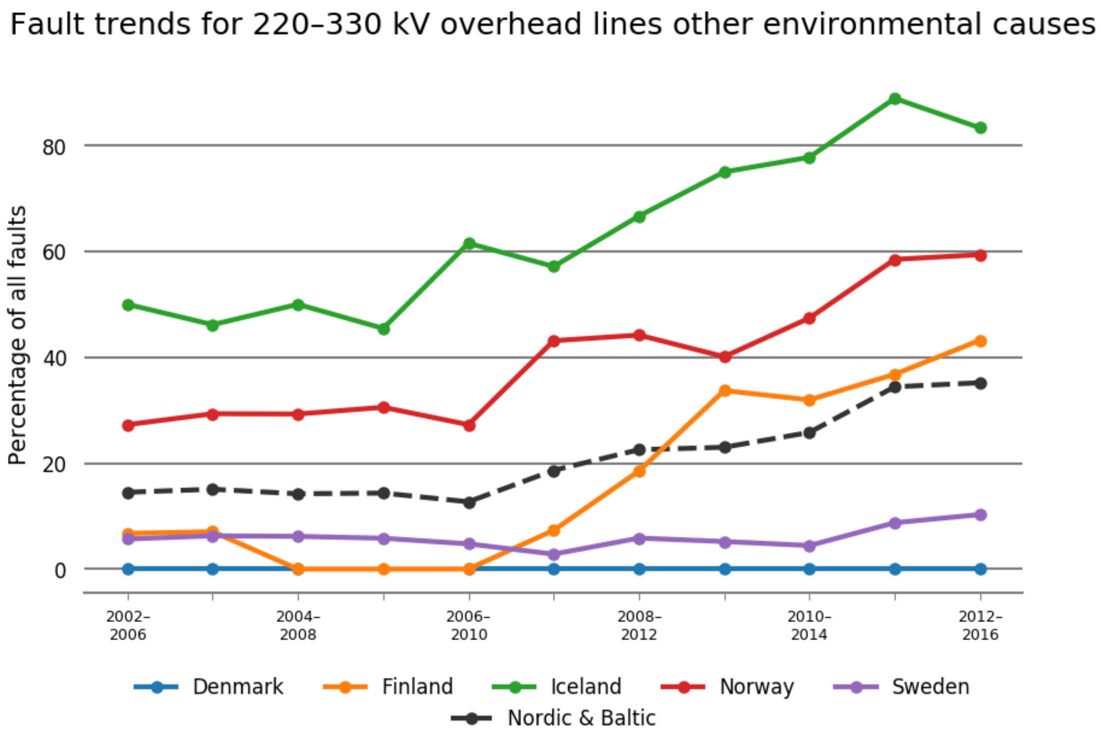

Figure 6.6.3 Fault trends as five-year averages for 220–330 kV other environmental causes for each Nordic country

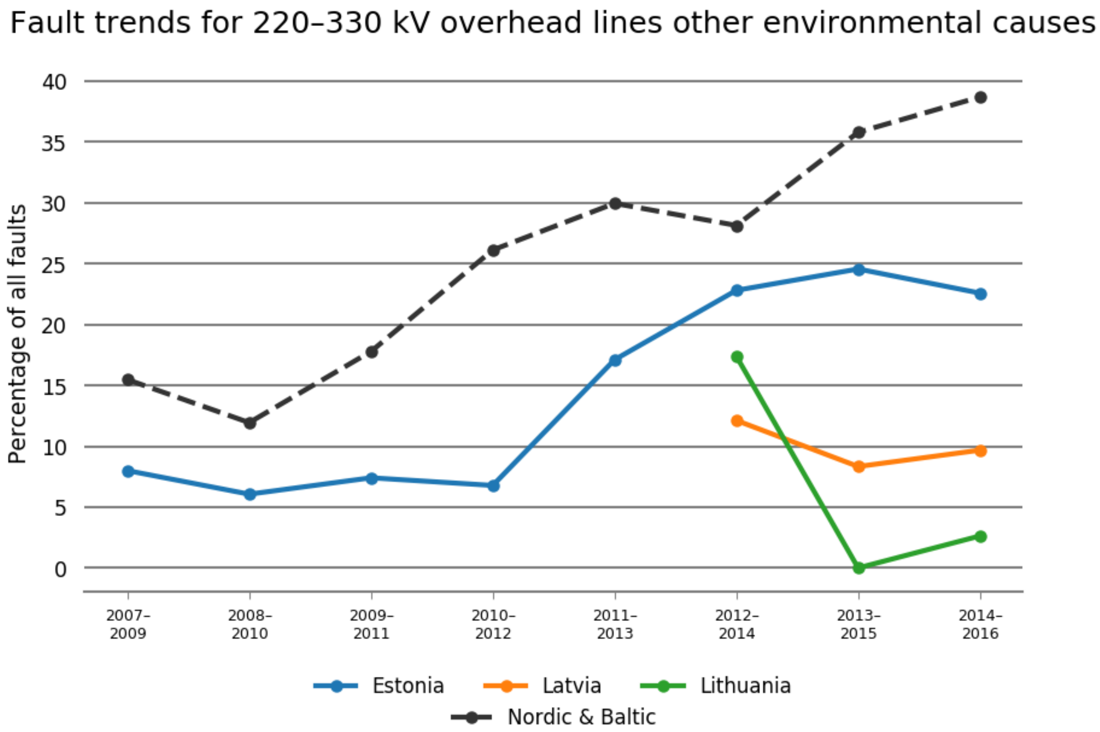

Figure 6.6.4 Fault trends as three-year averages for 220–330 kV other environmental causes for each Baltic country. Estonia has reported data since 2007 and Latvia and Lithuania have reported data since 2012.

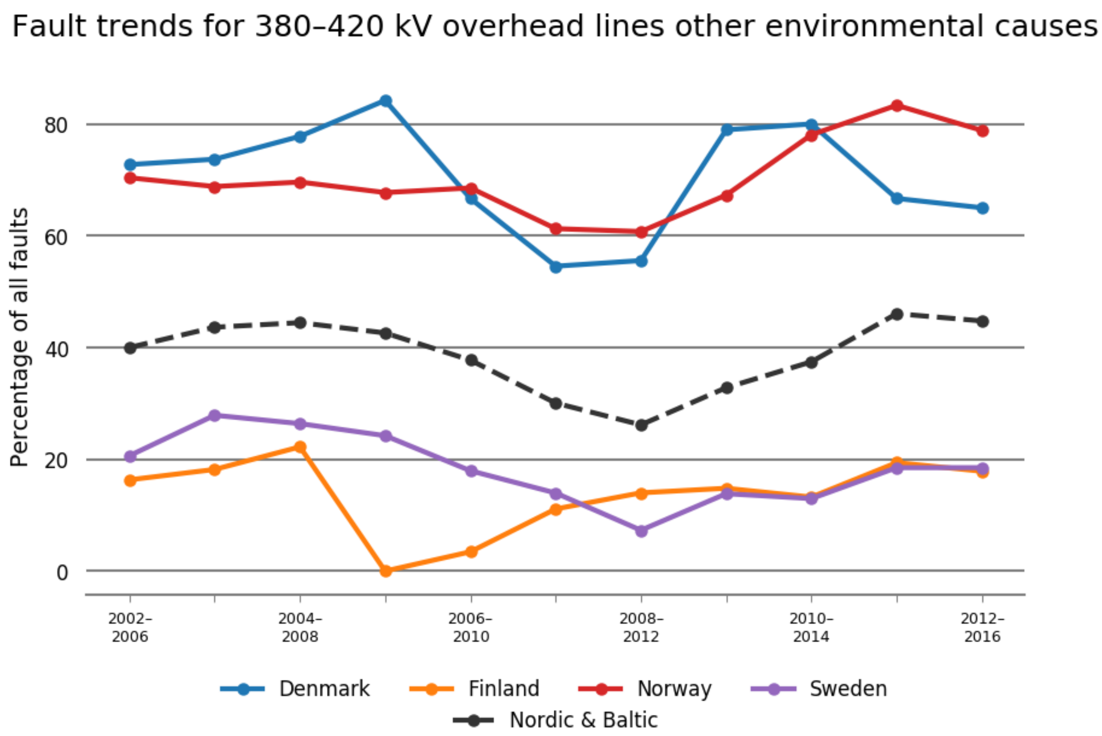

Figure 6.6.5 Fault trends as five-year averages for 380–420 kV other environmental causes for each Nordic country

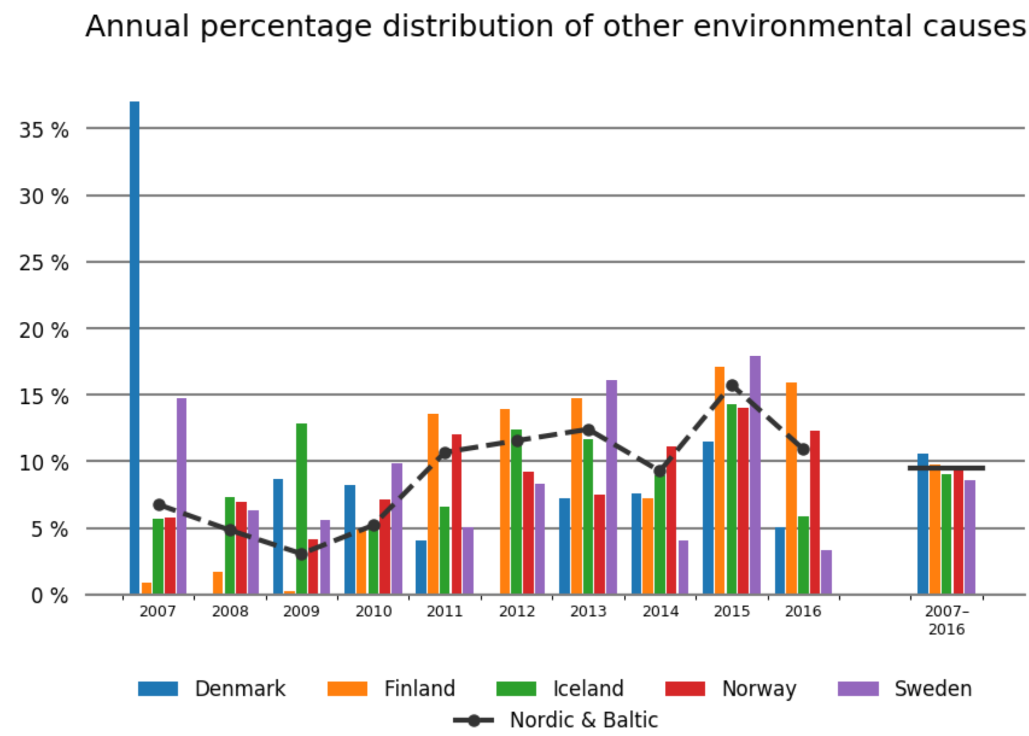

Figure 6.6.6 Percentage distribution of other environmental causes annually for the Nordic countries

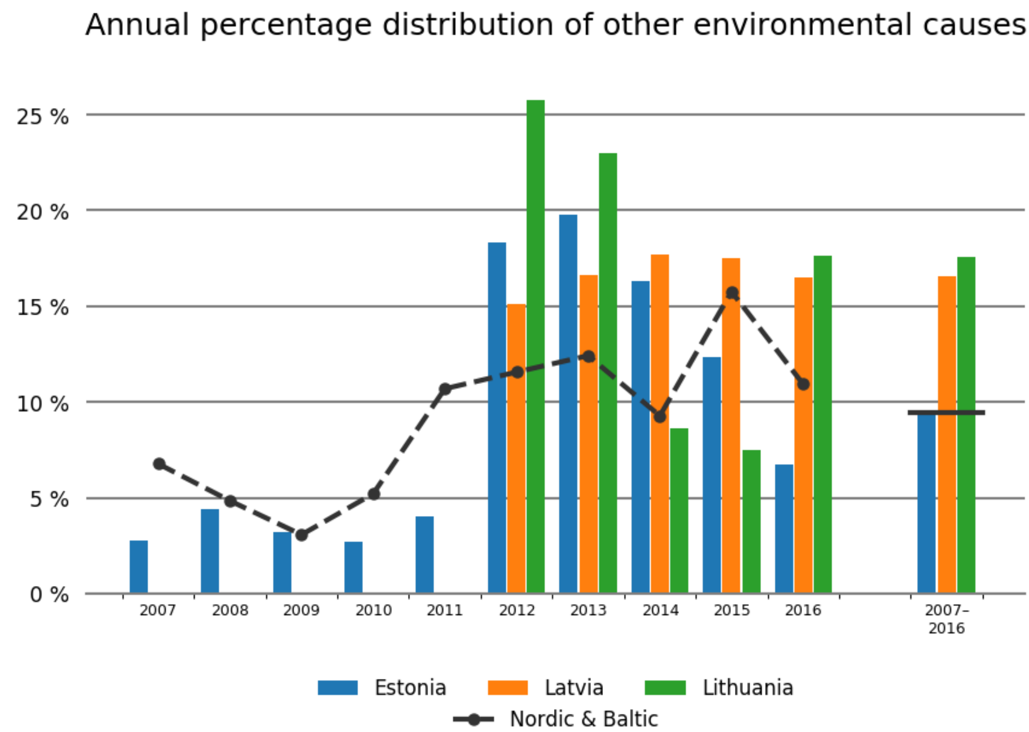

Figure 6.6.7 Annual percentage distribution of other environmental causes and the average for Estonia during 2007–2016 and for Latvia and Lithuania during 2012–2016

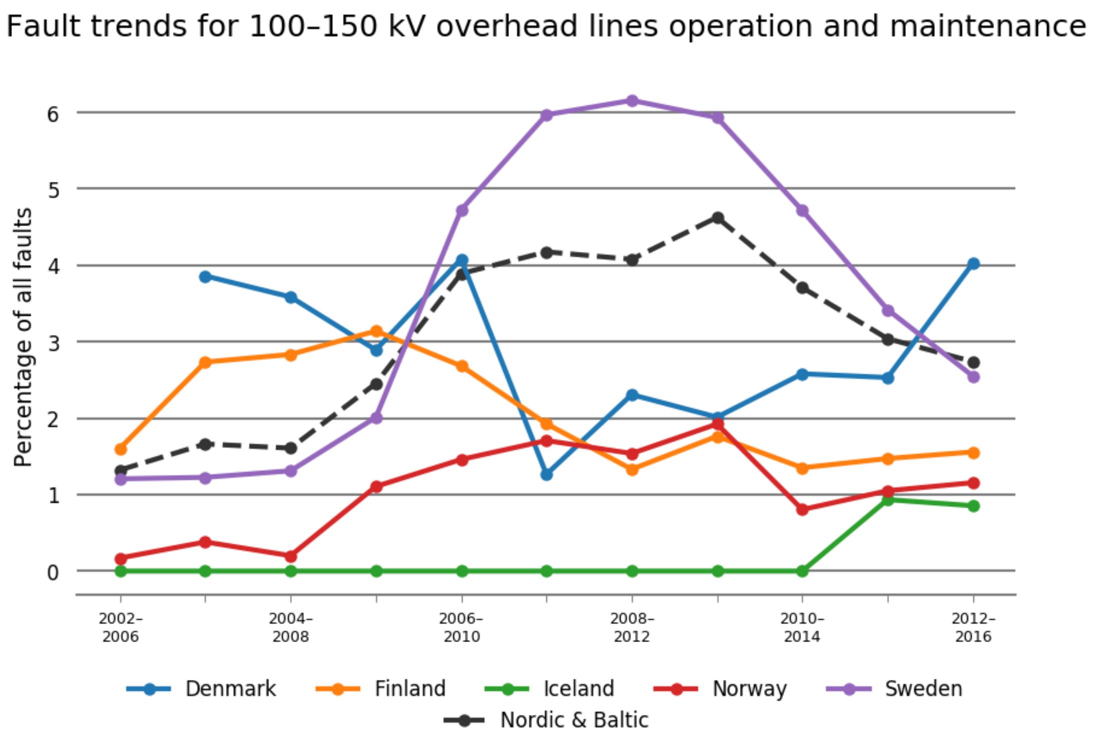

Figure 6.6.8 Fault trends as five-year averages for 100–150 kV operation and maintenance faults for each Nordic country

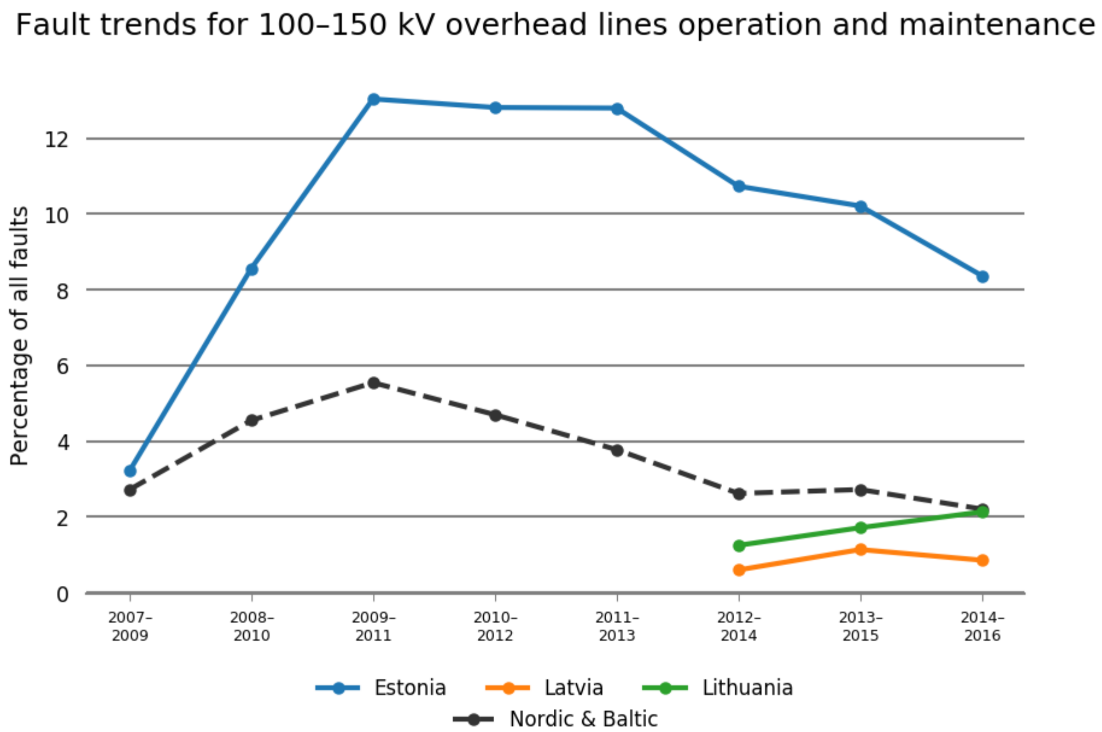

Figure 6.6.9 Fault trends as three-year averages for 100–150 kV operation and maintenance faults for each Baltic country. Estonia has reported data since 2007 and Latvia and Lithuania have reported data since 2012.

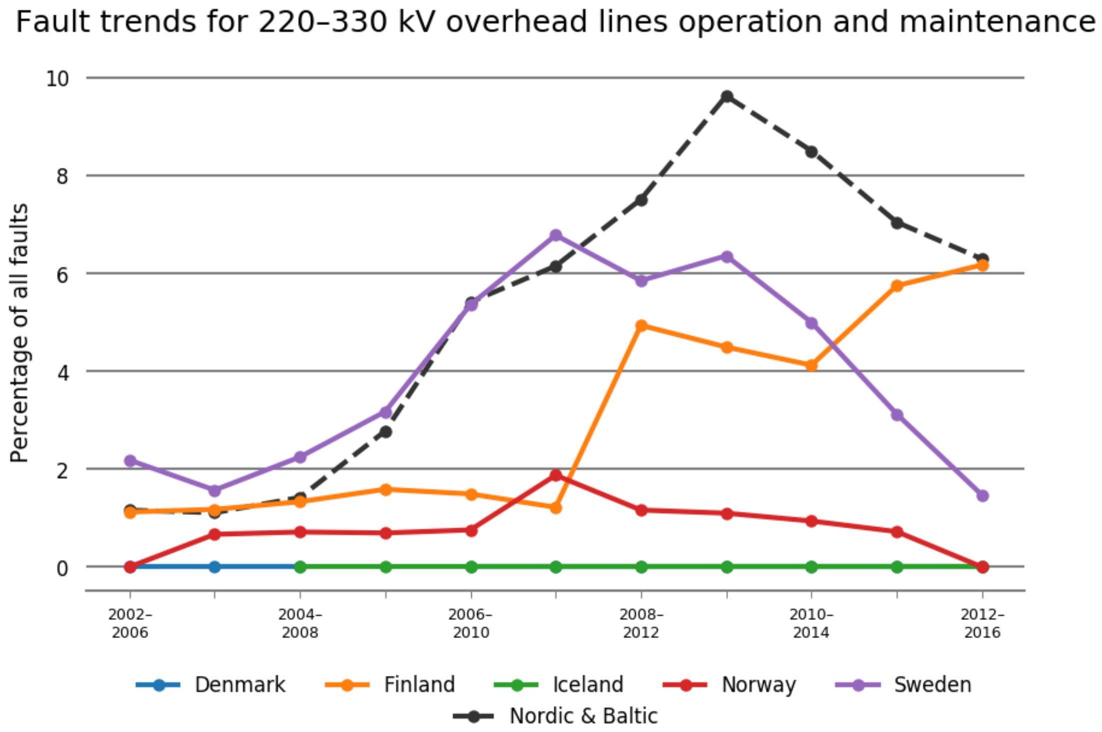

Figure 6.6.10 Fault trends as five-year averages for 220–330 kV operation and maintenance for each Nordic country

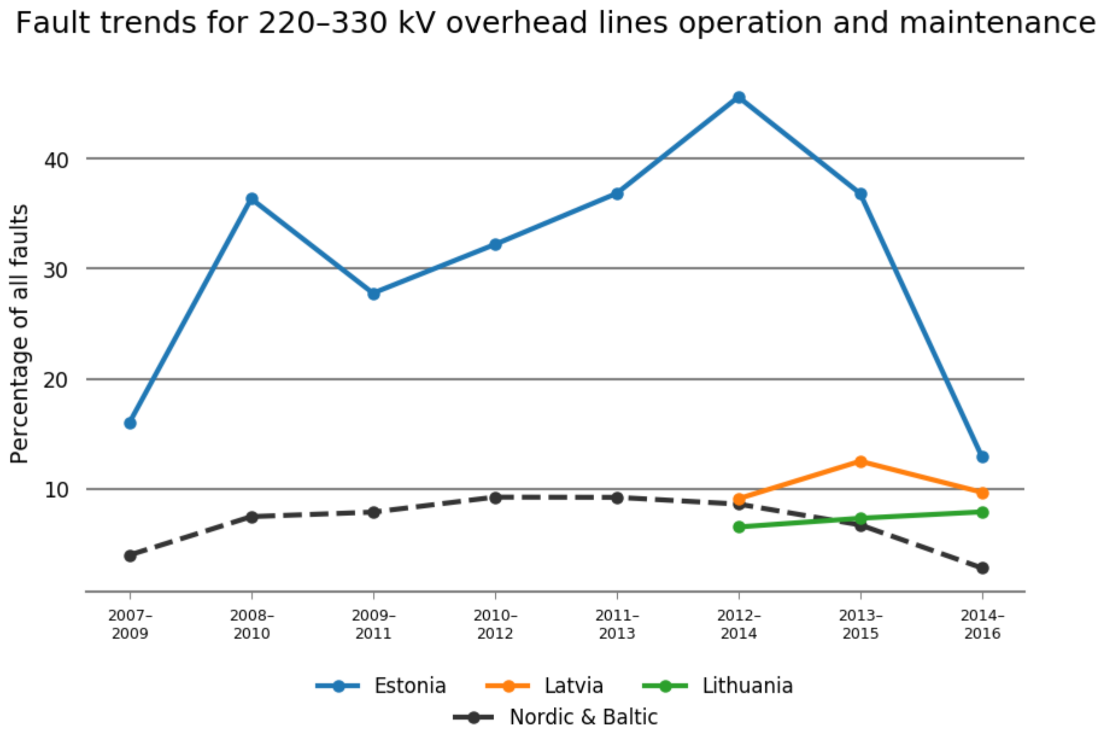

Figure 6.6.11 Fault trends as three-year averages for 220–330 kV operation and maintenance for each Baltic country. Estonia has reported data since 2007 and Latvia and Lithuania have reported data since 2012.

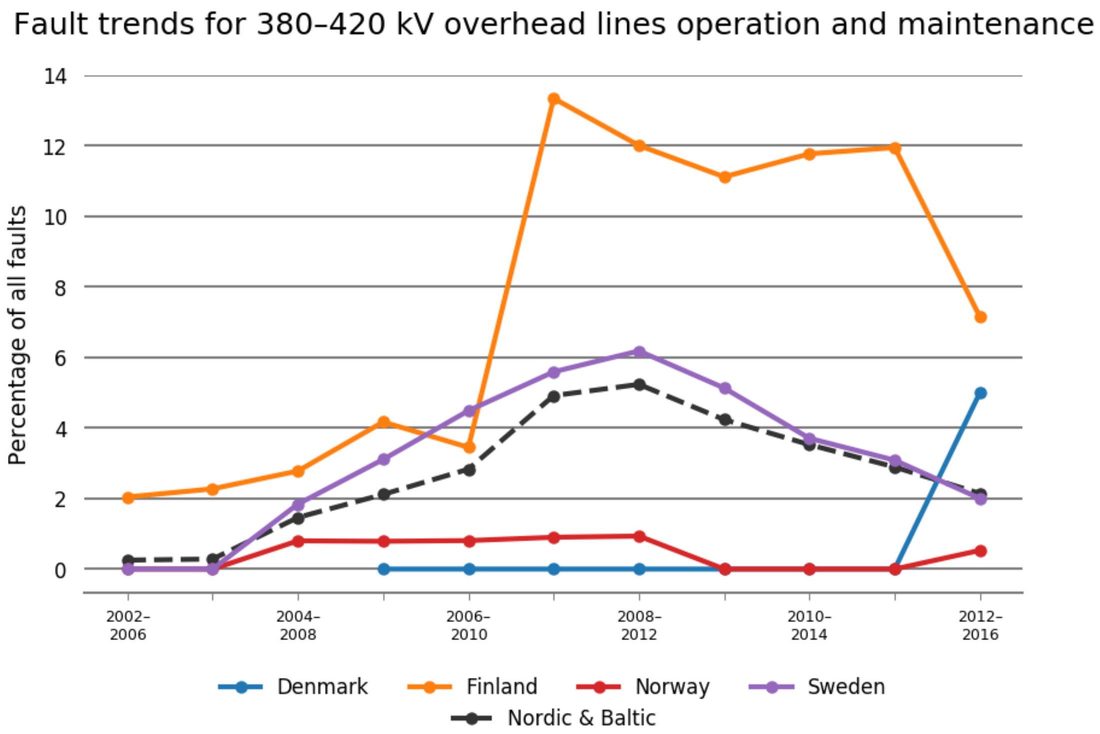

Figure 6.6.12 Fault trends as five-year averages for 380–420 kV operation and maintenance for each Nordic country

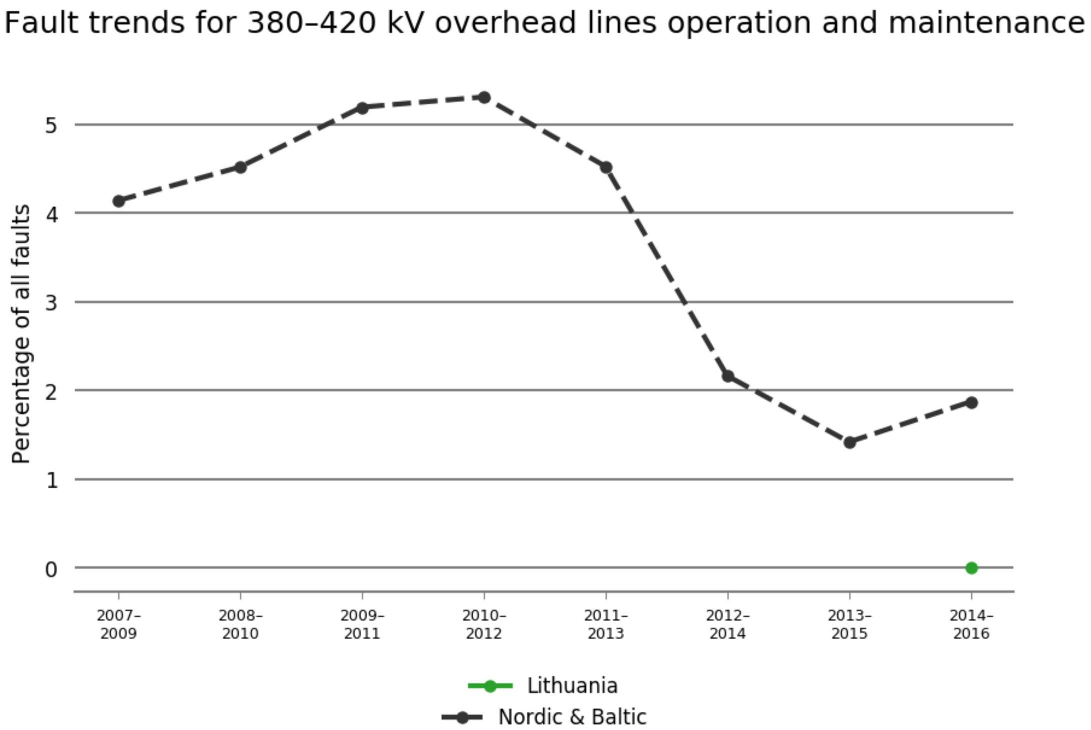

Figure 6.6.13 Fault trends as three-year averages for 380–420 kV operation and maintenance for Lithuania. Lithuania has reported data since 2012.