# Nordic and Baltic Grid Disturbance Statistics 2017

Regional Group Nordic

European Network of
Transmission System Operators
for Electricity

entsoe

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# 1 Introduction

This report is an overview of the Nordic and Baltic HVAC transmission grid disturbance statistics for the year 2017. 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 Nordic synchronous grid. Figure 1.1.1 presents the grids of the statistics.

The report includes the faults causing disturbances in the 100–420 kV grids and is made according to the *Guidelines for Classification of Grid Disturbances above 100 kV* [2], which is published by ENTSO-E.

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 2017.
- Chapter 3 presents the disturbances and focuses on the analysis and allocation of the causes of disturbances. The distribution of disturbances during the year 2017 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 multiple faults and their relations to single fault situations.
- Chapter 6 presents the faults in different components. A summary of all the faults is followed by the presentation of more detailed statistics.

## 1.1 History

The Nordic and Baltic Grid Disturbance Statistics has a long history with common rules made already in 1964. In the beginning, the statistics covered Denmark, Finland, Norway and Sweden and was published by Nordel[1] in Swedish "Driftstörningsstatistik" (Eng. Fault statistics) along with a short summary in English. Iceland joined in 1994.

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 1.1.1: The Nordic and Baltic main grids [4]. The disturbance data of the whole Denmark is included in this report, although only the grid of eastern Denmark belongs to the Nordic synchronous grid.

## 1.2 The Scope and limitations of the statistics

The scope of the statistics, per the guidelines [2], 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
- HVDC units. However, DISTAC produces a separate report with HVDC statistics called *Nordic and Baltic HVDC Utilisation and Unavailability Statistics* [3].

The statistics cover the main systems and associated network devices with a voltage level of more than 100 kV. Control equipment and installations for reactive compensation are also included in the statistics. Figure 1.2.1 presents a graphical interpretation of the components included in the statistics.

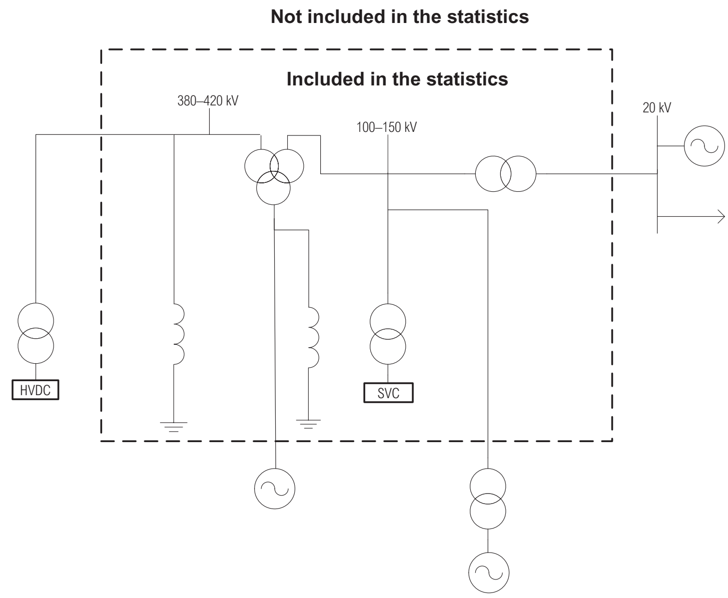


Figure 1.2.1: A graphical representation of the included components in the statistics.

Although the statistics are built upon common guidelines [2], 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.

## 1.3 Available data in the report

Most charts and tables include data for the period 2008–2017. In some cases, where older data has been available, even longer periods have been used. However, not all of the participating TSO's have data for the whole period 2008–2017. In these cases, the tables and figures show all the available data. In this report, Latvia and Lithuania have reported for the period 2012–2017.

Therefore, the ten-year average values for Latvia and Lithuania are calculated from the years 2012–2017 and the trend curves for the Baltic countries use a 3-year period instead of a 5-year period.

## 1.4 Definitions

This chapter defines terms and key concepts that are essential when examining this report. Each concept has its own section.

### 1.4.1 Fault categories

Each disturbance and fault must have a cause reported to it. For disturbances, the cause is the same as the cause of its primary fault. For faults, the cause is the cause that has the most significant impact on the fault. Table 1.4.1 presents the cause categories used in this report. The exact definitions are listed in Section 4.2.9 in the HVAC Guidelines [2].

Table 1.4.1: The fault cause categories used in the Nordic and Baltic Grid Disturbance Statistics as defined in the HVAC Guidelines for classification of disturbances above 100 kV [2].

| Fault cause | Explanation |
|---|---|
| Lightning | The category Lightning is separated from the environmental causes because its impact is insignificant from a maintenance perspective. This is mainly because the Nordic grid is well protected against lightning. |
| Other environmental causes | Moisture, ice, low temperatures, earthquakes, pollution, rain, salt, snow, vegetation, wind, heat, forest fires etc. |
| External influences | Fire due to a third party, animals and birds, aircraft, excavation, collision, explosion, tree felling, vandalism. |
| Operation and maintenance | Lack of monitoring, fault in settings, fault in connection plan, fault in relay plan, incorrect operation, fault in documentation, human fault. |
| Technical equipment | Dimensioning, fault in technical documentation (e.g., guidelines, manuals), design, corrosion, materials, installation, production, vibration, ageing. |
| Other | Operating problems, faults at customers', faults in other networks, problems in conjunction with faults in other components, system causes, other |
| Unknown | |

# 1.5 Voltage levels in the Nordic and Baltic networks

Table 1.5.1 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 1.5.2 presents the coverage of the statistics in each country.

Table 1.5.1: 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 | UN / P % | 400 kV / 100 % | 220 kV / 100 % | 150 kV / 62 %<br>132 kV / 38 % |
| Estonia | UN / P % | - | 330 kV / 92 %<br>220 kV / 8 % | 110 kV / 100 % |
| Finland | UN / P % | 400 kV / 100 % | 220 kV / 100 % | 110 kV / 100 % |
| Iceland | UN / P % | - | 220 kV / 100 % | 132 kV / 100 % |
| Latvia | UN / P % | - | 330 kV / 100 % | 110 kV / 100 % |
| Lithuania | UN / P % | 400 kV / 100 % | 330 kV / 100 % | 110 kV / 100 % |
| Norway | UN / P % | 420 kV / 100 % | 300 kV / 90 %<br>220 kV / 10 % | 132 kV / 98 %<br>110 kV / 2 % |
| Sweden | UN / P % | 400 kV / 100 % | 220 kV / 100 % | 130 kV / 100 % |

Table 1.5.2: Percentage of national networks included in the statistics. 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.

| | 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] Finland's 110 kV network is not fully covered because some regional grid owners did not deliver data.

Finland: The data covers approximately 94 % of the Finnish 110 kV lines and approximately 93 % of the 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.

## 1.6 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 C.

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

# 2 Summary

In 2017, the energy not supplied (ENS) due to faults in the Nordic main grid reached 4.2 GWh and 212 MWh in the Baltic main grids. Totally, there was 4.4 GWh of ENS in the Nordic and Baltic main grid, which is below the ten-year average 7.2 GWh. The number of disturbances in the Nordic and Baltic 100–420 kV grids amounted to 1358, which is below the 10-year average of 1850.4 disturbances. Out of these disturbances, 371 caused ENS, which is also below the 10-year average of 388.8 disturbances causing ENS.

The following sections present the summaries for each Nordic and Baltic country. This includes an overview of the number and causes of disturbances and the resulting energy not supplied. In addition, the summaries present the most important issues in 2017 referred by the country's Transmission System Operator.

## 2.1 Summary of Denmark

In Denmark, the energy not supplied (ENS) caused by disturbances reached 94.4 MWh in 2017 (10-year average 26.7 MWh). There were 53 grid disturbances (10-year average 55.2) and 4 of them caused ENS. On average, 7.4 disturbances per year caused ENS in 2009–2017.

In 2017, 100 % of the total ENS was caused by substation faults. The most significant reasons for the amount of ENS were operation and maintenance (60 %) and technical equipment (40 %). Most of the disturbances were caused by technical equipment (30 %) and operation and maintenance (22 %).

The three most substantial disturbances in 2017 were the following:

- All lines and transformers in a 132 kV substation in Copenhagen tripped during maintenance work on 4 October. The trip was caused by human error, when a disconnector was connected to the wrong busbar. The outage lasted 25 minutes and caused 35 MWh of ENS.
- The support-insulator of a busbar in a 150 kV station in Mid-Jutland broke on 29 October. The support-insulator broke because of a manufacturing error in its porcelain part. The outage lasted 101 minutes and caused 36 MWh of ENS.
- A busbar in a 150 kV station near the city of Horsens was wrongfully disconnected due to human error during maintenance work. The outage lasted 7 minutes and caused 14 MWh of ENS.

## 2.2 Summary of Estonia

In Estonia, the energy not supplied (ENS) caused by disturbances reached 36 MWh in 2017 (10-year average 29.5 MWh). There were 123 grid disturbances (10-year average 216.7) and 36 of them caused ENS. On average, 29.5 disturbances per year caused ENS in 2009–2017.

In 2017, 60 % of the total ENS was caused by compensation faults. The most significant reasons for the amount of ENS were technical equipment (78 %) and operation and maintenance (14 %). Most of the disturbances were caused by technical equipment (78 %) and operation and maintenance (14 %).

The three most substantial disturbances in 2017 were the following:

- The 330 kV circuit breakers of two parallel autotransformers tripped due to unsuccessful reclosing of a 1-phase earth fault on a 110 kV line on 29 April. The 1-phase fault on the 110 kV line was caused by a tree.
- The antenna of a military truck shorted a 110 kV line on 17 May. While the backup protection of another 110 kV line and the earth fault protection of a 110 kV transformer worked, the incident tripped the line itself and a parallel line.
- Two 110 kV transformers tripped due to a fault in the 6 kV grid on 16 October. The first transformer tripped because the differential protection malfunctioned due to a circuit failure on the transformer's secondary side and the second transformer tripped because the current protection malfunctioned due to a blocking logic error.

## 2.3 Summary of Finland

In Finland, the energy not supplied (ENS) caused by disturbances reached 355.9 MWh in 2017 (10-year average 362.3 MWh). There were 329 grid disturbances (10-year average 453.8) and 91 of them caused ENS. On average, 80.6 disturbances per year caused ENS in 2009–2017.

In 2017, 70 % of the total ENS was caused by overhead line faults. The most significant reasons for the amount of ENS were other environmental causes (50 %) and lightning (23 %). Most of the disturbances were caused by unknown causes (40 %) and other environmental causes (33 %). The three most substantial disturbances in 2017 were the following:

- A 110 kV transmission line tripped due to a one-phase permanent earth fault on 12 December 2017 in Southern Finland. The line tripped due to an exceptional amount of snow and hard wind that caused the ground wire of a 110 kV overhead line to hit the current conductor. The incident caused 162.8 MWh of ENS.
- A 110 kV transmission line tripped due to lightning on 31 July 2017. Relay protection fault caused a multiphase permanent fault. The incident caused 53.4 MWh of ENS.
- 110 kV transmission line tripped due to lightning on 31 August 2017. A fault in the relay delayed the auto-reclosing and caused a one-phase fault. The incident caused 20.8 MWh of ENS.

## 2.4 Summary of Iceland

In Iceland, the energy not supplied (ENS) caused by disturbances reached 1400 MWh in 2017 (10-year average 1010 MWh). There were 31 grid disturbances (10-year average 33) and 19 of them caused ENS. On average, 18.2 disturbances per year caused ENS in 2009–2017.

Registered grid disturbances were 31 compared to last year's 43, but ENS was dramatically higher. 5 disturbances caused the majority of ENS this year (1201 MWh), and one of them caused 849 MWh ENS.

In 2017, 82 % of the total ENS was caused by substation faults. The most significant reasons for the amount of ENS were operation and maintenance (72 %) and technical equipment (18 %). Most of the disturbances were caused by technical equipment (22 %) and operation and maintenance (77 %).

The three most substantial disturbances in the 220 and 132 kV network in 2017 were the following:

- Unforeseen behaviour in protection equipment while doing maintenance in the 220 kV network caused a major trip 18 January 2017. This resulted in a widespread disturbance, with an aluminium plant among the customers, and caused 848.5 MWh of ENS.
- An emergency trip by a power intensive user on 17 May affected the relay protection scheme and caused a system split. Furthermore, imbalance between production and load in one of the islands caused the island to trip and widespread load shedding. The incident caused 126.5 MWh of ENS.
- Four production units in power station BUR tripped 15 June and caused a system split and load shedding. The incident caused of 86.2 MWh ENS.

## 2.5 Summary of Latvia

In Latvia, the energy not supplied (ENS) caused by disturbances was 90.3 MWh in 2017 (6-year average 90.9 MWh). There were 149 grid disturbances (6-year average 145.0) and 25 of them caused ENS. On average, 18.0 disturbances per year caused ENS in 2012–2017.

In 2017, 60 % of the total ENS was caused by faults in substations and 40 % were caused by faults on overhead lines. The most significant reasons for the amount of ENS were external influences 54 %) and technical equipment (23 %). Most of the disturbances were caused by external influences (25 %) and other environmental causes (21 %). 40 % of all disturbances were automatic reclosing.

The three most substantial disturbances in 2017 were the following:

- A yacht sailed into double lines and outed them both. However, a third line was connected to the one of the faulty lines because the substation was under reconstruction. The disturbance caused a blackout of the substation, that lasted for more than two hours and caused 25.5 MWh of ENS.
- A damaged isolator of a 110 kV busbar disconnector broke during manual operation and tripped both busbars in the substation. The substation had 18 110 kV units. The disturbance tripped 6 additional substations for 50 minutes and caused 19.7 MWh of ENS.
- The feeding line of a substation tripped because a tree fell on it. The tree fell due to damage by beavers. There was no backup line available as it was under planned maintenance. This resulted in a blackout for the substation. The repairs took almost 5 hours and caused 14.7 MWh of ENS.

## 2.6 Summary of Lithuania

In Lithuania, the energy not supplied (ENS) caused by disturbances reached 74.6 MWh in 2017 (6-year average 40.9 MWh). There were 141 grid disturbances (6-year average 164.2) and 15 of them caused ENS. On average, 19.5 disturbances per year caused ENS in 2012–2017.

In 2017, 69 % of the total ENS was caused by substation faults faults and 31 % was caused by line faults. The most significant reasons for the amount of ENS were lightning (67 %) and external influences (28 %). Most of the disturbances were caused by unknown causes (32 %) and external influences (27 %).

The two most substantial disturbances in 2017 were the following:

- A transformer in a substation disconnected due to a trip in a 110 kV transmission line on 11 July 2017. The primary fault of the disturbance was lightning and the secondary fault was a fault in the control equipment in the substation. The incident caused 67 % of the total ENS in 2017.
- A 110 kV transmission line tripped 29 June 2017 because a tree fell on it during a storm. Furthermore, two more conditions aggravated the incident. First, the control equipment failed to disconnect transmission line. Second, the overhead line was in radial feeding mode because of maintenance work elsewhere. The incident disconnected ten substations in total.

## 2.7 Summary of Norway

In Norway, the energy not supplied (ENS) caused by disturbances reached 1113.7 MWh in 2017 (10-year average 3559.1 MWh). There were 257 grid disturbances (10-year average 292.3) and 68 of them caused ENS. On average, 89.1 disturbances per year caused ENS in 2009–2017.

In 2017, 61 % of the total ENS was caused by overhead line faults and 29 % were caused by substation faults. The most significant reasons for the amount of ENS were other environmental causes (60 %) and technical equipment (17 %). Most of the disturbances were caused by other environmental causes (32 %) and operation and maintenance (21 %).

The three most substantial disturbances in 2017 were the following:

- A 300 kV line in Lerdoela-Fortun tripped due to snow and ice. The incident affected mostly industrial load and aluminium smelters and caused 337 MWh of ENS.
- A 132 kV line in Roligheten tripped due to polluted snow. The incident caused 155 MWh of ENS.
- A 300 kV line between Lille-Sotra and Kolsnes tripped and caused 155 MWh of ENS. The outage affected mostly oil refinery compressors.

## 2.8 Summary of Sweden

In Sweden, the energy not supplied (ENS) caused by disturbances reached 964.7 MWh in 2017 (10-year average 1916.7 MWh). There were 275 grid disturbances (10-year average 502.2) and 113 of them caused ENS. On average, 148.0 disturbances per year caused ENS in 2009–2017.

In 2017, 45 % of the total ENS was caused by substation faults and 31 % were caused by overhead line faults. The most significant reasons for the amount of ENS were technical equipment (32 %) and other (24 %). Most of the disturbances were caused by unknown causes (37 %) and technical equipment (20 %).

The most substantial disturbances in 2017 were the following:

- During commissioning of a new power transformer for Svenska kraftnät at the substation Karlslund on 400 kV, a relay protection in another substation on 130 kV tripped a power transformer unintentionally, affecting approximately 60 000 customers (resulting in almost 60 MWh of ENS) in the city Örebro together with the surrounding area.
- In addition several smaller events occurred throughout the year; A busbar fault due to a rice-lamp landing on a busbar at January 1st causing approximately 30 MWh ENS. An overhead earth wire fell down causing approximately 45 MWh ENS.

# 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 2017, together with the development of the number of disturbances over the ten-year period 2008–2017.

Grid disturbances are defined as:

> Outages, forced or unintended disconnection or failed reconnection as a result of faults in the power grid [2] [1].

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. The voltage level of a disturbance is determined by the voltage level of its primary fault.

## 3.1 Annual number of disturbances during the period 2008–2017

The number of disturbances during the year 2017 in the Nordic and Baltic main grids was 1358 and the combined ten-year average in the Nordic countries and Estonia and 6-year average in the Baltic countries was 1726.7. 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 2017 and the annual average for the period 2008–2017 for the complete 100–420 kV grids.

Table 3.1.1: The number of grid disturbances in 2017 and the average

| | Disturbances | | Disturbances causing ENS | |
|---|---|---|---|---|
| Country | Number 2017 | Average 2008–2017 | Number 2017 | Average 2009–2017[2] |
| Denmark | 53 | 55.2 | 4 | 7.4 |
| Estonia | 123 | 216.7 | 36 | 29.5 |
| Finland | 329 | 441.4 | 91 | 72.5 |
| Iceland | 31 | 33.4 | 19 | 16.4 |
| Latvia[1] | 149 | 145.0 | 25 | 18.0 |
| Lithuania[1] | 141 | 164.2 | 15 | 19.5 |
| Norway | 257 | 292.3 | 68 | 80.2 |
| Sweden | 275 | 502.2 | 113 | 145.3 |
| Nordic | 945 | 1324.5 | 295 | 321.8 |
| Baltic | 413 | 525.9 | 76 | 67.0 |
| Nordic & Baltic | 1358 | 1850.4 | 371 | 388.8 |

[1] The average values of Latvia and Lithuania use the period 2012–2017.
[2] The time period is 2009–2017 because every country does not have complete data before 2009.

Figure 3.1.1 and 3.1.2 shows the development of the number of disturbances during the period 2008–2017.

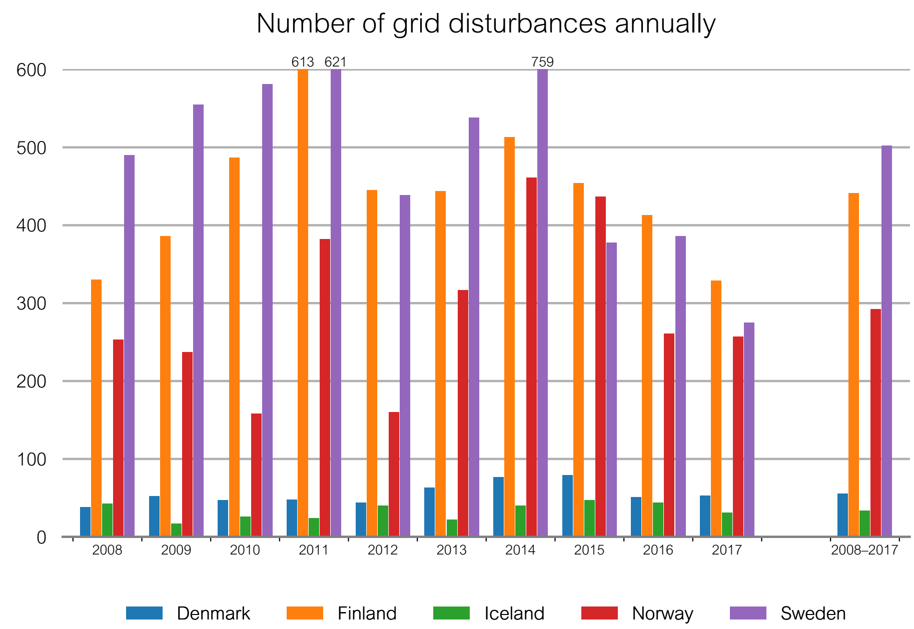


Figure 3.1.1: The annual number of grid disturbances and the average in each Nordic country for the period 2008–2017.

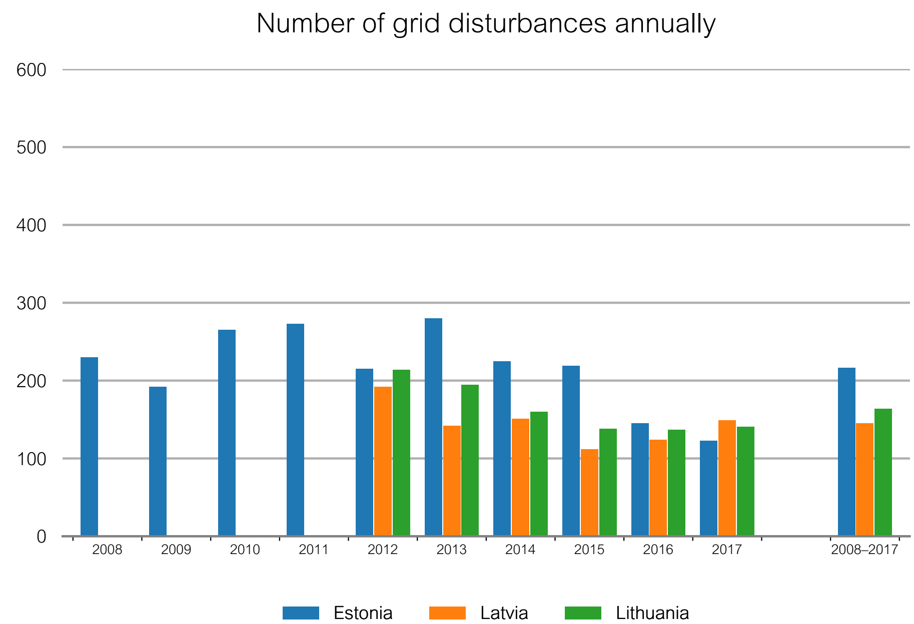


Figure 3.1.2: The annual number of grid disturbances and the average in each Baltic country for the period 2008–2017.

## 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.

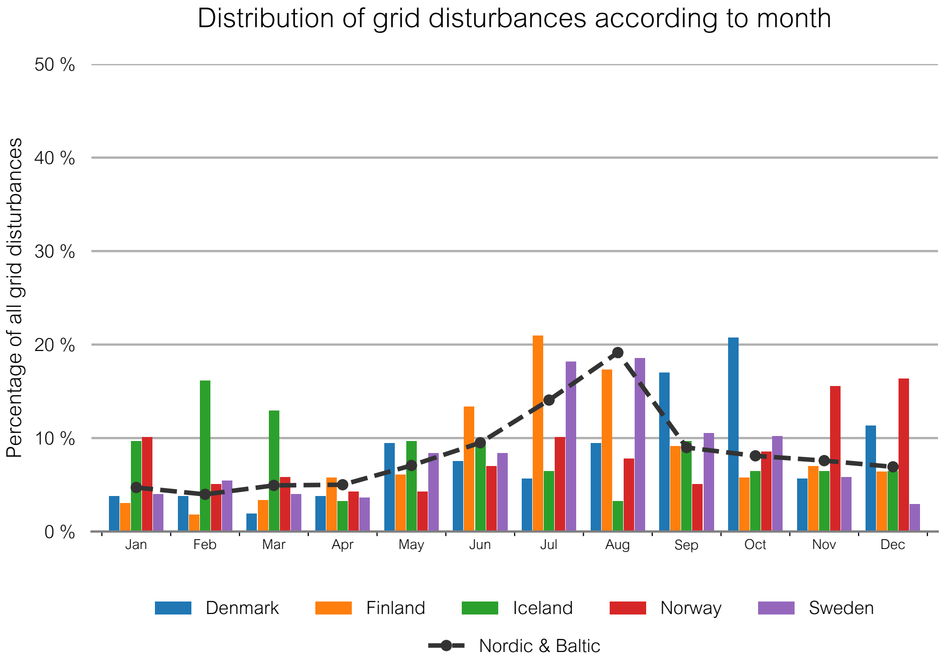


Figure 3.2.1: Percentage distribution of grid disturbances per month in 2017 in each Nordic country. For all countries, except Iceland, the number of disturbances is usually largest during the summer period. This is often caused by the amount of lightning strokes during summer.

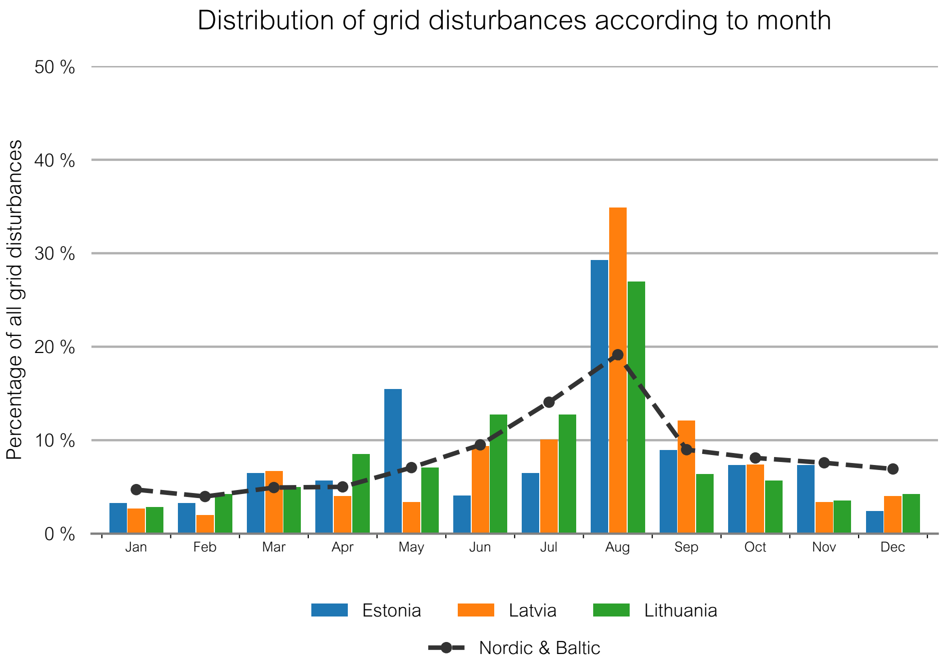


Figure 3.2.2: Percentage distribution of grid disturbances per month in 2017 in each Baltic country.

Figure 3.2.3 presents the respective average values for the period 2008–2017 in the Nordic countries and Figure 3.2.4 presents the average values for the period 2012–2017 in the Baltic countries.

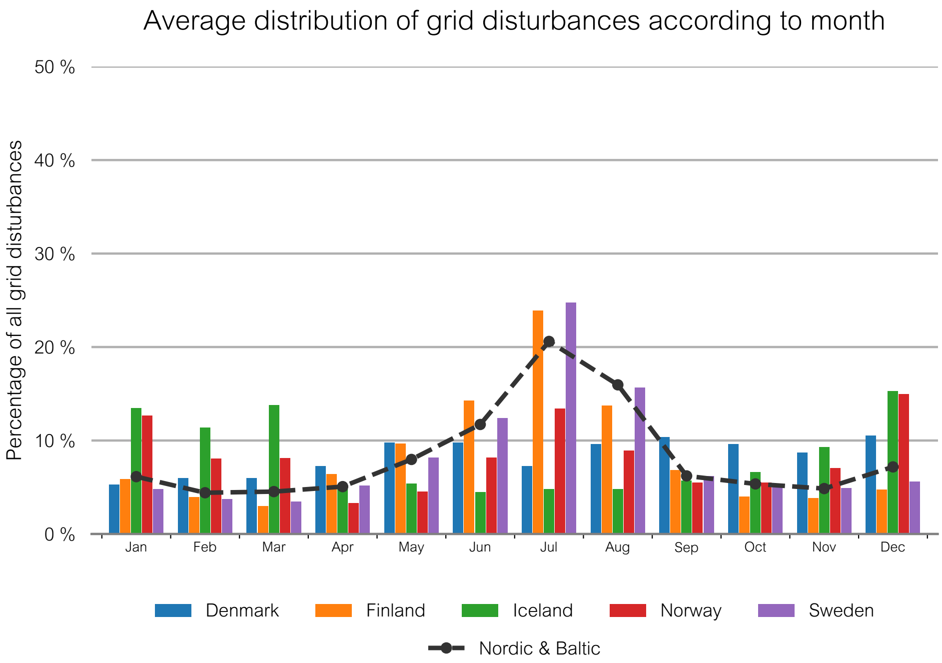


Figure 3.2.3: Average percentage distribution of grid disturbances per month during 2008–2017 in each Nordic country. For all countries, except Iceland, the number of disturbances is usually largest during the summer period. This is often caused by the amount of lightning strokes during summer.

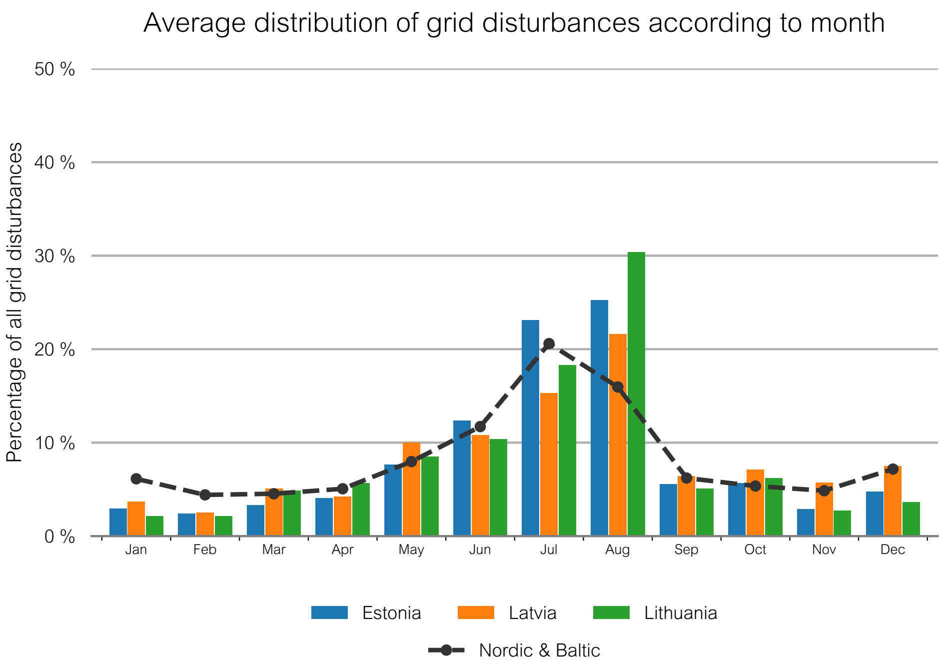


Figure 3.2.4: Average percentage distribution of grid disturbances per month during 2008–2017 in Estonia and during 2012–2017 in Latvia and Lithuania.

## 3.3 Disturbances distributed per cause

This chapter presents disturbances according to cause. This report uses seven different options for fault causes and list the primary cause of the event as the starting point. The fault categories used are defined in Chapter 1.4.1.

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.

Each country in these statistics has its own detailed way of gathering data per fault cause as is explained in Appendix B. The guidelines [2] 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 distributed by its cause for the year 2017. Figure 3.3.3 presents the respective average values for the period 2008–2017 in the Nordic countries and Figure 3.3.4 presents the average values during 2009–2017 in Estonia and during 2012–2017 in Latvia and Lithuania.

Many disturbances caused by unknown reasons probably have their real cause in the categories other environmental cause and lightning.

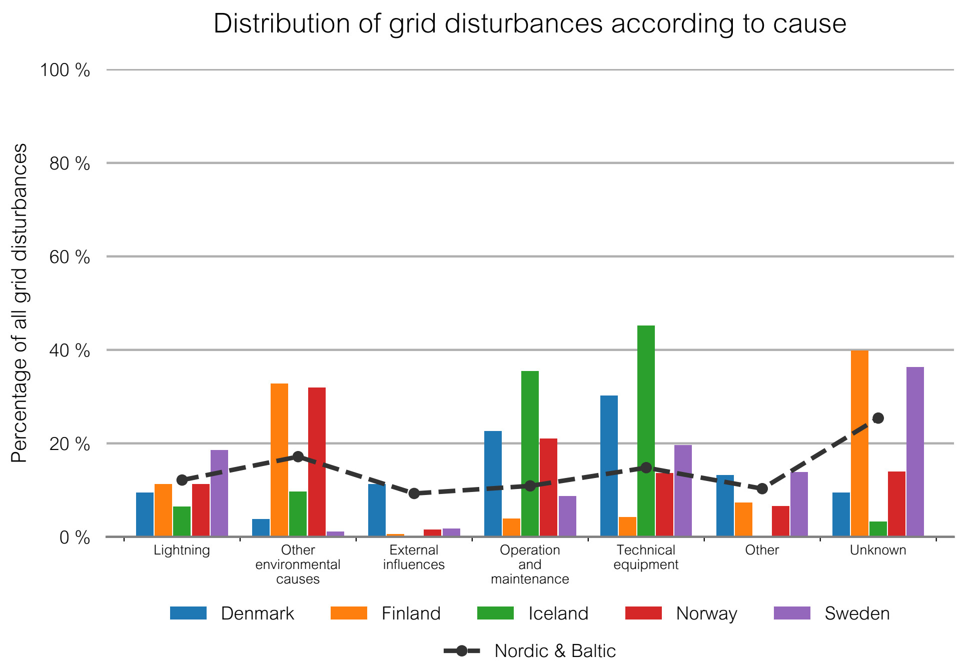


Figure 3.3.1: Percentage distribution of grid disturbances per cause in 2017 in each Nordic country.

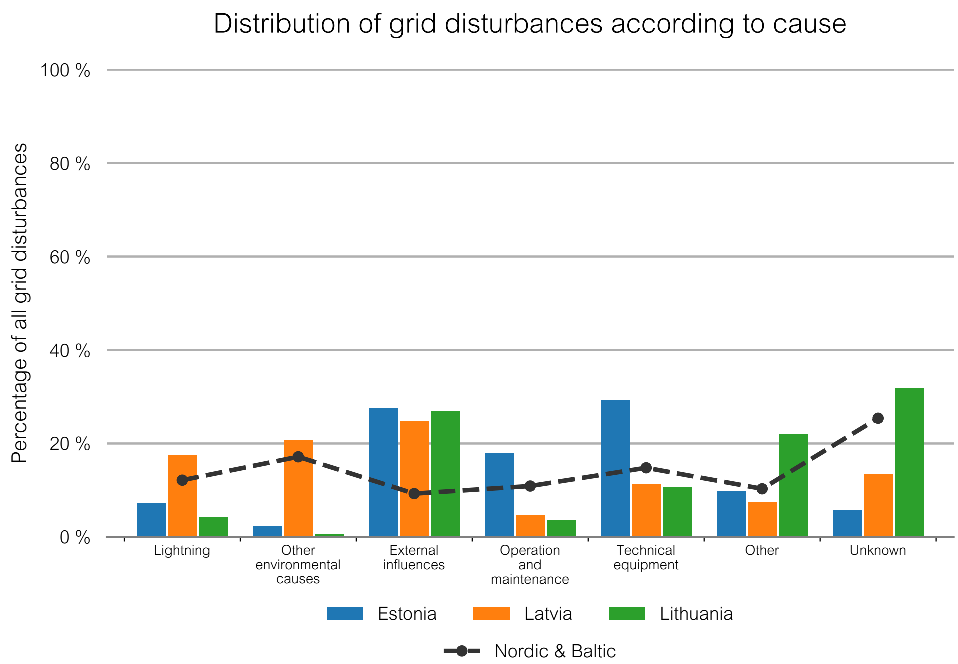


Figure 3.3.2: Percentage distribution of grid disturbances per cause in 2017 in each Baltic country.

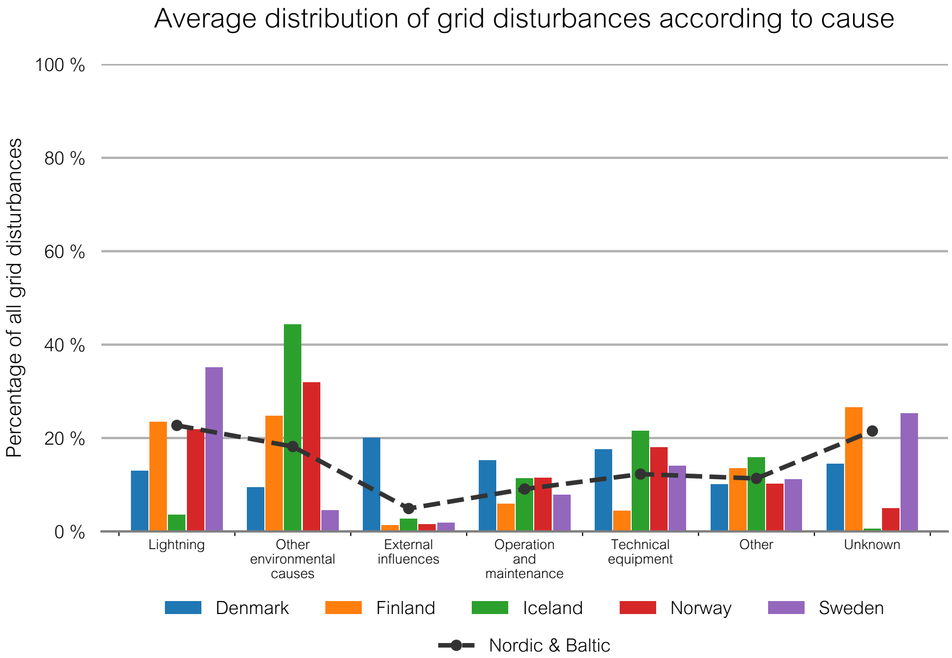


Figure 3.3.3: Average distribution of grid disturbances per cause during 2008–2017 in each Nordic country.

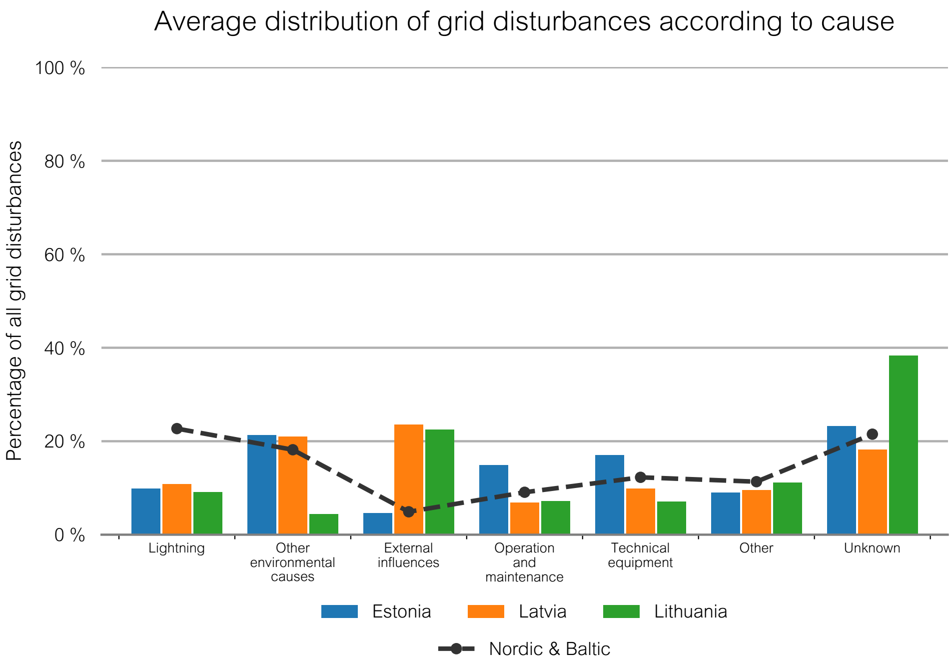


Figure 3.3.4: Average distribution of grid disturbances per cause during 2008–2017 in Estonia and during 2012–2017 in Latvia and Lithuania.

Figure 3.3.5 and Figure 3.3.6 present disturbances that caused ENS for all voltage levels in terms of the primary fault distributed by its cause for the year 2017. Figure 3.3.7 presents the respective average values for the period 2009–2017 in the Nordic countries and Figure 3.3.8 presents the average values during 2009–2017 in Estonia and during 2012–2017 in Latvia and Lithuania.

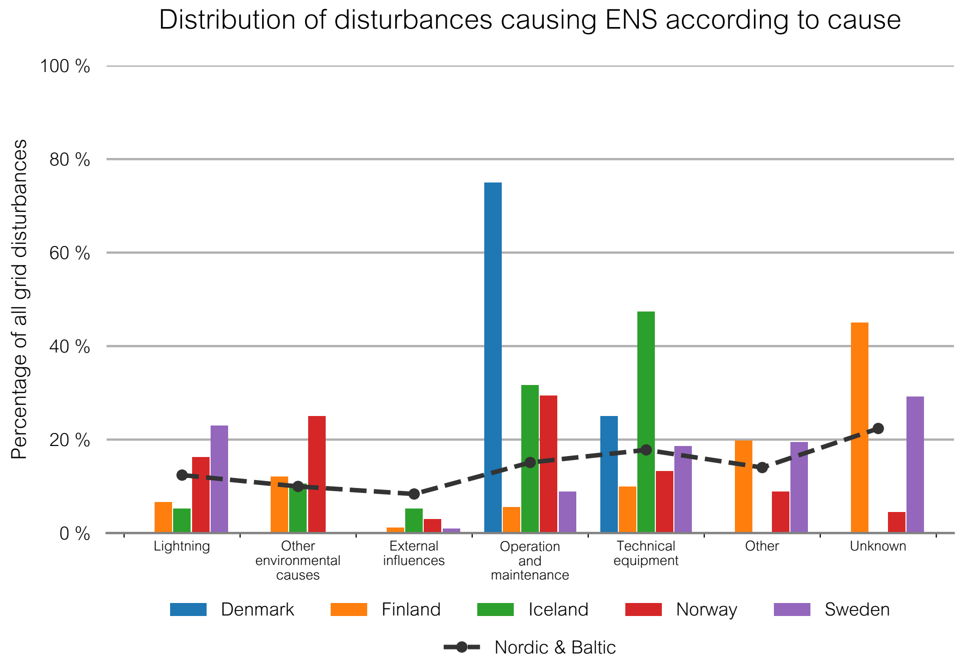


Figure 3.3.5: Percentage distribution of grid disturbances causing ENS per cause in 2017 in each Nordic country.

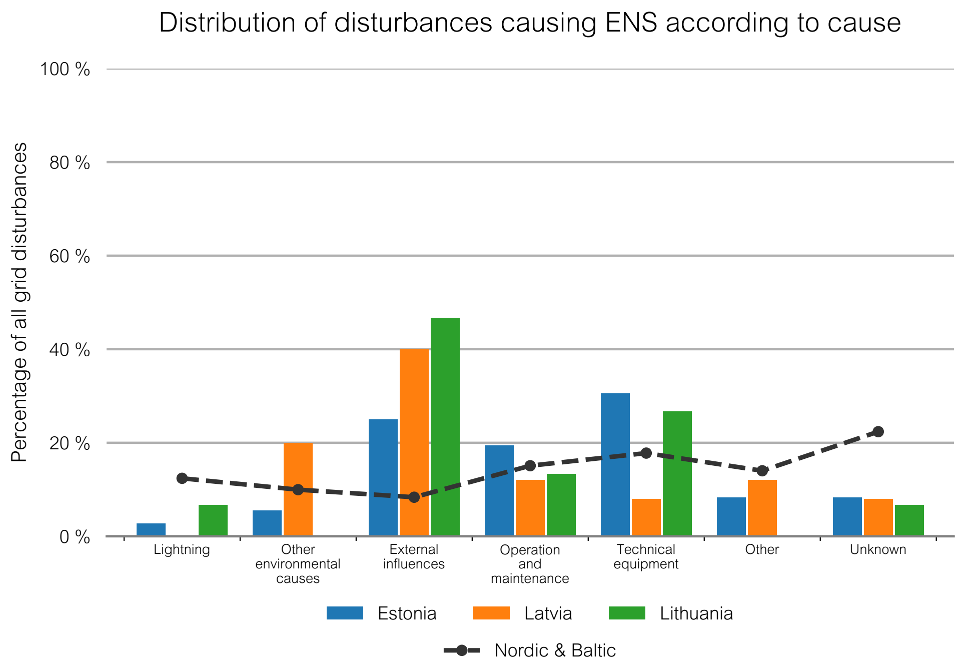


Figure 3.3.6: Percentage distribution of grid disturbances causing ENS per cause in 2017 in each Baltic country.

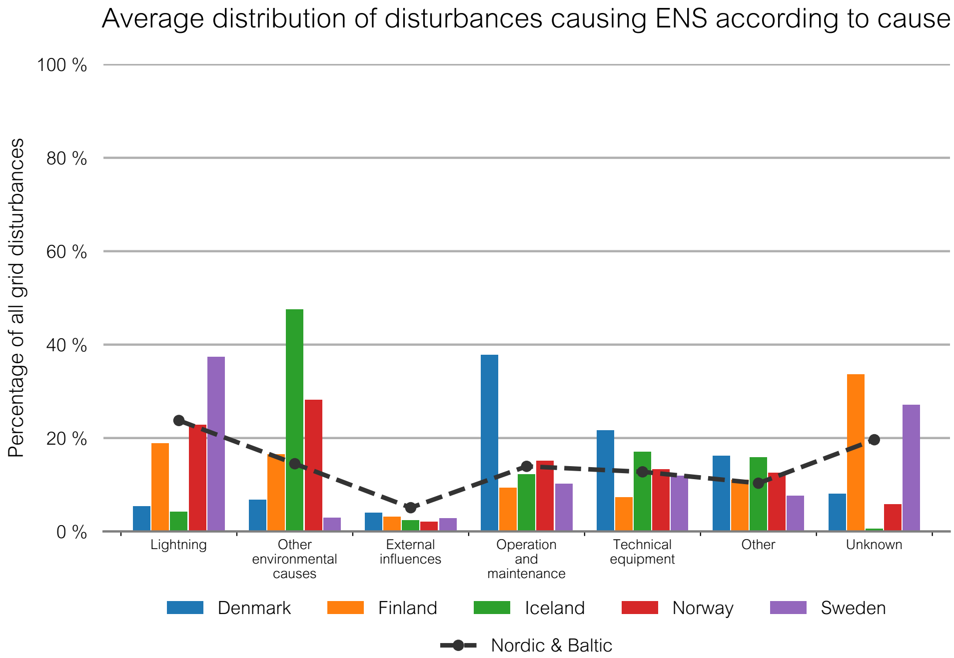


Figure 3.3.7: Average distribution of grid disturbances causing ENS per cause during 2009–2017 in each Nordic country. The average starts at 2009 because all countries do not have complete data of disturbances causing ENS before that.

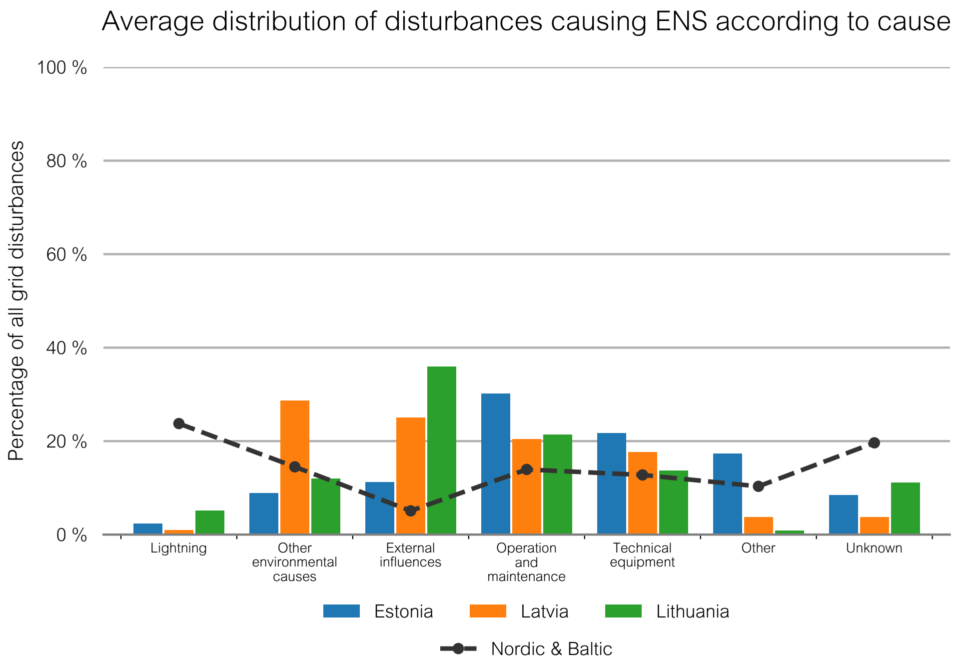


Figure 3.3.8: Average distribution of grid disturbances causing ENS per cause during 2009–2017 in Estonia and during 2012–2017 in Latvia and Lithuania. The average starts at 2009 because all countries do not have complete data of disturbances causing ENS before that.

# 4 Energy not supplied (ENS)

This chapter presents an overview of energy not supplied (ENS). This includes the amount of ENS in 2017 and the average during 2008–2017. Furthermore, ENS has been divided according to voltage level in Section 4.2, compared with consumption in Section 4.3, distributed per month in Section 4.4, distributed per cause in Section 4.5 and finally distributed per power system component in Section 4.6.

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 [2].

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 A.

## 4.1 Overview of energy not supplied (ENS)

Table 4.1.1 shows the amount of energy not supplied in 2017 and the annual average for the period 2008–2017. 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 2017 and the annual average for the period 2008–2017

| | ENS (MWh) | |
|---|---|---|
| Country | 2017 | 2008–2017 |
| Denmark | 94.4 | 26.7 |
| Estonia | 46.7 | 177.0 |
| Finland | 355.9 | 374.3 |
| Iceland | 1610.0 | 1057.7 |
| Latvia[1] | 90.3 | 90.9 |
| Lithuania[1] | 74.6 | 40.9 |
| Norway | 1113.7 | 3559.1 |
| Sweden[2] | 964.7 | 1909.7 |
| Nordic | 4138.7 | 6927.4 |
| Baltic | 211.6 | 308.9 |
| Nordic & Baltic | 4350.3 | 7236.3 |

[1] The average values of Latvia and Lithuania use the period 2012–2017.
[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 per voltage level

This section presents energy not supplied (ENS) per voltage level. The used voltage levels are 100–150 kV, 220–330 kV and 380–420 kV. It should be noted, that the ENS in this section only contains ENS caused inside each TSO's own statistical area.

Table 4.2.1 shows the amount of energy not supplied and its distribution per voltage level. The voltage level of a disturbance is determined by the voltage level of its primary fault.

Table 4.2.1: Energy not supplied (ENS) in each Nordic and Baltic country in 2017 and the annual average during 2008–2017. Furthermore, the average percentage distribution of ENS per voltage level during 2008–2017 is shown. The voltage level is determined by the voltage level of each individual fault. It should be noted, that the total amount of ENS includes ENS caused by faults outside the TSO's statistical area, while the ENS divided by voltage level only includes ENS caused inside the TSO's statistical area. Therefore, an additional category named ***Other***, which reflects the effect of faults from the outside grid to the 100–420 kV grid, has been included.

| | ENS (MWh) | | Average ENS (%) per voltage level during 2008–2017 | | | |
|---|---|---|---|---|---|---|
| Country | 2017 | 2008–2017 | 100–150 kV | 220–330 kV | 380–420 kV | Other[2] |
| Denmark | 94.4 | 26.7 | 95 | 0 | 0 | 6 |
| Estonia | 46.7 | 177.0 | 84 | 1 | 0 | 21 |
| Finland | 355.9 | 374.3 | 91 | 2 | 3 | 8 |
| Iceland | 1610.0 | 1057.7 | 32 | 63 | 0 | 18 |
| Latvia[1] | 90.3 | 90.9 | 100 | 0 | 0 | 0 |
| Lithuania[1] | 74.6 | 40.9 | 97 | 3 | 0 | 0 |
| Norway | 1113.7 | 3559.1 | 33 | 8 | 59 | 0 |
| Sweden | 964.7 | 1909.7 | 79 | 13 | 3 | 5 |
| Nordic | 4138.7 | 6927.4 | 49 | 17 | 31 | 5 |
| Baltic | 211.6 | 308.9 | 88 | 1 | 0 | 15 |
| Nordic & Baltic | 4350.3 | 7236.3 | 50 | 17 | 30 | 5 |

[1] The average values of Latvia and Lithuania use the period 2012–2017.

[2] The category *Other* contains energy not supplied from system faults, auxiliary equipment, lower voltage level networks and the connections to foreign countries, etc. Additionally, it is not included in the total ENS. Instead, it shows the degree of effect from the outside grid to the 100–420 kV grid. This is described further in the guidelines [2].

Figure 4.2.1 presents the energy not supplied per the different voltage levels in 2017 and Figure 4.2.2 summarises the energy not supplied per the different voltage levels during 2008–2017 in the Nordic countries and Estonia and during 2012–2017 in Latvia and Lithuania. The values only account for faults and the caused ENS inside each country's own statistical area.

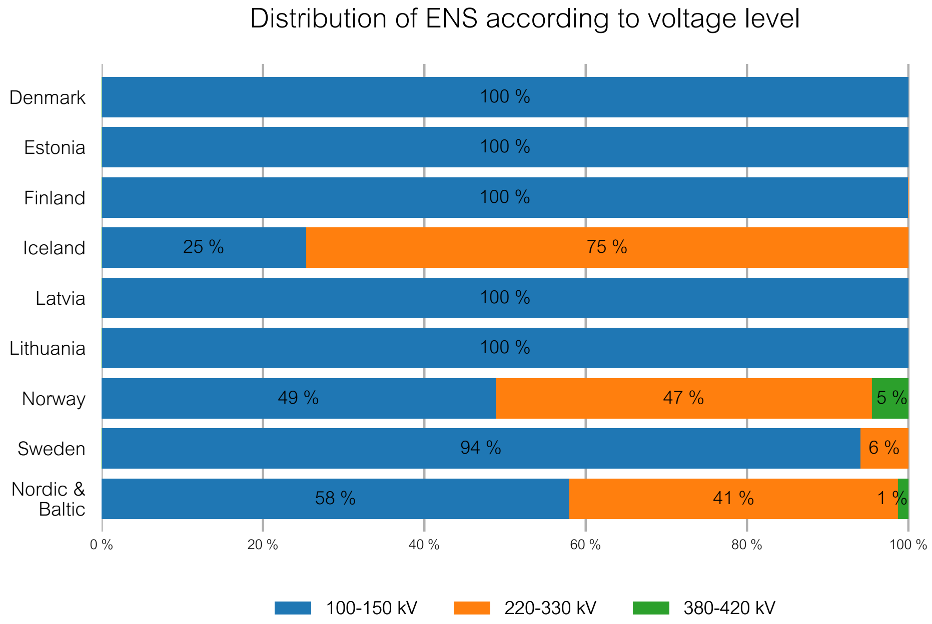


Figure 4.2.1: Percentage distribution of energy not supplied (ENS) per voltage level in 2017. It should be noted, that the ENS in this figure only includes ENS caused by faults inside the TSO's statistical area.

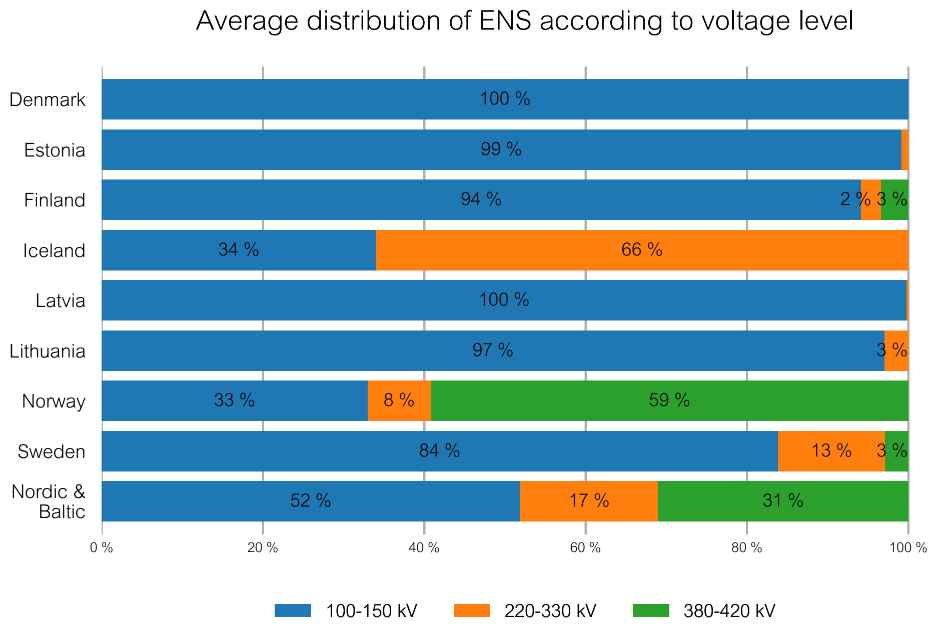


Figure 4.2.2: Percentage distribution of Energy not supplied per voltage level during 2008–2017 in the Nordic countries and Estonia and during 2012–2017 in Latvia and Lithuania. It should be noted, that the ENS in this figure only includes ENS caused by faults inside the TSO's statistical area.

## 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. Ppm (parts per million) represents ENS as a proportional value of the consumed energy, which is calculated: ENS × $10^6$ / consumption. The value of ENS is the total amount of ENS caused by all faults, that is, faults inside the statistical area and faults from outside the own grid that effect other statistical area.

Table 4.3.1: Energy not supplied (ENS) in each Nordic and Baltic country in 2017 and the annual average for the period 2008–2017. The value of ENS is the total amount of ENS caused by all faults, that is, faults inside the statistical area and faults from outside the own grid that effect other statistical area.

| | Consumption (TWh) | ENS (MWh) | ENS / consumption (ppm) | |
|---|---|---|---|---|
| Country | 2017 | 2017 | 2017 | 2008–2017 |
| Denmark | 34.0 | 94.4 | 2.8 | 0.8 |
| Estonia | 8.5 | 46.7 | 5.5 | 23.2 |
| Finland | 85.5 | 355.9 | 4.2 | 4.4 |
| Iceland | 18.5 | 1610.0 | 87.0 | 60.5 |
| Latvia[1] | 7.3 | 90.3 | 12.4 | 13.0 |
| Lithuania[1] | 11.7 | 74.6 | 6.4 | 4.0 |
| Norway | 132.9 | 1113.7 | 8.4 | 26.9 |
| Sweden | 140.1 | 964.7 | 6.9 | 13.7 |
| Nordic | 411.0 | 4138.7 | 10.1 | 17.0 |
| Baltic | 27.5 | 211.6 | 7.7 | 14.3 |
| Nordic & Baltic | 438.5 | 4350.3 | 9.9 | 16.9 |

[1] The average values of Latvia and Lithuania use the period 2012–2017.

Figure 4.3.1 and Figure 4.3.2 presents the progression of ENS in relation to the consumption during the period 2008–2017 in the Nordic countries and Estonia and during the period 2012–2017 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.

Furthermore, Figure 4.3.3 shows ENS per total line length annually and the average during 2008–2017 in each Nordic country and Estonia and during 2012–2017 in Latvia and Lithuania. The total line length is the sum of the lengths of overhead lines and cables.

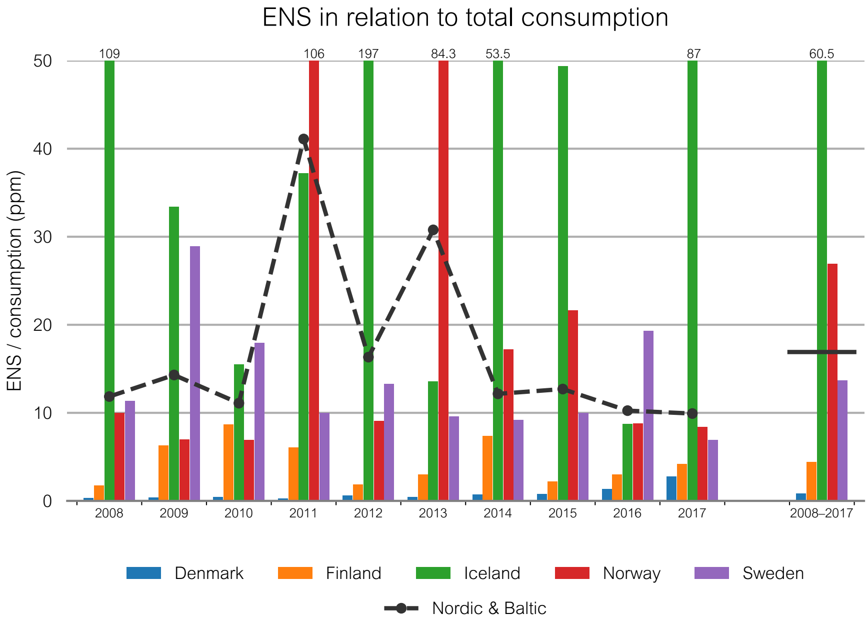


Figure 4.3.1: Annual energy not supplied (ENS) divided by consumption (ppm) during 2008–2017 in the Nordic countries. The value of ENS is the total amount of ENS caused by all faults, that is, faults inside the statistical area and faults from outside the own grid that effect other statistical area. This figure has the following remarks:

- Iceland's high values are a result of power intensive industries that cause substantial amounts of ENS even during short interruptions.
- 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 are a result of various elements such as having a meshed grid and compared to the other Nordic countries, a mild climate.

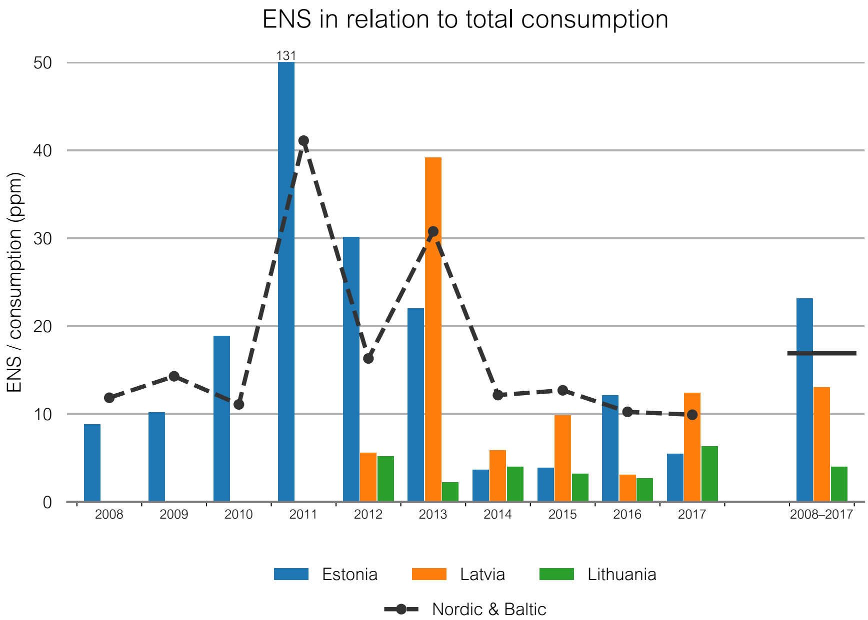


Figure 4.3.2: Annual energy not supplied (ENS) divided by consumption (ppm) during 2008–2017 in Estonia and during 2012–2017 in Latvia and Lithuania during 2012–2017. The value of ENS is the total amount of ENS caused by all faults, that is, faults inside the statistical area and faults from outside the own grid that effect other statistical area.

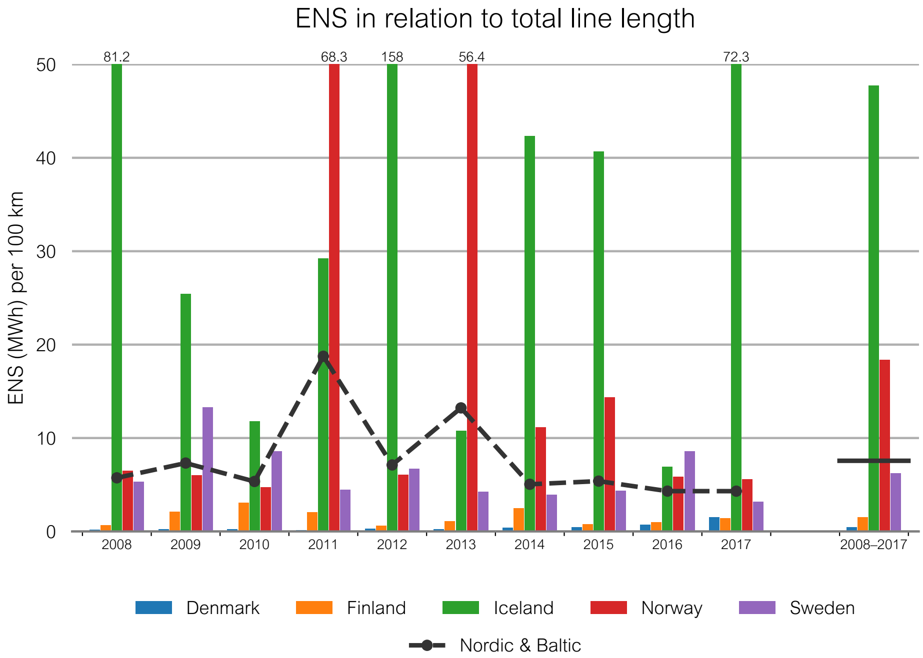


Figure 4.3.3: Annual ENS divided by total line length during 2008–2017 in the Nordic countries. The value of ENS is the total amount of ENS caused by all faults, that is, faults inside the statistical area and faults from outside the own grid that effect other statistical area. The total line length is the sum of the lengths of overhead lines and cables.

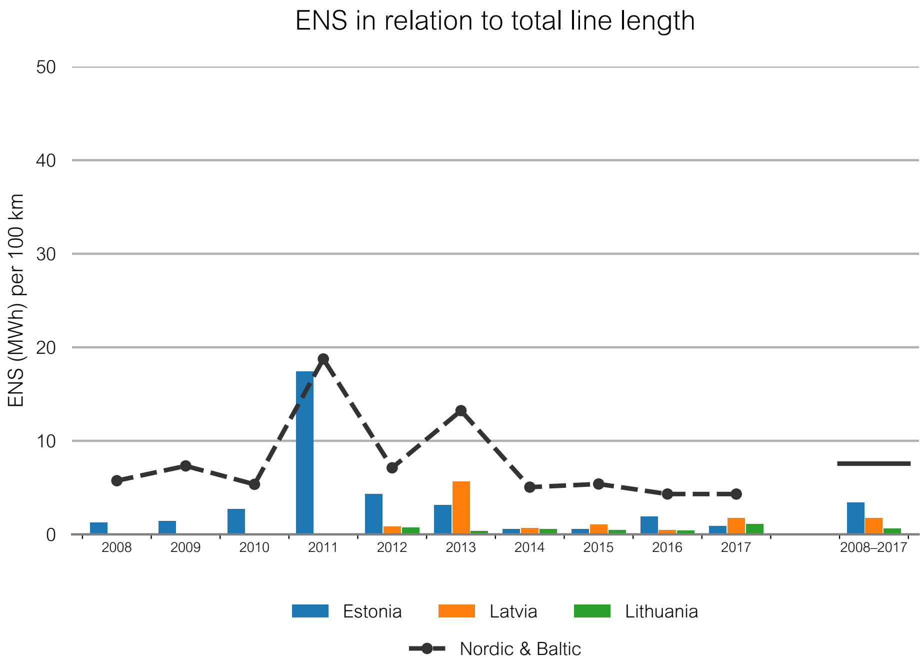


Figure 4.3.4: Annual ENS divided by total line length during 2008–2017 in Estonia and during 2012–2017 in Latvia and Lithuania during 2012–2017. The value of ENS is the total amount of ENS caused by all faults, that is, faults inside the statistical area and faults from outside the own grid that effect other statistical area. The total line length is the sum of the lengths of overhead lines and cables.

# 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 2017. Figure 4.4.3 presents the average during 2008–2017 in the Nordic countries and Figure 4.4.4 presents the average during 2012–2017 in the Baltic countries.

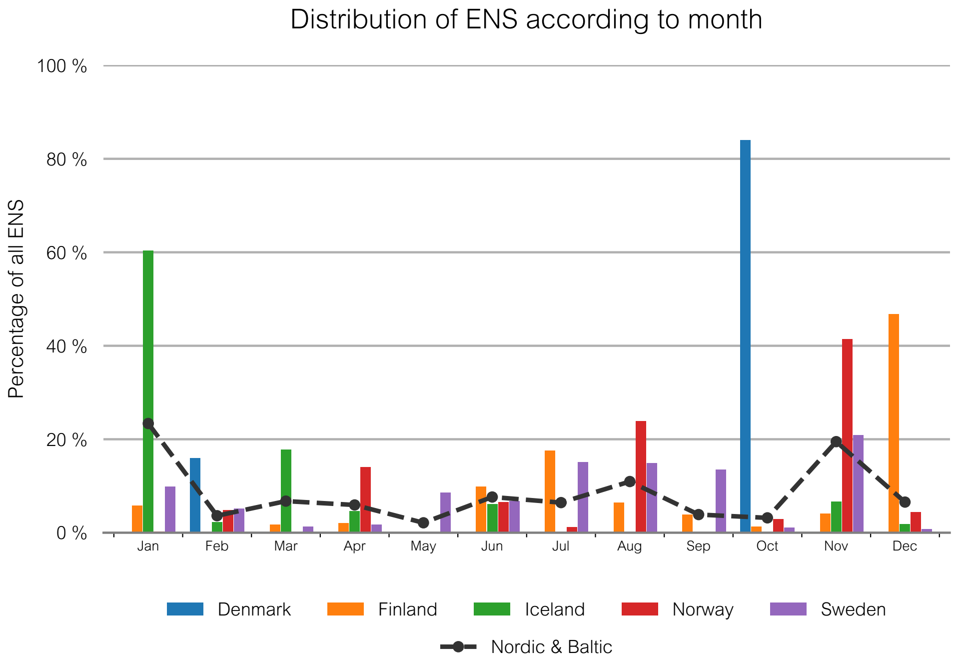


Figure 4.4.1: Percentage distribution of ENS per month in 2017 in each Nordic country.

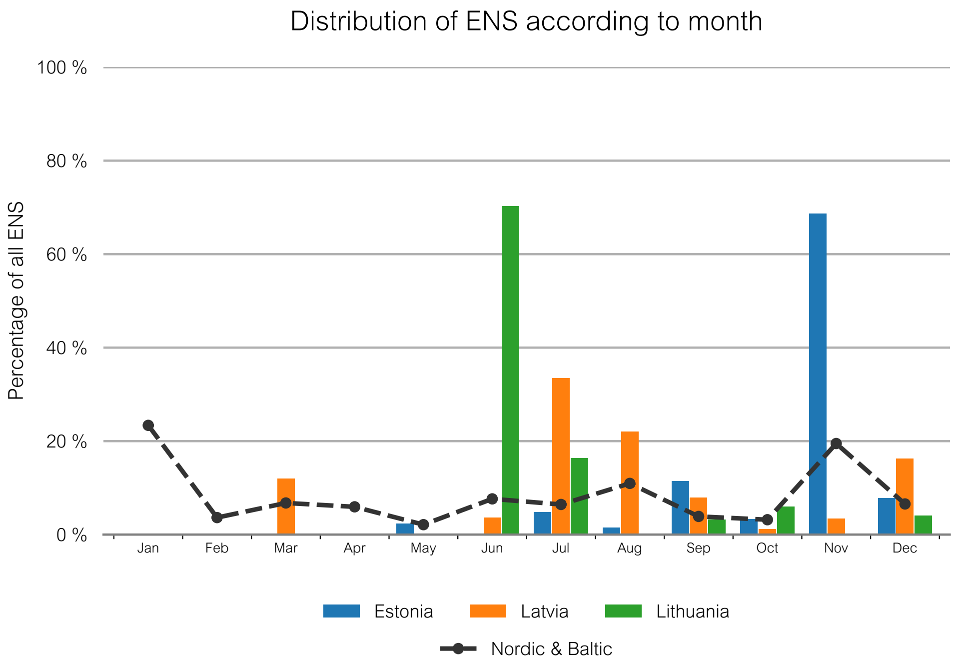


Figure 4.4.2: Percentage distribution of ENS per month in 2017 in each Baltic country.

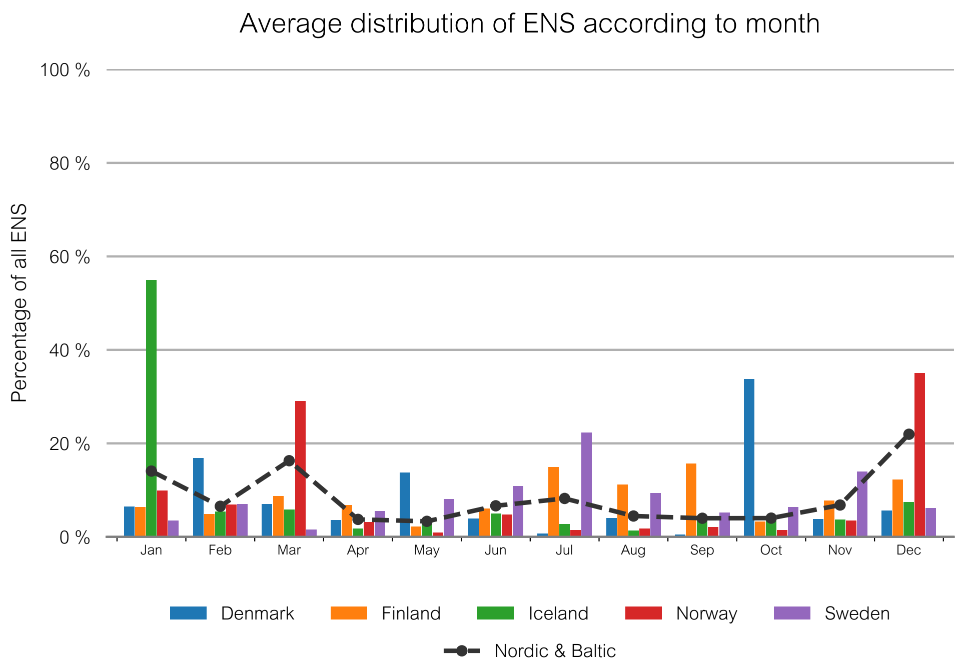


Figure 4.4.3: Average distribution of ENS per month during 2008–2017 in each Nordic country.

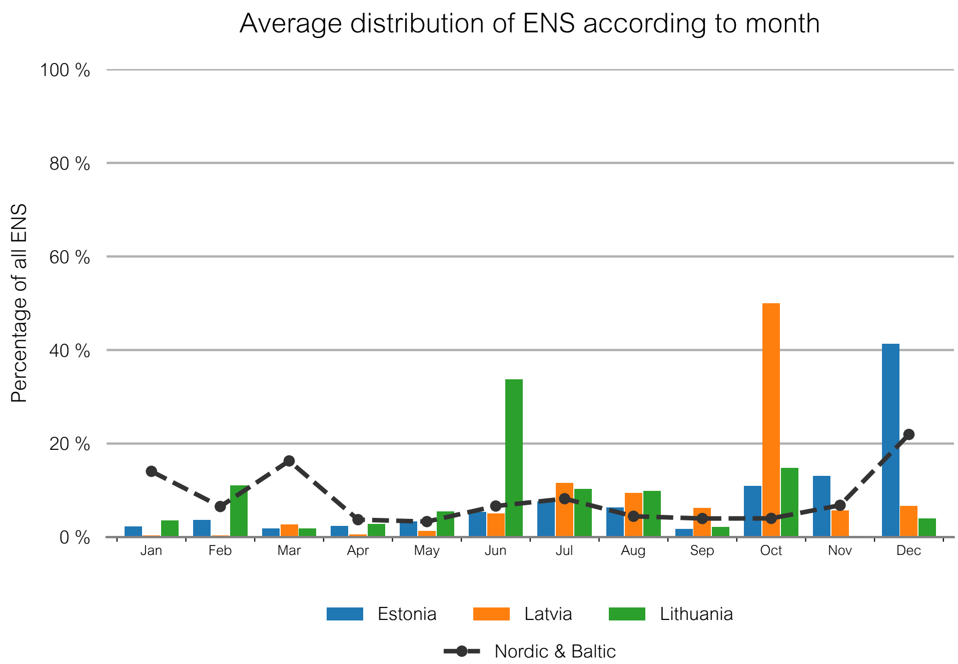


Figure 4.4.4: Average distribution of ENS per month during 2008–2017 in Estonia and during 2012–2017 in Latvia and Lithuania.

# 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 2017. Figure 4.5.3 presents the average for the period 2008–2017 in the Nordic countries and Figure 4.5.4 presents the average for the period 2012–2017 in the Baltic countries. Appendix B provides more details about how each country investigates line faults.

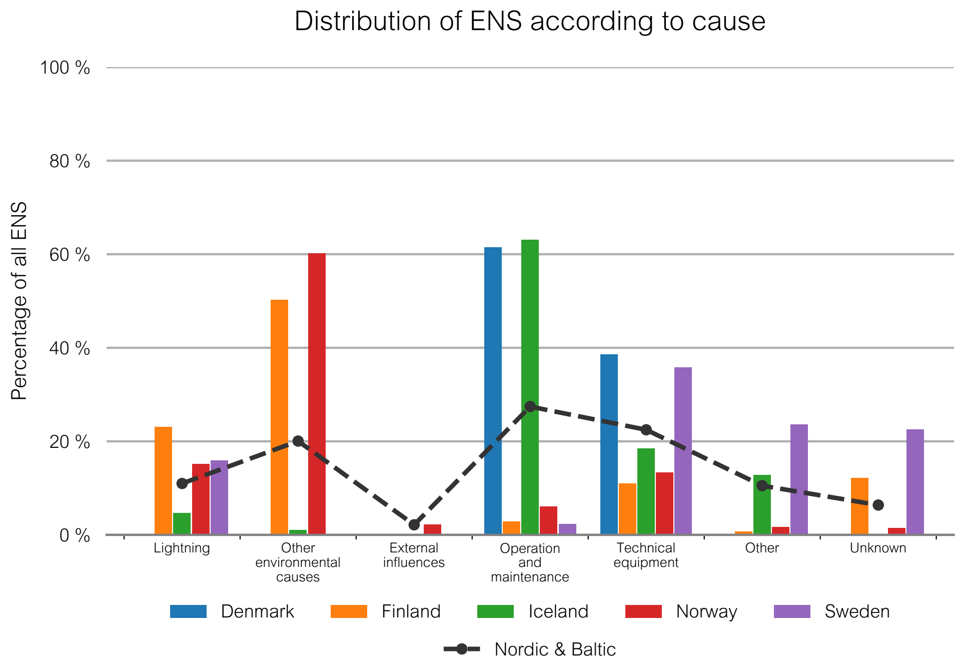


Figure 4.5.1: Percentage distribution of ENS per cause in 2017 in each Nordic country.

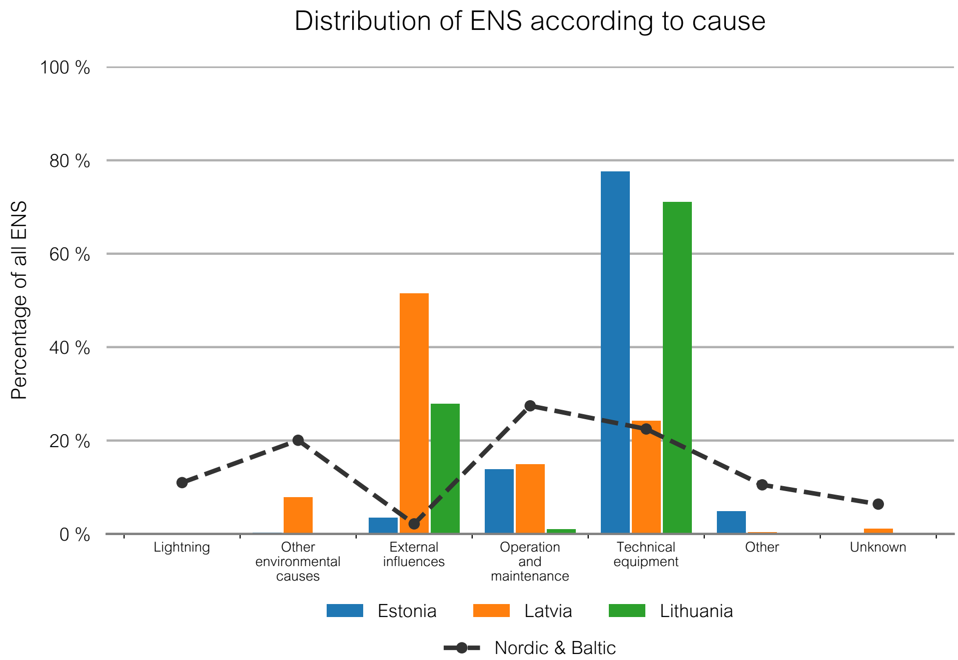


Figure 4.5.2: Percentage distribution of ENS per cause in 2017 in each Baltic country.

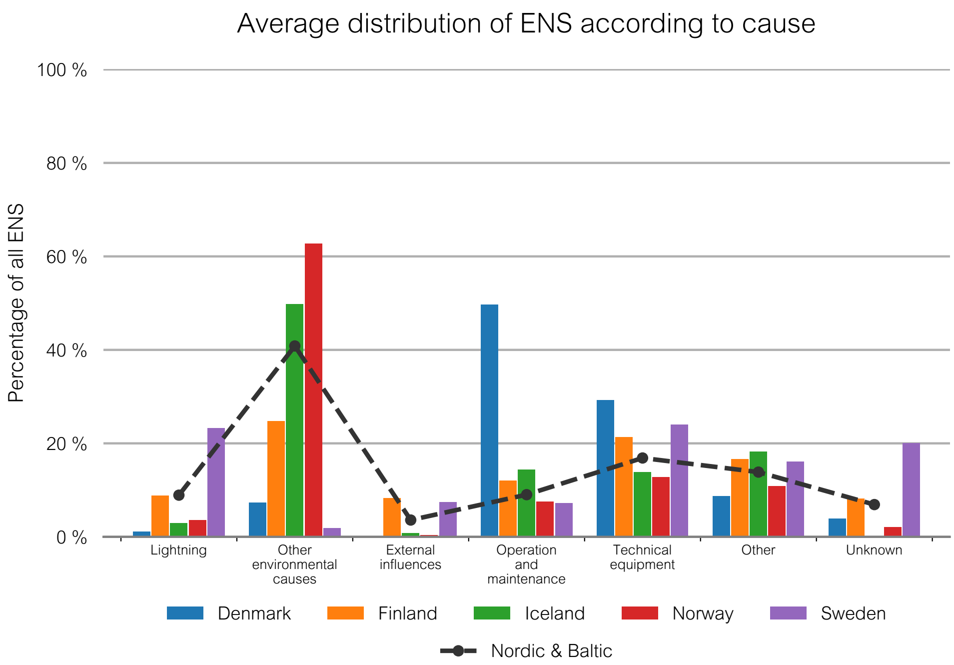


Figure 4.5.3: Average distribution of ENS per cause during 2008–2017 in each Nordic country.

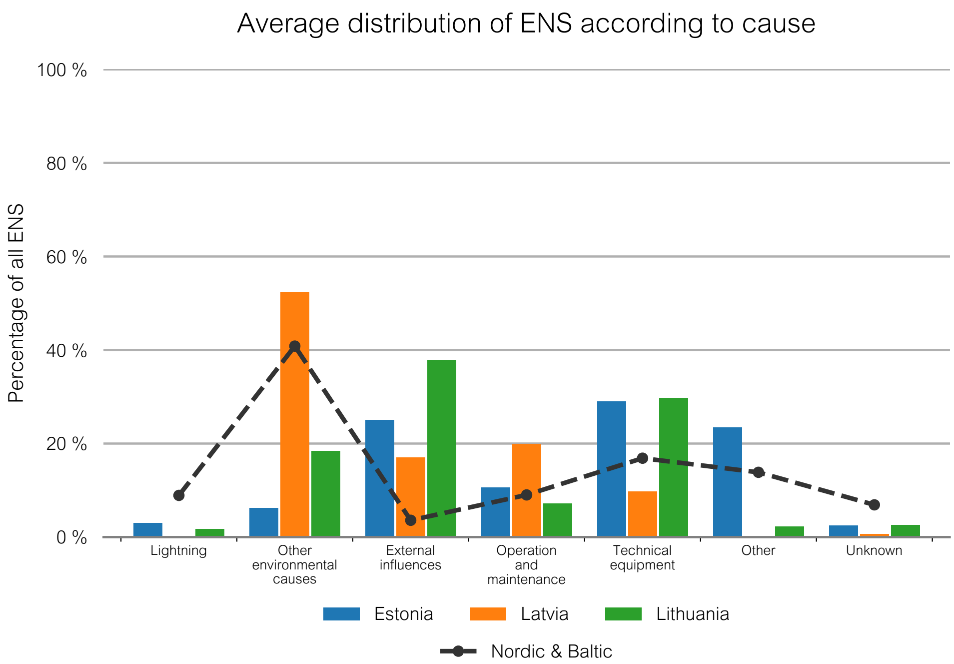


Figure 4.5.4: Average distribution of ENS per cause during 2008–2017 in Estonia and during 2012–2017 in Latvia and Lithuania.

## 4.6 Energy not supplied (ENS) distributed per component

Table 4.6.1 presents the distribution of energy not supplied per installation. The sum of the ENS divided per installation may not be exactly 100 % because all the ENS is not always connected with a cause. Table 4.6.2 and Table 4.6.3 show the distribution of energy not supplied per component.

Table 4.6.1: Energy not supplied (ENS) in each Nordic and Baltic country in 2017 and the annual average during 2008–2017. Furthermore, the sum of the ENS divided per installation may not be exactly 100 % because all the ENS is not always connected with a cause. 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.

| | ENS (MWh) | | Average ENS (%) per installation during 2008–2017 | | |
|---|---|---|---|---|---|
| Country | 2017 | 2008–2017 | Overhead lines | Cable | Station |
| Denmark | 94.4 | 26.7 | 3 | 0 | 91 |
| Estonia | 46.7 | 177.0 | 59 | 1 | 19 |
| Finland | 355.9 | 374.3 | 61 | 0 | 30 |
| Iceland | 1610.0 | 1057.7 | 24 | 1 | 58 |
| Latvia[1] | 90.3 | 90.9 | 69 | 0 | 31 |
| Lithuania[1] | 74.6 | 40.9 | 55 | 1 | 44 |
| Norway | 1113.7 | 3559.1 | 69 | 2 | 29 |
| Sweden | 964.7 | 1909.7 | 31 | 5 | 55 |
| Nordic | 4138.7 | 6927.4 | 51 | 3 | 41 |
| Baltic | 211.6 | 308.9 | 61 | 1 | 24 |
| Nordic & Baltic | 4350.3 | 7236.3 | 51 | 2 | 40 |

[1] The average values of Latvia and Lithuania use the period 2012–2017.

Table 4.6.2: Percentage distribution of energy not supplied per HVAC component in 2017 and the average during 2008–2017 in each Nordic country. 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.

| | Denmark | | Finland | | Iceland | | Norway | | Sweden | | Average | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fault location | 2017 | 2008–2017 | 2017 | 2008–2017 | 2017 | 2008–2017 | 2017 | 2008–2017 | 2017 | 2008–2017 | 2017 | 2008–2017 |
| Cable | 0 | 0 | 0 | 0 | 0 | 1 | 10 | 2 | 5 | 5 | 4 | 3 |
| Overhead line | 0 | 3 | 70 | 61 | 6 | 24 | 61 | 69 | 31 | 30 | 32 | 50 |
| Line faults | 0 | 3 | 70 | 62 | 6 | 24 | 71 | 71 | 36 | 35 | 36 | 53 |
| Power transformers | 0 | 14 | 0 | 3 | 16 | 3 | 0 | 3 | 9 | 8 | 8 | 5 |
| Instrument transformers | 0 | 7 | 6 | 4 | 0 | 0 | 0 | 2 | 8 | 5 | 2 | 3 |
| Circuit breakers | 4 | 8 | 15 | 3 | 0 | 29 | 1 | 1 | 1 | 3 | 2 | 6 |
| Busbar | 96 | 46 | 4 | 1 | 0 | 4 | 3 | 3 | 7 | 2 | 5 | 3 |
| Common ancillary equipment | 0 | 0 | 0 | 2 | 0 | 0 | 1 | 3 | 0 | 0 | 0 | 2 |
| Control equipment[2] | 0 | 8 | 3 | 12 | 59 | 16 | 7 | 8 | 11 | 4 | 28 | 8 |
| Disconnectors and earth connectors | 0 | 8 | 1 | 2 | 1 | 0 | 14 | 3 | 1 | 6 | 5 | 3 |
| Other substation faults | 0 | 0 | 0 | 2 | 5 | 4 | 3 | 6 | 9 | 29 | 5 | 12 |
| Surge arresters and spark gaps | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Substation faults | 100 | 91 | 30 | 29 | 82 | 57 | 29 | 29 | 45 | 56 | 55 | 41 |
| Reactor | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| Series capacitor | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Shunt capacitor | 0 | 1 | 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 |
| Synchronous compensator | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Compensation faults | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| Faults in adjoining statistical area | 0 | 0 | 0 | 0 | 12 | 14 | 0 | 0 | 1 | 1 | 5 | 2 |
| System faults | 0 | 6 | 0 | 8 | 0 | 4 | 0 | 0 | 17 | 4 | 4 | 2 |
| Unknown | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Other faults | 0 | 6 | 0 | 8 | 13 | 18 | 0 | 0 | 18 | 5 | 9 | 5 |

[2] The category control equipment includes also protection.

Table 4.6.3: Percentage distribution of energy not supplied per HVAC component in 2017 and the average in each Baltic country. Estonia uses the period 2008–2017 for its average and Latvia and Lithuania use the period 2012–2017. 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.

| | Estonia | | Latvia[1] | | Lithuania[1] | | Average | |
|---|---|---|---|---|---|---|---|---|
| Fault location | 2017 | 2008–2017 | 2017 | 2012–2017 | 2017 | 2012–2017 | 2017 | 2012–2017 |
| Cable | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 |
| Overhead line | 26 | 59 | 60 | 69 | 31 | 55 | 42 | 61 |
| Line faults | 26 | 60 | 60 | 69 | 31 | 56 | 42 | 62 |
| Power transformers | 3 | 4 | 1 | 4 | 0 | 2 | 1 | 4 |
| Instrument transformers | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 |
| Circuit breakers | 2 | 2 | 0 | 0 | 0 | 2 | 1 | 1 |
| Control equipment[2] | 0 | 1 | 18 | 19 | 68 | 36 | 31 | 8 |
| Busbar | 0 | 1 | 0 | 3 | 0 | 1 | 0 | 1 |
| Common ancillary equipment | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Disconnectors and earth connectors | 0 | 0 | 22 | 5 | 0 | 1 | 9 | 1 |
| Surge arresters and spark gaps | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| Other substation faults | 0 | 9 | 0 | 0 | 0 | 1 | 0 | 6 |
| Substation faults | 6 | 17 | 40 | 31 | 69 | 44 | 43 | 23 |
| Reactor | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Series capacitor | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Shunt capacitor | 63 | 2 | 0 | 0 | 0 | 0 | 14 | 1 |
| SVC and statcom | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Synchronous compensator | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Compensation faults | 63 | 2 | 0 | 0 | 0 | 0 | 14 | 1 |
| Faults in adjoining statistical area | 5 | 21 | 0 | 0 | 0 | 0 | 1 | 15 |
| System faults | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Unknown | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Other faults | 5 | 21 | 0 | 0 | 0 | 0 | 1 | 15 |

[1] The average values of Latvia and Lithuania use the period 2012–2017.
[2] The category control equipment includes also protection.

# 5 Disturbances with multiple faults

This chapter presents fault statistics about disturbances with multiple faults. A grid disturbance with multiple faults occurs when a disturbance has more than one fault, as specified in the *Guidelines for Classification of Grid Disturbances above 100 kV* in Section 4.1.2 [2]. The probability of a disturbance having more than one fault is significantly smaller than it having only a single fault. However, disturbances with multiple faults tend to cause more ENS. This is partly because the main grids are designed to withstand a single fault without degrading the performance.

Section 5.1 gives an overview of disturbances with multiple faults and the relation of multiple faults and disturbances. Section 5.2 presents disturbances with multiple faults distributed per cause and Section 5.3 presents the distribution of ENS caused by grid disturbances with multiple faults. The following chapters present the distribution of single and disturbances with multiple faults along with the energy not supplied per cause and voltage levels.

It should be noted, that this chapter is still new to this report and is under development. Therefore, only data for 2017 is presented as there is not enough historical data available. Average values and trend curves can be presented when a sufficient amount of data about disturbances with multiple faults has been collected.

## 5.1 Overview of disturbances with multiple faults

Table 5.1.1 presents the number of disturbances, disturbances causing ENS and disturbances with multiple faults in 2017. Furthermore, it presents also the ENS caused by disturbances and disturbances with multiple faults separately. The total ENS caused by disturbances may be lower than the ENS caused by all the faults collectively, because disturbances are only reported when they are caused in the own 100–420 kV grid.

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

Table 5.1.1: The number of disturbances, disturbances causing ENS, total ENS (MWh) and the number of disturbances with multiple faults and amount of ENS (MWh) caused by them in 2017. The total ENS caused by disturbances may be lower than the ENS caused by all the faults collectively, because disturbances are only reported when they are caused in the own 100–420 kV grid.

| | Disturbances in 2017 | | | Disturbances with multiple faults in 2017 | |
|---|---|---|---|---|---|
| Country | Number | causing ENS | ENS (MWh) | Number | ENS (MWh) |
| Denmark | 53 | 4 | 94.4 | 9 | 4.0 |
| Estonia | 123 | 36 | 46.7 | 9 | 26.6 |
| Finland | 329 | 91 | 355.9 | 13 | 21.5 |
| Iceland | 31 | 19 | 1404.2 | 8 | 0.0 |
| Latvia | 149 | 25 | 90.3 | 20 | 19.1 |
| Lithuania | 141 | 15 | 74.6 | 12 | 50.0 |
| Norway | 257 | 68 | 1113.7 | 24 | 170.2 |
| Sweden | 275 | 113 | 964.7 | 10 | 32.0 |
| Nordic | 945 | 295 | 3929.0 | 64 | 227.6 |
| Baltic | 413 | 76 | 211.6 | 41 | 95.7 |
| Nordic & Baltic | 1358 | 371 | 4140.5 | 105 | 323.3 |

## 5.2 Disturbances with multiple faults distributed per cause

Figure 5.2.1 and Figure 5.2.2 present the percentage distribution of disturbances with multiple faults per cause in 2017.

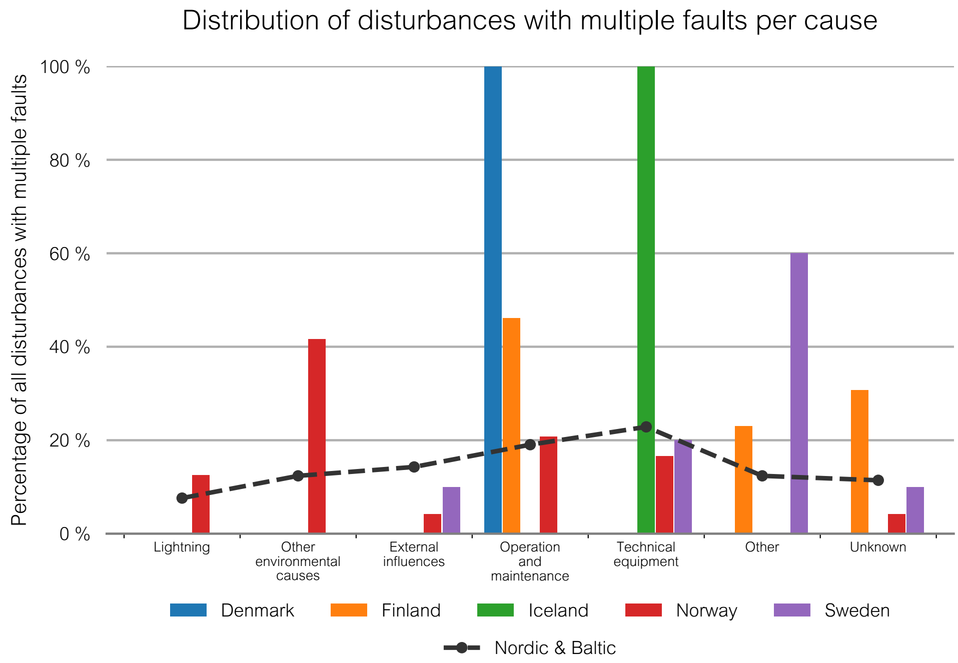


Figure 5.2.1: Percentage distribution of disturbances with multiple faults per cause in the Nordic countries in 2017.

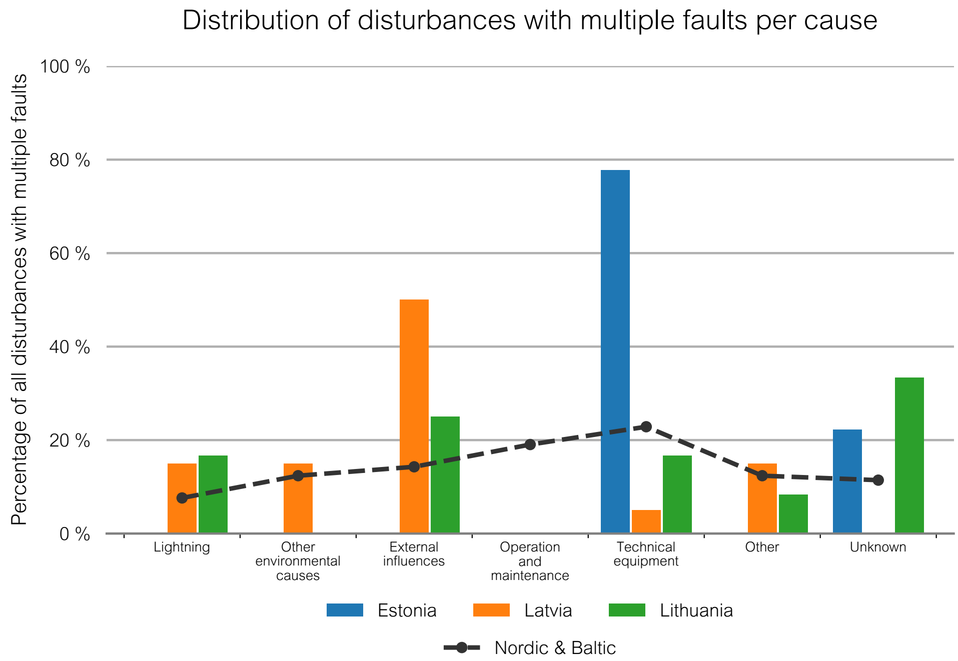


Figure 5.2.2: Percentage distribution of disturbances with multiple faults per cause in the Baltic countries in 2017.

Figure 5.2.3 and Figure 5.2.4 present the percentage distribution of secondary faults faults per cause in 2017.

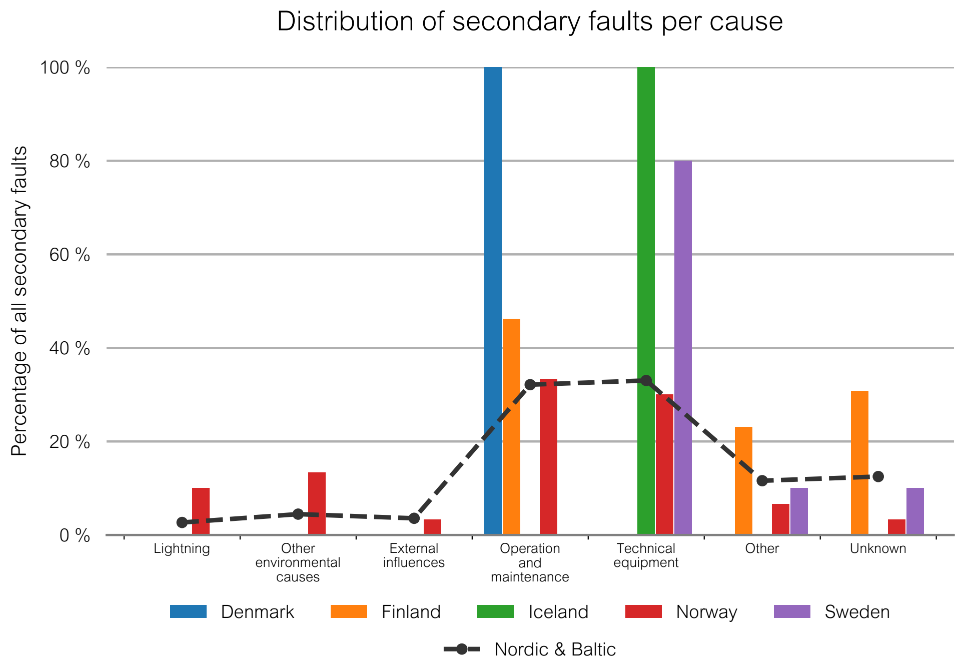


Figure 5.2.3: Percentage distribution of secondary faults per cause in the Nordic countries in 2017.

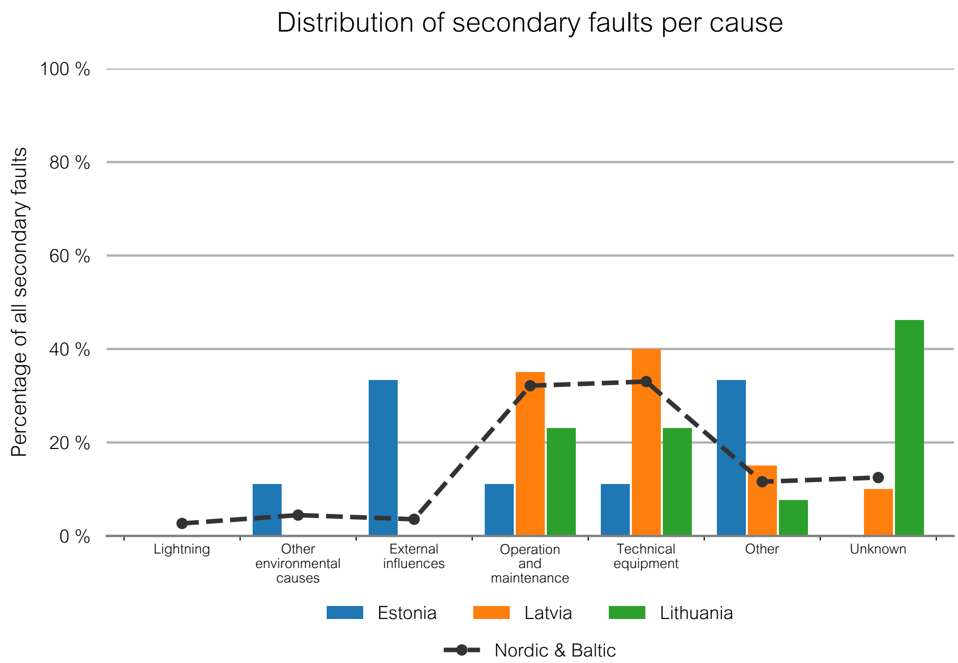


Figure 5.2.4: Percentage distribution of secondary faults per cause in the Baltic countries in 2017.

## 5.3 Energy not supplied distributed per cause

Figure 5.3.1 and Figure 5.3.2 present the percentage distribution of ENS, caused by disturbances with multiple faults, per cause in 2017.

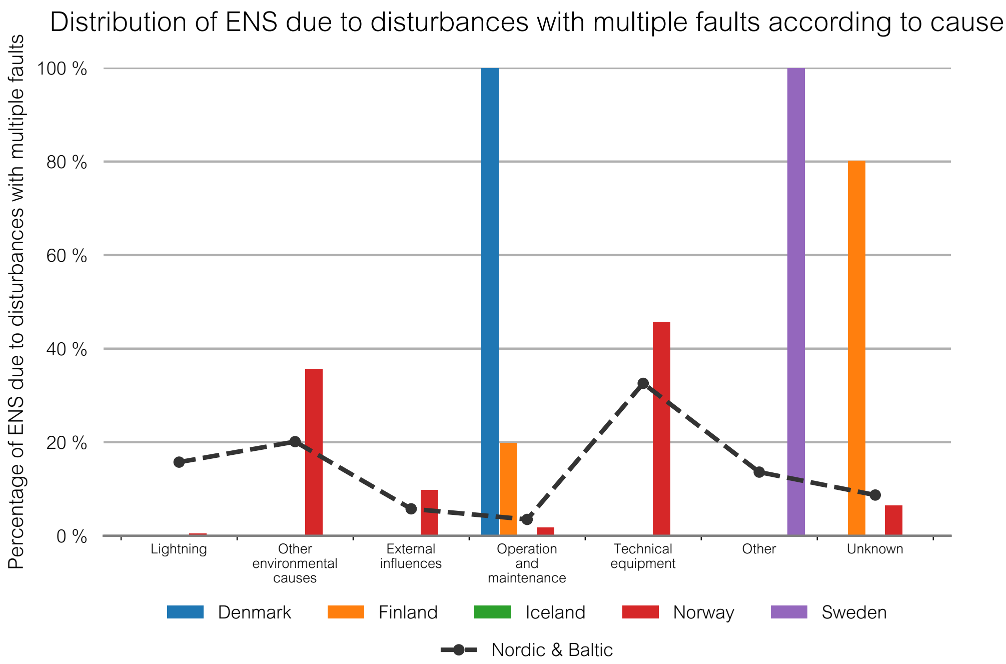


Figure 5.3.1: Percentage distribution of the ENS, caused by disturbances with multiple faults, per cause in 2017 in the Nordic countries.

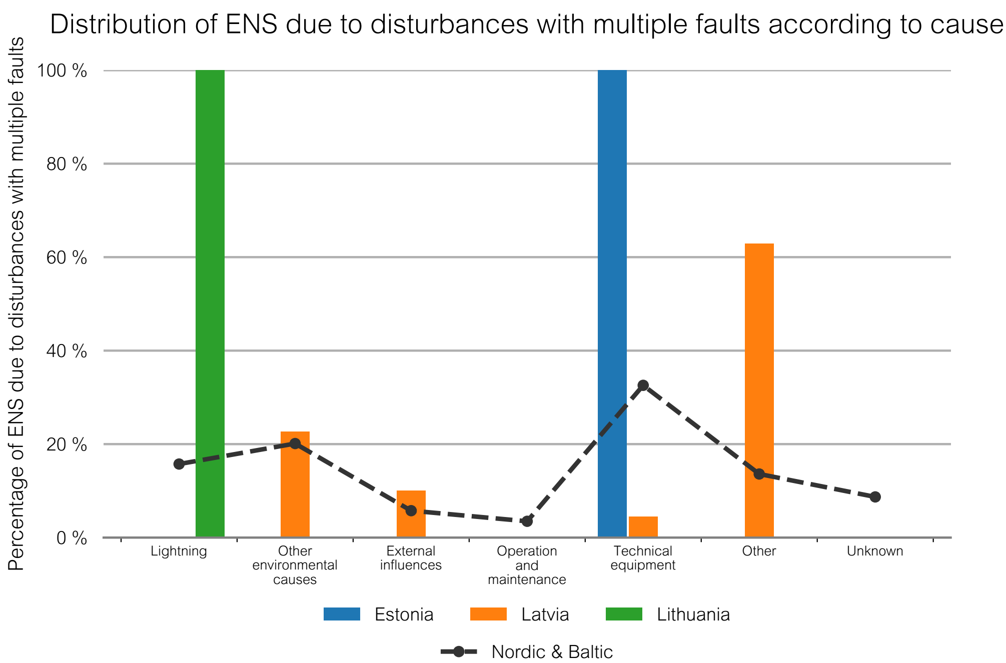


Figure 5.3.2: Percentage distribution of the ENS, caused by disturbances with multiple faults, per cause in 2017 in the Baltic countries.

Figure 5.3.3 and Figure 5.3.4 present the percentage distribution of ENS, caused by secondary faults, per cause in 2017.

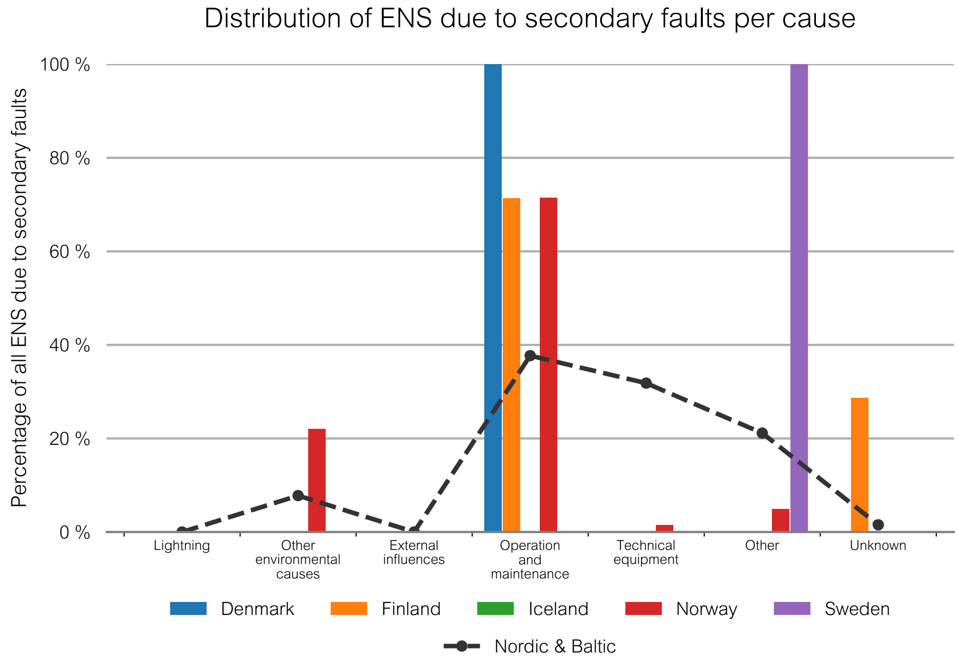


Figure 5.3.3: Percentage distribution of ENS, caused by secondary faults, per cause in the Nordic countries in 2017.

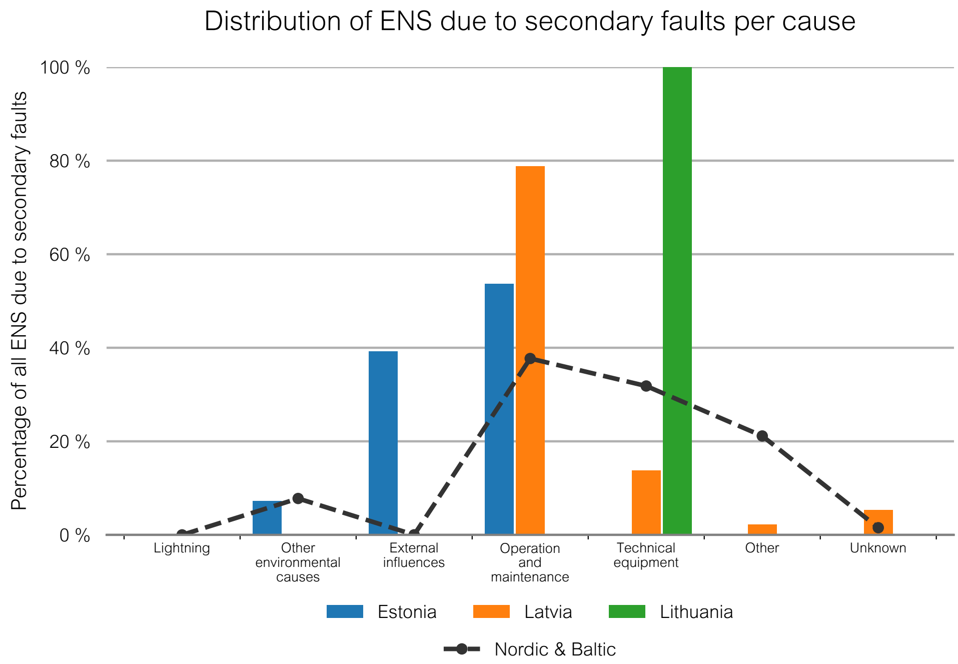


Figure 5.3.4: Percentage distribution of ENS, caused by secondary faults, per cause in the Baltic countries in 2017.

# 6 Faults in power system components

This chapter presents an overview of all faults in the Nordic and Baltic transmission grid. Furthermore, faults for each type of power system component are presented. It should be noted, that the grid in each country contains a different set of components. To keep the data comparable, the values have been scaled according to the length or amount of components installed in each country. Readers who need more detailed data should use the national statistics published by the national regulators.

A component fault is defined as:

> The inability of a component to perform its required function [1].

A fault in a component implies that the component is not able to perform its function properly. This may be caused by several reasons, for example manufacturing defects or insufficient maintenance. In this report, the cause of a fault is defined as the cause that has the most significant impact on the fault. The fault causes used in these statistics are presented in Chapter 1.4.1.

It should be noted, that a fault is only reported if the fault results in a trip.

Section 6.1 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. Furthermore, the chapters present fault trends for each component.

## 6.1 Overview of faults

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.

Table 6.1.1 presents the number of faults in 2017 and the average for 2008–2017. Table 6.1.2 presents the number of faults and disturbances and their average ratio.

Table 6.1.1: Number of faults and the ENS in each Nordic and Baltic country in 2017 and the average for 2008–2017.

| | Number of faults | | ENS (MWh) | |
|---|---|---|---|---|
| Country | 2017 | 2008–2017 | 2017 | 2008–2017 |
| Denmark | 62 | 62.8 | 94.4 | 26.7 |
| Estonia | 132 | 220.4 | 46.7 | 177.0 |
| Finland | 342 | 464.0 | 355.9 | 374.3 |
| Iceland | 63 | 48.2 | 1610.0 | 1057.7 |
| Latvia[1] | 169 | 157.5 | 90.3 | 90.9 |
| Lithuania[1] | 154 | 174.5 | 74.6 | 40.9 |
| Norway | 287 | 339.5 | 1113.7 | 3559.1 |
| Sweden | 285 | 516.1 | 964.7 | 1909.7 |
| Nordic | 1039 | 1430.6 | 4138.7 | 6927.4 |
| Baltic | 455 | 552.4 | 211.6 | 308.9 |
| Nordic & Baltic | 1494 | 1983.0 | 4350.3 | 7236.3 |

[1] The average values of Latvia and Lithuania use the period 2012–2017.

Table 6.1.2: Number of faults, grid disturbances and the average ratio in each Nordic and Baltic country in 2017 and the average for 2008–2017.

| | Faults | | Disturbances | | Ratio |
|---|---|---|---|---|---|
| Country | 2017 | 2008–2017 | 2017 | 2008–2017 | 2008–2017 |
| Denmark | 62 | 62.8 | 53 | 55.2 | 1.1 |
| Estonia | 132 | 220.4 | 123 | 216.7 | 1.0 |
| Finland | 342 | 464.0 | 329 | 441.4 | 1.1 |
| Iceland | 63 | 48.2 | 31 | 33.4 | 1.4 |
| Latvia[1] | 169 | 157.5 | 149 | 145.0 | 1.1 |
| Lithuania[1] | 154 | 174.5 | 141 | 164.2 | 1.1 |
| Norway | 287 | 339.5 | 257 | 292.3 | 1.2 |
| Sweden | 285 | 516.1 | 275 | 502.2 | 1.0 |
| Nordic | 1039 | 1430.6 | 945 | 1324.5 | 1.1 |
| Baltic | 455 | 552.4 | 413 | 525.9 | 1.0 |
| Nordic & Baltic | 1494 | 1983.0 | 1358 | 1850.4 | 1.1 |

[1] The average values of Latvia and Lithuania use the period 2012–2017.

Table 6.1.3, Table 6.1.4 and Table 6.1.5 present the distribution of faults and energy not supplied in terms of voltage level and country. In addition, the tables show the number of power transformers and the total length of overhead lines and cables. This is shown in order to give a perception 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 6.1.3: An overview of faults in the 380–420 kV grid. This includes the number power transformers and the total length of 380–420 kV overhead lines and cables and the number of faults and the amount of ENS in the 380–420 kV grid caused by the faults in 2017 and the average during 2008–2017. Note that the number of faults includes all faults; not just faults on lines and in power transformers.

| | Size of 380–420 kV grid | | Faults (380–420 kV) | | ENS (MWh) | |
|---|---|---|---|---|---|---|
| Country | Power transformers | Lines[3] (km) | 2017 | 2008–2017 | 2017 | 2008–2017 |
| Denmark | 31 | 1518 | 16 | 8.7 | 0.0 | 0.0 |
| Estonia | 0 | 0 | 0 | 0.0 | 0.0 | 0.0 |
| Finland | 62 | 5927 | 14 | 26.1 | 0.0 | 12.3 |
| Iceland | 0 | 0 | 0 | 0.0 | 0.0 | 0.0 |
| Latvia[1] | 0 | 0 | 0 | 0.0 | 0.0 | 0.0 |
| Lithuania[2] | 0 | 102 | 1 | 0.5 | 0.0 | 0.0 |
| Norway | 100 | 3291 | 76 | 70.9 | 50.2 | 2101.4 |
| Sweden | 71 | 10579 | 58 | 102.0 | 0.0 | 52.2 |
| Nordic | 264 | 21315 | 164 | 207.7 | 50.2 | 2165.9 |
| Baltic | 0 | 102 | 1 | 0.5 | 0.0 | 0.0 |
| Nordic & Baltic | 264 | 21417 | 165 | 208.2 | 50.2 | 2165.9 |

[1] The average values of Latvia and Lithuania use the period 2012–2017.
[2] Lithuania started maintaining their 380–420 kV grid in 2012.
[3] The length of lines is the sum of the length of cables and overhead lines.

Table 6.1.4: An overview of faults in the 220–330 kV grid. This includes the number power transformers and the total length of 220–330 kV overhead lines and cables and the number of faults and the amount of ENS in the 220–330 kV grid caused by the faults in 2017 and the average during 2008–2017. Note that the number of faults includes all faults; not just faults on lines and in power transformers.

| | Size of 220–330 kV grid | | Faults (220–330 kV) | | ENS (MWh) | |
|---|---|---|---|---|---|---|
| Country | Power transformers | Lines[2] (km) | 2017 | 2008–2017 | 2017 | 2008–2017 |
| Denmark | 8 | 230 | 1 | 0.9 | 0.0 | 0.0 |
| Estonia | 26 | 1856 | 22 | 22.2 | 0.0 | 1.3 |
| Finland | 18 | 1639 | 3 | 19.0 | 0.1 | 8.8 |
| Iceland | 15 | 858 | 14 | 13.2 | 1048.4 | 665.8 |
| Latvia[1] | 25 | 1346 | 14 | 16.5 | 0.0 | 0.2 |
| Lithuania[1] | 24 | 1761 | 11 | 19.2 | 0.0 | 1.2 |
| Norway | 266 | 5453 | 51 | 90.0 | 519.5 | 278.1 |
| Sweden | 111 | 4198 | 36 | 59.7 | 46.7 | 240.3 |
| Nordic | 418 | 12376 | 105 | 182.8 | 1614.7 | 1192.9 |
| Baltic | 75 | 4963 | 47 | 57.9 | 0.0 | 2.7 |
| Nordic & Baltic | 493 | 17340 | 152 | 240.7 | 1614.7 | 1195.6 |

[1] The average values of Latvia and Lithuania use the period 2012–2017.
[2] The length of lines is the sum of the length of cables and overhead lines.

Table 6.1.5: An overview of faults in the 100–150 kV grid. This includes the number power transformers and the total length of 100–150 kV overhead lines and cables and the number of faults and the amount of ENS in the 100–150 kV grid caused by the faults in 2017 and the average during 2008–2017. Note that the number of faults includes all faults; not just faults on lines and in power transformers.

| | Size of 100–150 kV grid | | Faults (100–150 kV) | | ENS (MWh) | |
|---|---|---|---|---|---|---|
| Country | Power transformers | Lines[3] (km) | 2017 | 2008–2017 | 2017 | 2008–2017 |
| Denmark | 229 | 4373 | 38 | 48.0 | 94.4 | 25.4 |
| Estonia | 215 | 3493 | 99 | 172.7 | 44.5 | 148.0 |
| Finland | 1209 | 17343 | 324 | 399.5 | 355.8 | 339.2 |
| Iceland | 38 | 1370 | 25 | 29.3 | 355.8 | 343.7 |
| Latvia[1] | 248 | 3894 | 138 | 125.8 | 89.9 | 90.7 |
| Lithuania[1] | 416 | 5070 | 111 | 137.0 | 74.6 | 39.7 |
| Norway | 913 | 11158 | 160 | 178.0 | 544.0 | 1171.0 |
| Sweden | 831 | 15431 | 164 | 317.3 | 739.9 | 1518.1 |
| Nordic | 3220 | 49676 | 711 | 972.1 | 2089.9 | 3397.4 |
| Baltic | 879 | 12456 | 348 | 435.5 | 208.9 | 278.4 |
| Nordic & Baltic | 4099 | 62132 | 1059 | 1407.6 | 2298.8 | 3675.8 |

[1] The average values of Latvia and Lithuania use the period 2012–2017.
[2] The length of lines is the sum of the length of cables and overhead lines.

Table 6.1.6 presents the number of faults in 2017, the average number of faults during 2008–2017 and the average percentage distribution of faults per installation during 2008–2017. Table 6.1.7 and Table 6.1.8 show the percentage distribution of faults according to component. The component groups used in these statistics are further described in the guidelines [2].

Furthermore, it should be noted that all countries do not own 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 6.1.6: Number of faults in each Nordic and Baltic country in 2017 and the average during 2008–2017 in the Nordic countries and Estonia and during 2012–2017 in Latvia and Lithuania. Furthermore, the average percentage distribution of faults per installation during 2008–2017 in the Nordic countries and Estonia and during 2012–2017 in Latvia and Lithuania is presented.

| | Number of faults | | Percentage of faults per installation during 2008–2017 | | |
|---|---|---|---|---|---|
| Country | 2017 | 2008–2017 | Overhead lines | Cable | Station |
| Denmark | 62 | 62.8 | 51 | 6 | 42 |
| Estonia | 132 | 220.4 | 74 | 0 | 25 |
| Finland | 342 | 464.0 | 83 | 0 | 16 |
| Iceland | 63 | 48.2 | 54 | 1 | 45 |
| Latvia[1] | 169 | 157.5 | 73 | 0 | 27 |
| Lithuania[1] | 154 | 174.5 | 78 | 0 | 22 |
| Norway | 287 | 339.5 | 49 | 1 | 49 |
| Sweden | 285 | 516.1 | 62 | 1 | 36 |
| Nordic | 1039 | 1430.6 | 65 | 1 | 33 |
| Baltic | 455 | 552.4 | 75 | 0 | 25 |
| Nordic & Baltic | 1494 | 1983.0 | 67 | 1 | 32 |

[1] The average values of Latvia and Lithuania use the period 2012–2017.

Table 6.1.7: Percentage distribution of faults per HVAC component in 2017 and the average during 2008–2017 in each Nordic country.

| | Denmark | | Finland | | Iceland | | Norway | | Sweden | | Average | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fault location | 2017 | 2008–2017 | 2017 | 2008–2017 | 2017 | 2008–2017 | 2017 | 2008–2017 | 2017 | 2008–2017 | 2017 | 2008–2017 |
| Cable | 5 | 5 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Overhead line | 21 | 46 | 85 | 80 | 10 | 40 | 40 | 49 | 52 | 58 | 55 | 62 |
| Line faults | 26 | 52 | 86 | 80 | 10 | 40 | 41 | 51 | 54 | 59 | 56 | 63 |
| Power transformers | 8 | 6 | 3 | 2 | 10 | 4 | 3 | 3 | 5 | 6 | 4 | 4 |
| Instrument transformers | 6 | 3 | 1 | 1 | 0 | 0 | 2 | 2 | 1 | 1 | 2 | 1 |
| Circuit breakers | 15 | 5 | 2 | 1 | 8 | 5 | 9 | 4 | 1 | 2 | 5 | 2 |
| Control equipment[1] | 13 | 14 | 5 | 8 | 25 | 19 | 23 | 17 | 15 | 7 | 15 | 11 |
| Busbar | 6 | 3 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 |
| Common ancillary equipment | 3 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 0 |
| Disconnectors and earth connectors | 3 | 2 | 1 | 0 | 2 | 0 | 1 | 2 | 1 | 1 | 1 | 1 |
| Surge arresters and spark gaps | 2 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 |
| Other substation faults | 2 | 4 | 1 | 2 | 5 | 2 | 9 | 12 | 5 | 8 | 4 | 7 |
| Substation faults | 58 | 37 | 12 | 14 | 49 | 30 | 52 | 44 | 31 | 27 | 33 | 27 |
| Reactor | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 1 | 1 |
| Series capacitor | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 3 | 1 | 2 |
| Shunt capacitor | 0 | 0 | 0 | 0 | 3 | 2 | 3 | 1 | 0 | 0 | 1 | 1 |
| SVC and statcom | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 4 | 3 | 2 | 2 | 2 |
| Synchronous compensator | 5 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| Compensation faults | 5 | 3 | 2 | 2 | 3 | 3 | 7 | 6 | 6 | 7 | 5 | 5 |
| Faults in adjoining statistical area | 11 | 8 | 0 | 4 | 3 | 7 | 0 | 0 | 7 | 5 | 3 | 4 |
| System faults | 0 | 0 | 0 | 0 | 35 | 19 | 0 | 0 | 2 | 1 | 3 | 1 |
| Unknown | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Other faults | 11 | 8 | 0 | 4 | 38 | 27 | 0 | 0 | 9 | 6 | 6 | 5 |

[1] The category control equipment includes also protection.

Table 6.1.8: Percentage distribution of faults per HVAC component in 2017 and the average in each Baltic country. Estonia uses the period 2008–2017 for its average and Latvia and Lithuania use the period 2012–2017.

| | Estonia | | Latvia[1] | | Lithuania[1] | | Average | |
|---|---|---|---|---|---|---|---|---|
| Fault location | 2017 | 2008–2017 | 2017 | 2012–2017 | 2017 | 2012–2017 | 2017 | 2012–2017 |
| Cable | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| Overhead line | 51 | 68 | 64 | 66 | 60 | 70 | 59 | 68 |
| Line faults | 51 | 68 | 65 | 66 | 60 | 70 | 59 | 68 |
| Power transformers | 13 | 4 | 2 | 5 | 0 | 1 | 4 | 3 |
| Instrument transformers | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 |
| Circuit breakers | 5 | 3 | 2 | 2 | 3 | 5 | 3 | 3 |
| Control equipment[2] | 1 | 2 | 14 | 14 | 11 | 9 | 9 | 7 |
| Busbar | 0 | 1 | 2 | 1 | 1 | 1 | 1 | 1 |
| Common ancillary equipment | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| Disconnectors and earth connectors | 2 | 3 | 1 | 1 | 0 | 1 | 1 | 2 |
| Surge arresters and spark gaps | 0 | 0 | 1 | 0 | 2 | 0 | 1 | 0 |
| Other substation faults | 8 | 8 | 1 | 0 | 1 | 0 | 3 | 5 |
| Substation faults | 30 | 22 | 23 | 24 | 19 | 20 | 24 | 22 |
| Reactor | 2 | 0 | 2 | 1 | 0 | 0 | 1 | 0 |
| Series capacitor | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Shunt capacitor | 8 | 0 | 0 | 0 | 0 | 0 | 2 | 0 |
| SVC and statcom | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| Synchronous compensator | 2 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| Compensation faults | 11 | 1 | 2 | 1 | 1 | 0 | 4 | 1 |
| Faults in adjoining statistical area | 8 | 9 | 10 | 9 | 20 | 10 | 13 | 9 |
| System faults | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Unknown | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Other faults | 8 | 9 | 10 | 9 | 20 | 10 | 13 | 9 |

[1] The average values of Latvia and Lithuania use the period 2012–2017.
[2] The category control equipment includes also protection.

## 6.2 Faults on overhead lines

The tables and figures in this section present overhead line faults in 2017 and during 2008–2017 at the voltage levels 100–150 kV, 220–330 kV and 380–420 kV. Overhead lines and underground cables are the backbone of the transmission grid, that make country wide power transmission possible in the transmissions grids worldwide. Overhead lines are used more often than cables because they are easier and more economical to install and repair. However, they are more prone to faults than underground cables.

Chapter 6.2.1 presents fault statistics for 380–420 kV overhead lines, Chapter 6.2.2 for 220–330 kV overhead lines and Chapter 6.2.3 100–150 kV overhead lines. The figures and tables present the number of faults and permanent faults per 100 km overhead line in 2017 as well as the average values during 2008–2017 in the Nordic countries and Estonia and during 2012–2017 in Latvia and Lithuania. Furthermore, faults according to the cause categories, defined in Chapter 1.4.1, are presented. Finally, Chapter 6.2.4 presents trend figures for the number of faults per 100 km overhead line length. The trends are calculated by 5-year moving averages for the Nordic countries during 1995–2017 and by 3-year moving averages for the Baltic countries during 2007–2017. With the help of the trend curve, it may be possible to estimate the number of faults in the future.

### 6.2.1 380–420 kV overhead lines

This section presents fault statistics for 380–420 kV overhead lines. This includes a table with an overview of overhead line faults and figures with the annual number of faults and faults according to cause in 2017 and the average during 2008–2017. The fault causes used in these statistics are presented in Chapter 1.4.1.

Table 6.2.1 shows the length of 380–420 kV overhead lines and the number of faults for 380–420 kV overhead lines. Furthermore, the percentage of faults that were permanent faults and 1-phase faults are presented. The data consists of the values for the year 2017 and for the period 2008–2017.

It should be noted, that only Denmark, Finland, Lithuania, Norway and Sweden own 380–420 kV equipment. Therefore, only these countries are presented in the figures in this section.

Table 6.2.1: Overview of faults for 380–420 kV overhead lines.

| | Length (km) | Faults | Faults per 100 km | | % of faults during 2008–2017 | |
|---|---|---|---|---|---|---|
| Country | 2017 | 2017 | 2017 | 2008–2017 | 1-phase faults | Permanent faults |
| Denmark | 1314 | 3 | 0.23 | 0.25 | 43.8 | 3.1 |
| Estonia | 0 | 0 | 0.00 | 0.00 | 0.0 | 0.0 |
| Finland | 5927 | 4 | 0.07 | 0.20 | 67.0 | 8.0 |
| Iceland | 0 | 0 | 0.00 | 0.00 | 0.0 | 0.0 |
| Latvia | 0 | 0 | 0.00 | 0.00 | 0.0 | 0.0 |
| Lithuania[1] | 102 | 1 | 0.98 | 1.47 | 100.0 | 33.3 |
| Norway | 3266 | 33 | 1.01 | 1.11 | 69.1 | 5.7 |
| Sweden | 10564 | 22 | 0.21 | 0.35 | 82.6 | 2.4 |
| Nordic | 21071 | 62 | 0.29 | 0.41 | 74.0 | 4.4 |
| Baltic | 102 | 1 | 0.98 | 1.47 | 100.0 | 33.3 |
| Nordic & Baltic | 21173 | 63 | 0.30 | 0.41 | 74.1 | 4.5 |

[1] Lithuania started maintaining their 380–420 kV grid in 2012. Therefore, their average use the period 2012–2017.

Figure 6.2.1 presents the annual number of 380–420 kV overhead line faults per 100 km line length during 2008–2017 and the average for the period 2008–2017 in Denmark, Finland, Lithuania, Norway and Sweden. Figure 6.2.2 presents the same, but for 380–420 kV permanent overhead line faults per 100 km line length.

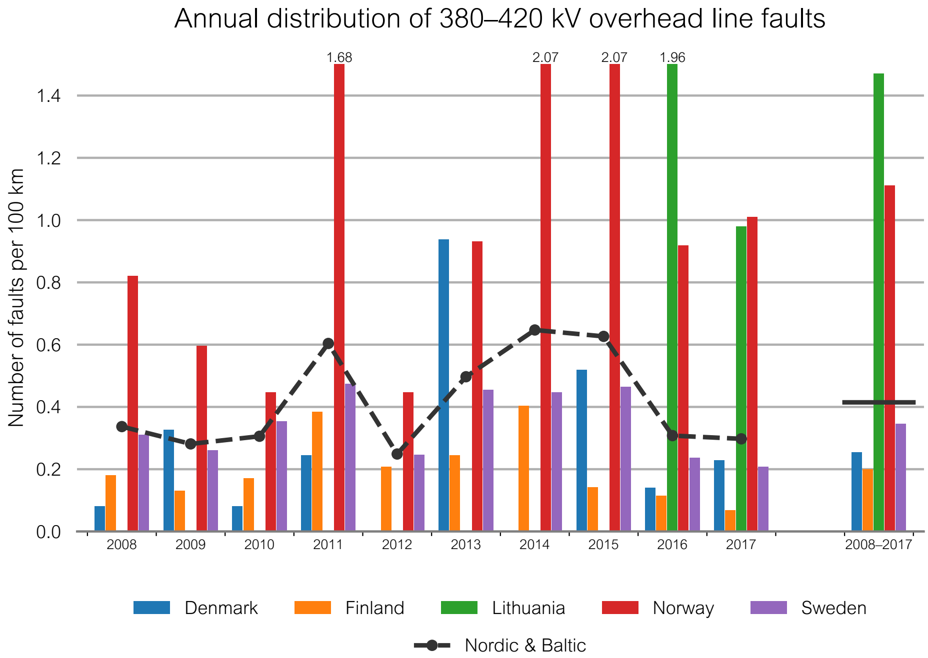


Figure 6.2.1: Annual distribution of 380–420 kV overhead line faults and the average during 2008–2017 in Denmark, Finland, Lithuania, Norway and Sweden.

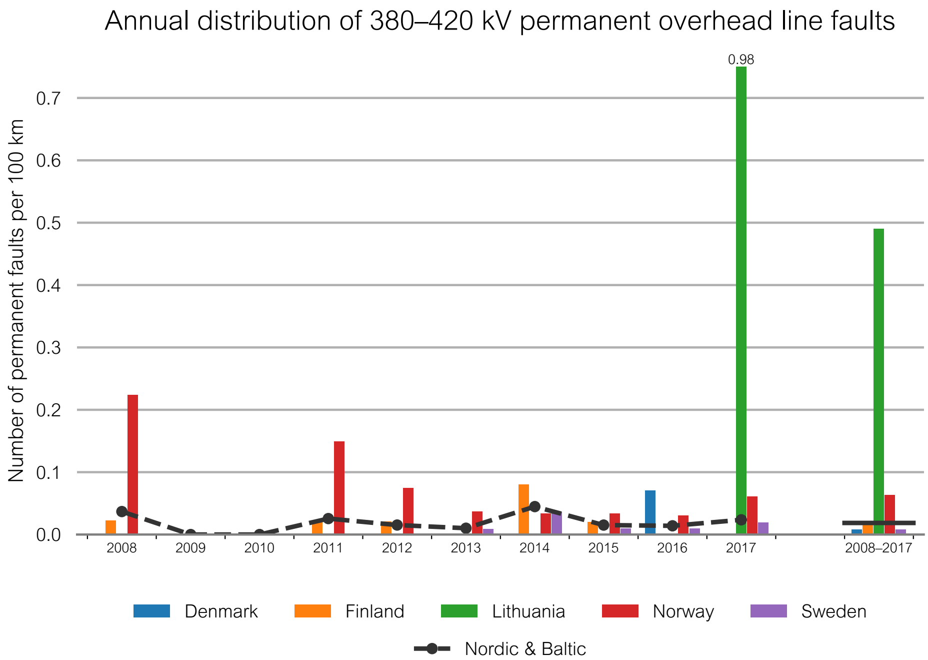


Figure 6.2.2: Annual distribution of 380–420 kV permanent overhead line faults and the average during 2008–2017 in Denmark, Finland, Lithuania, Norway and Sweden.

Figure 6.2.3 presents the number of 380–420 kV overhead line faults per cause in 2017 in Denmark, Finland, Lithuania, Norway and Sweden.

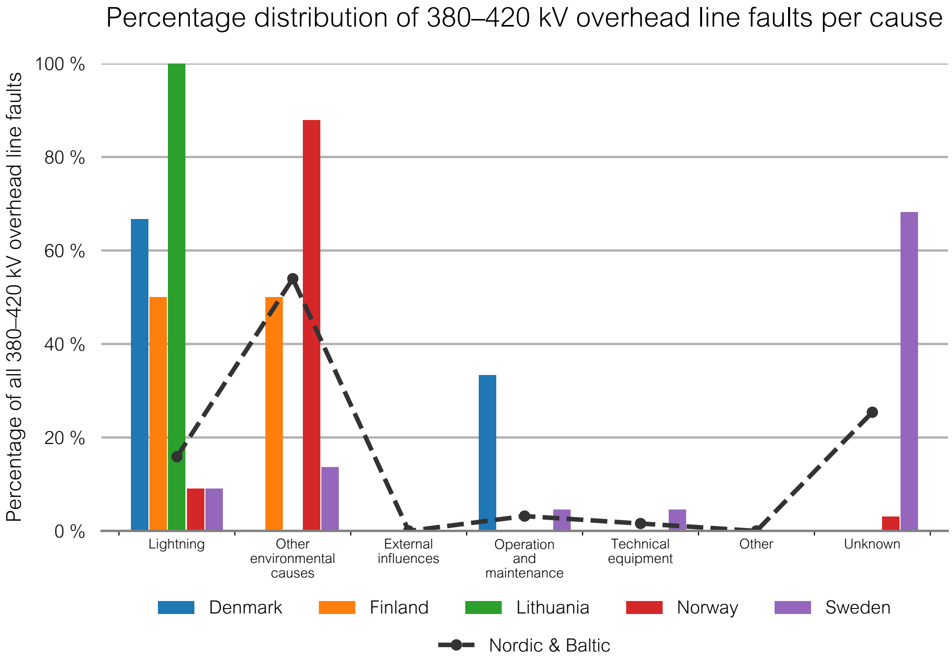


Figure 6.2.3: Percentage distribution of 380–420 kV overhead line faults per cause in 2017 in Denmark, Finland, Lithuania, Norway and Sweden.

Figure 6.2.4 presents the average number of 380–420 kV overhead line faults per cause during 2008–2017 in Denmark, Finland, Lithuania, Norway and Sweden.

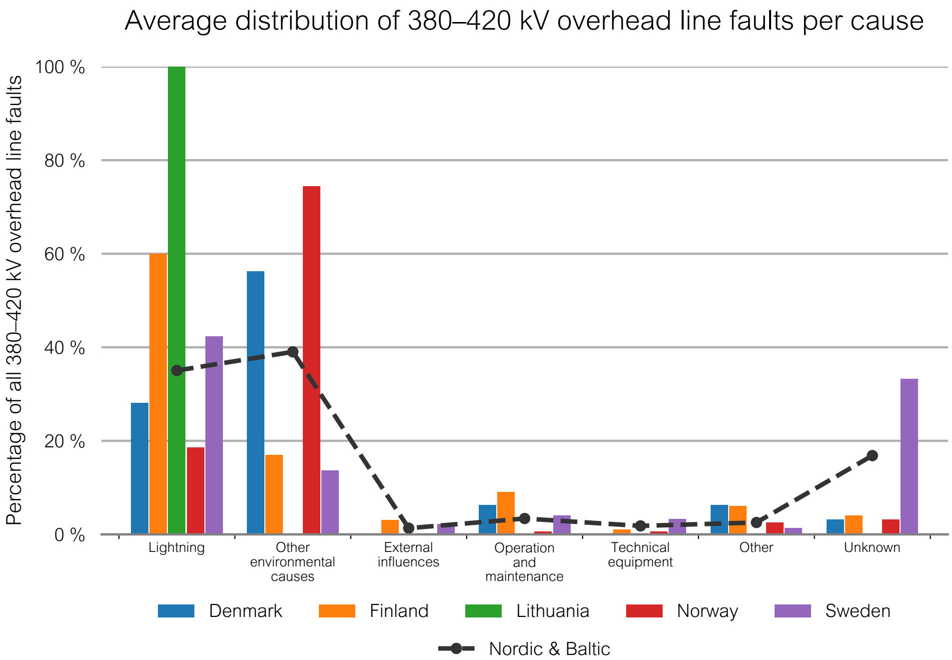


Figure 6.2.4: Average distribution of 380–420 kV overhead line faults per cause during 2008–2017 in Denmark, Finland, Lithuania, Norway and Sweden.

### 6.2.2 220–330 kV overhead lines

This section presents fault statistics for 220–330 kV overhead lines. This includes a table with an overview of overhead line faults and figures with the annual number of faults and faults according to cause in 2017 and the average during 2008–2017. The fault causes used in these statistics are presented in Chapter 1.4.1.

Table 6.2.2 shows the length of 220–330 kV overhead lines and the number of faults for 220–330 kV overhead lines. Furthermore, the percentage of faults that were permanent faults and 1-phase faults are presented. The data consists of the values for the year 2017 and for the period 2008–2017.

Table 6.2.2: Overview of faults for 220–330 kV overhead lines.

| | Length (km) | Faults | Faults per 100 km | | % of faults during 2008–2017 | |
|---|---|---|---|---|---|---|
| Country | 2017 | 2017 | 2017 | 2008–2017 | 1-phase faults | Permanent faults |
| Denmark | 65 | 1 | 1.53 | 0.49 | 100.0 | 0.0 |
| Estonia | 1856 | 4 | 0.22 | 0.82 | 47.2 | 42.4 |
| Finland | 1639 | 3 | 0.18 | 0.63 | 74.5 | 4.7 |
| Iceland | 857 | 2 | 0.23 | 0.34 | 0.0 | 3.4 |
| Latvia[1] | 1333 | 7 | 0.53 | 0.72 | 88.1 | 16.9 |
| Lithuania[1] | 1761 | 5 | 0.28 | 0.75 | 89.7 | 15.4 |
| Norway | 5355 | 8 | 0.15 | 0.74 | 64.2 | 7.6 |
| Sweden | 4028 | 19 | 0.47 | 0.76 | 60.5 | 4.2 |
| Nordic | 11943 | 33 | 0.28 | 0.70 | 62.7 | 5.8 |
| Baltic | 4950 | 16 | 0.32 | 0.78 | 67.6 | 29.5 |
| Nordic & Baltic | 16893 | 49 | 0.29 | 0.71 | 63.9 | 11.4 |

[1] The average values of Latvia and Lithuania use the period 2012–2017.

Figure 6.2.5 and Figure 6.2.6 present the annual number of 220–330 kV overhead line faults per 100 km line length during 2008–2017 and the average for the period 2008–2017 in the Nordic and Baltic countries, respectively. Figure 6.2.7 and Figure 6.2.8 present the same, but for permanent 220–330 kV overhead line faults per 100 km line length.

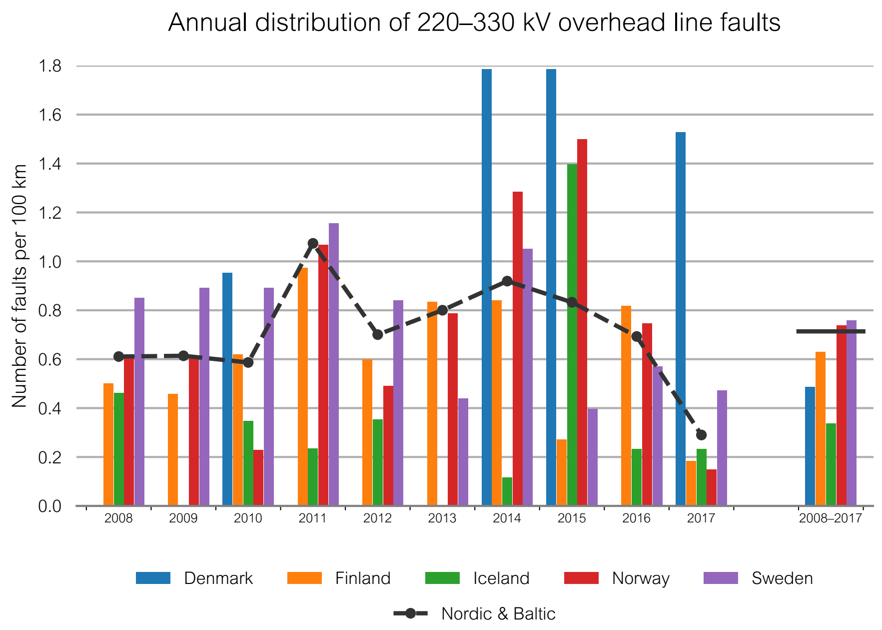


Figure 6.2.5: Annual distribution of 220–330 kV overhead lines faults and the average during 2008–2017 in each Nordic country.

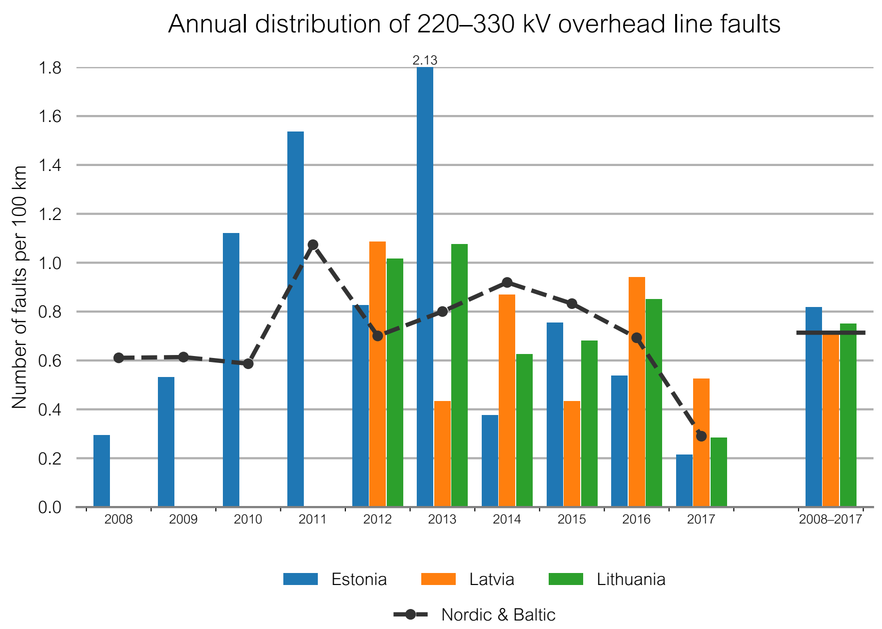


Figure 6.2.6: Annual distribution of 220–330 kV overhead lines faults and the average during 2008–2017 in Estonia and during 2012–2017 in Latvia and Lithuania. This figure has the following remarks:

- Estonia has worked extensively to decrease the number of faults in their 100–150 kV overhead lines. This has been done by cutting trees, fixing dimensions and so on in order to improve the line corridors. Furthermore, there has not been any great storms lately.

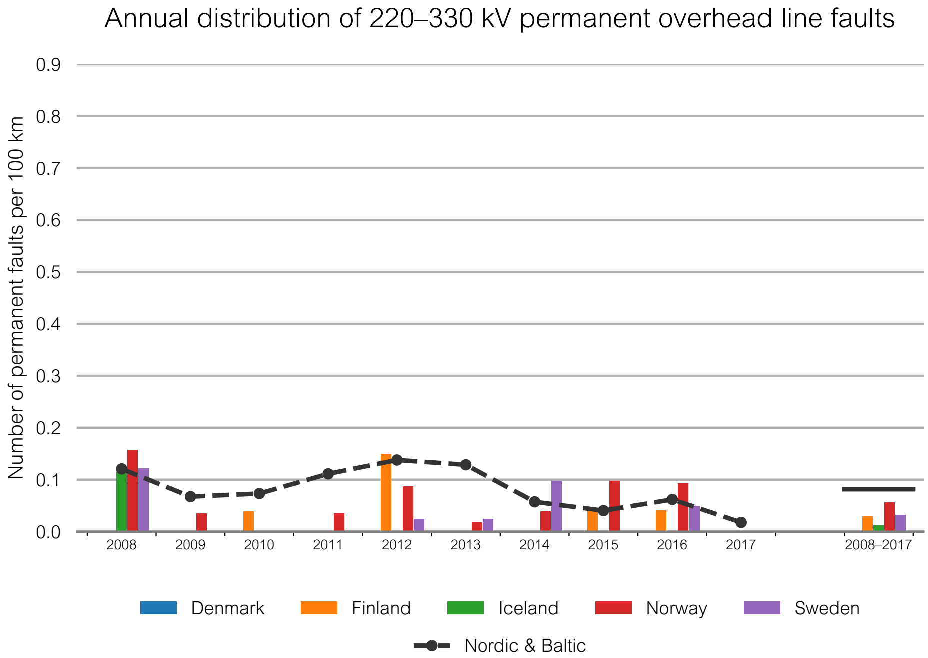


Figure 6.2.7: Annual distribution of for 220–330 kV permanent overhead line faults and the average during 2008–2017 in each Nordic country. This figure has the following remarks:

- Denmark's high values are caused by a minimal amount of faults because they own a relatively short length of overhead lines compared to the other countries.

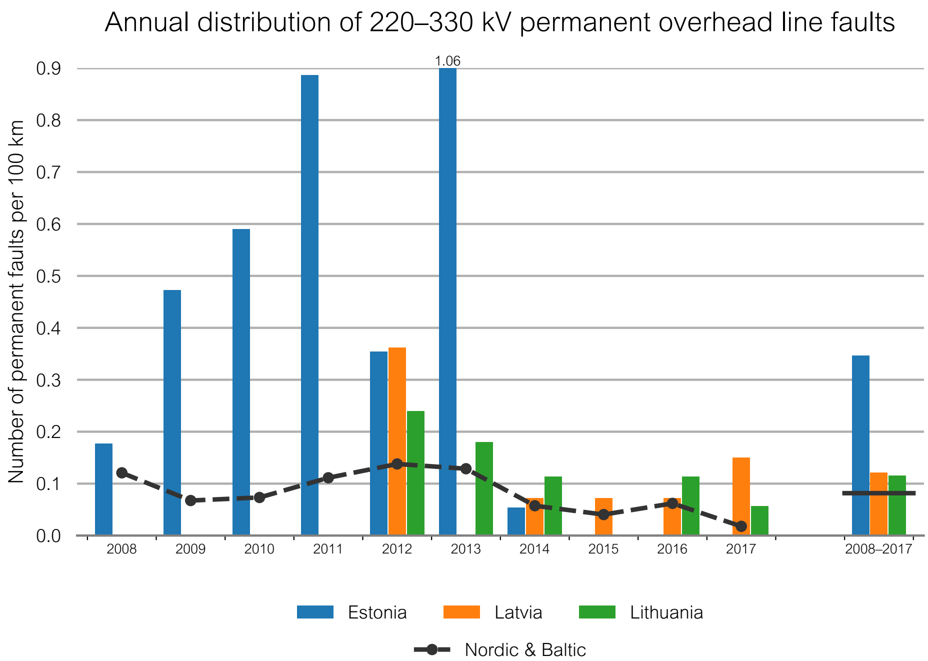


Figure 6.2.8: Annual distribution of for 220–330 kV permanent overhead line faults and the average during 2008–2017 in Estonia and during 2012–2017 in Latvia and Lithuania.

Figure 6.2.9 and Figure 6.2.10 present the number of 220–330 kV overhead line faults per cause in 2017 in the Nordic and Baltic countries.

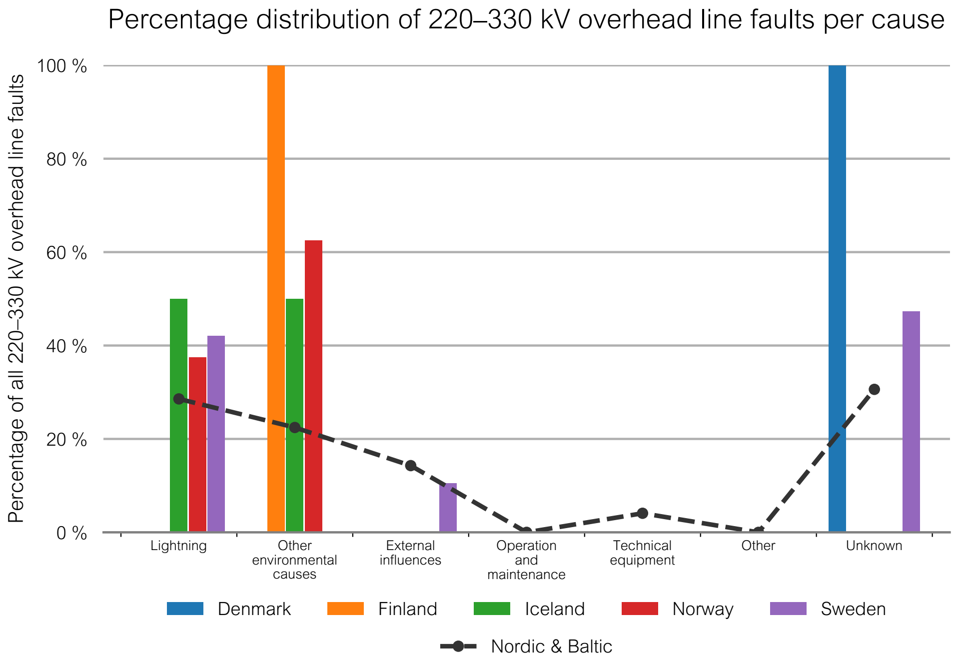


Figure 6.2.9: Percentage distribution of 220–330 kV overhead line faults per cause in 2017 in each Nordic country.

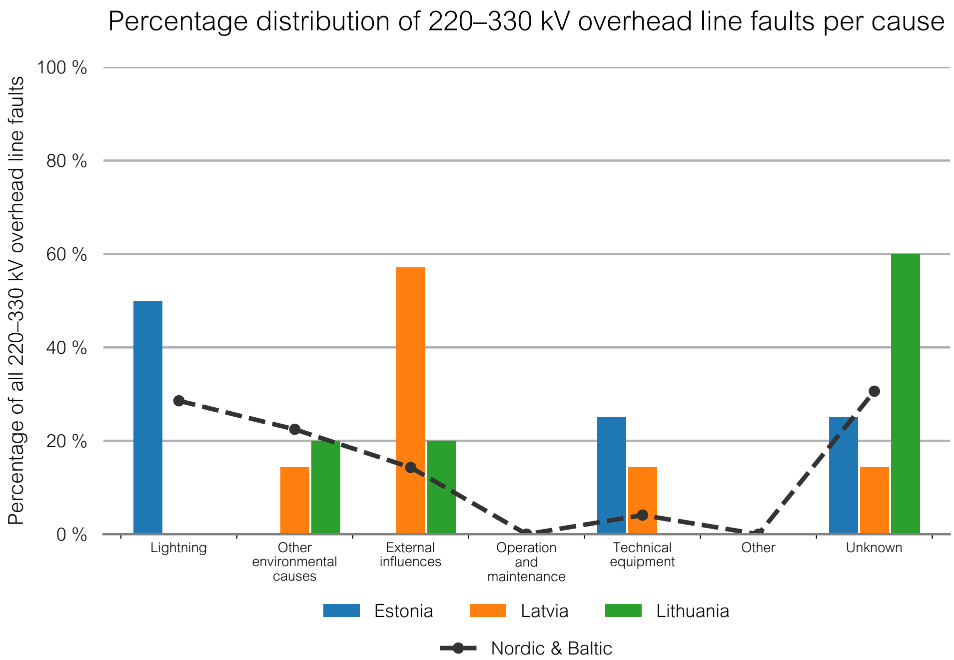


Figure 6.2.10: Percentage distribution of 220–330 kV overhead line faults per cause in 2017 in each Baltic country.

Figure 6.2.11 and Figure 6.2.12 present the average number of 220–330 kV overhead line faults per cause during 2008–2017 in the Nordic countries and Estonia and during 2012–2017 in Latvia and Lithuania.

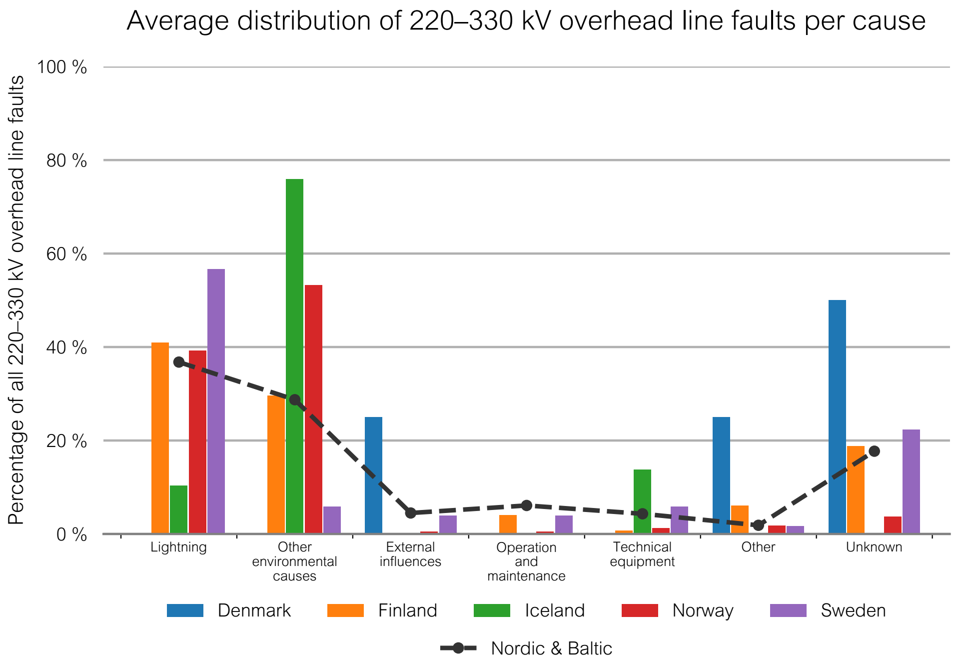


Figure 6.2.11: Average distribution of 220–330 kV overhead line faults per cause during 2008–2017 in each Nordic country.

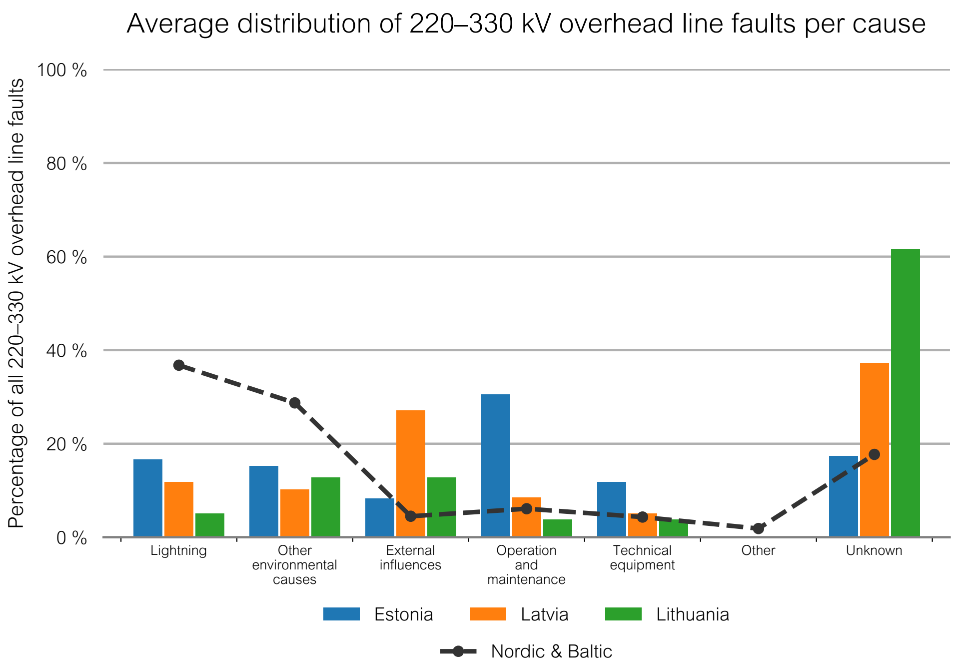


Figure 6.2.12: Average distribution of 220–330 kV overhead line faults per cause during 2008–2017 in Estonia and during 2012–2017 in Latvia and Lithuania.

### 6.2.3 100–150 kV overhead lines

This section presents fault statistics for 100–150 kV overhead lines. This includes a table with an overview of overhead line faults and figures with the annual number of faults and faults according to cause in 2017 and the average during 2008–2017. The fault causes used in these statistics are presented in Chapter 1.4.1.

Table 6.2.3 shows the length of 100–150 kV overhead lines and the number of faults for 100–150 kV overhead lines. Furthermore, the percentage of faults that were permanent faults and 1-phase faults are presented. The data consists of the values for the year 2017 and for the period 2008–2017.

Table 6.2.3: Overview of faults for 100–150 kV overhead lines.

| | Length (km) | Faults | Faults per 100 km | | % of faults during 2008–2017 | |
|---|---|---|---|---|---|---|
| Country | 2017 | 2017 | 2017 | 2008–2017 | 1-phase faults | Permanent faults |
| Denmark | 3013 | 9 | 0.30 | 0.75 | 57.8 | 3.9 |
| Estonia | 3429 | 63 | 1.84 | 3.94 | 40.2 | 14.7 |
| Finland | 17071 | 285 | 1.67 | 2.06 | 74.1 | 4.4 |
| Iceland | 1248 | 4 | 0.32 | 1.29 | 1.2 | 0.6 |
| Latvia[1] | 3818 | 102 | 2.67 | 2.46 | 75.4 | 36.6 |
| Lithuania[1] | 4980 | 86 | 1.73 | 2.19 | 88.2 | 15.7 |
| Norway[2] | 10736 | 74 | 0.69 | 0.89 | 35.0 | 20.8 |
| Sweden | 14960 | 108 | 0.72 | 1.52 | 24.1 | 4.2 |
| Nordic | 47029 | 480 | 1.02 | 1.51 | 50.4 | 6.4 |
| Baltic | 12227 | 251 | 2.05 | 2.95 | 60.2 | 19.8 |
| Nordic & Baltic | 59255 | 731 | 1.23 | 1.73 | 53.0 | 10.0 |

[1] The average values of Latvia and Lithuania use the period 2012–2017.
[2] The Norwegian grid includes a resonant earthed system, which contributes to the low number of single-phase earth faults in Norway.

Figure 6.2.13 and Figure 6.2.14 present the annual number of 100–150 kV overhead line faults per 100 km line length during 2008–2017 and the average for the period 2008–2017 in the Nordic and Baltic countries, respectively. Figure 6.2.15 and Figure 6.2.16 present the same, but for permanent 100–150 kV overhead line faults per 100 km line length.

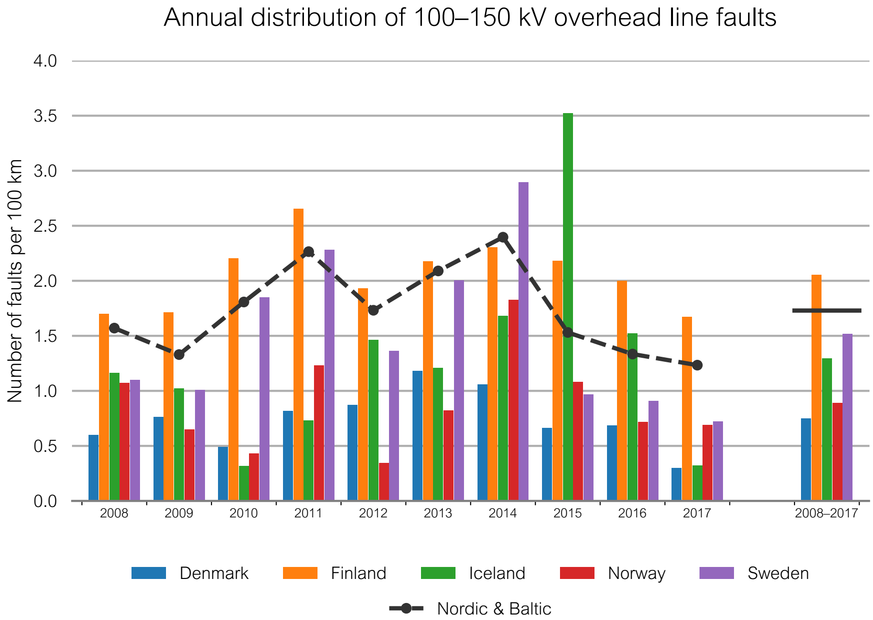


Figure 6.2.13: Annual distribution of 100–150 kV overhead line faults and the average during 2008–2017 in each Nordic country.

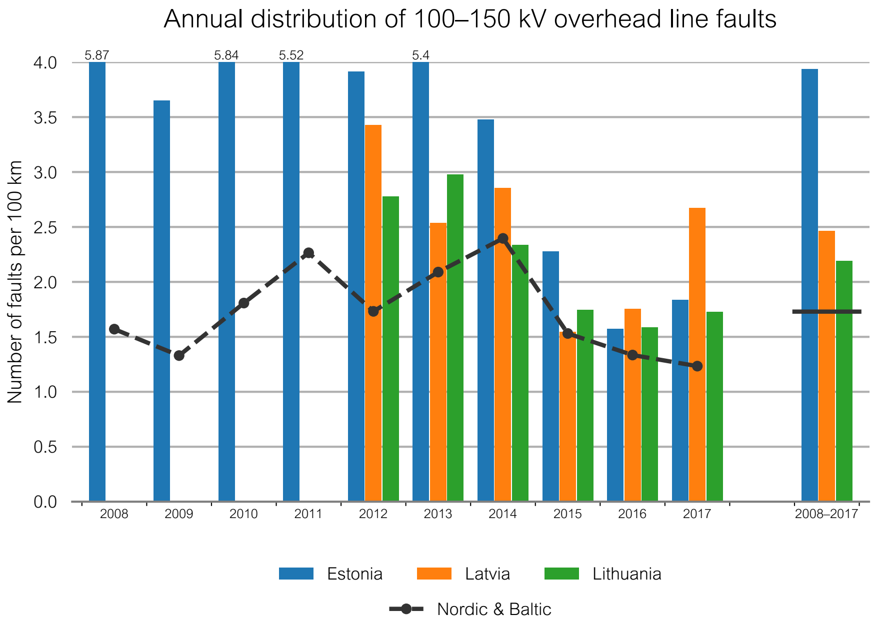


Figure 6.2.14: Annual distribution of 100–150 kV overhead line faults and the average during 2008–2017 in Estonia and during 2012–2017 in Latvia and Lithuania. This figure has the following remarks:

- Estonia has worked extensively to decrease the number of faults in their 100–150 kV overhead lines. This has been done by cutting trees, fixing dimensions and so on in order to improve the line corridors. Furthermore, there has not been any great storms lately.

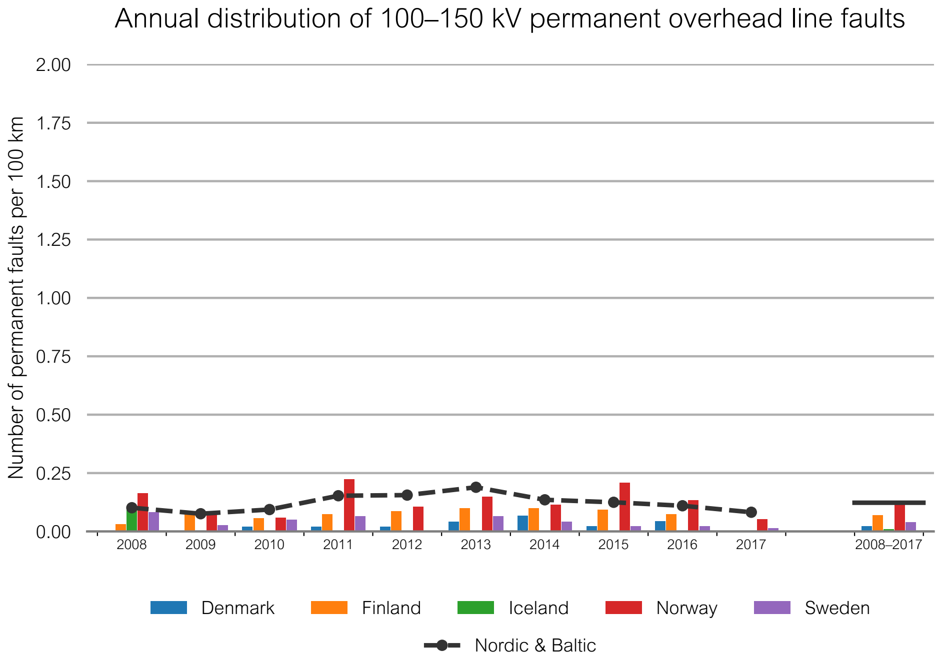


Figure 6.2.15: Annual distribution of 100–150 kV permanent overhead line faults and the average during 2008–2017 in each Nordic country.

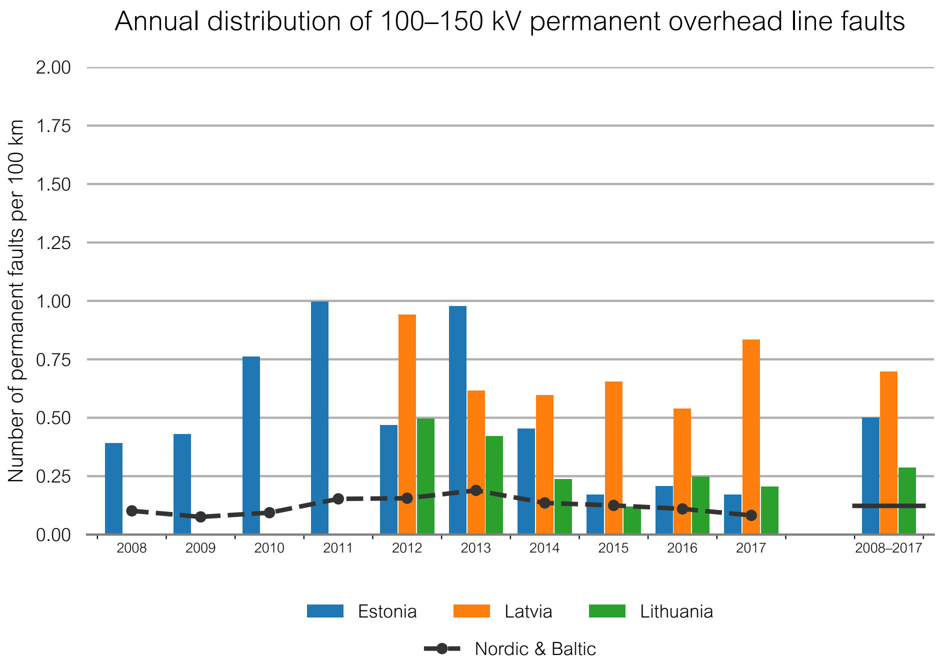


Figure 6.2.16: Annual distribution of 100–150 kV permanent overhead line faults and the average during 2008–2017 in Estonia and during 2012–2017 in Latvia and Lithuania.

Figure 6.2.17 and Figure 6.2.18 present the number of 100–150 kV overhead line faults per cause in 2017 in the Nordic and Baltic countries.

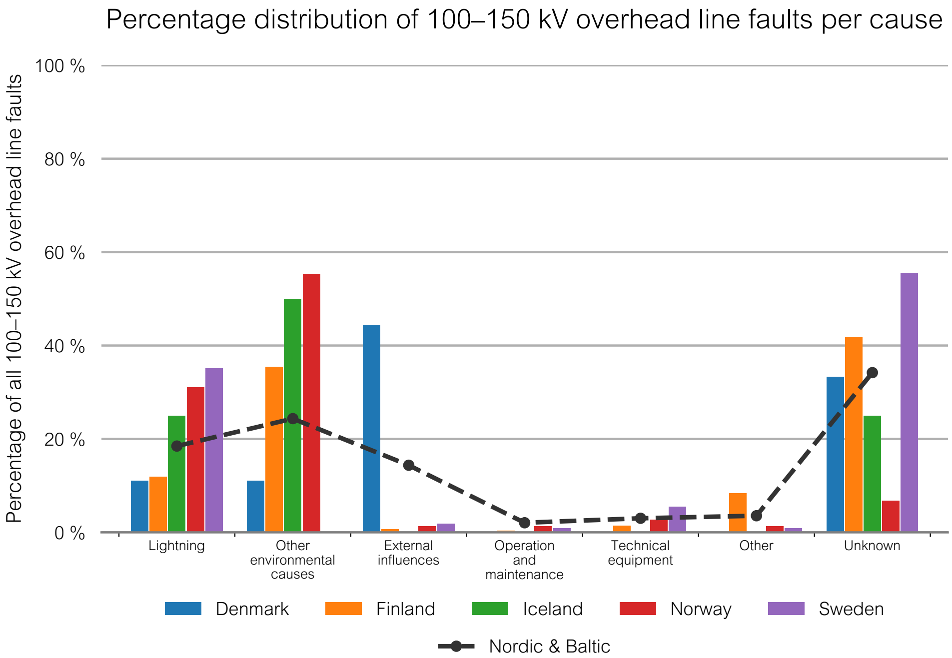


Figure 6.2.17: Percentage distribution of 100–150 kV overhead line faults per cause in 2017 in each Nordic country.

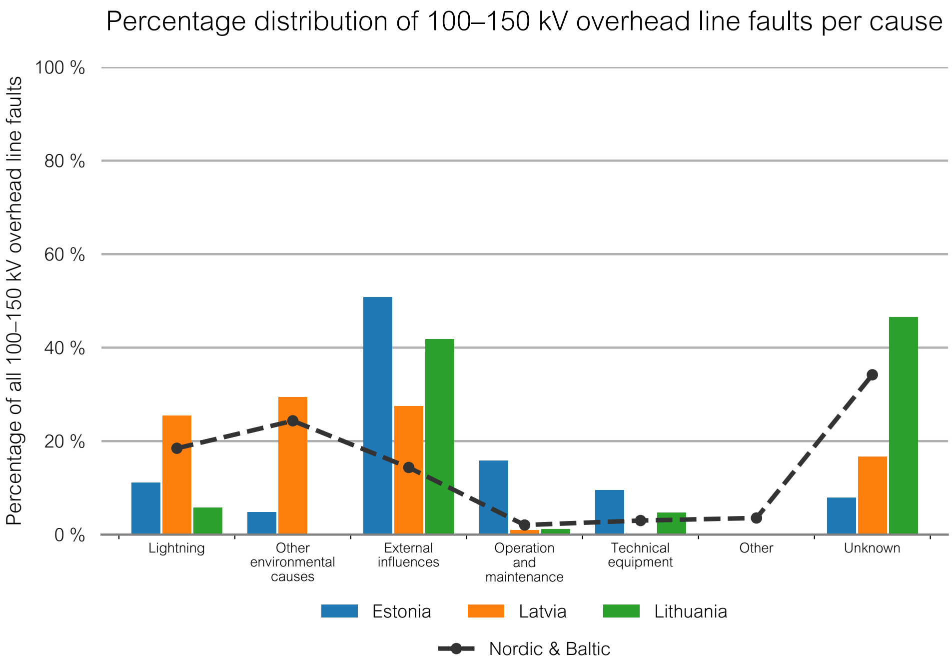


Figure 6.2.18: Percentage distribution of 100–150 kV overhead line faults per cause in 2017 in each Baltic country.

Figure 6.2.19 and Figure 6.2.20 present the average number of 100–150 kV overhead line faults per cause during 2008–2017 in the Nordic countries and Estonia and during 2012–2017 in Latvia and Lithuania.

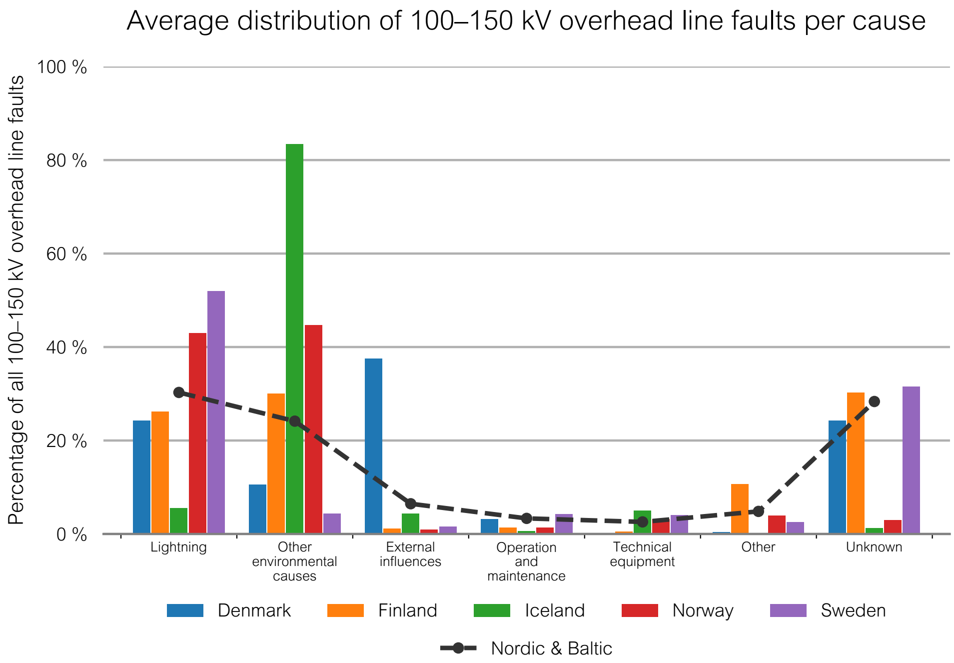


Figure 6.2.19: Average distribution of 100–150 kV overhead line faults per cause during 2008–2017 in each Nordic country.

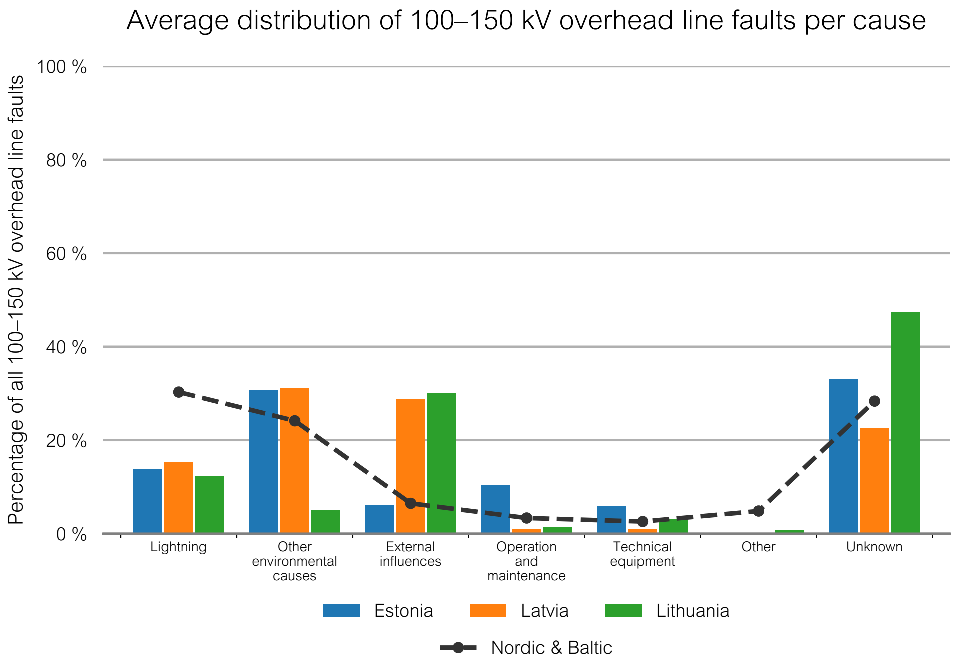


Figure 6.2.20: Average distribution of 100–150 kV overhead line faults per cause during 2008–2017 in Estonia and during 2012–2017 in Latvia and Lithuania.

## 6.2.4 Fault trends for overhead lines

The figures in this section present fault trends for overhead lines at the voltage levels 100–150 kV, 220–330 kV and 380–420 kV. The Nordic countries use a 5-year rolling average, that is calculated by dividing the sum of the faults by the total overhead line length for each 5-year period. The rolling average for the Baltic countries is calculated similarly, but with 3-year periods. The trend curves are proportioned to overhead line length in order to get comparable results between countries.

Figure 6.2.21 presents 380–420 kV fault trends for Denmark, Finland, Lithuania, Norway and Sweden, Figure 6.2.22 presents the Nordic 220–330 kV fault trends, Figure 6.2.23 presents the Baltic 220–330 kV fault trends, Figure 6.2.24 presents the Nordic 100–150 kV fault trends and Figure 6.2.25 presents the Baltic 100–150 kV fault trends.

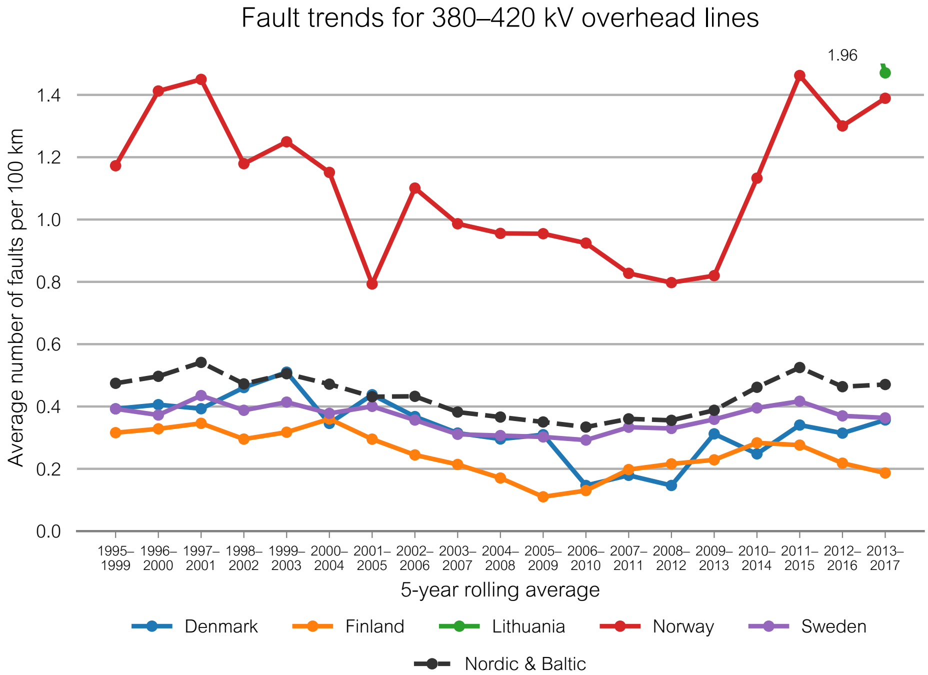


Figure 6.2.21: Fault trends as 5-year rolling averages for 380–420 kV overhead lines in Denmark, Finland, Lithuania, Norway and Sweden.

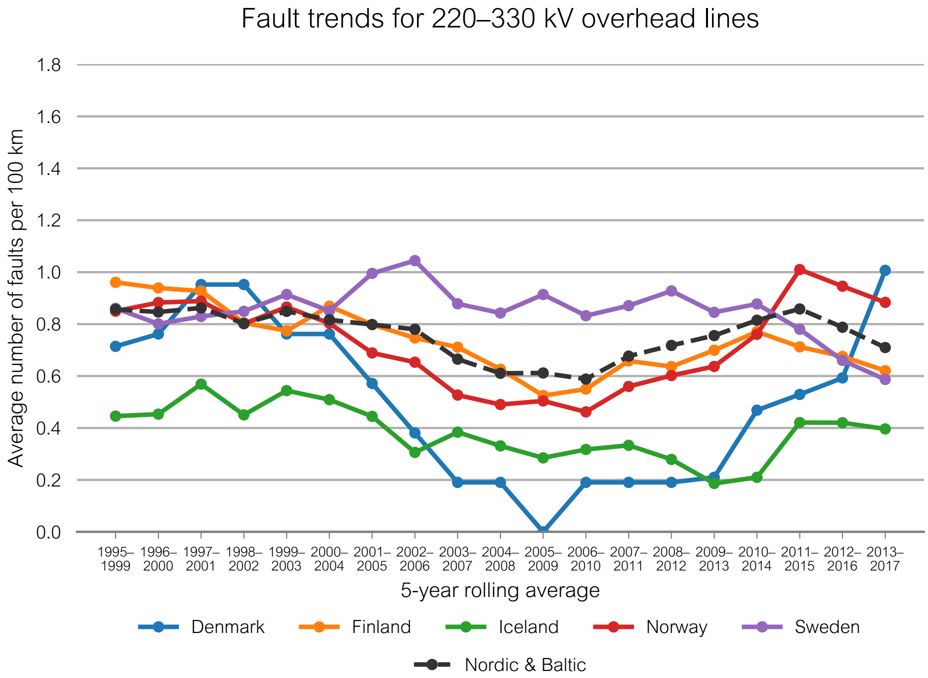


Figure 6.2.22: Fault trends as 5-year rolling averages for 220–330 kV overhead lines in each Nordic country.

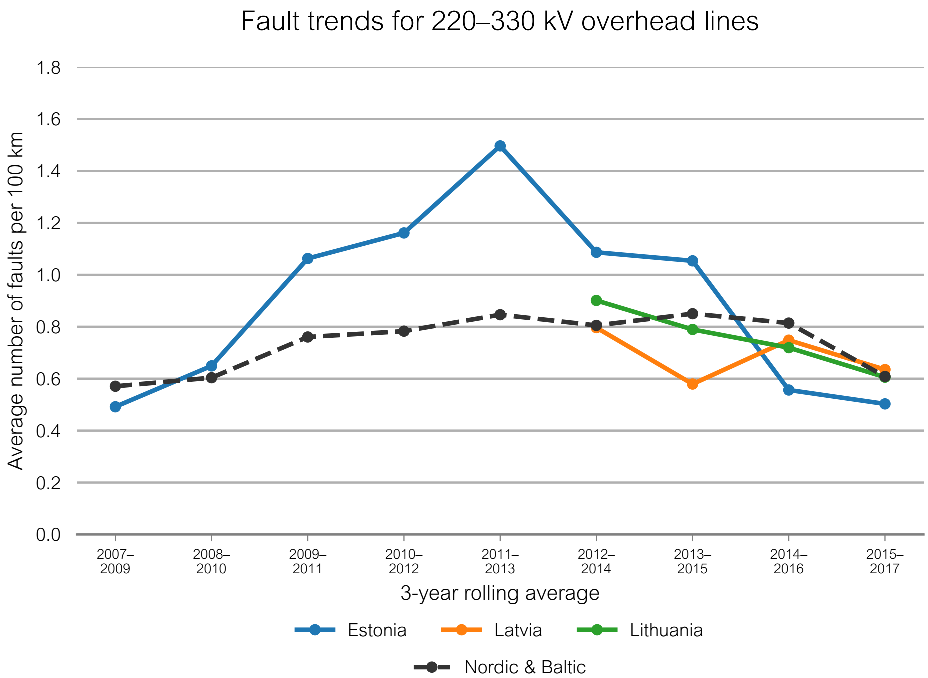


Figure 6.2.23: Fault trends as 3-year rolling averages for 220–330 kV overhead lines in each Baltic country. This figure has the following remarks:

- Estonia has worked extensively to decrease the number of faults in their 100–150 kV overhead lines. This has been done by cutting trees, fixing dimensions and so on in order to improve the line corridors. Furthermore, there has not been any great storms lately.

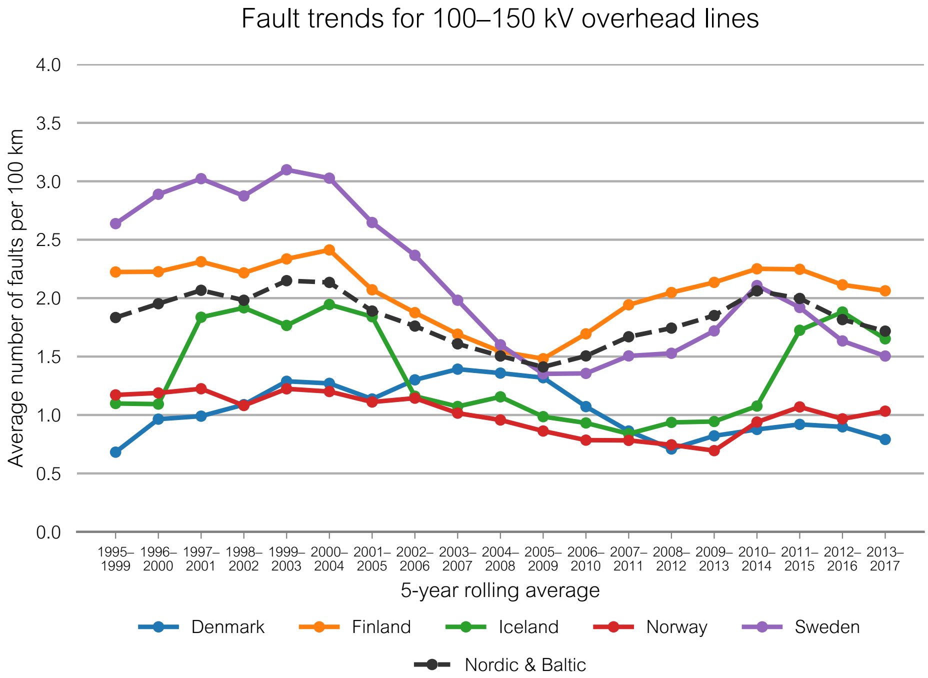


Figure 6.2.24: Fault trends as 5-year rolling averages for 100–150 kV overhead lines in each Nordic country.

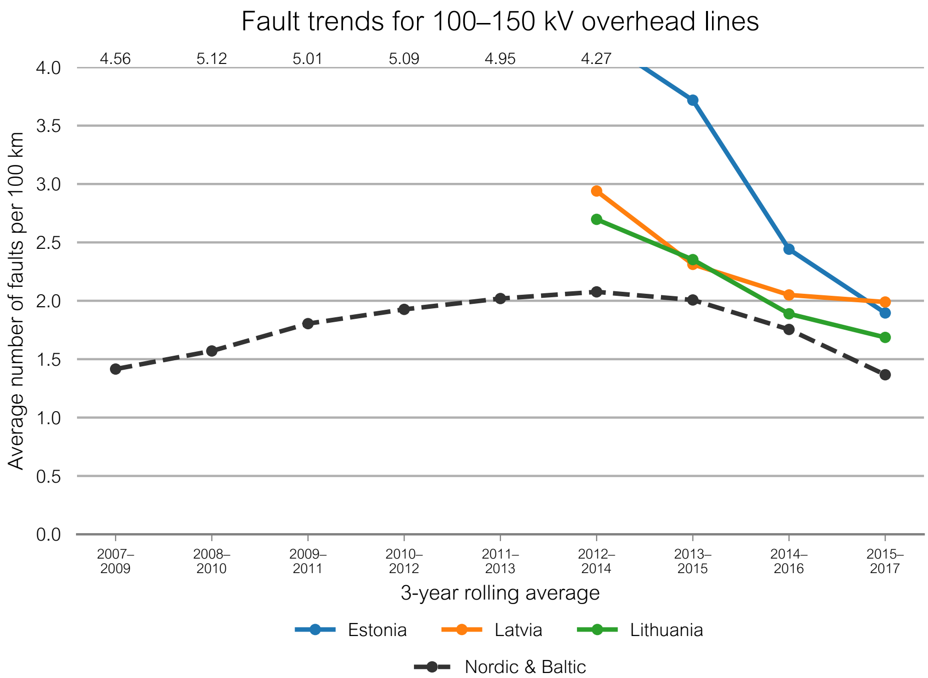


Figure 6.2.25: Fault trends as 3-year rolling averages for 100–150 kV overhead lines in each Baltic country. This figure has the following remarks:

- Estonia has worked extensively to decrease the number of faults in their 100–150 kV overhead lines. This has been done by cutting trees, fixing dimensions and so on in order to improve the line corridors. Furthermore, there has not been any great storms lately.

## 6.3 Faults in cables

The tables and figures in this section present cable faults in 2017 and during 2008–2017 at the voltage levels 100–150 kV, 220–330 kV and 380–420 kV. Underground cables and overhead lines are the parts that make country wide power transmission possible in the transmissions grids worldwide. Overhead lines are used more often than cables because they are easier and more economical to install and repair. However, they are more prone to faults than underground cables.

Chapter 6.3.1 presents fault statistics for 380–420 kV cables, Chapter 6.3.2 for 220–330 kV cables and Chapter 6.3.3 100–150 kV cables. The figures and tables present the number of faults and permanent faults per 100 km cable in 2017 as well as the average values during 2008–2017 in the Nordic countries and Estonia and during 2012–2017 in Latvia and Lithuania. Furthermore, faults according to the cause categories, defined in Chapter 1.4.1, are presented. Finally, Chapter 6.3.4 presents trend figures for the number of faults per 100 km cable length. The trends are calculated by 5-year moving averages for the Nordic countries during 1995–2017 and by 3-year moving averages for the Baltic countries during 2007–2017. With the help of the trend curve, it may be possible to estimate the number of faults in the future.

### 6.3.1 380–420 kV cables

This section presents fault statistics for 380–420 kV cables. This includes a table with an overview of cable faults and figures with the annual number of faults and faults according to cause in 2017 and the average during 2008–2017. The fault causes used in these statistics are presented in Chapter 1.4.1.

Table 6.3.1 shows the length of 380–420 kV cables and the number of faults for 380–420 kV cables. Furthermore, the percentage of faults that were permanent faults and 1-phase faults are presented. The data consists of the values for the year 2017 and for the period 2008–2017.

It should be noted, that only Denmark, Finland, Lithuania, Norway and Sweden own 380–420 kV equipment. Therefore, only these countries are presented in the figures in this section.

Table 6.3.1: Overview of faults for 380–420 kV cables.

| | Length (km) | Faults | Faults per 100 km | | % of faults during 2008–2017 | |
|---|---|---|---|---|---|---|
| Country | 2017 | 2017 | 2017 | 2008–2017 | 1-phase faults | Permanent faults |
| Denmark | 204 | 0 | 0.00 | 0.10 | 100.0 | 100.0 |
| Estonia | 0 | 0 | 0.00 | 0.00 | 0.0 | 0.0 |
| Finland | 0 | 0 | 0.00 | 0.00 | 0.0 | 0.0 |
| Iceland | 0 | 0 | 0.00 | 0.00 | 0.0 | 0.0 |
| Latvia | 0 | 0 | 0.00 | 0.00 | 0.0 | 0.0 |
| Lithuania[1] | 0 | 0 | 0.00 | 0.00 | 0.0 | 0.0 |
| Norway[2] | 25 | 1 | 4.00 | 2.80 | 42.9 | 100.0 |
| Sweden | 15 | 1 | 6.80 | 1.07 | 100.0 | 100.0 |
| Nordic | 244 | 2 | 0.82 | 0.65 | 55.6 | 100.0 |
| Baltic | 0 | 0 | 0.00 | 0.00 | 0.0 | 0.0 |
| Nordic & Baltic | 244 | 2 | 0.82 | 0.65 | 55.6 | 100.0 |

[1] Lithuania started maintaining their 380–420 kV grid in 6. Therefore, their average use the period 2016–2017.
[2] Cables in Norway include cables in resonant earthed grids.

Figure 6.3.1 presents the annual number of 380–420 kV cable faults per 100 km line length during 2008–2017 and the average for the period 2008–2017 in Denmark, Finland, Lithuania, Norway and Sweden.

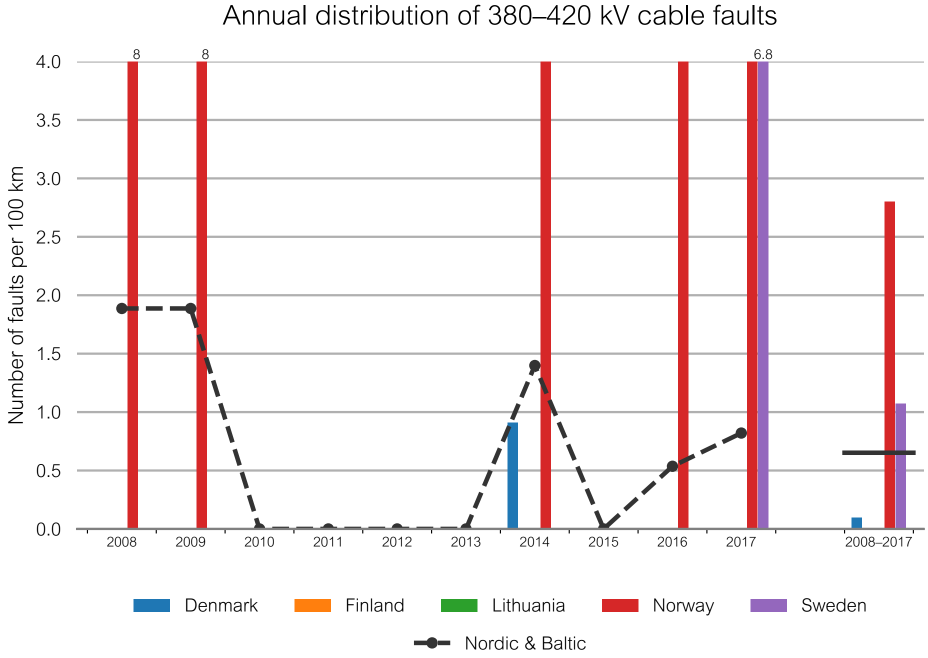


Figure 6.3.1: Annual distribution of 380–420 kV cable faults and the average during 2008–2017 in Denmark, Finland, Lithuania, Norway and Sweden. Only Denmark, Norway and Sweden own cables in the 380–420 kV voltage level.

- Norway's and Sweden's high values are caused by a minimal amount of faults because they own a relatively short length of cables compared to the other countries.

Figure 6.3.2 presents the number of 380–420 kV cable faults per cause in 2017 in Denmark, Finland, Lithuania, Norway and Sweden.

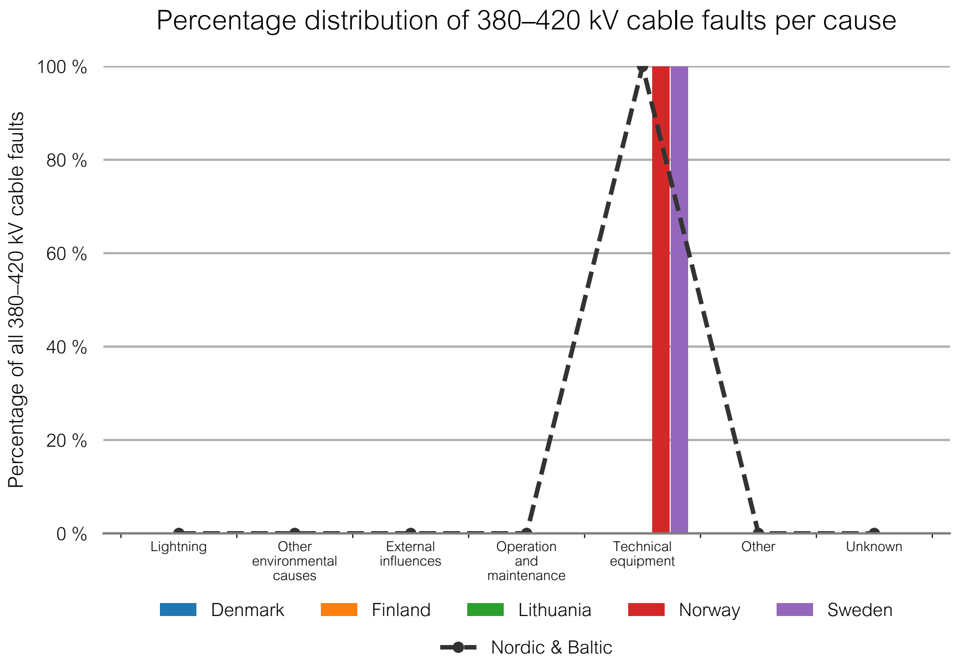


Figure 6.3.2: Percentage distribution of 380–420 kV cable faults per cause in 2017 in Denmark, Finland, Lithuania, Norway and Sweden. Only Denmark, Norway and Sweden own cables in the 380–420 kV voltage level.

Figure 6.3.3 presents the average number of 380–420 kV cable faults per cause during 2008–2017 in Denmark, Finland, Lithuania, Norway and Sweden.

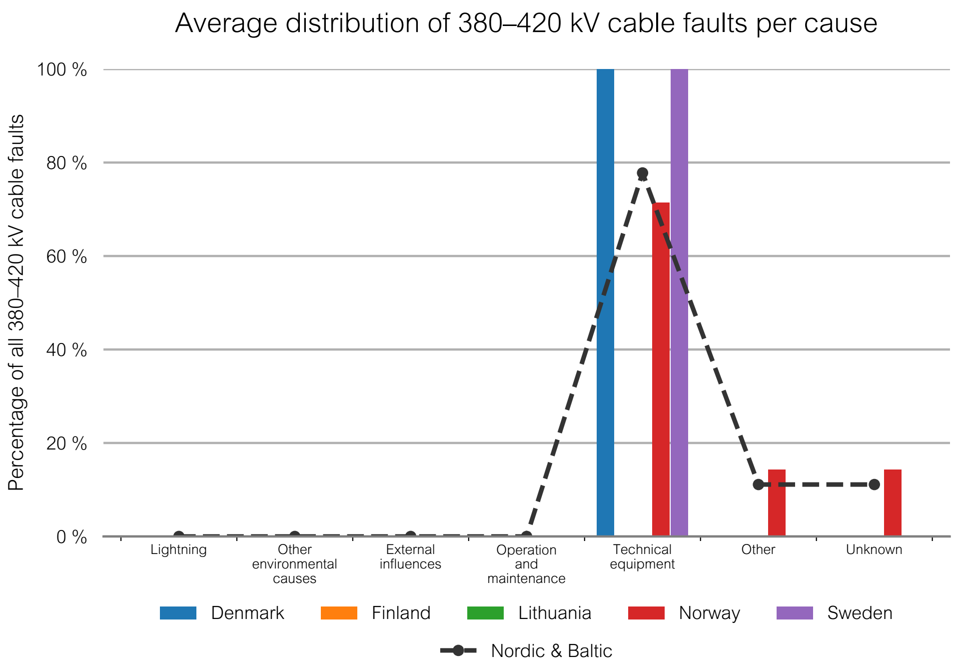


Figure 6.3.3: Percentage distribution of 380–420 kV cable faults per cause during 2008–2017 in Denmark, Finland, Lithuania, Norway and Sweden. Only Denmark, Norway and Sweden own cables in the 380–420 kV voltage level.

## 6.3.2 220–330 kV cables

This section presents fault statistics for 220–330 kV cables. This includes a table with an overview of cable faults and figures with the annual number of faults and faults according to cause in 2017 and the average during 2008–2017. The fault causes used in these statistics are presented in Chapter 1.4.1.

Table 6.3.2 shows the length of 220–330 kV cables and the number of faults for 220–330 kV cables. Furthermore, the percentage of faults that were permanent faults and 1-phase faults are presented. The data consists of the values for the year 2017 and for the period 2008–2017.

Table 6.3.2: Overview of faults for 220–330 kV cables.

| | Length (km) | Faults | Faults per 100 km | | % of faults during 2008–2017 | |
|---|---|---|---|---|---|---|
| Country | 2017 | 2017 | 2017 | 2008–2017 | 1-phase faults | Permanent faults |
| Denmark | 164 | 0 | 0.00 | 0.36 | 100.0 | 100.0 |
| Estonia | 0 | 0 | 0.00 | 0.00 | 0.0 | 0.0 |
| Finland | 0 | 0 | 0.00 | 0.00 | 0.0 | 0.0 |
| Iceland | 1 | 0 | 0.00 | 0.00 | 0.0 | 0.0 |
| Latvia[1] | 14 | 1 | 7.33 | 1.22 | 100.0 | 100.0 |
| Lithuania[1] | 0 | 0 | 0.00 | 0.00 | 0.0 | 0.0 |
| Norway[2] | 98 | 0 | 0.00 | 0.14 | 100.0 | 100.0 |
| Sweden | 170 | 1 | 0.59 | 1.22 | 20.0 | 73.3 |
| Nordic | 433 | 1 | 0.23 | 0.71 | 33.3 | 77.8 |
| Baltic | 14 | 1 | 7.33 | 1.22 | 100.0 | 100.0 |
| Nordic & Baltic | 447 | 2 | 0.45 | 0.73 | 36.8 | 78.9 |

[1] The average values of Latvia and Lithuania use the period 2012–2017.
[2] Cables in Norway include cables in resonant earthed grids.

Figure 6.3.4 and Figure 6.3.5 present the annual number of 220–330 kV cable faults per 100 km line length during 2008–2017 and the average for the period 2008–2017 in the Nordic and Baltic countries, respectively.

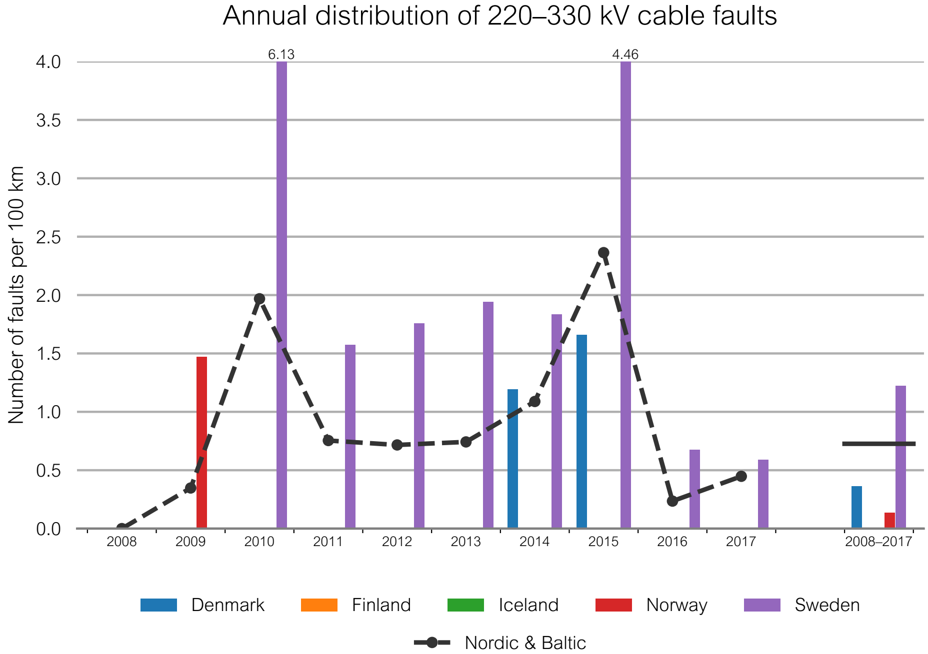


Figure 6.3.4: Annual distribution of 220–330 kV cable faults and the average during 2008–2017 in each Nordic country.

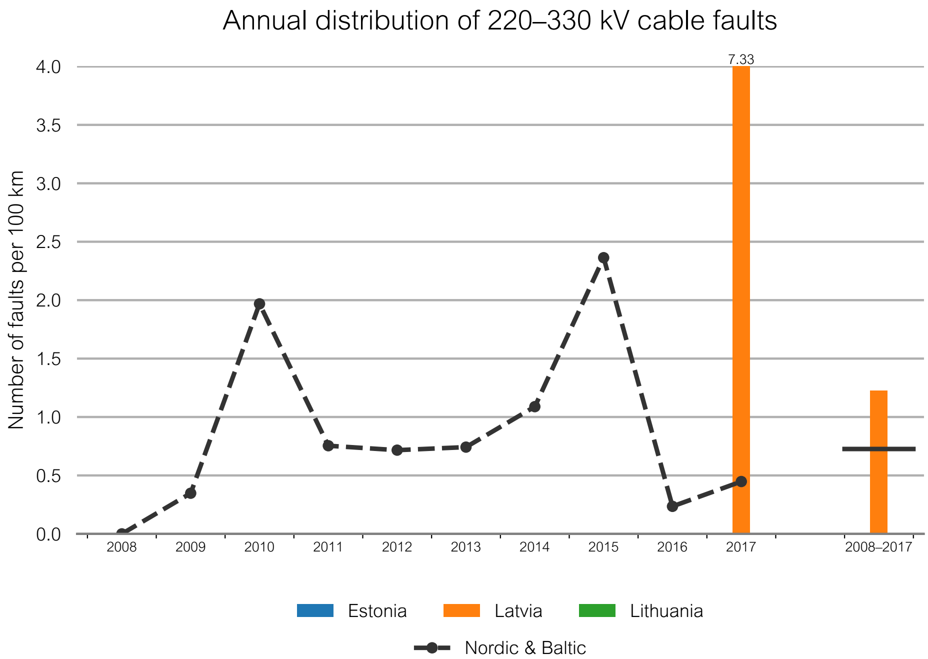


Figure 6.3.5: Annual distribution of 220–330 kV cable faults and the average during 2008–2017 in Estonia and during 2012–2017 in Latvia and Lithuania. This figure has the following remarks:

- Latvia's high value in 2017 is caused by 1 fault because they own a very short length of 220–330 kV cable.

Figure 6.3.6 and Figure 6.3.7 present the number of 220–330 kV cable faults per cause in 2017 in the Nordic and Baltic countries.

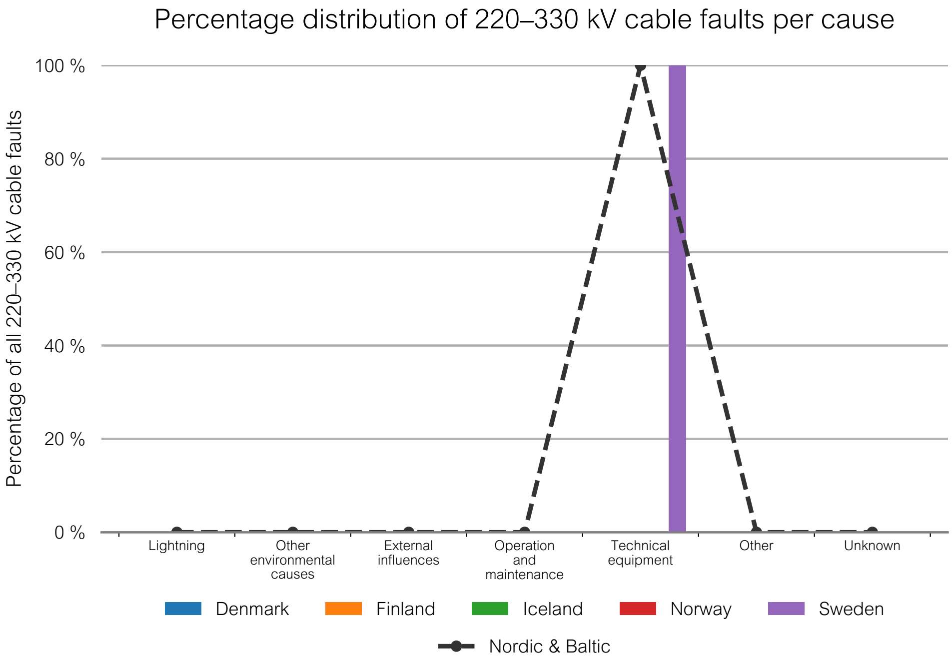


Figure 6.3.6: Percentage distribution of 220–330 kV cable faults per cause in 2017 in each Nordic country.

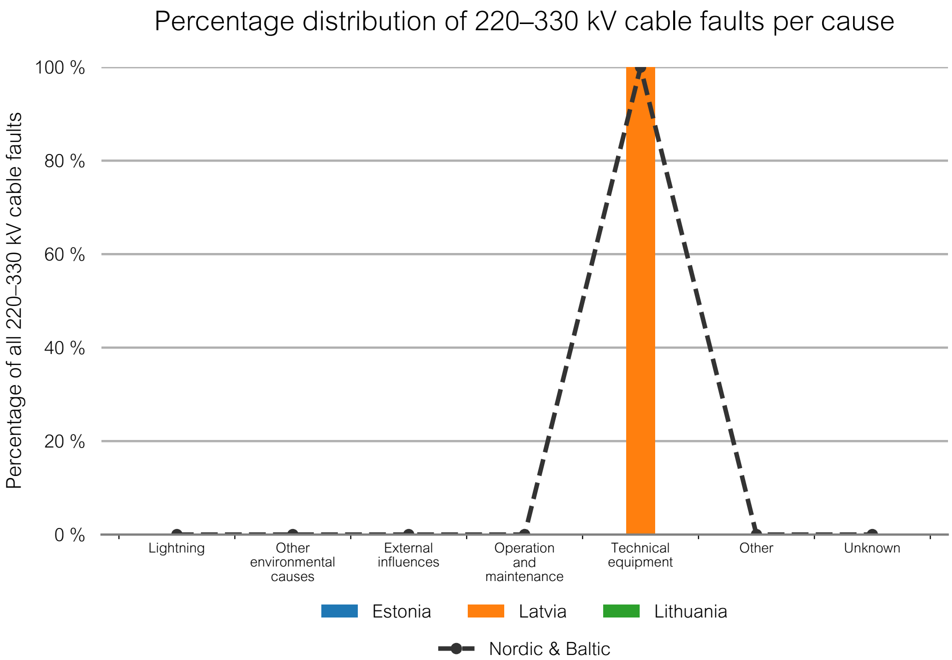


Figure 6.3.7: Percentage distribution of 220–330 kV cable faults per cause in 2017 in each Baltic country.

Figure 6.3.8 and Figure 6.3.9 present the average number of 220–330 kV cable faults per cause during 2008–2017 in the Nordic countries and Estonia and during 2012–2017 in Latvia and Lithuania.

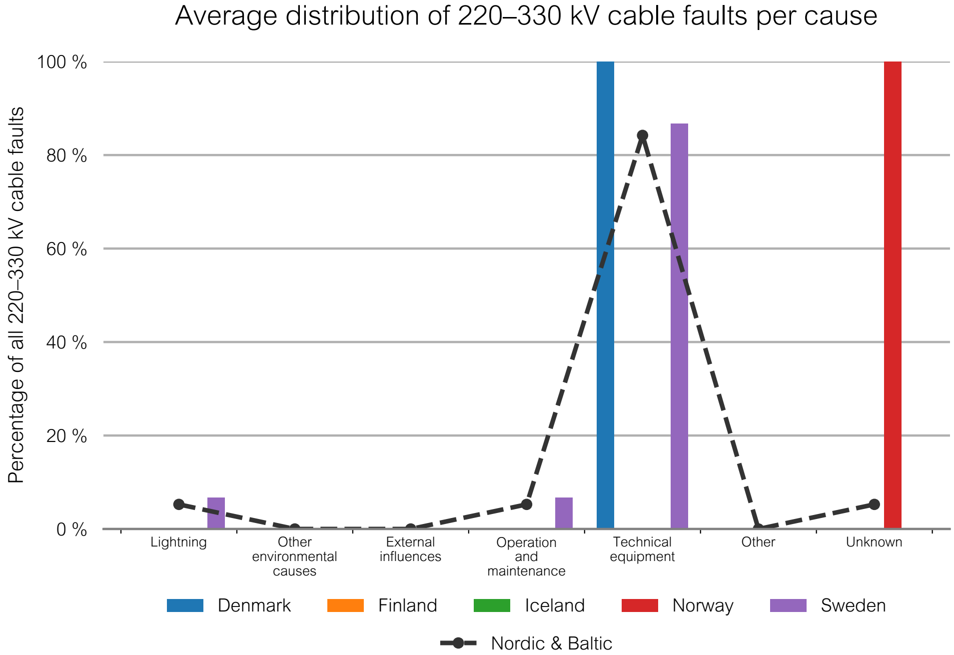


Figure 6.3.8: Average distribution of 220–330 kV cable faults per cause during 2008–2017 in each Nordic country.

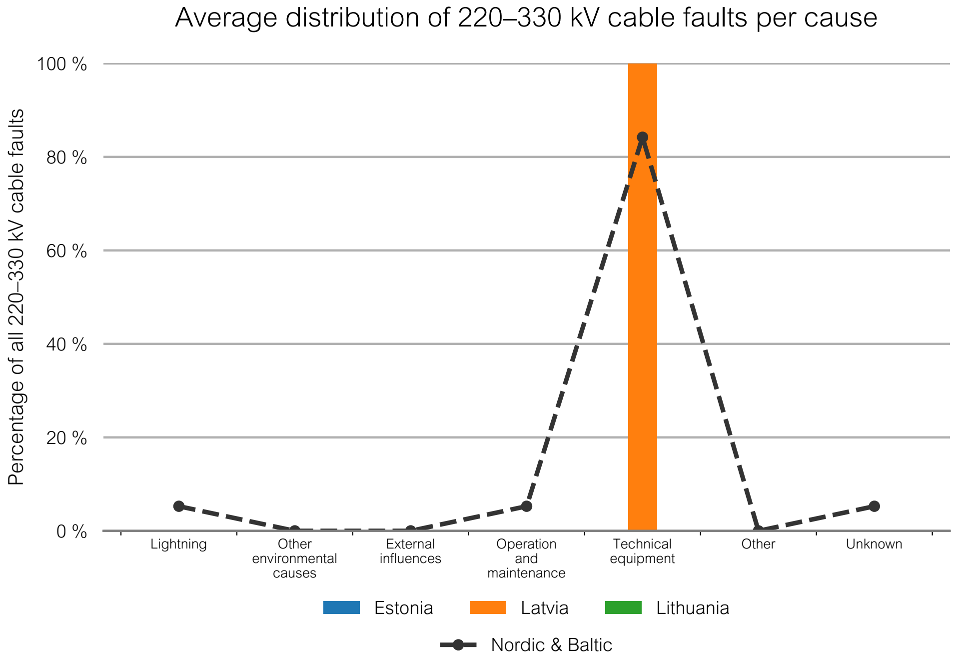


Figure 6.3.9: Average distribution of 220–330 kV cable faults per cause during 2008–2017 in Estonia and during 2012–2017 in Latvia and Lithuania.

### 6.3.3 100–150 kV cables

This section presents fault statistics for 100–150 kV cables. This includes a table with an overview of cable faults and figures with the annual number of faults and faults according to cause in 2017 and the average during 2008–2017. The fault causes used in these statistics are presented in Chapter 1.4.1.

Table 6.3.3 presents the length of 100–150 kV cables and the number of faults for 100–150 kV cables. Furthermore, the percentage of faults that were permanent faults and 1-phase faults are presented. The data consists of the values for the year 2017 and for the period 2008–2017.

Table 6.3.3: Overview of faults for 100–150 kV cables.

| | Length (km) | Faults | Faults per 100 km | | % of faults during 2008–2017 | |
|---|---|---|---|---|---|---|
| Country | 2017 | 2017 | 2017 | 2008–2017 | 1-phase faults | Permanent faults |
| Denmark | 1359 | 3 | 0.22 | 0.35 | 67.7 | 54.8 |
| Estonia | 64 | 0 | 0.00 | 0.75 | 125.0 | 75.0 |
| Finland | 272 | 1 | 0.37 | 0.46 | 80.0 | 50.0 |
| Iceland | 123 | 0 | 0.00 | 0.29 | 0.0 | 66.7 |
| Latvia[1] | 75 | 0 | 0.00 | 0.47 | 100.0 | 200.0 |
| Lithuania[1] | 90 | 0 | 0.00 | 0.23 | 0.0 | 100.0 |
| Norway[2] | 422 | 2 | 0.47 | 1.75 | 45.7 | 100.0 |
| Sweden | 471 | 2 | 0.42 | 1.59 | 32.4 | 64.9 |
| Nordic | 2647 | 8 | 0.30 | 0.76 | 49.1 | 71.6 |
| Baltic | 229 | 0 | 0.00 | 0.50 | 100.0 | 100.0 |
| Nordic & Baltic | 2877 | 8 | 0.28 | 0.74 | 51.6 | 73.0 |

[1] The average values of Latvia and Lithuania use the period 2012–2017.
[2] Cables in Norway include cables in resonant earthed grids.

Figure 6.3.10 and Figure 6.3.11 present the annual number of 100–150 kV cable faults per 100 km line length during 2008–2017 and the average for the period 2008–2017 in the Nordic and Baltic countries, respectively.

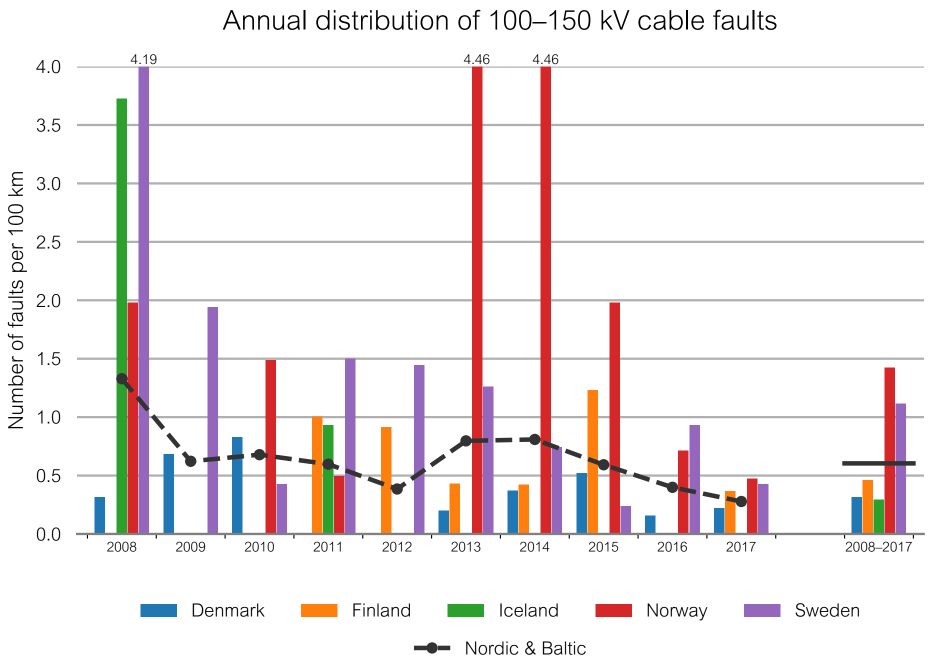


Figure 6.3.10: Annual distribution of 100–150 kV cable faults and the average during 2008–2017 in each Nordic country.

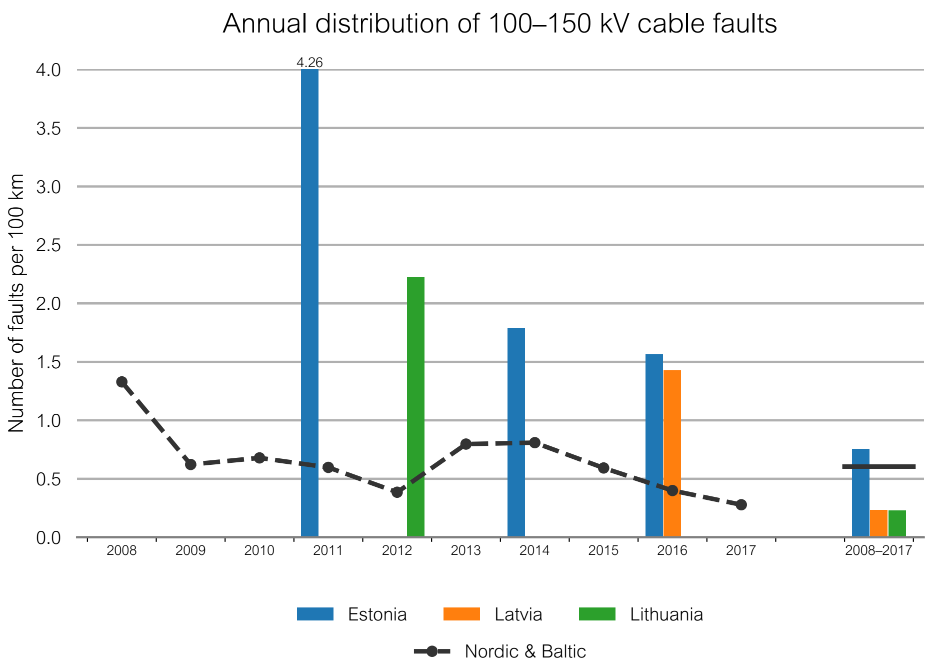


Figure 6.3.11: Annual distribution of 100–150 kV cable faults and the average during 2008–2017 in Estonia and during 2012–2017 in Latvia and Lithuania.

Figure 6.3.12 and Figure 6.3.13 present the number of 100–150 kV cable faults per cause in 2017 in the Nordic and Baltic countries.

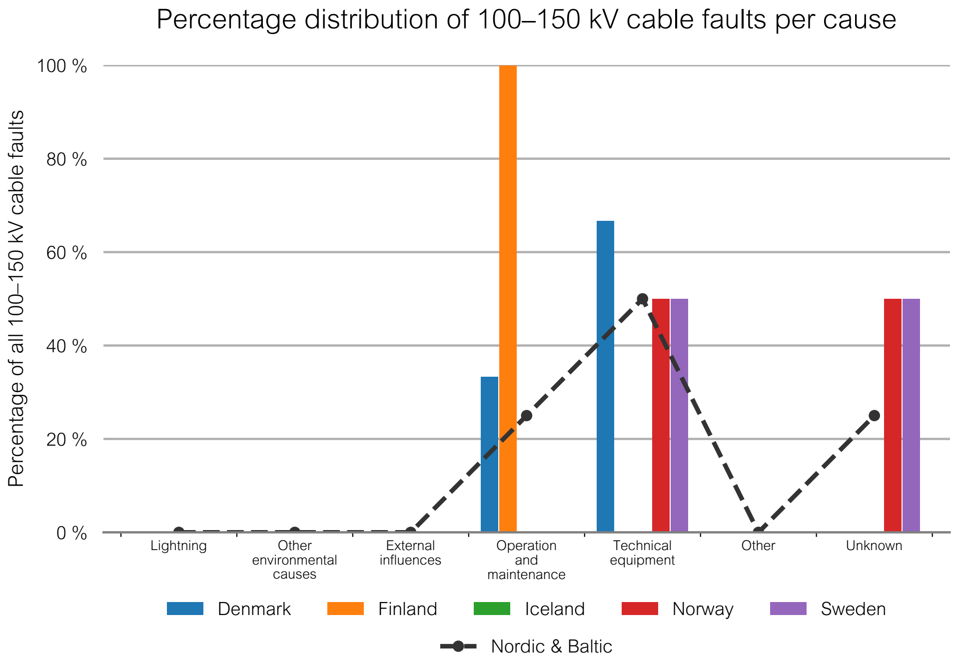


Figure 6.3.12: Percentage distribution of 100–150 kV cable faults per cause in 2017 in each Nordic country.

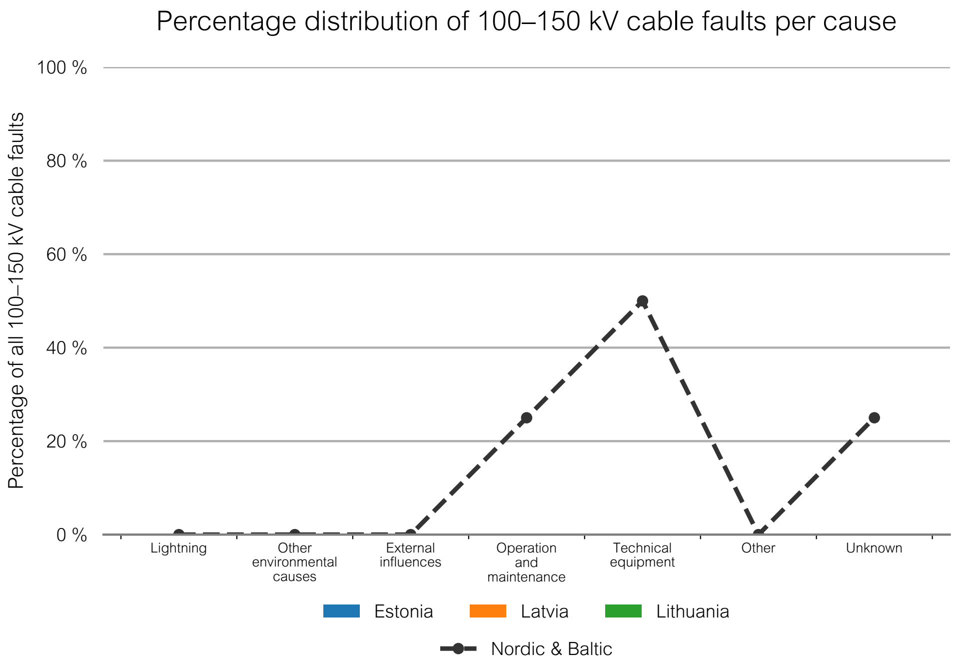


Figure 6.3.13: Percentage distribution of 100–150 kV cable faults per cause in 2017 in each Baltic country . The Baltic countries had no faults in 2017.

Figure 6.3.14 and Figure 6.3.15 present the average number of 100–150 kV cable faults per cause during 2008–2017 in the Nordic countries and Estonia and during 2012–2017 in Latvia and Lithuania.

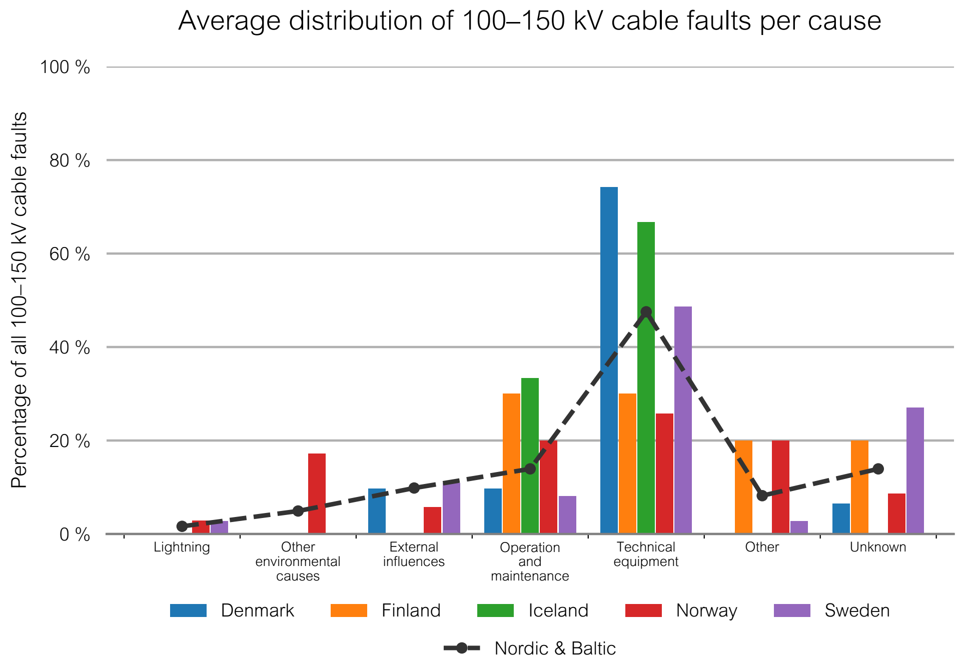


Figure 6.3.14: Average distribution of 100–150 kV cable faults per cause in 2008–2017 in each Nordic country.

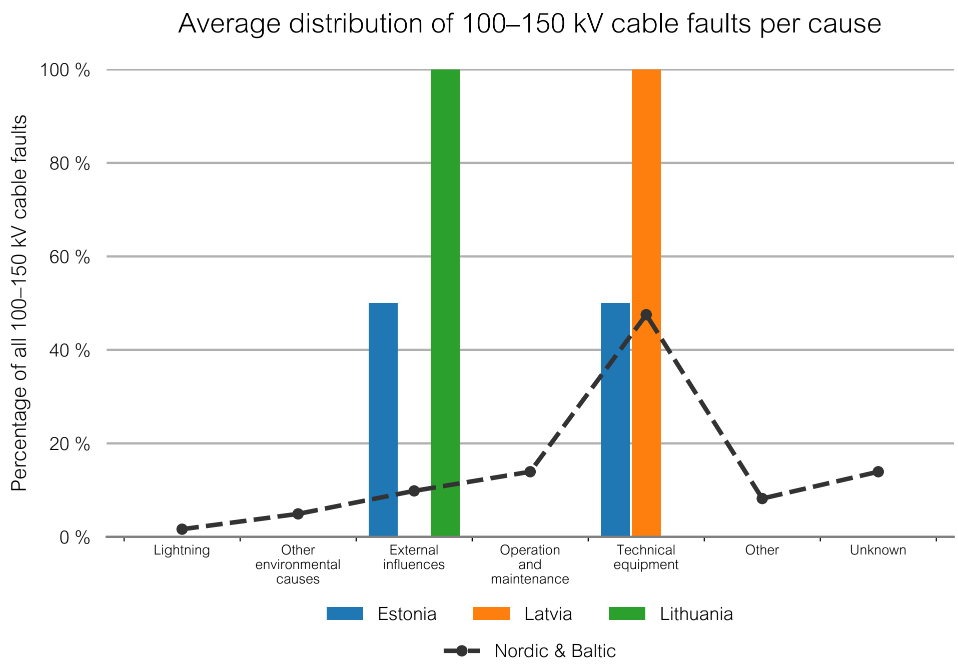


Figure 6.3.15: Average distribution of 100–150 kV cable faults per cause during 2008–2017 in Estonia and during 2012–2017 in Latvia and Lithuania.

## 6.3.4 Fault trends cables

The figures in this section present fault trends for cables at the voltage levels 100–150 kV, 220–330 kV and 380–420 kV. The Nordic countries use a 5-year rolling average, that is calculated by dividing the sum of the faults by the total cable length for each 5-year period. The rolling average for the Baltic countries is calculated similarly, but with 3-year periods. The trend curves are proportioned to cable length in order to get comparable results between countries.

Figure 6.3.16 presents the Nordic 100–420 kV fault trends and Figure 6.3.17 presents the Baltic 100–420 kV fault trends.

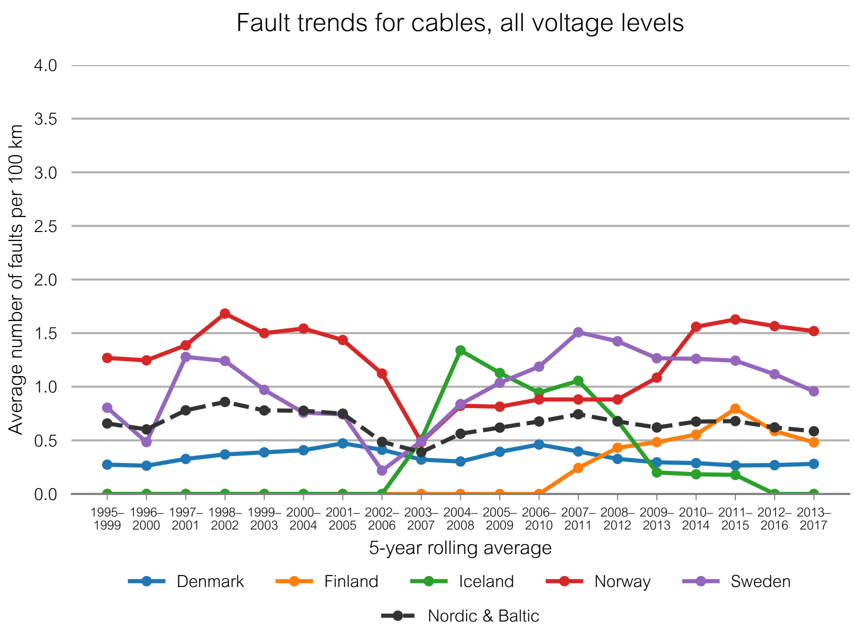


Figure 6.3.16: Fault trends as 5-year rolling averages for cables for all voltage levels in each Nordic country. This figure has the following remarks:

- 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 6.3.10.

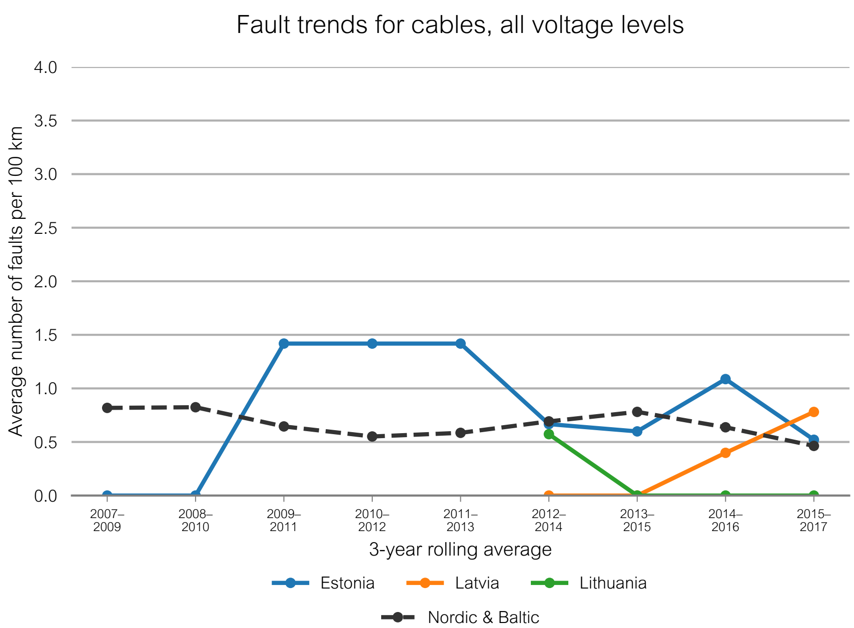


Figure 6.3.17: Fault trends as 3-year rolling averages for cables all voltage levels in each Baltic country.

## 6.4 Faults in power transformers

The tables and figures in this section present power transformer faults in 2017 and during 2008–2017 at the voltage levels 100–150 kV, 220–330 kV and 380–420 kV. Power transformers are essential when power needs to be transferred from where power is generated or imported to where power is consumed or exported. They allow the grid owner to optimize the voltage level in order to minimize transmission losses. The rated voltage of a power transformer is defined in these statistics as the winding with the highest voltage, as stated in the guidelines in Section 6.2 [2].

Chapter 6.4.1 presents fault statistics for 380–420 kV power transformers, Chapter 6.4.2 for 220–330 kV power transformers and Chapter 6.4.3 100–150 kV power transformers. The figures and tables present the number of power transformer faults per 100 devices in 2017 as well as the average values during 2008–2017 in the Nordic countries and Estonia and during 2012–2017 in Latvia and Lithuania. Furthermore, faults according to the cause categories, defined in Chapter 1.4.1, are presented. Finally, Chapter 6.4.4 presents trend figures for the number of faults per 100 devices. The trends are calculated by 5-year moving averages for the Nordic countries during 1995–2017 and by 3-year moving averages for the Baltic countries during 2007–2017. With the help of the trend curve, it may be possible to estimate the number of faults in the future.

### 6.4.1 380–420 kV power transformers

This section presents fault statistics for 380–420 kV power transformers. This includes a table with an overview of power transformer faults and figures with the annual number of faults and faults according to cause in 2017 and the average during 2008–2017. The fault causes used in these statistics are presented in Chapter 1.4.1.

Table 6.4.1 shows the number of 380–420 kV power transformers and the number of faults for 380–420 kV power transformers. Furthermore, the amount of ENS caused by the faults is presented. The data consists of the values for the year 2017 and for the period 2008–2017.

It should be noted, that only Denmark, Finland, Lithuania, Norway and Sweden own 380–420 kV equipment. Therefore, only these countries are presented in the figures in this section.

Table 6.4.1: Overview of faults for 380–420 kV power transformers.

| | Devices | Faults | Faults per 100 devices | | ENS (MWh) | |
|---|---|---|---|---|---|---|
| Country | 2017 | 2017 | 2017 | 2008–2017 | 2017 | 2008–2017 |
| Denmark | 31 | 2 | 6.45 | 3.24 | 0.0 | 0.0 |
| Estonia | 0 | 0 | 0.00 | 0.00 | 0.0 | 0.0 |
| Finland | 62 | 2 | 3.23 | 2.14 | 0.0 | 0.0 |
| Iceland | 0 | 0 | 0.00 | 0.00 | 0.0 | 0.0 |
| Latvia | 0 | 0 | 0.00 | 0.00 | 0.0 | 0.0 |
| Lithuania | 0 | 0 | 0.00 | 0.00 | 0.0 | 0.0 |
| Norway | 100 | 2 | 2.00 | 2.25 | 0.0 | 73.0 |
| Sweden | 71 | 0 | 0.00 | 2.80 | 0.0 | 17.9 |
| Nordic | 264 | 6 | 2.27 | 2.50 | 0.0 | 90.9 |
| Baltic | 0 | 0 | 0.00 | 0.00 | 0.0 | 0.0 |
| Nordic & Baltic | 264 | 6 | 2.27 | 2.50 | 0.0 | 90.9 |

Figure 6.4.1 presents the annual number of 380–420 kV power transformer faults per 100 devices during 2008–2017 and the average for the period 2008–2017 in Denmark, Finland, Lithuania, Norway and Sweden.

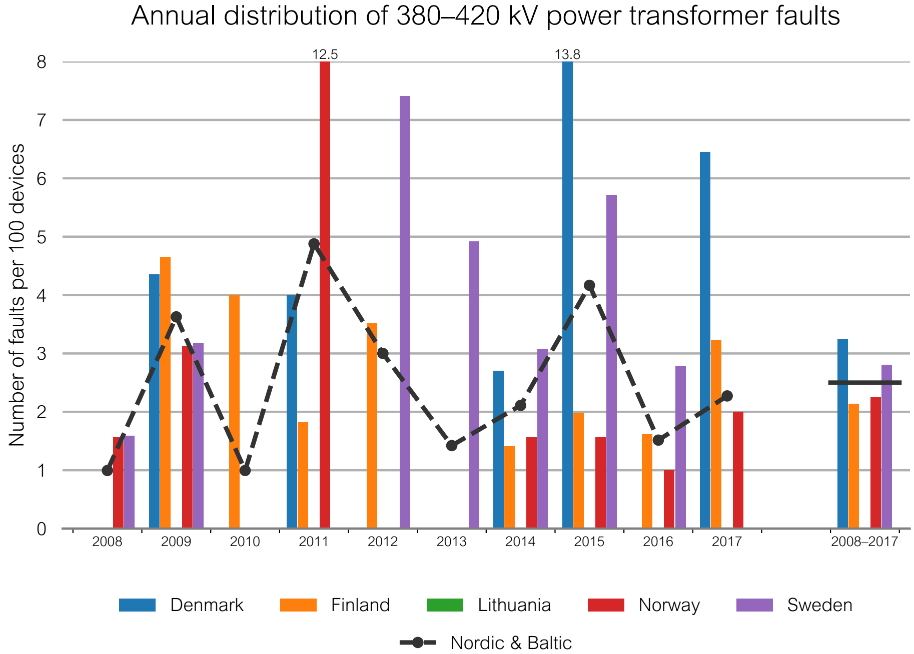


Figure 6.4.1: Annual distribution of 380–420 kV power transformer faults and the average during 2008–2017 in Denmark, Finland, Lithuania, Norway and Sweden. Lithuania does not own 380–420 kV power transformers.

Figure 6.4.2 presents the number of 380–420 kV power transformer faults per cause in 2017 in Denmark, Finland, Lithuania, Norway and Sweden.

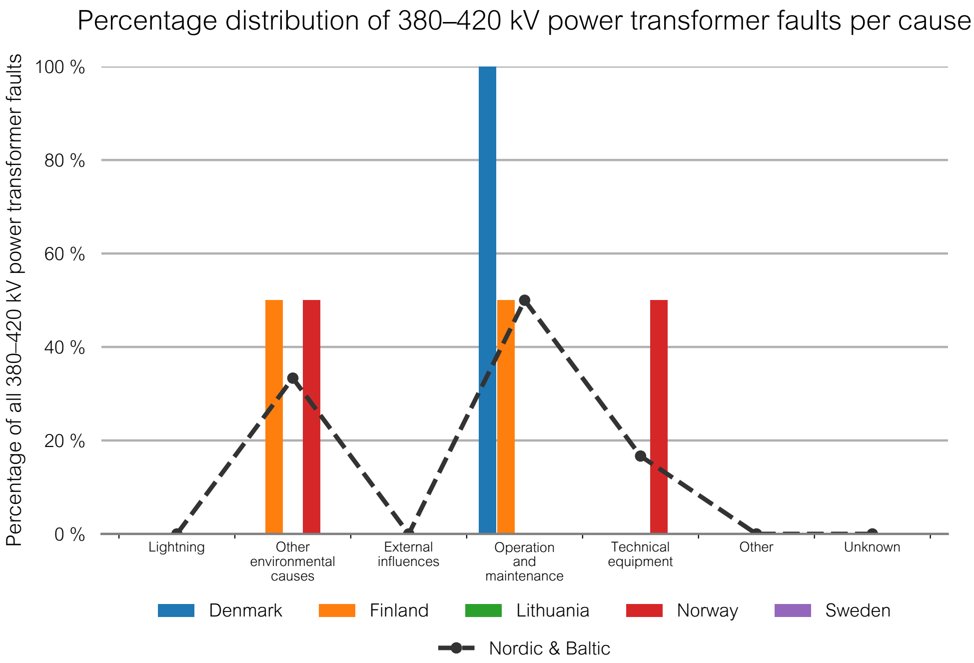


Figure 6.4.2: Percentage distribution of 380–420 kV power transformer faults per cause in 2017 in Denmark, Finland, Lithuania, Norway and Sweden. Lithuania does not own 380–420 kV power transformers.

Figure 6.4.3 presents the average number of 380–420 kV power transformer faults per cause during 2008–2017 in Denmark, Finland, Lithuania, Norway and Sweden.

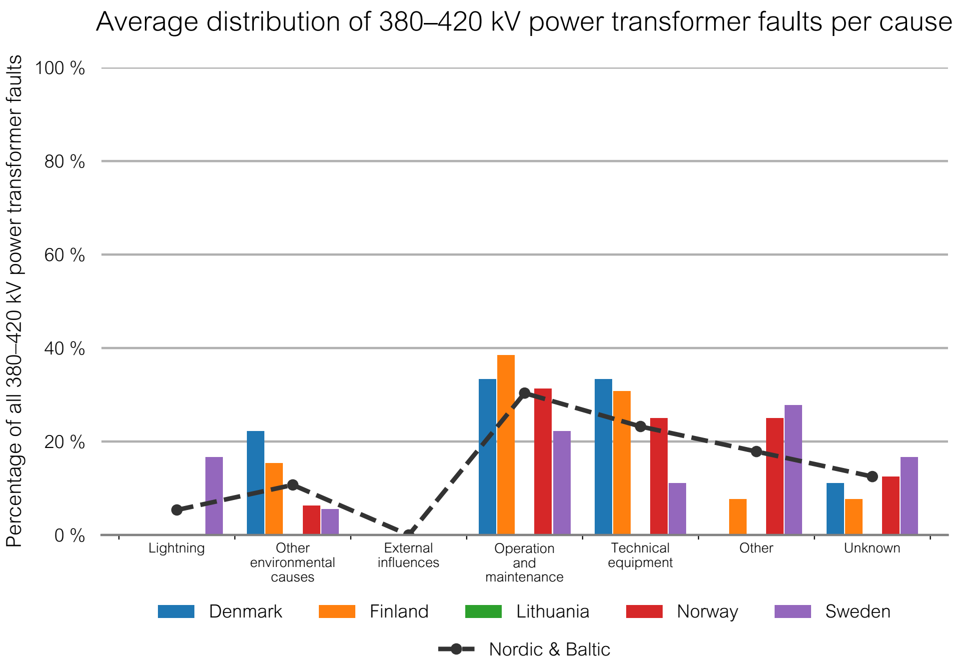


Figure 6.4.3: Average distribution of 380–420 kV power transformer faults per cause during 2008–2017 in Denmark, Finland, Lithuania, Norway and Sweden. Lithuania does not own 380–420 kV power transformers.

## 6.4.2 220–330 kV power transformers

This section presents fault statistics for 220–330 kV power transformers. This includes a table with an overview of power transformer faults and figures with the annual number of faults and faults according to cause in 2017 and the average during 2008–2017. The fault causes used in these statistics are presented in Chapter 1.4.1.

Table 6.4.2 shows the number of 220–330 kV power transformers and the number of faults for 220–330 kV power transformers. Furthermore, the amount of ENS caused by the faults is presented. The data consists of the values for the year 2017 and for the period 2008–2017.

Table 6.4.2: Overview of faults for 220–330 kV power transformers.

| | Devices | Faults | Faults per 100 devices | | ENS (MWh) | |
|---|---|---|---|---|---|---|
| Country | 2017 | 2017 | 2017 | 2008–2017 | 2017 | 2008–2017 |
| Denmark | 8 | 0 | 0.00 | 2.33 | 0.0 | 0.0 |
| Estonia | 26 | 4 | 15.38 | 10.18 | 0.0 | 0.0 |
| Finland | 18 | 0 | 0.00 | 2.58 | 0.0 | 0.0 |
| Iceland | 15 | 1 | 6.67 | 8.47 | 0.0 | 2.9 |
| Latvia[1] | 25 | 0 | 0.00 | 6.00 | 0.0 | 0.0 |
| Lithuania[1] | 24 | 0 | 0.00 | 4.26 | 0.0 | 0.8 |
| Norway | 266 | 3 | 1.13 | 0.75 | 0.0 | 8.7 |
| Sweden | 111 | 4 | 3.60 | 4.24 | 0.0 | 21.0 |
| Nordic | 418 | 8 | 1.91 | 1.96 | 0.0 | 32.5 |
| Baltic | 75 | 4 | 5.33 | 7.35 | 0.0 | 0.8 |
| Nordic & Baltic | 493 | 12 | 2.43 | 2.57 | 0.0 | 33.3 |

[1] The average values of Latvia and Lithuania use the period 2012–2017.

Figure 6.4.4 and Figure 6.4.5 present the annual number of 220–330 kV power transformer faults per 100 devices during 2008–2017 and the average for the period 2008–2017 in the Nordic and Baltic countries, respectively.

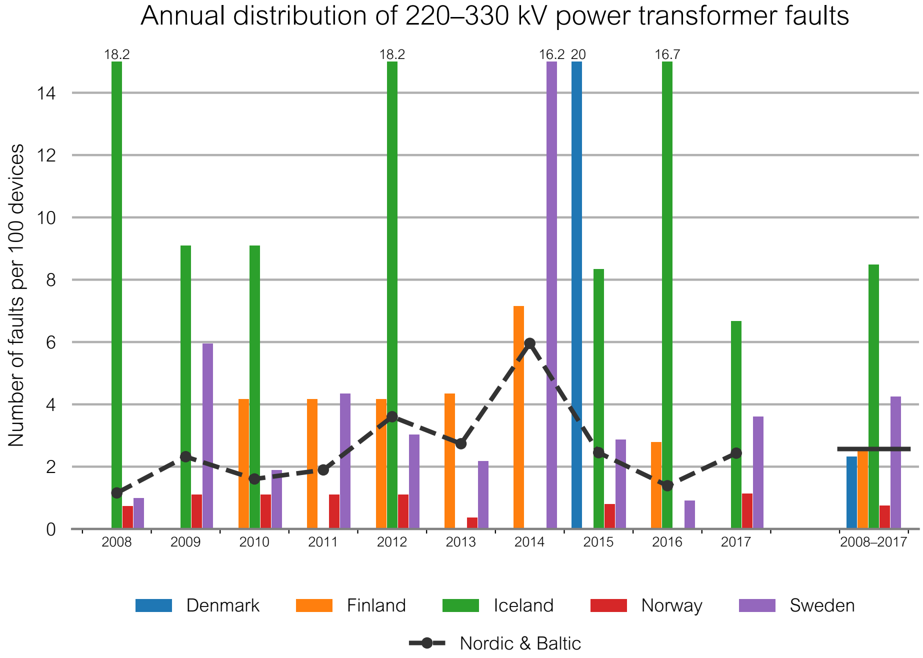


Figure 6.4.4: Annual distribution of faults for 220–330 kV power transformers during 2008–2017 and the average for each Nordic country.

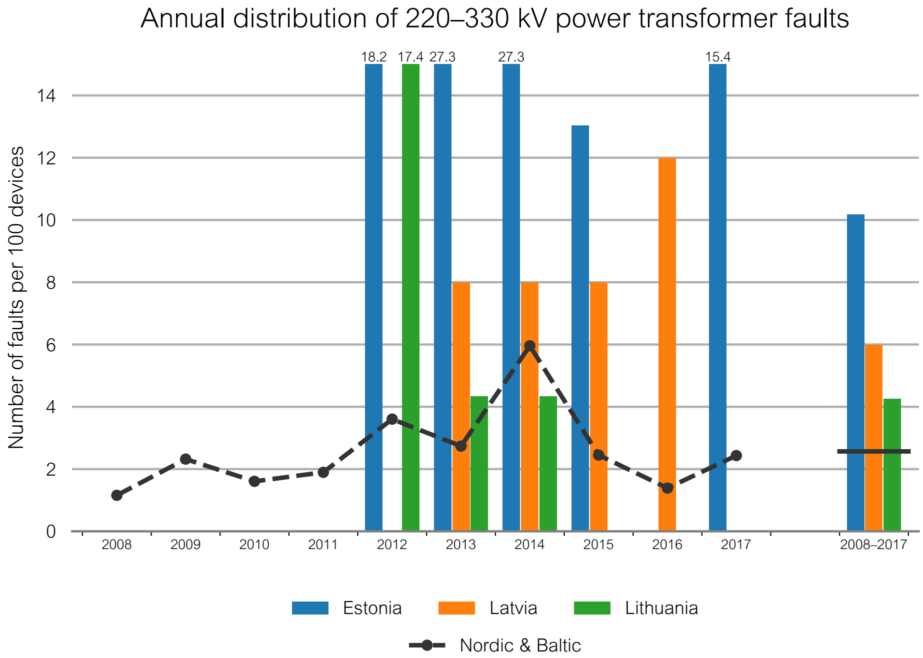


Figure 6.4.5: Annual distribution of faults for 220–330 kV power transformers during 2008–2017 for Estonia and during 2012–2017 for Latvia and Lithuania.

Figure 6.4.6 and Figure 6.4.7 present the number of 220–330 kV power transformer faults per cause in 2017 in the Nordic and Baltic countries.

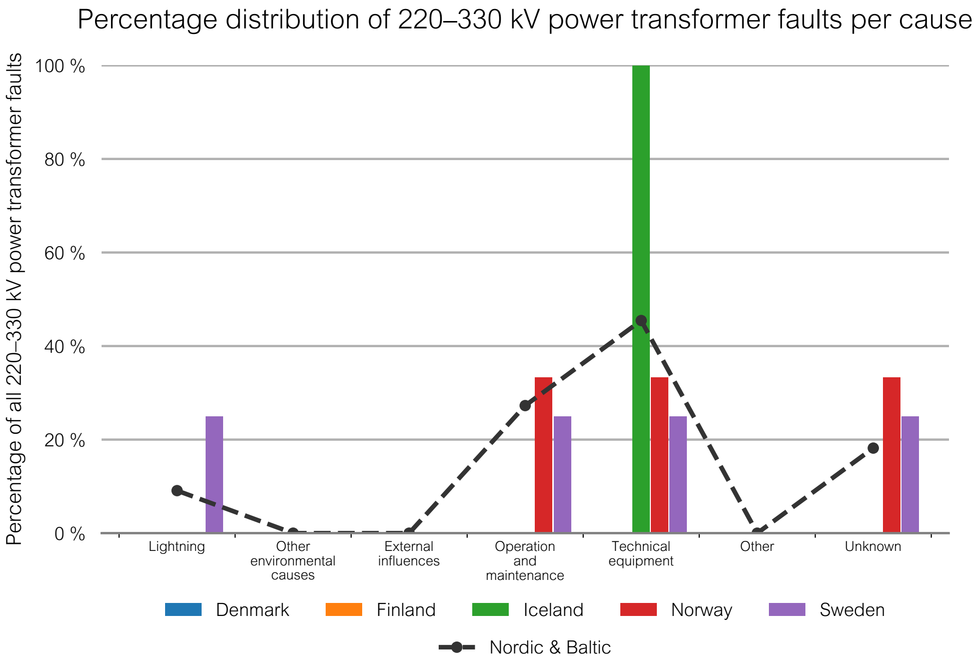


Figure 6.4.6: Percentage distribution of 220–330 kV power transformer faults per cause in 2017 in each Nordic country.

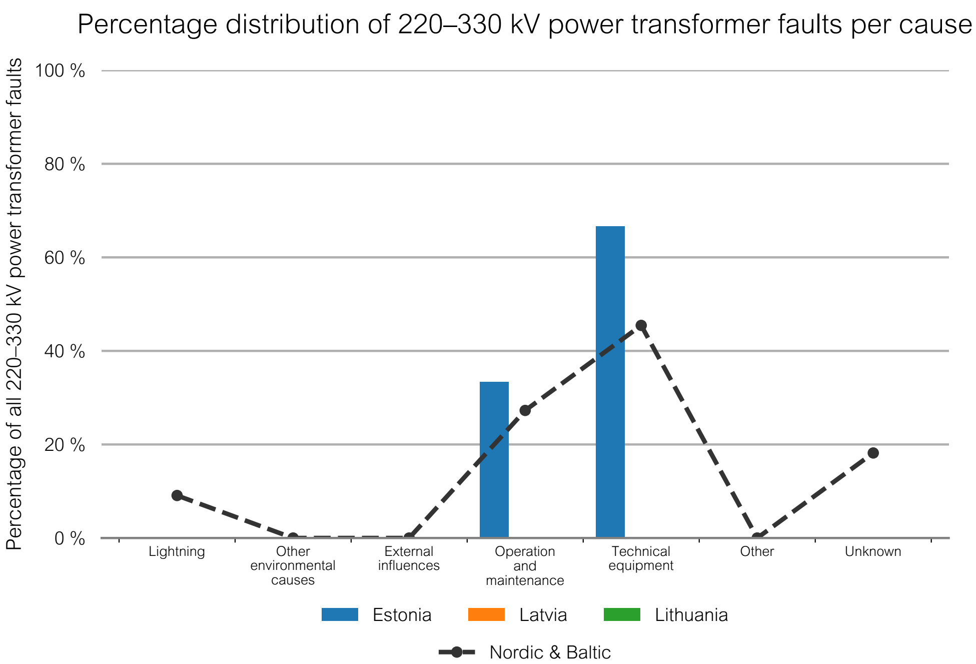


Figure 6.4.7: Percentage distribution of 220–330 kV power transformer faults per cause in 2017 in each Baltic country.

Figure 6.4.8 and Figure 6.4.9 present the average number of 220–330 kV power transformer faults per cause during 2008–2017 in the Nordic countries and Estonia and during 2012–2017 in Latvia and Lithuania.

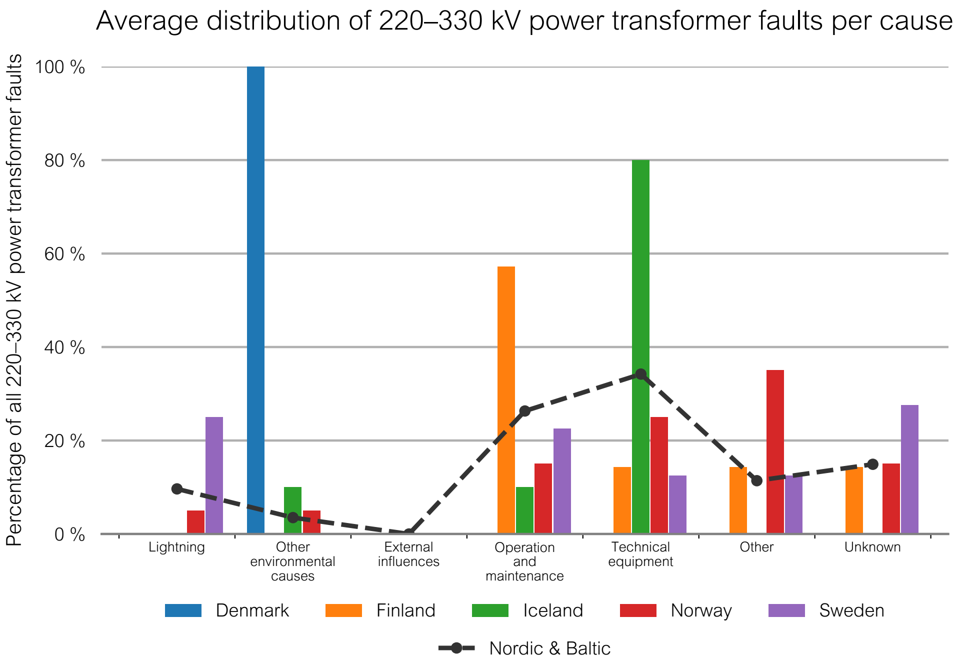


Figure 6.4.8: Average distribution of 220–330 kV power transformer faults per cause during 2008–2017 in each Nordic country.

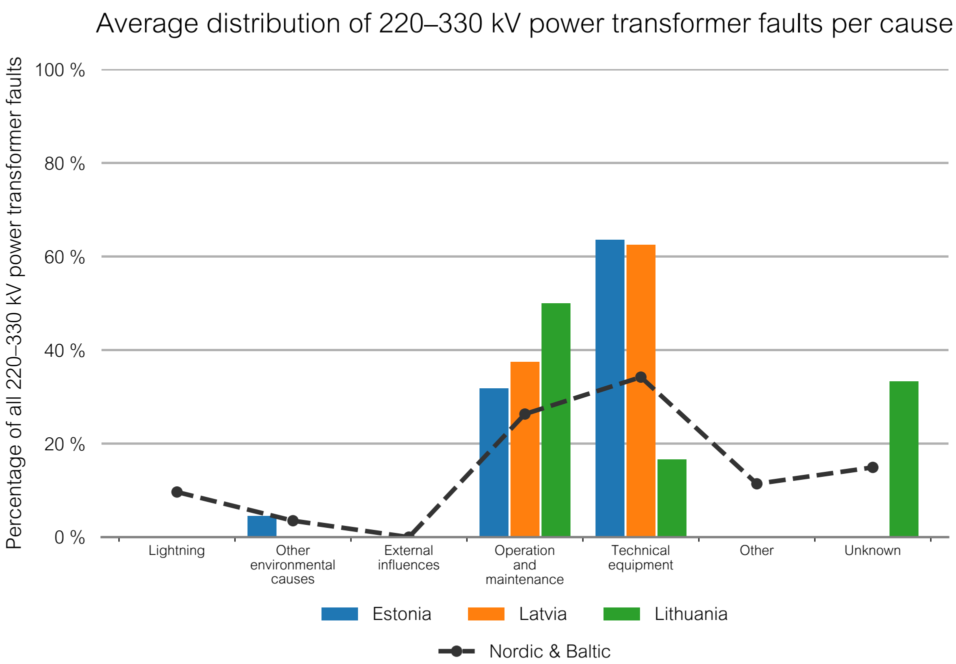


Figure 6.4.9: Average distribution of 220–330 kV power transformer faults per cause during 2008–2017 in Estonia and during 2012–2017 in Latvia and Lithuania.

### 6.4.3 100–150 kV power transformers

This section presents fault statistics for 100–150 kV power transformers. This includes a table with an overview of power transformer faults and figures with the annual number of faults and faults according to cause in 2017 and the average during 2008–2017. The fault causes used in these statistics are presented in Chapter 1.4.1.

Table 6.4.3 shows the number of 100–150 kV power transformers and the number of faults for 100–150 kV power transformers. Furthermore, the amount of ENS caused by the faults is presented. The data consists of the values for the year 2017 and for the period 2008–2017.

Table 6.4.3: Overview of faults for 100–150 kV power transformers.

| | Devices | Faults | Faults per 100 devices | | ENS (MWh) | |
|---|---|---|---|---|---|---|
| Country | 2017 | 2017 | 2017 | 2008–2017 | 2017 | 2008–2017 |
| Denmark | 229 | 3 | 1.31 | 1.10 | 0.0 | 3.6 |
| Estonia | 215 | 13 | 6.05 | 3.01 | 1.6 | 7.0 |
| Finland | 1209 | 8 | 0.66 | 0.54 | 1.7 | 10.2 |
| Iceland | 38 | 5 | 13.16 | 2.30 | 249.9 | 27.4 |
| Latvia[1] | 248 | 3 | 1.21 | 2.37 | 0.7 | 3.4 |
| Lithuania[1] | 416 | 0 | 0.00 | 0.08 | 0.0 | 0.0 |
| Norway | 913 | 4 | 0.44 | 0.67 | 3.5 | 38.1 |
| Sweden | 831 | 10 | 1.20 | 3.24 | 90.6 | 107.7 |
| Nordic | 3220 | 30 | 0.93 | 1.36 | 345.7 | 186.9 |
| Baltic | 879 | 16 | 1.82 | 1.67 | 2.3 | 10.4 |
| Nordic & Baltic | 4099 | 46 | 1.12 | 1.41 | 348.0 | 197.3 |

[1] The average values of Latvia and Lithuania use the period 2012–2017.

Figure 6.4.10 and Figure 6.4.11 present the annual number of 100–150 kV power transformer faults per 100 devices during 2008–2017 and the average for the period 2008–2017 in the Nordic and Baltic countries, respectively.

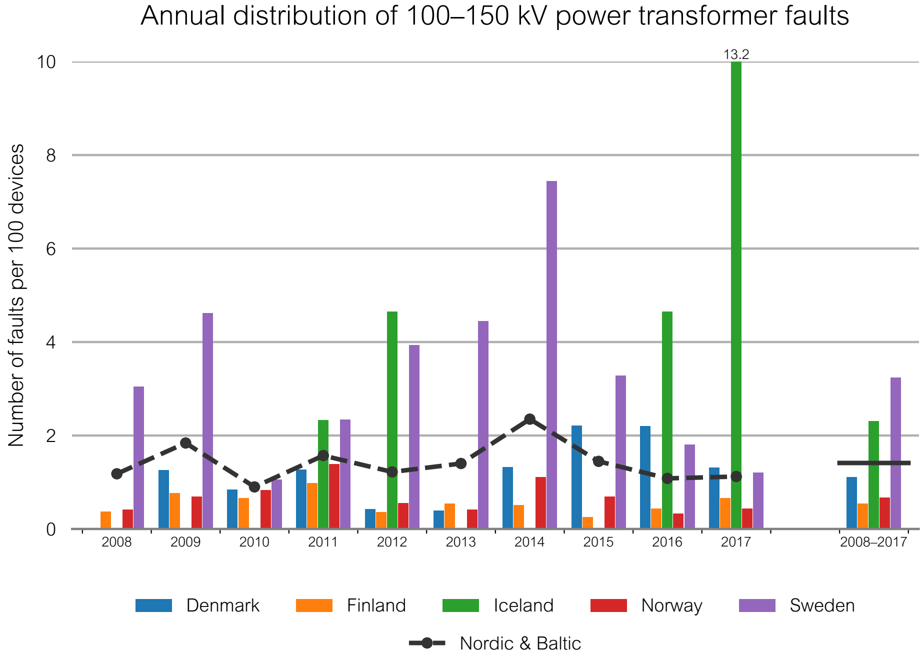


Figure 6.4.10: Annual distribution of 100–150 kV power transformer faults and the average during 2008–2017 in each Nordic country.

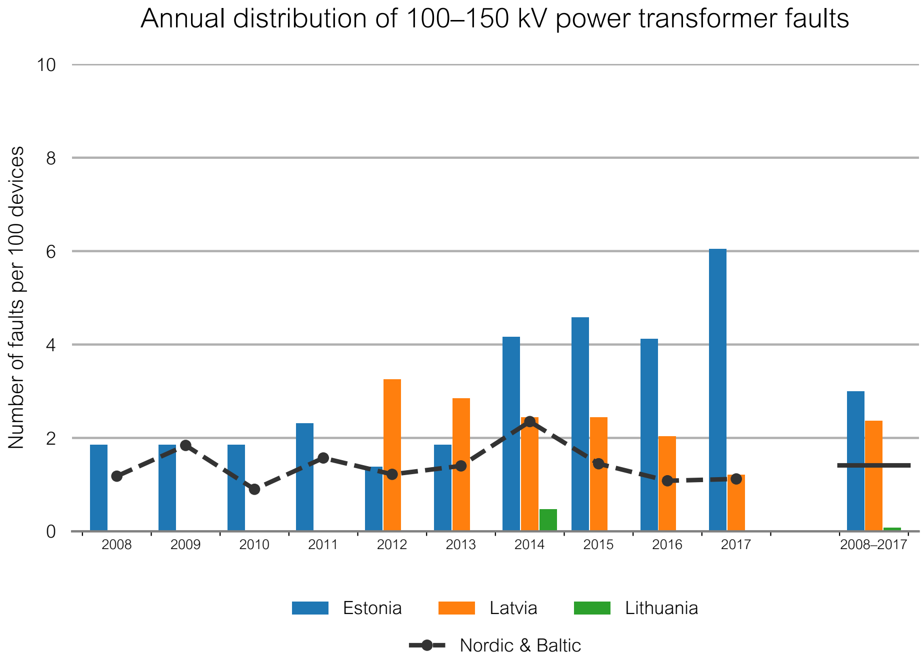


Figure 6.4.11: Annual distribution of 100–150 kV power transformer faults and the average during 2008–2017 in Estonia and during 2012–2017 in Latvia and Lithuania.

Figure 6.4.12 and Figure 6.4.13 present the number of 100–150 kV power transformer faults per cause in 2017 in the Nordic and Baltic countries.

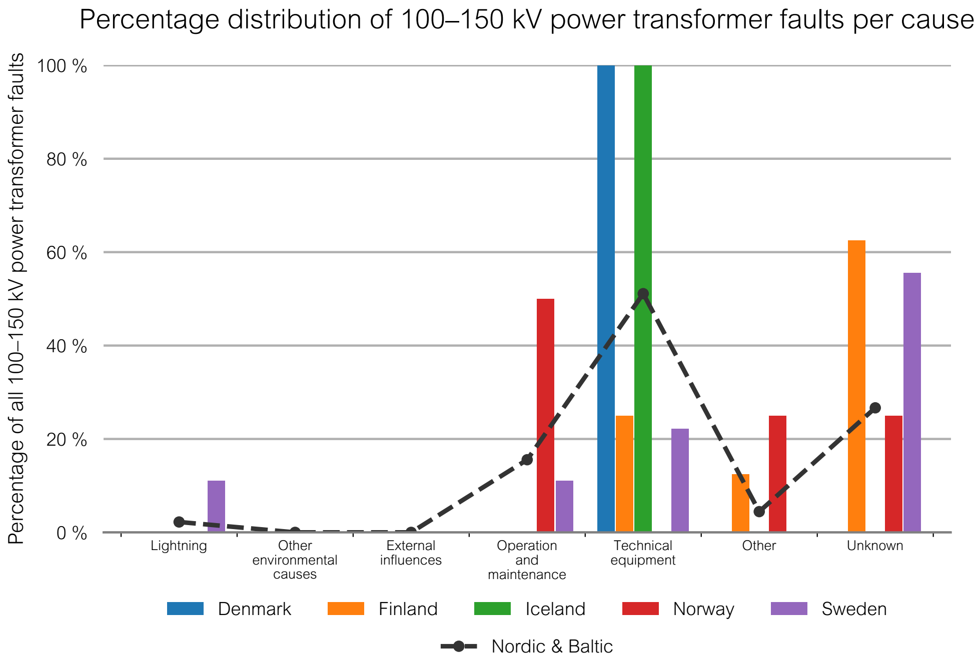


Figure 6.4.12: Percentage distribution of 100–150 kV power transformer faults per cause in 2017 in each Nordic country.

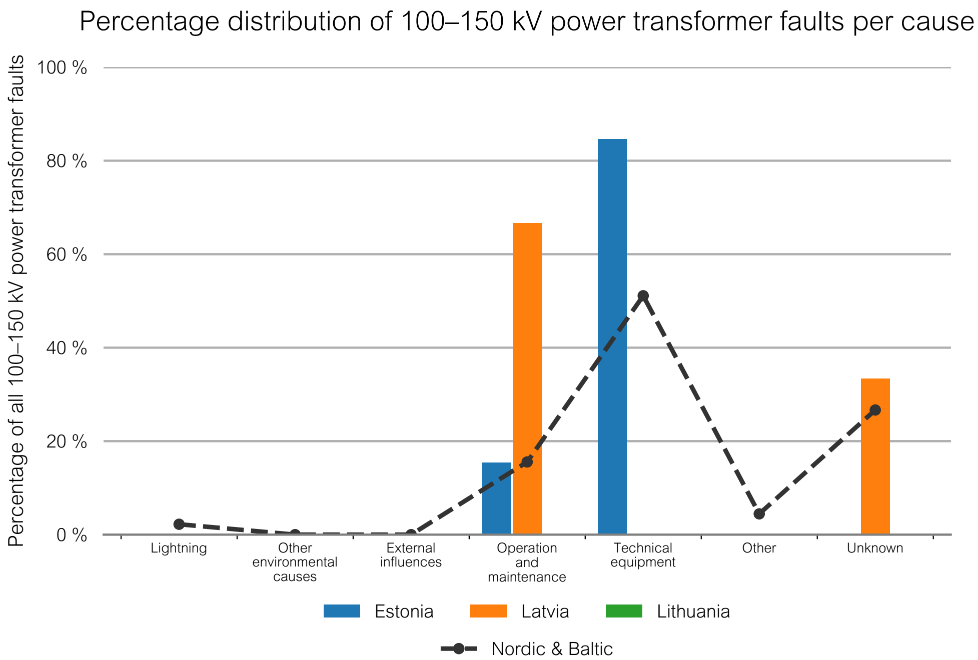


Figure 6.4.13: Percentage distribution of 100–150 kV power transformer faults per cause in 2017 in each Baltic country.

Figure 6.4.14 and Figure 6.4.15 present the average number of 100–150 kV power transformer faults per cause during 2008–2017 in the Nordic countries and Estonia and during 2012–2017 in Latvia and Lithuania.

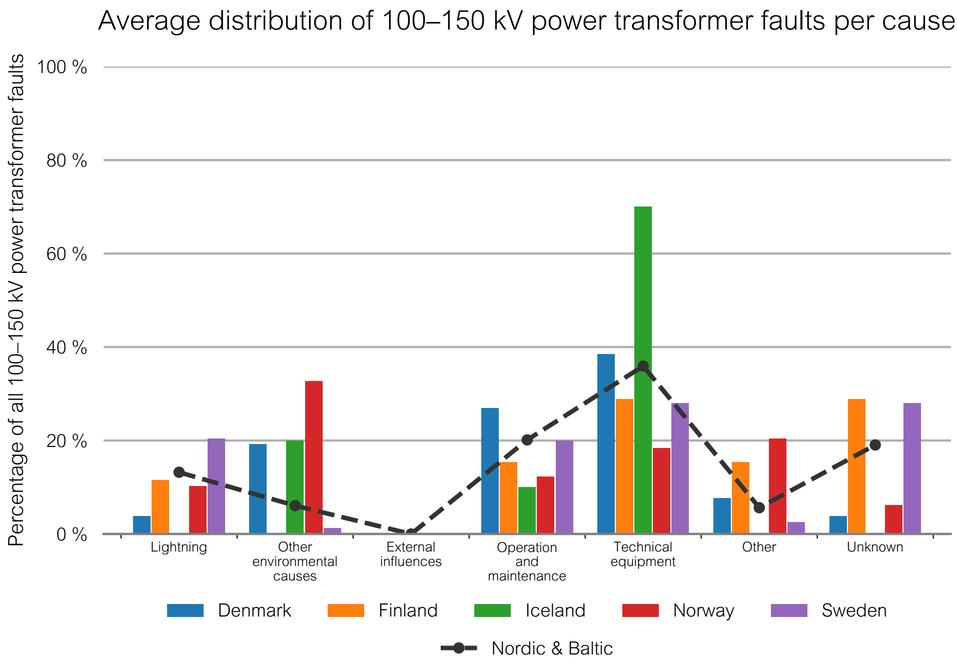


Figure 6.4.14: Average distribution of 100–150 kV power transformer faults per cause during 2008–2017 in each Nordic country.

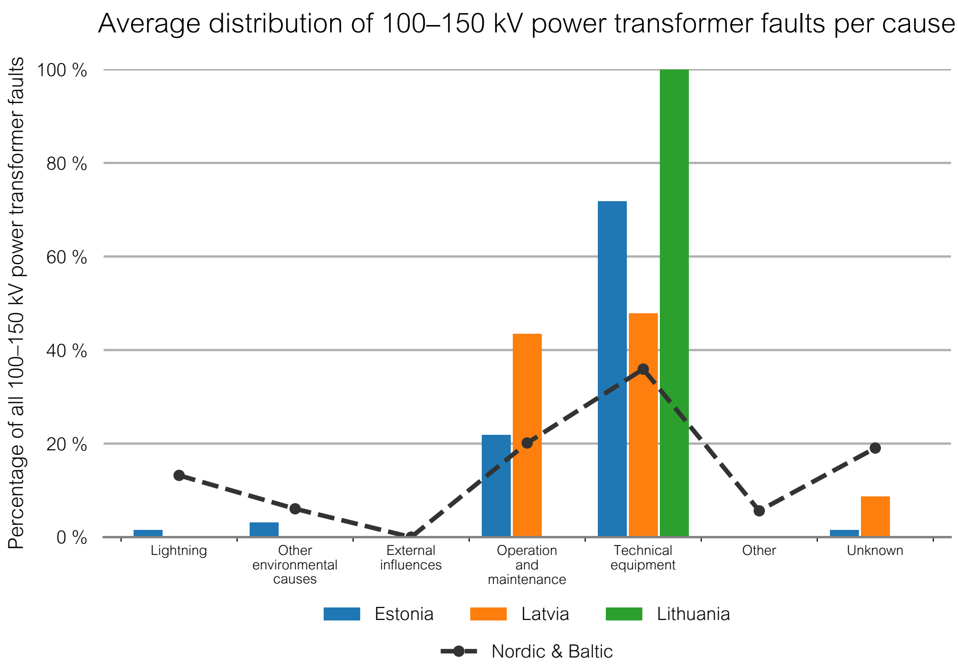


Figure 6.4.15: Average distribution of 100–150 kV power transformer faults per cause during 2008–2017 in Estonia and during 2012–2017 in Latvia and Lithuania.

## 6.4.4 Fault trends power transformers

The figures in this section present fault trends for power transformers at the voltage levels 100–150 kV, 220–330 kV and 380–420 kV. The Nordic countries use a 5-year rolling average, that is calculated by dividing the sum of the faults by the total number of devices for each 5-year period. The rolling average for the Baltic countries is calculated similarly, but with 3-year periods. The trend curves are proportioned to the number of power transformers in order to get comparable results between countries.

Figure 6.4.16 presents 380–420 kV fault trends for Denmark, Finland, Lithuania, Norway and Sweden, Figure 6.4.17 presents the Nordic 220–330 kV fault trends, Figure 6.4.18 presents the Baltic 220–330 kV fault trends, Figure 6.4.19 presents the Nordic 100–150 kV fault trends and Figure 6.4.20 presents the Baltic 100–150 kV fault trends.

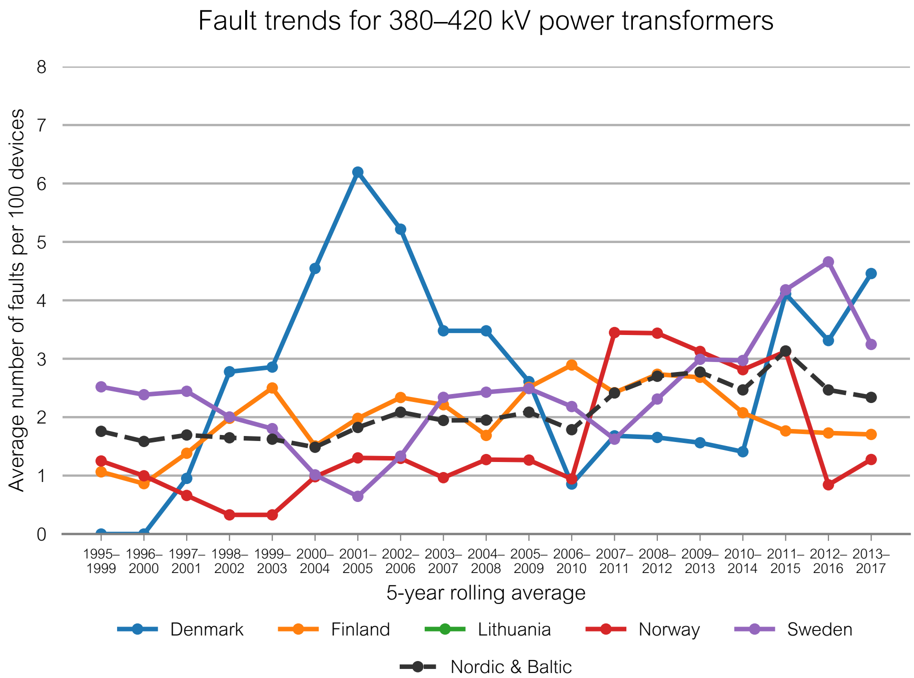


Figure 6.4.16: Fault trends as 5-year rolling averages for 380–420 kV power transformers in Denmark, Finland, Lithuania, Norway and Sweden.

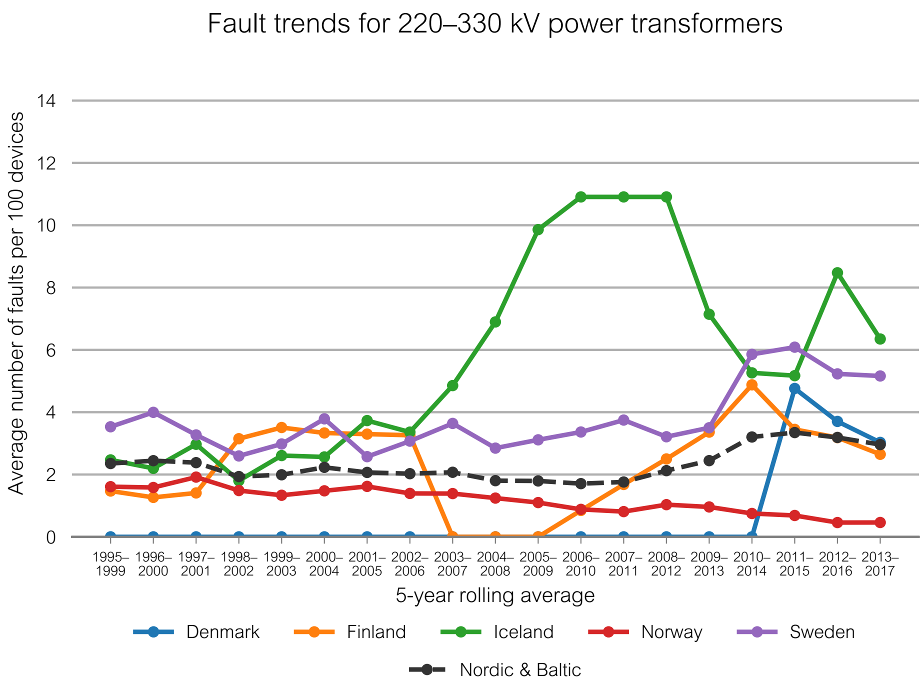


Figure 6.4.17: Fault trends as 5-year rolling averages for 220–330 kV power transformers in each Nordic country.

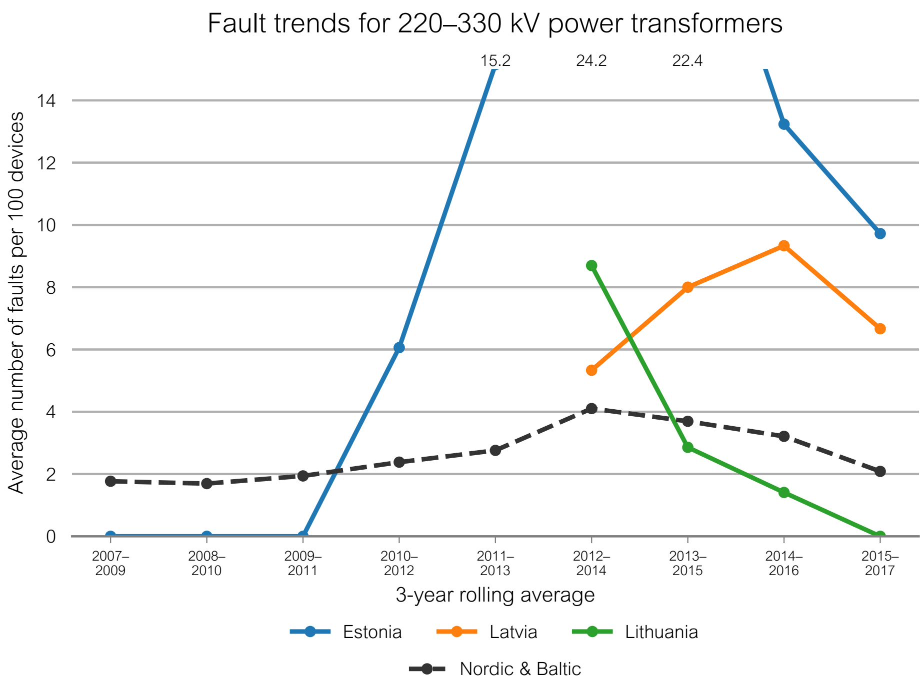


Figure 6.4.18: Fault trends as 3-year rolling averages for 220–330 kV power transformers in each Baltic country.

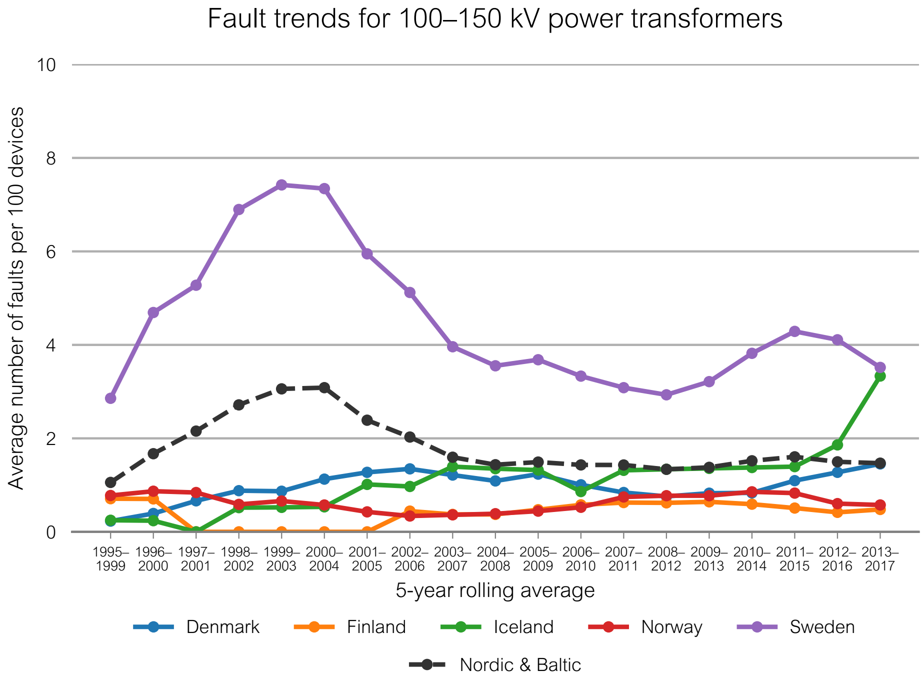


Figure 6.4.19: Fault trends as 5-year rolling averages for 100–150 kV power transformers in each Nordic country.

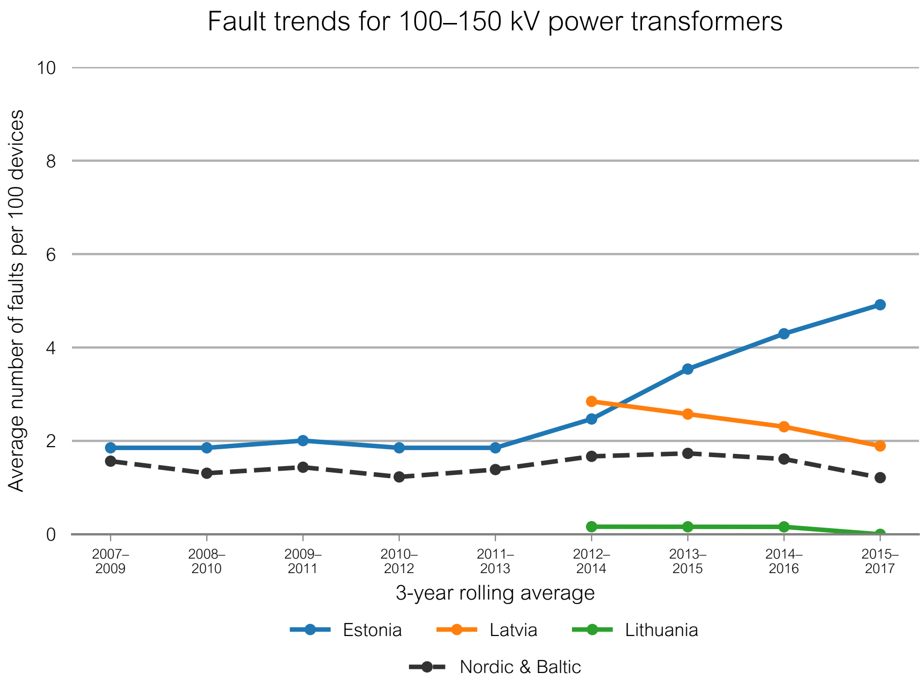


Figure 6.4.20: Fault trends as 3-year rolling averages for 100–150 kV power transformers in each Baltic country.

## 6.5 Faults in instrumental transformers

The tables and figures in this section present instrumental transformer faults in 2017 and during 2008–2017 at the voltage levels 100–150 kV, 220–330 kV and 380–420 kV. Instrumental transformers provide the necessary power to metering and protection devices in the power grid. These, in turn, trigger the necessary protection relays when needed and allow the grid owner to monitor the state of the system. Both current and voltage transformers are included in instrumental transformers.

Chapter 6.5.1 presents fault statistics for 380–420 kV instrumental transformers, Chapter 6.5.2 for 220–330 kV instrumental transformers and Chapter 6.5.3 100–150 kV instrumental transformers. The figures and tables present the number of faults instrumental transformer per 100 devices in 2017 as well as the average values during 2008–2017 in the Nordic countries and Estonia and during 2012–2017 in Latvia and Lithuania. Furthermore, faults according to the cause categories, defined in Chapter 1.4.1, are presented. Finally, Chapter 6.5.4 presents trend figures for the number of faults per 100 devices. The trends are calculated by 5-year moving averages for the Nordic countries during 1995–2017 and by 3-year moving averages for the Baltic countries during 2007–2017. With the help of the trend curve, it may be possible to estimate the number of faults in the future.

### 6.5.1 380–420 kV instrumental transformers

This section presents fault statistics for 380–420 kV instrument transformers. This includes a table with an overview of instrument transformer faults and figures with the annual number of faults and faults according to cause in 2017 and the average during 2008–2017. The fault causes used in these statistics are presented in Chapter 1.4.1.

Table 6.5.1 shows the number of 380–420 kV instrumental transformers and the number of faults for 380–420 kV instrumental transformers. Furthermore, the amount of ENS caused by the faults is presented. The data consists of the values for the year 2017 and for the period 2008–2017.

It should be noted, that only Denmark, Finland, Lithuania, Norway and Sweden own 380–420 kV equipment. Therefore, only these countries are presented in the figures in this section.

Table 6.5.1: Overview of faults for 380–420 kV instrumental transformers.

| | Devices | Faults | Faults per 100 devices | | ENS (MWh) | |
|---|---|---|---|---|---|---|
| Country | 2017 | 2017 | 2017 | 2008–2017 | 2017 | 2008–2017 |
| Denmark | 227 | 4 | 1.76 | 0.11 | 0.0 | 0.0 |
| Estonia | 0 | 0 | 0.00 | 0.00 | 0.0 | 0.0 |
| Finland | 588 | 0 | 0.00 | 0.02 | 0.0 | 0.0 |
| Iceland | 0 | 0 | 0.00 | 0.00 | 0.0 | 0.0 |
| Latvia | 0 | 0 | 0.00 | 0.00 | 0.0 | 0.0 |
| Lithuania[1] | 9 | 0 | 0.00 | 0.00 | 0.0 | 0.0 |
| Norway | 930 | 2 | 0.22 | 0.16 | 0.0 | 34.0 |
| Sweden | 1359 | 0 | 0.00 | 0.16 | 0.0 | 28.3 |
| Nordic | 3104 | 6 | 0.19 | 0.13 | 0.0 | 62.3 |
| Baltic | 9 | 0 | 0.00 | 0.00 | 0.0 | 0.0 |
| Nordic & Baltic | 3113 | 6 | 0.19 | 0.13 | 0.0 | 62.3 |

[1] Lithuania started maintaining their 380–420 kV grid in 2016. Therefore, their average use the period 2016–2017.

Figure 6.5.1 presents the annual number of 380–420 kV instrumental transformer faults per 100 devices during 2008–2017 and the average for the period 2008–2017 in Denmark, Finland, Lithuania, Norway and Sweden.

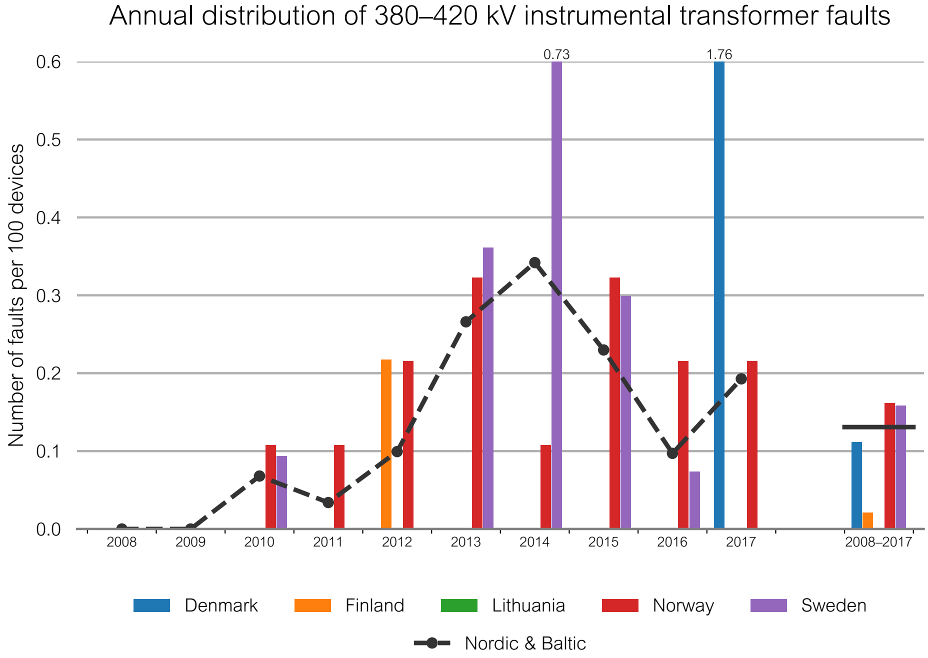


Figure 6.5.1: Annual distribution of 380–420 kV instrumental transformer faults and the average during 2008–2017 in Denmark, Finland, Lithuania, Norway and Sweden. This figure has the following remarks:

- The high value for Sweden in 2014 is caused by 7 instrumental transformers that exploded that year. 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.
- The high value for Denmark in 2017 is caused by 4 faults, of which 3 were caused by voltage transformers of a specific synchronous condenser. They were mounted in a complex environment, which resulted in vibrations in the core of the voltage transformers.

Figure 6.5.2 presents the number of 380–420 kV instrumental transformer faults per cause in 2017 in Denmark, Finland, Lithuania, Norway and Sweden.

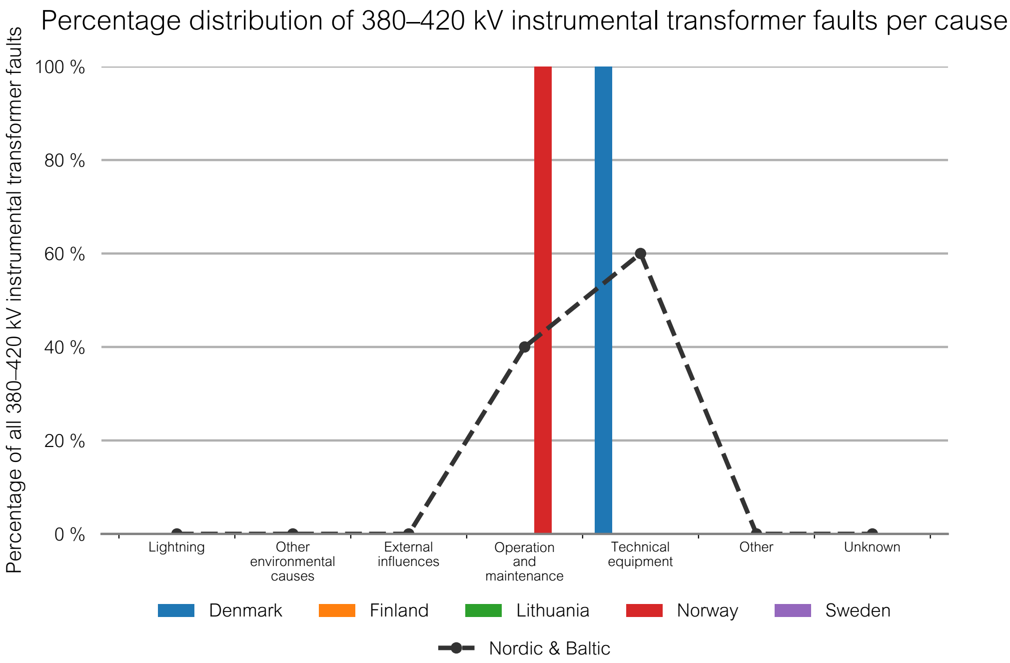


Figure 6.5.2: Percentage distribution of 380–420 kV instrumental transformer faults per cause in 2017 in Denmark, Finland, Lithuania, Norway and Sweden.

Figure 6.5.3 presents the average number of 380–420 kV instrumental transformer faults per cause during 2008–2017 in Denmark, Finland, Lithuania, Norway and Sweden.

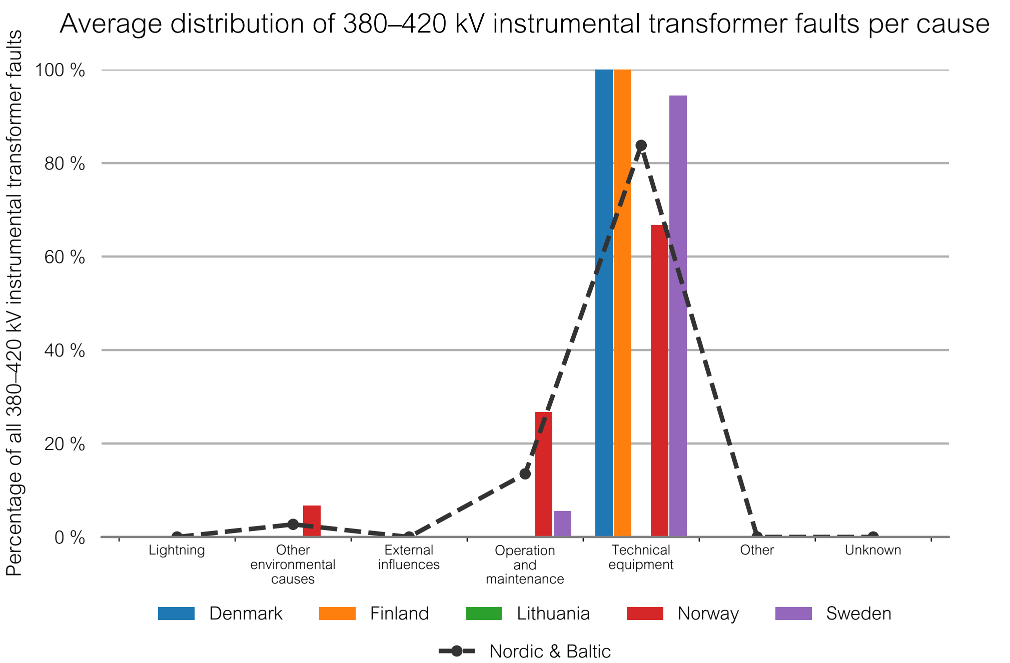


Figure 6.5.3: Average distribution of 380–420 kV instrumental transformer faults per cause during 2008–2017 in Denmark, Finland, Lithuania, Norway and Sweden.

### 6.5.2 220–330 kV instrumental transformers

This section presents fault statistics for 220–330 kV instrument transformers. This includes a table with an overview of instrument transformer faults and figures with the annual number of faults and faults according to cause in 2017 and the average during 2008–2017. The fault causes used in these statistics are presented in Chapter 1.4.1.

Table 6.5.2 shows the number of 220–330 kV instrumental transformers and the number of faults for 220–330 kV instrumental transformers. Furthermore, the amount of ENS caused by the faults is presented. The data consists of the values for the year 2017 and for the period 2008–2017.

Table 6.5.2: Overview of faults for 220–330 kV instrumental transformers.

| | Devices | Faults | Faults per 100 devices | | ENS (MWh) | |
|---|---|---|---|---|---|---|
| Country | 2017 | 2017 | 2017 | 2008–2017 | 2017 | 2008–2017 |
| Denmark | 17 | 0 | 0.00 | 0.79 | 0.0 | 0.0 |
| Estonia | 180 | 1 | 0.56 | 0.29 | 0.0 | 0.0 |
| Finland | 437 | 0 | 0.00 | 0.06 | 0.0 | 0.0 |
| Iceland | 444 | 0 | 0.00 | 0.00 | 0.0 | 0.0 |
| Latvia[1] | 200 | 0 | 0.00 | 0.08 | 0.0 | 0.0 |
| Lithuania[1] | 220 | 1 | 0.45 | 0.24 | 0.0 | 0.0 |
| Norway | 2805 | 2 | 0.07 | 0.07 | 0.0 | 4.0 |
| Sweden | 684 | 0 | 0.00 | 0.06 | 0.0 | 2.2 |
| Nordic | 4387 | 2 | 0.05 | 0.07 | 0.0 | 6.3 |
| Baltic | 600 | 2 | 0.33 | 0.22 | 0.0 | 0.0 |
| Nordic & Baltic | 4987 | 4 | 0.08 | 0.08 | 0.0 | 6.3 |

[1] The average values of Latvia and Lithuania use the period 2012–2017.

Figure 6.5.4 and Figure 6.5.5 present the annual number of 220–330 kV instrumental transformer faults per 100 devices during 2008–2017 and the average for the period 2008–2017 in the Nordic and Baltic countries, respectively.

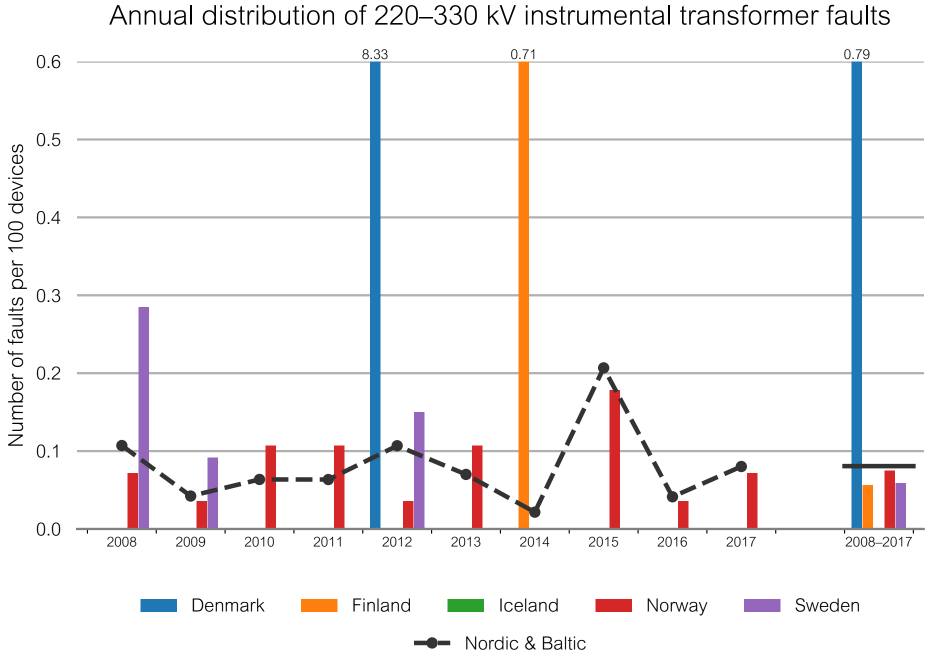


Figure 6.5.4: Annual distribution of 220–330 kV instrumental transformer faults and the average during 2008–2017 in each Nordic country.

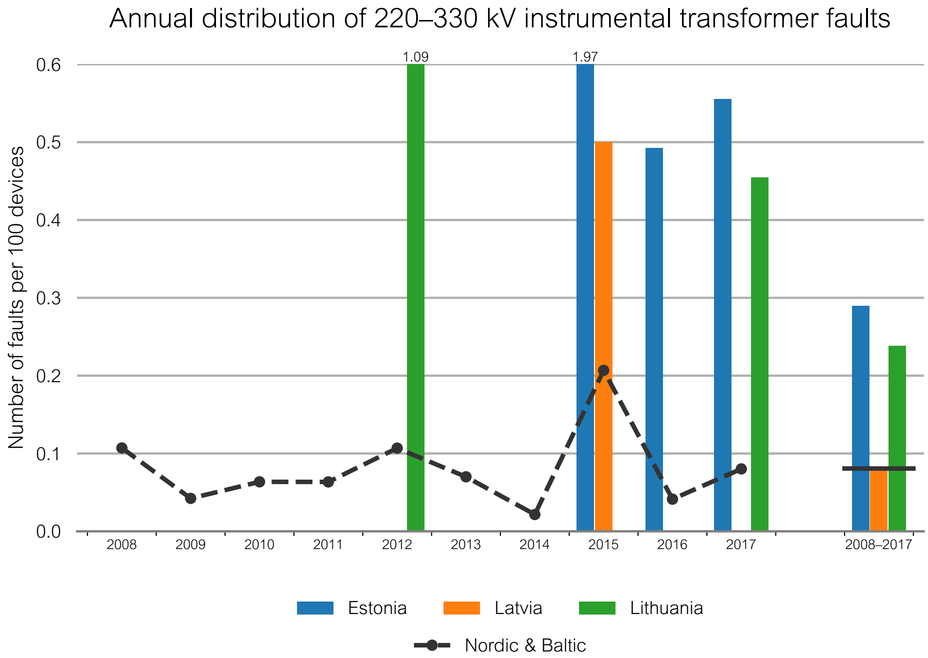


Figure 6.5.5: Annual distribution of 220–330 kV instrumental transformer faults and the average during 2008–2017 in Estonia and during 2012–2017 in Latvia and Lithuania.

Figure 6.5.6 and Figure 6.5.7 present the number of 220–330 kV instrumental transformer faults per cause in 2017 in the Nordic and Baltic countries.

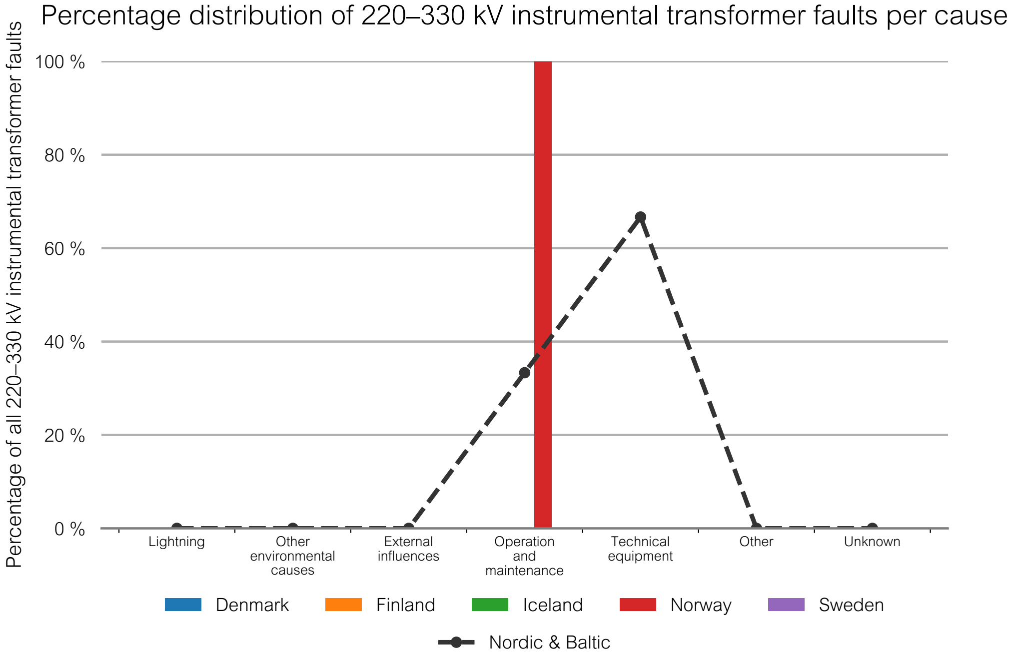


Figure 6.5.6: Percentage distribution of 220–330 kV instrumental transformer faults per cause in 2017 in each Nordic country.

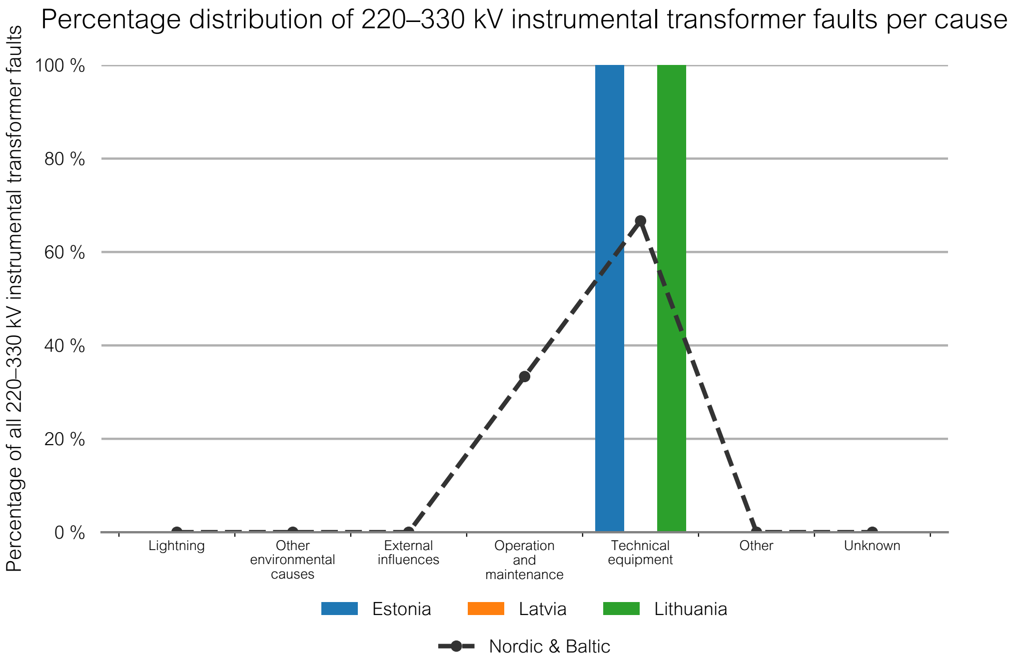


Figure 6.5.7: Percentage distribution of 220–330 kV instrumental transformer faults per cause in 2017 in each Baltic country.

Figure 6.5.8 and Figure 6.5.9 present the average number of 220–330 kV instrumental transformer faults per cause during 2008–2017 in the Nordic countries and Estonia and during 2012–2017 in Latvia and Lithuania.

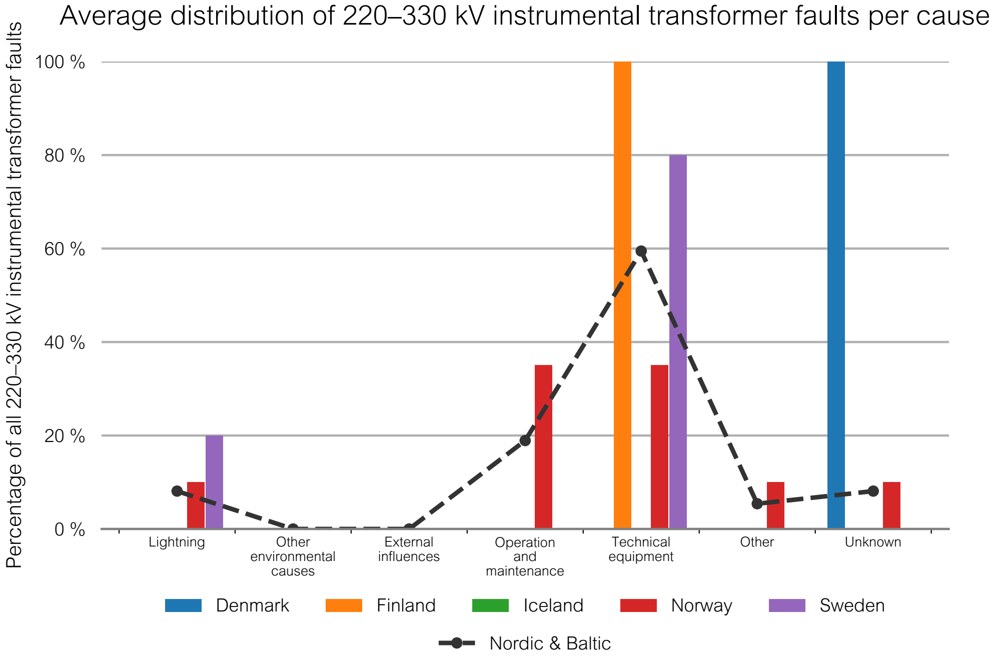


Figure 6.5.8: Average distribution of 220–330 kV instrumental transformer faults per cause during 2008–2017 in each Nordic country.

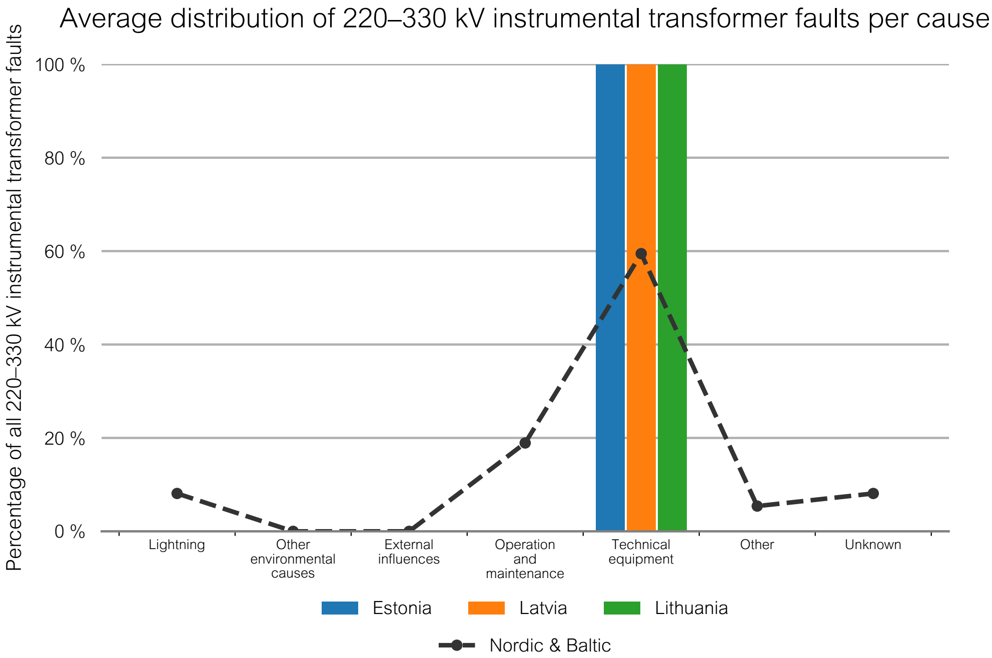


Figure 6.5.9: Average distribution of 220–330 kV instrumental transformer faults per cause during 2008–2017 in Estonia and during 2012–2017 in Latvia and Lithuania.

### 6.5.3 100–150 kV instrumental transformers

This section presents fault statistics for 100–150 kV instrument transformers. This includes a table with an overview of instrument transformer faults and figures with the annual number of faults and faults according to cause in 2017 and the average during 2008–2017. The fault causes used in these statistics are presented in Chapter 1.4.1.

Table 6.5.3 shows the number of 100–150 kV instrumental transformers and the number of faults for 100–150 kV instrumental transformers. Furthermore, the amount of ENS caused by the faults is presented. The data consists of the values for the year 2017 and for the period 2008–2017.

Table 6.5.3: Overview of faults for 100–150 kV instrumental transformers.

| | Devices | Faults | Faults per 100 devices | | ENS (MWh) | |
|---|---|---|---|---|---|---|
| Country | 2017 | 2017 | 2017 | 2008–2017 | 2017 | 2008–2017 |
| Denmark | 965 | 0 | 0.00 | 0.06 | 0.0 | 1.9 |
| Estonia | 990 | 0 | 0.00 | 0.07 | 0.0 | 1.7 |
| Finland | 3870 | 3 | 0.08 | 0.08 | 20.7 | 15.8 |
| Iceland | 611 | 0 | 0.00 | 0.00 | 0.0 | 0.0 |
| Latvia[1] | 930 | 1 | 0.11 | 0.05 | 0.0 | 0.0 |
| Lithuania[1] | 1108 | 1 | 0.09 | 0.08 | 0.0 | 0.2 |
| Norway | 7768 | 3 | 0.04 | 0.05 | 3.1 | 24.2 |
| Sweden | 3678 | 3 | 0.08 | 0.08 | 78.6 | 67.4 |
| Nordic | 16892 | 9 | 0.05 | 0.06 | 102.4 | 109.3 |
| Baltic | 3028 | 2 | 0.07 | 0.07 | 0.0 | 2.0 |
| Nordic & Baltic | 19920 | 11 | 0.06 | 0.06 | 102.4 | 111.2 |

[1] The average values of Latvia and Lithuania use the period 2012–2017.

Figure 6.5.10 and Figure 6.5.11 present the annual number of 100–150 kV instrumental transformer faults per 100 devices during 2008–2017 and the average for the period 2008–2017 in the Nordic and Baltic countries, respectively.

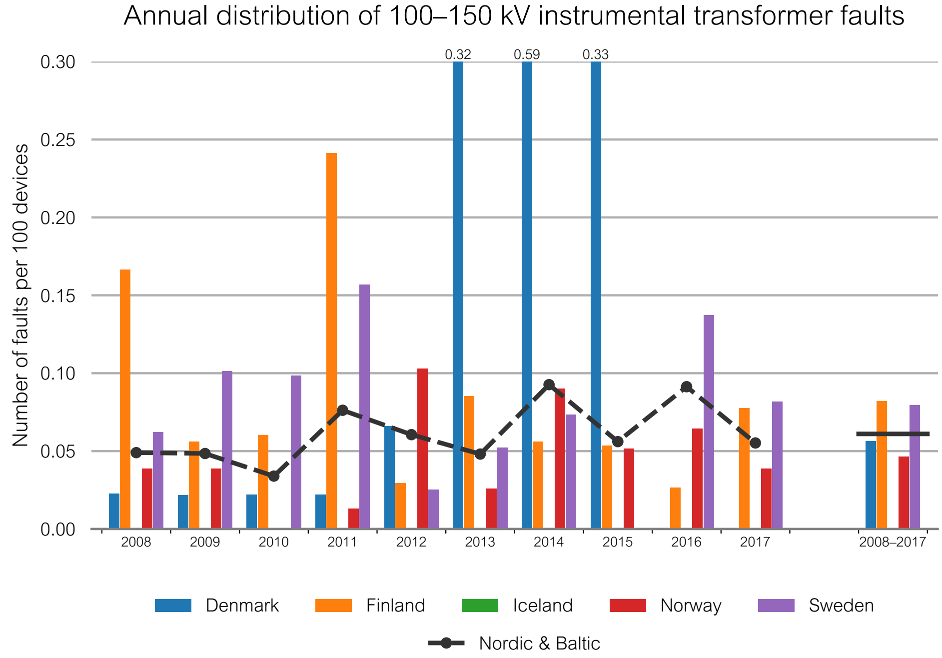


Figure 6.5.10: Annual distribution of 100–150 kV instrumental transformer faults and the average during 2008–2017 in each Nordic country.

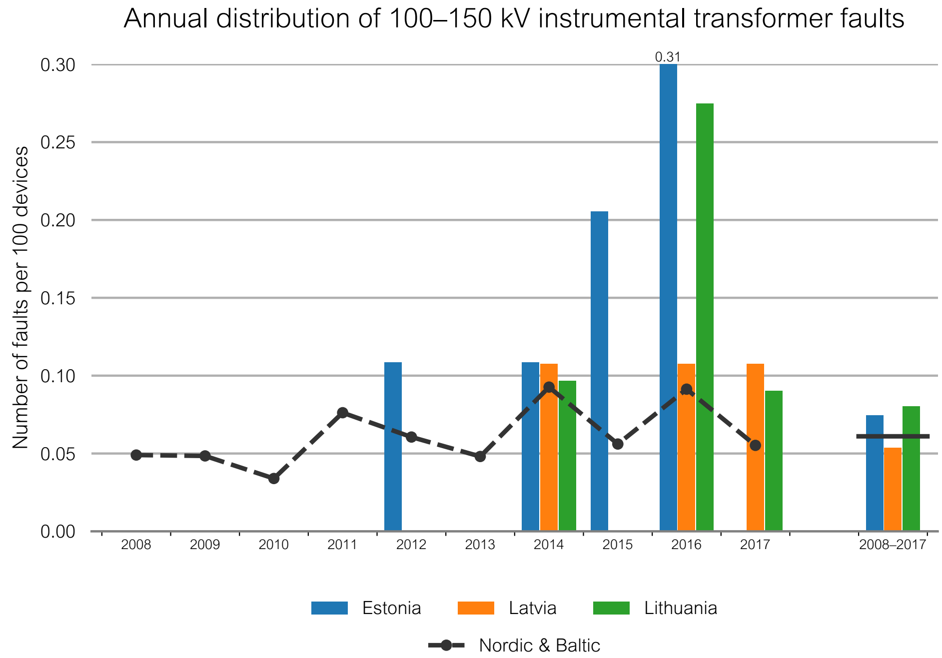


Figure 6.5.11: Annual distribution of 100–150 kV instrumental transformer faults and the average during 2008–2017 in Estonia and during 2012–2017 in Latvia and Lithuania.

Figure 6.5.12 and Figure 6.5.13 present the number of 100–150 kV instrumental transformer faults per cause in 2017 in the Nordic and Baltic countries.

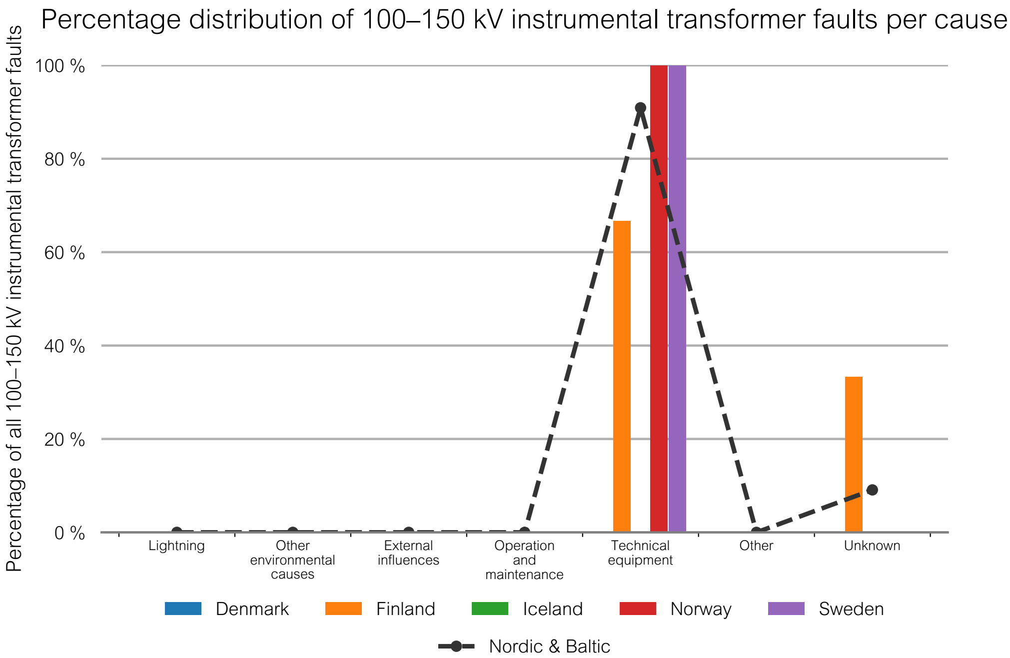


Figure 6.5.12: Percentage distribution of 100–150 kV instrumental transformer faults per cause in 2017 in each Nordic country.

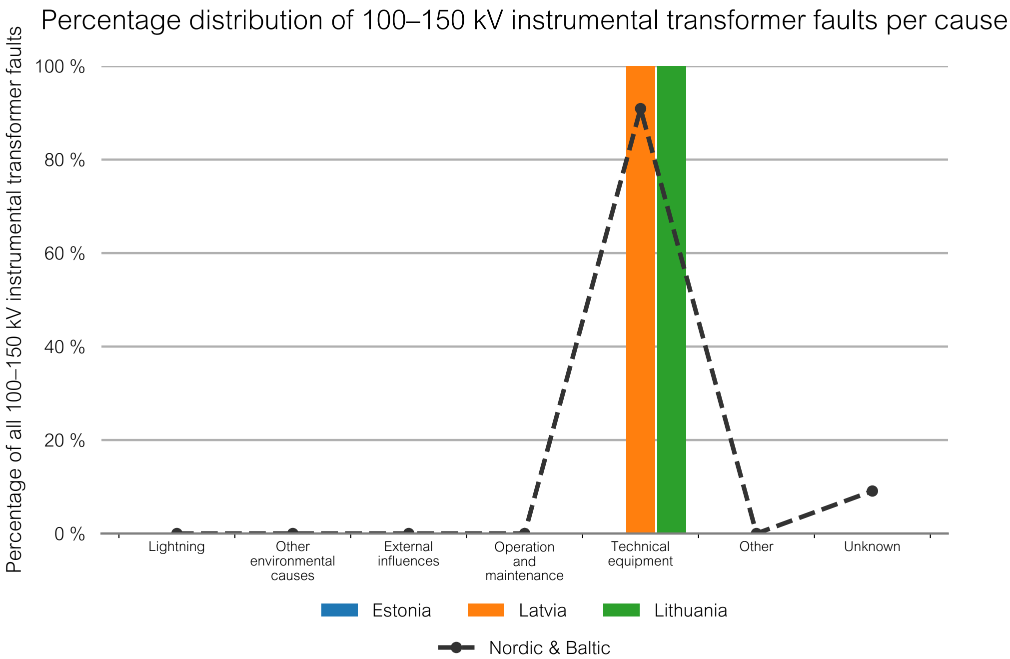


Figure 6.5.13: Percentage distribution of 100–150 kV instrumental transformer faults per cause in 2017 in each Baltic country.

Figure 6.5.14 and Figure 6.5.15 present the average number of 100–150 kV instrumental transformer faults per cause during 2008–2017 in the Nordic countries and Estonia and during 2012–2017 in Latvia and Lithuania.

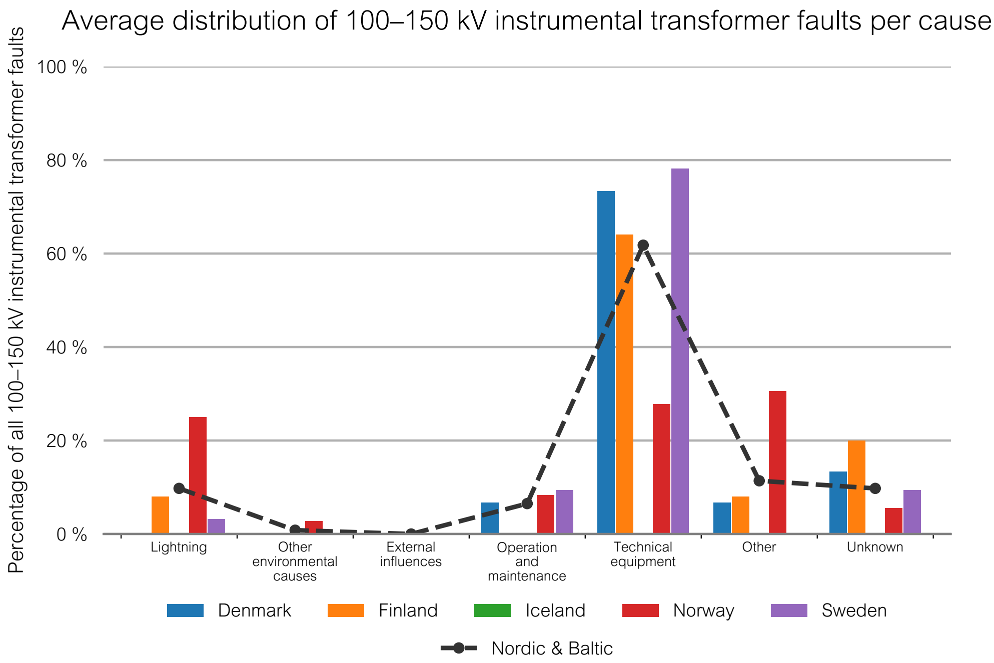


Figure 6.5.14: Average distribution of 100–150 kV instrumental transformer faults per cause during 2008–2017 in each Nordic country.

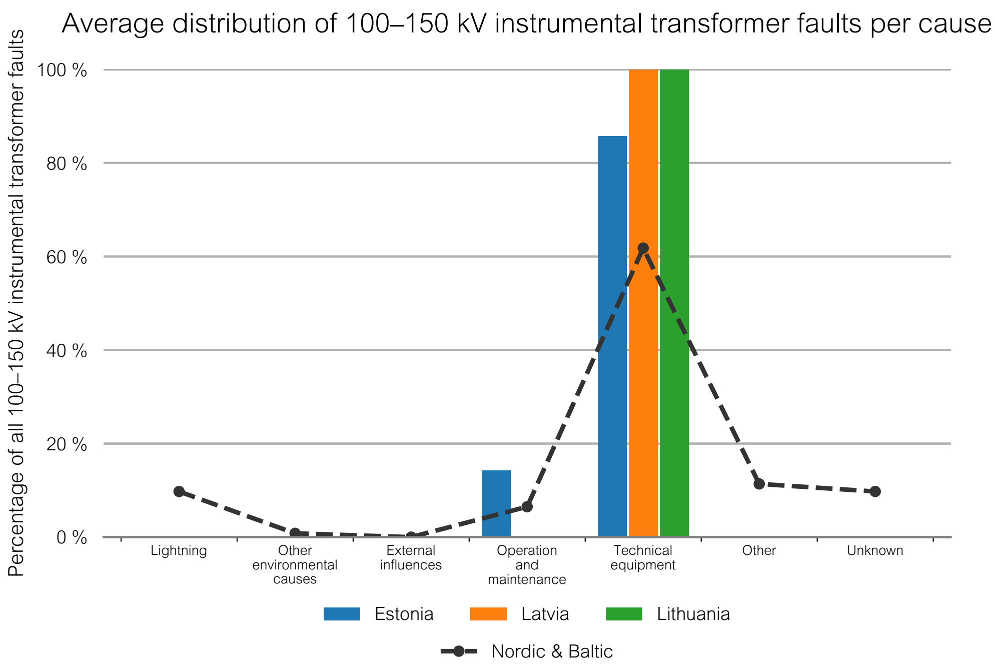


Figure 6.5.15: Average distribution of 100–150 kV instrumental transformer faults per cause during 2008–2017 in Estonia and during 2012–2017 in Latvia and Lithuania.

## 6.5.4 Fault trends for instrumental transformers

The figures in this section present fault trends for instrumental transformers at the voltage levels 100–150 kV, 220–330 kV and 380–420 kV. The Nordic countries use a 5-year rolling average, that is calculated by dividing the sum of the faults by the total number of devices for each 5-year period. The rolling average for the Baltic countries is calculated similarly, but with 3-year periods. The trend curves are proportioned the number of instrumental transformers in order to get comparable results between countries.

Figure 6.5.16 presents 380–420 kV fault trends for Denmark, Finland, Lithuania, Norway and Sweden, Figure 6.5.17 presents the Nordic 220–330 kV fault trends, Figure 6.5.18 presents the Baltic 220–330 kV fault trends, Figure 6.5.19 presents the Nordic 100–150 kV fault trends and Figure 6.5.20 presents the Baltic 100–150 kV fault trends.

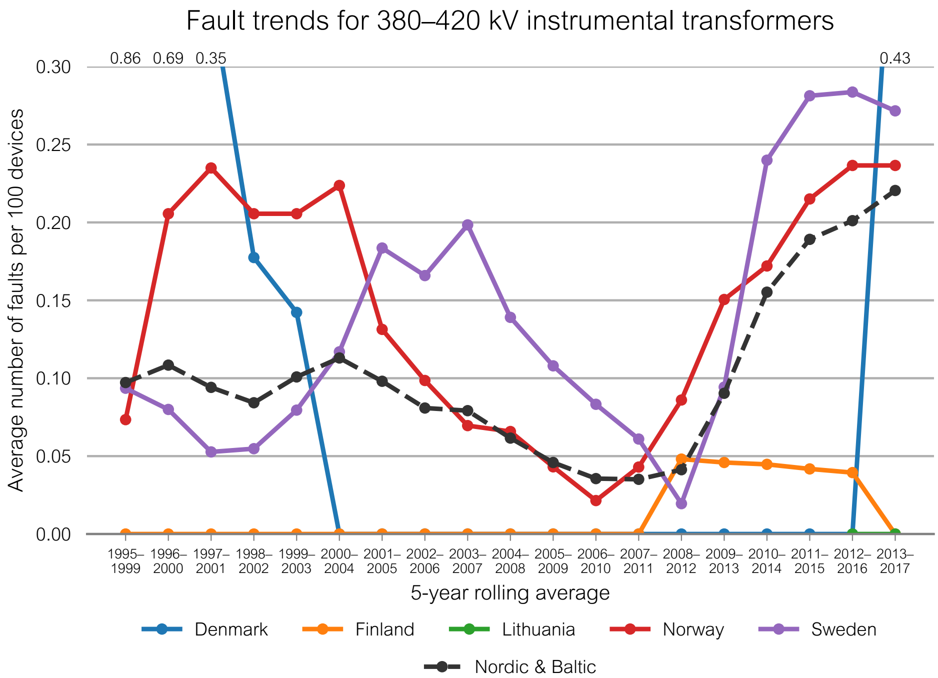


Figure 6.5.16: Fault trends as 5-year rolling averages for 380–420 kV instrumental transformers in Denmark, Finland, Lithuania, Norway and Sweden. This figure has the following remarks:

- The high value for Denmark in 2017 is caused by 4 faults, of which 3 were caused by voltage transformers for a specific synchronous condenser. They were mounted in a complex environment which resulted in vibrations to the core of the voltage transformers.
- Lithuania had no faults in their 380–420 kV instrumental transformers during 2012–2017.
- The high values for Sweden during 2010–2018 are caused by 7 instrumental 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.

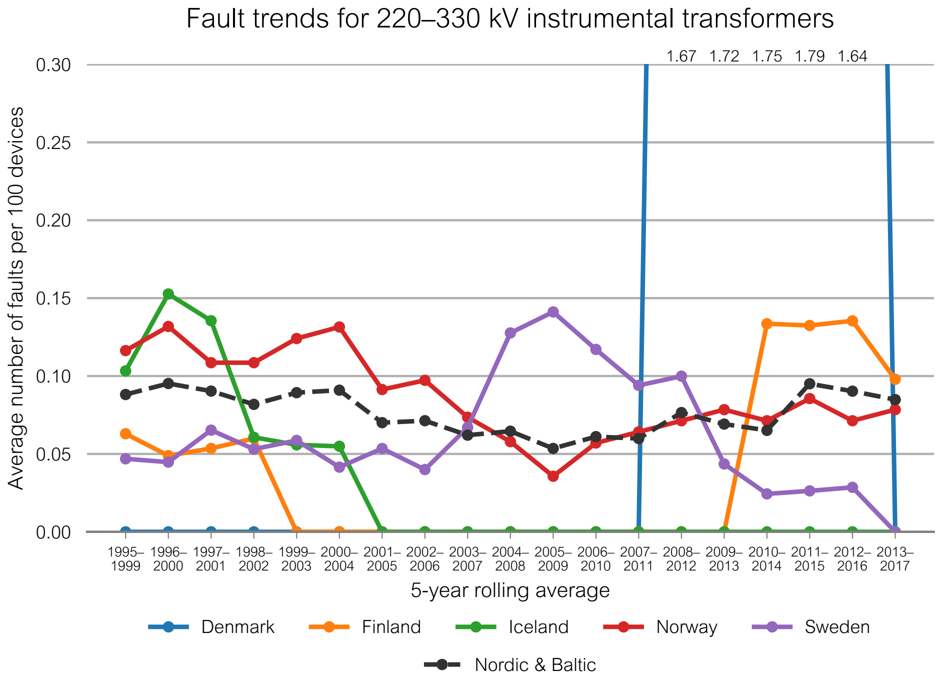


Figure 6.5.17: Fault trends as 5-year rolling averages for 220–330 kV instrumental transformers in each Nordic country. This figure has the following remarks:

- Denmark's high values during 2007–2016 are caused by 1 fault in 2012, as can be seen in Figure 6.5.4. The values seem to be extreme because Denmark owns significantly less instrumental transformers than the other countries.

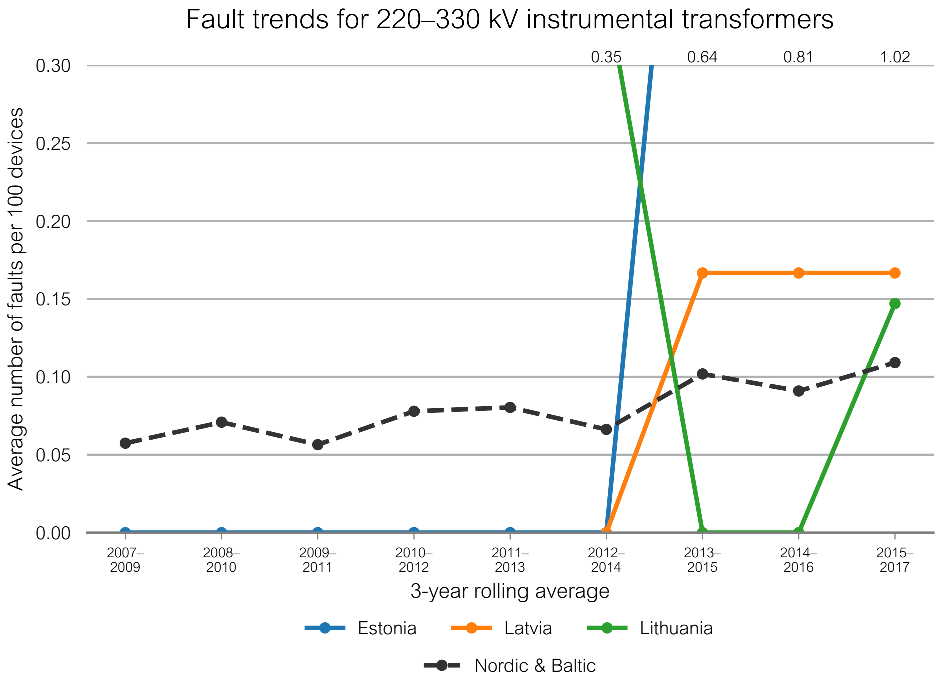


Figure 6.5.18: Fault trends as 3-year rolling averages for 220–330 kV instrumental transformers in each Baltic country.

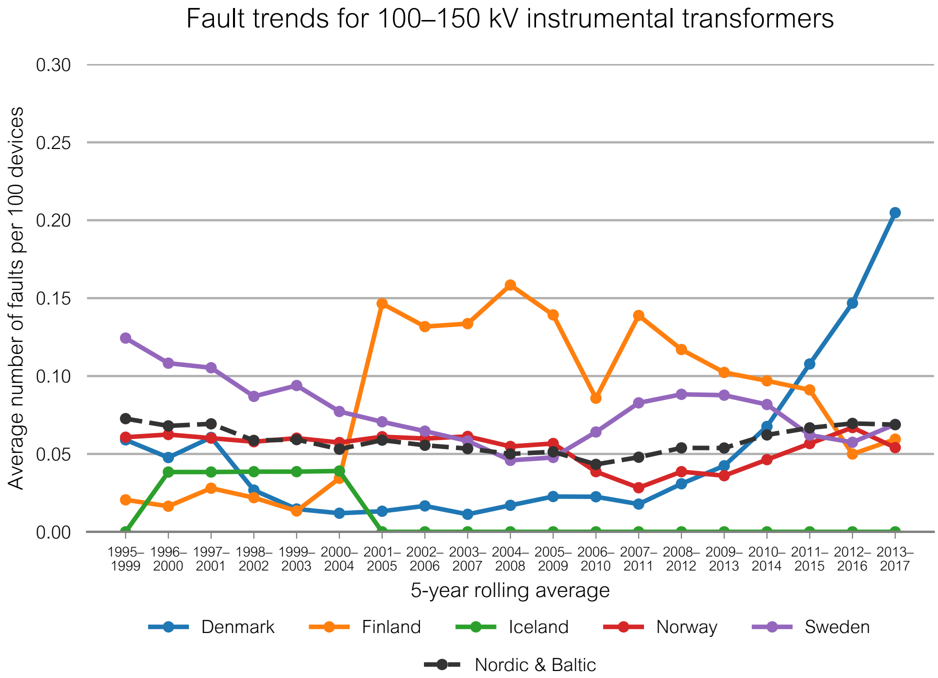


Figure 6.5.19: Fault trends as 5-year rolling averages for 100–150 kV instrumental transformers in each Nordic country.

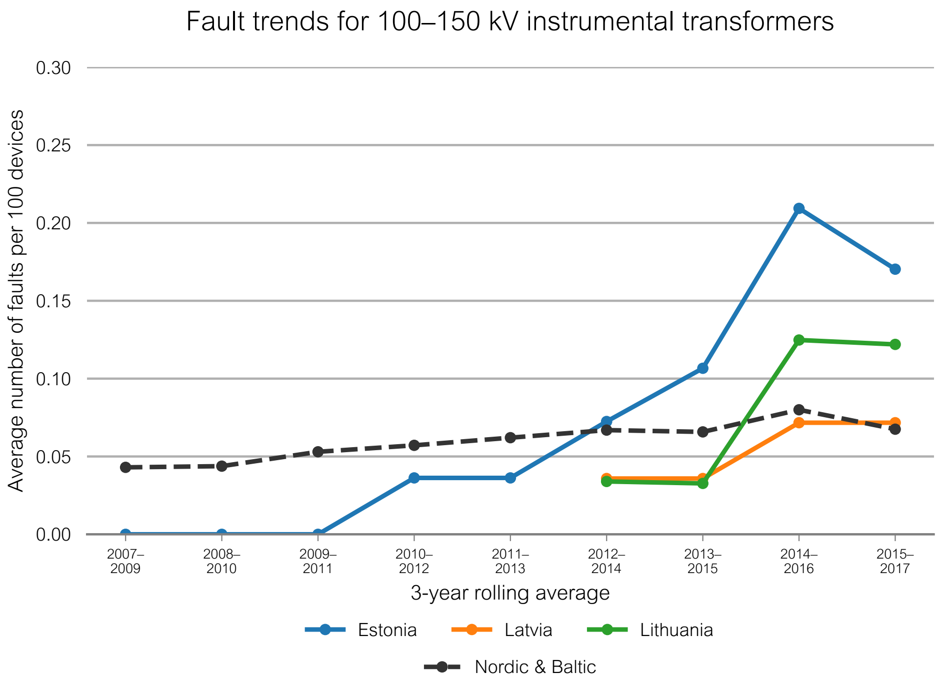


Figure 6.5.20: Fault trends as 3-year rolling averages for 100–150 kV instrumental transformers in each Baltic country.

## 6.6 Faults in circuit breakers

The tables and figures in this section present circuit breaker faults in 2017 and during 2008–2017 at the voltage levels 100–150 kV, 220–330 kV and 380–420 kV. Circuit breakers are used to protect the grid when it is experiencing faults. When functioning correctly, they break the power flow to the faulty part of the grid, thereby isolating the fault and preventing an outage from spreading further into the grid. Therefore, it is essential to keep the circuit breakers in good working condition.

Chapter 6.6.1 presents fault statistics for 380–420 kV cables, Chapter 6.6.2 for 220–330 kV cables and Chapter 6.6.3 100–150 kV cables. The figures and tables present the number of faults and permanent faults per 100 km cable in 2017 as well as the average values during 2008–2017 in the Nordic countries and Estonia and during 2012–2017 in Latvia and Lithuania. Furthermore, faults according to the cause categories, defined in Chapter 1.4.1, are presented. Finally, Chapter 6.6.4 presents trend figures for the number of circuit breaker faults per 100 devices. The trends are calculated by 5-year moving averages for the Nordic countries during 1995–2017 and by 3-year moving averages for the Baltic countries during 2007–2017. With the help of the trend curve, it may be possible to estimate the number of faults in the future.

### 6.6.1 380–420 kV circuit breakers

This section presents fault statistics for 380–420 kV circuit breakers. This includes a table with an overview of circuit breaker faults and figures with the annual number of faults and faults according to cause in 2017 and the average during 2008–2017. The fault causes used in these statistics are presented in Chapter 1.4.1.

Table 6.6.1 shows the number of 380–420 kV power transformers and the number of faults for 380–420 kV power transformers. Furthermore, the amount of ENS caused by the faults is presented. The data consists of the values for the year 2017 and for the period 2008–2017.

It should be noted, that only Denmark, Finland, Lithuania, Norway and Sweden own 380–420 kV equipment. Therefore, only these countries are presented in the figures in this section.

Table 6.6.1: Overview of faults for 380–420 kV circuit breakers.

| | Devices | Faults | Faults per 100 devices | | ENS (MWh) | |
|---|---|---|---|---|---|---|
| Country | 2017 | 2017 | 2017 | 2008–2017 | 2017 | 2008–2017 |
| Denmark | 227 | 1 | 0.44 | 0.23 | 0.0 | 0.0 |
| Estonia | 0 | 0 | 0.00 | 0.00 | 0.0 | 0.0 |
| Finland | 352 | 0 | 0.00 | 0.19 | 0.0 | 0.0 |
| Iceland | 0 | 0 | 0.00 | 0.00 | 0.0 | 0.0 |
| Latvia | 0 | 0 | 0.00 | 0.00 | 0.0 | 0.0 |
| Lithuania[1] | 5 | 0 | 0.00 | 0.00 | 0.0 | 0.0 |
| Norway | 453 | 3 | 0.66 | 0.62 | 0.0 | 4.5 |
| Sweden[2] | 592 | 1 | 0.17 | 0.86 | 0.0 | 0.1 |
| Nordic | 1624 | 5 | 0.31 | 0.58 | 0.0 | 4.7 |
| Baltic | 5 | 0 | 0.00 | 0.00 | 0.0 | 0.0 |
| Nordic & Baltic | 1629 | 5 | 0.31 | 0.58 | 0.0 | 4.7 |

[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. Furthermore, a reactor breaker is operated significantly more often than a line breaker, which in turn causes the high number of circuit breaker faults in Sweden.

Figure 6.6.1 presents the annual number of 380–420 kV power transformer faults per 100 devices during 2008–2017 and the average for the period 2008–2017 in Denmark, Finland, Lithuania, Norway and Sweden.

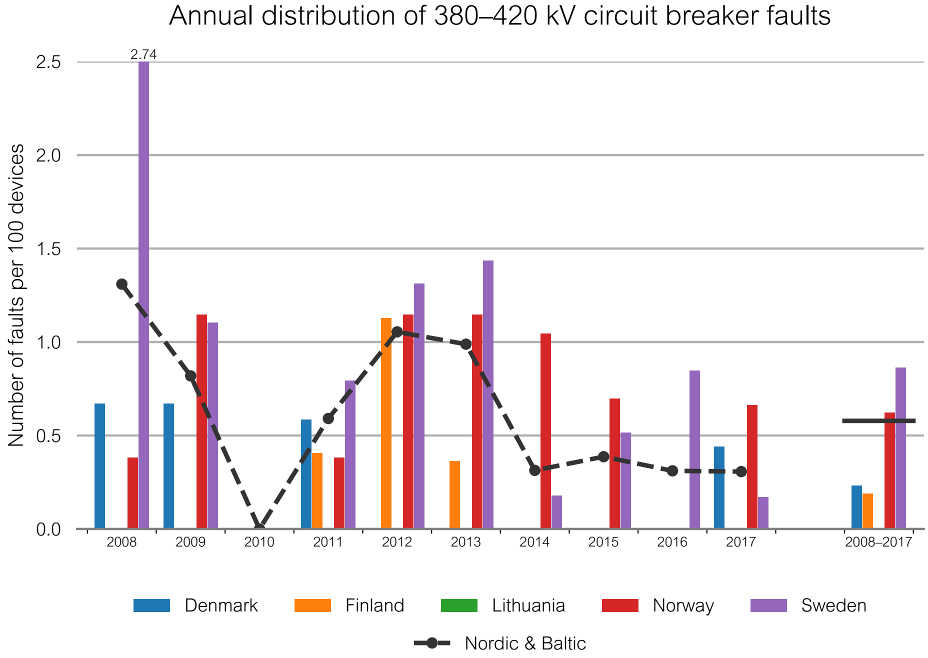


Figure 6.6.1: Annual distribution of 380–420 kV power transformer faults and the average during 2008–2017 in Denmark, Finland, Lithuania, Norway and Sweden. Lithuania had no faults in their 380–420 kV circuit breakers.

Figure 6.6.2 presents the number of 380–420 kV power transformer faults per cause in 2017 in Denmark, Finland, Lithuania, Norway and Sweden.

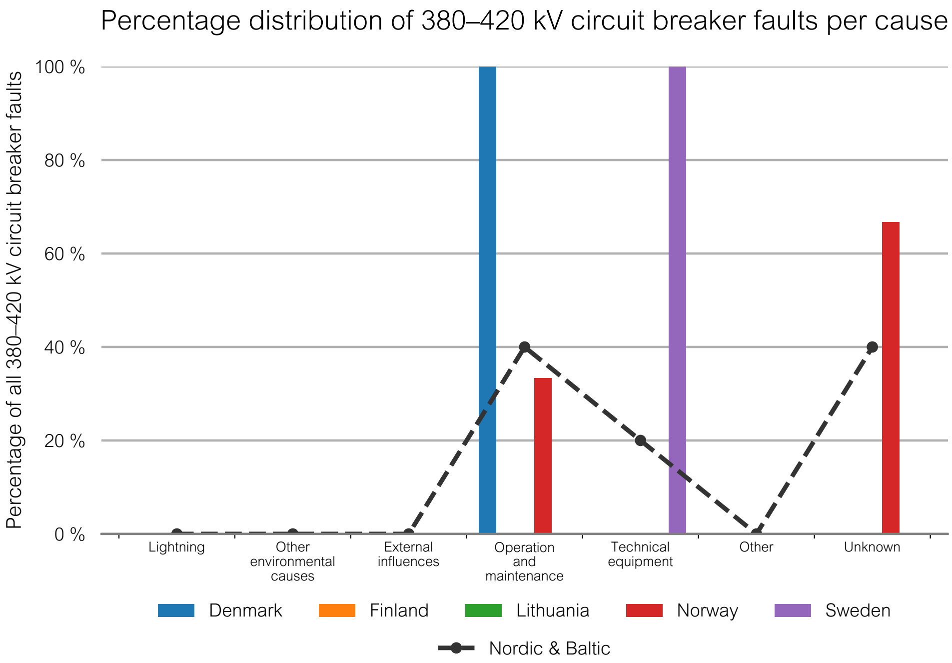


Figure 6.6.2: Percentage distribution of 380–420 kV power transformer faults per cause in Denmark, Finland, Lithuania, Norway and Sweden in 2017. Lithuania had no faults in their 380–420 kV circuit breakers.

Figure 6.6.3 presents the average number of 380–420 kV power transformer faults per cause during 2008–2017 in Denmark, Finland, Lithuania, Norway and Sweden.

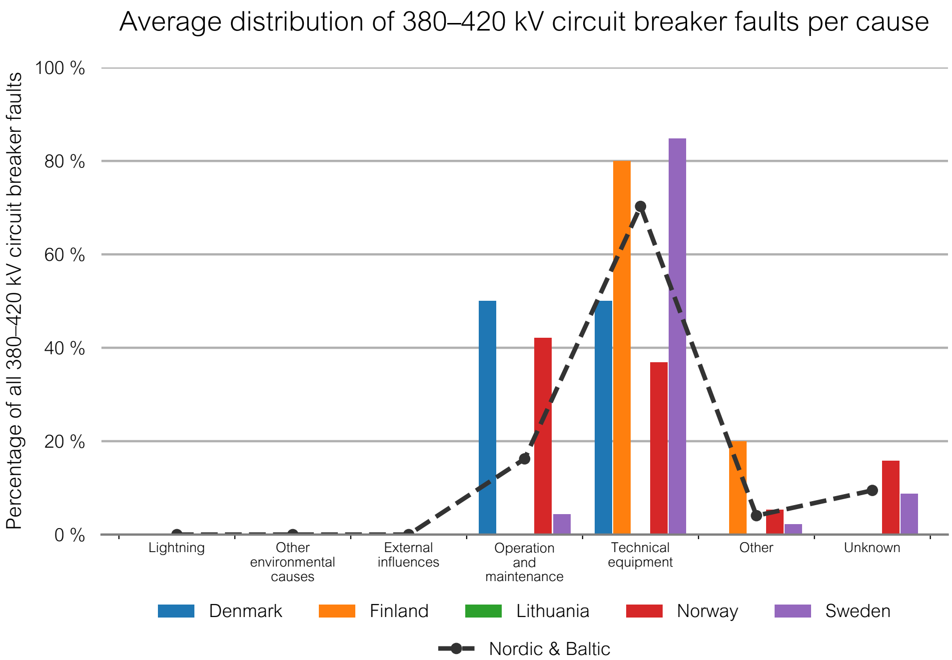


Figure 6.6.3: Average distribution of 380–420 kV power transformer faults per cause in Denmark, Finland, Lithuania, Norway and Sweden during 2008–2017. Lithuania had no faults in their 380–420 kV circuit breakers.

### 6.6.2 220–330 kV circuit breakers

This section presents fault statistics for 220–330 kV circuit breakers. This includes a table with an overview of circuit breaker faults and figures with the annual number of faults and faults according to cause in 2017 and the average during 2008–2017. The fault causes used in these statistics are presented in Chapter 1.4.1.

Table 6.6.2 shows the number of 220–330 kV circuit breakers and the number of faults for 220–330 kV circuit breakers. Furthermore, the amount of ENS caused by the faults is presented. The data consists of the values for the year 2017 and for the period 2008–2017.

Table 6.6.2: Overview of faults for 220–330 kV circuit breakers.

| | Devices | Faults | Faults per 100 devices | | ENS (MWh) | |
|---|---|---|---|---|---|---|
| Country | 2017 | 2017 | 2017 | 2008–2017 | 2017 | 2008–2017 |
| Denmark | 17 | 0 | 0.00 | 0.00 | 0.0 | 0.0 |
| Estonia | 121 | 4 | 3.31 | 1.50 | 0.0 | 0.0 |
| Finland | 78 | 0 | 0.00 | 0.22 | 0.0 | 0.0 |
| Iceland | 80 | 0 | 0.00 | 0.63 | 0.0 | 268.8 |
| Latvia[1] | 97 | 1 | 1.03 | 0.16 | 0.0 | 0.0 |
| Lithuania[1] | 113 | 0 | 0.00 | 0.65 | 0.0 | 0.0 |
| Norway | 730 | 3 | 0.41 | 0.52 | 0.0 | 16.6 |
| Sweden | 342 | 1 | 0.29 | 0.32 | 0.0 | 0.0 |
| Nordic | 1247 | 4 | 0.32 | 0.45 | 0.0 | 285.4 |
| Baltic | 331 | 5 | 1.51 | 0.95 | 0.0 | 0.0 |
| Nordic & Baltic | 1578 | 9 | 0.57 | 0.53 | 0.0 | 285.4 |

[1] The average values of Latvia and Lithuania use the period 2012–2017.

Figure 6.6.4 and Figure 6.6.5 present the annual number of 220–330 kV circuit breaker faults per 100 devices during 2008–2017 and the average for the period 2008–2017 in the Nordic and Baltic countries, respectively.

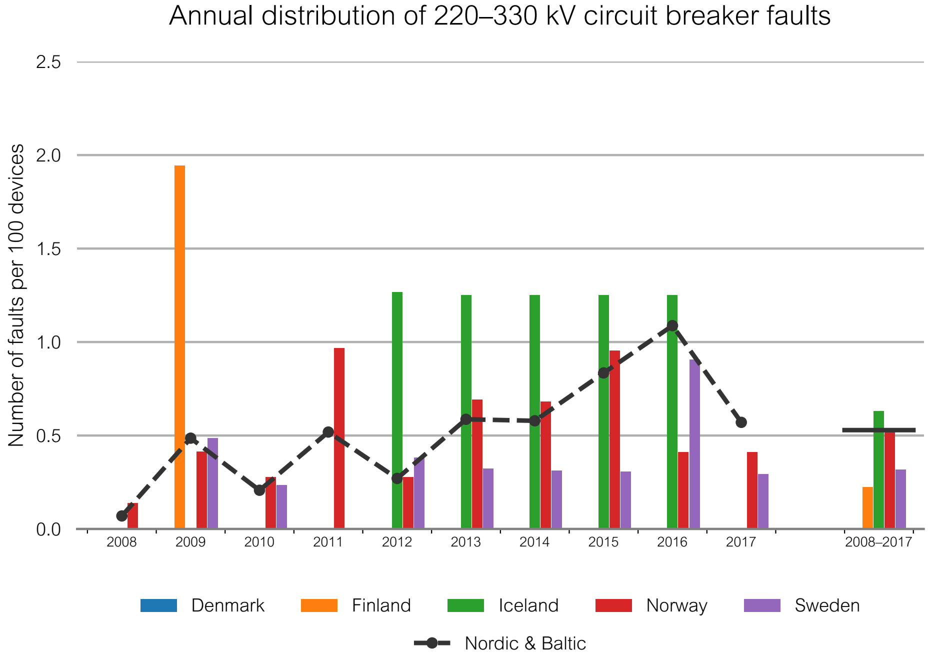


Figure 6.6.4: Annual distribution of 220–330 kV circuit breaker faults and the average during 2008–2017 in each Nordic country.

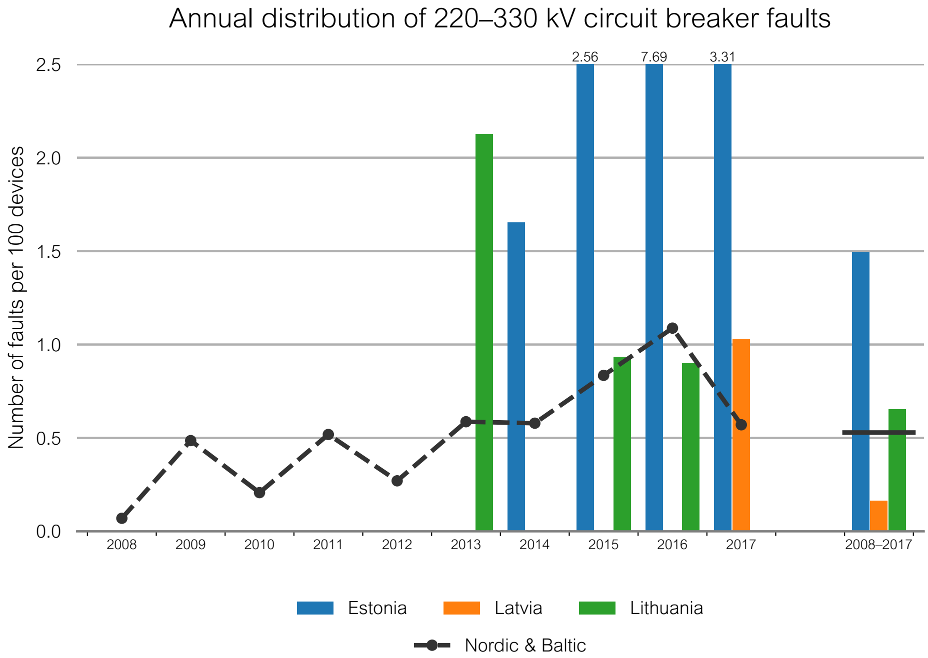


Figure 6.6.5: Annual distribution of 220–330 kV circuit breaker faults and the average during 2008–2017 in Estonia and during 2012–2017 in Latvia and Lithuania. This figure has the following remarks:

- Estonia's high values are caused by a relatively small number of faults (~4) in a small grid (121 220–330 kV circuit breakers).

Figure 6.6.6 and Figure 6.6.7 present the number of 220–330 kV circuit breaker faults per cause in 2017 in the Nordic and Baltic countries.

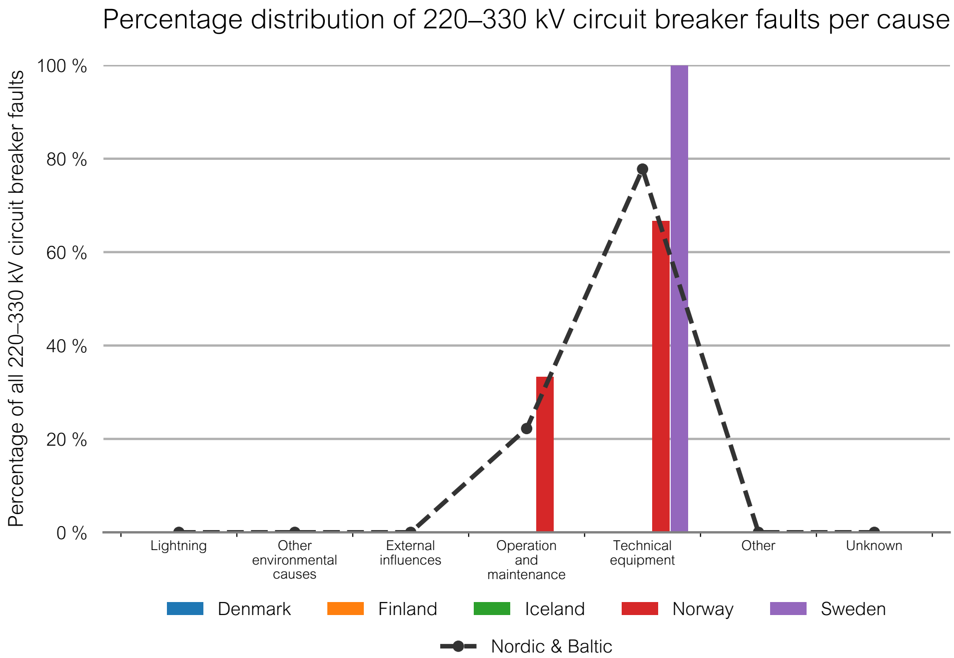


Figure 6.6.6: Percentage distribution of 220–330 kV circuit breaker faults per cause in 2017 in each Nordic country.

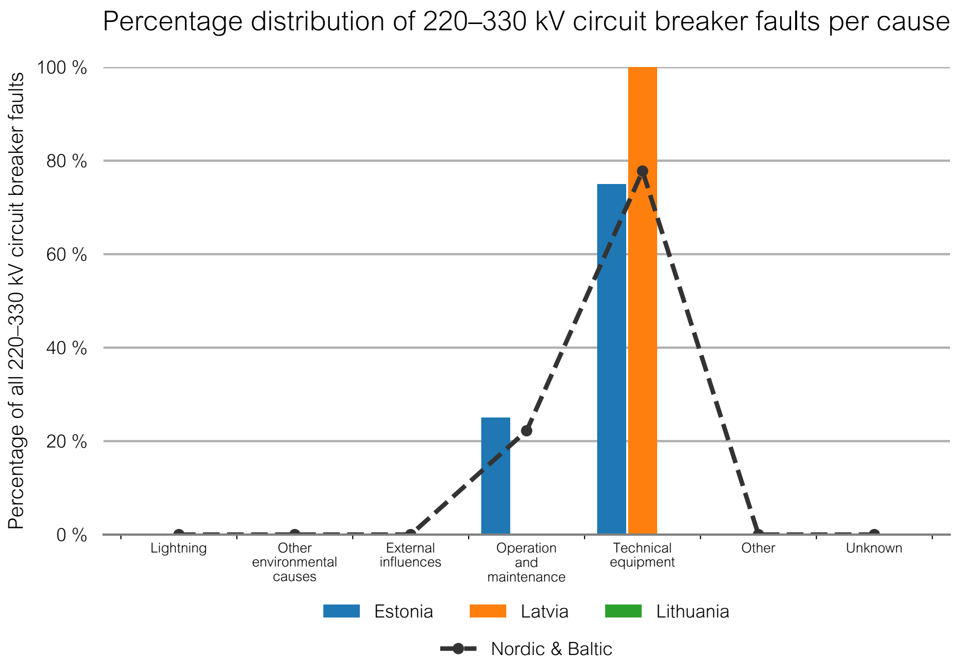


Figure 6.6.7: Percentage distribution of 220–330 kV circuit breaker faults per cause in 2017 in each Baltic country.

Figure 6.6.8 and Figure 6.6.9 present the average number of 220–330 kV circuit breaker faults per cause during 2008–2017 in the Nordic countries and Estonia and during 2012–2017 in Latvia and Lithuania.

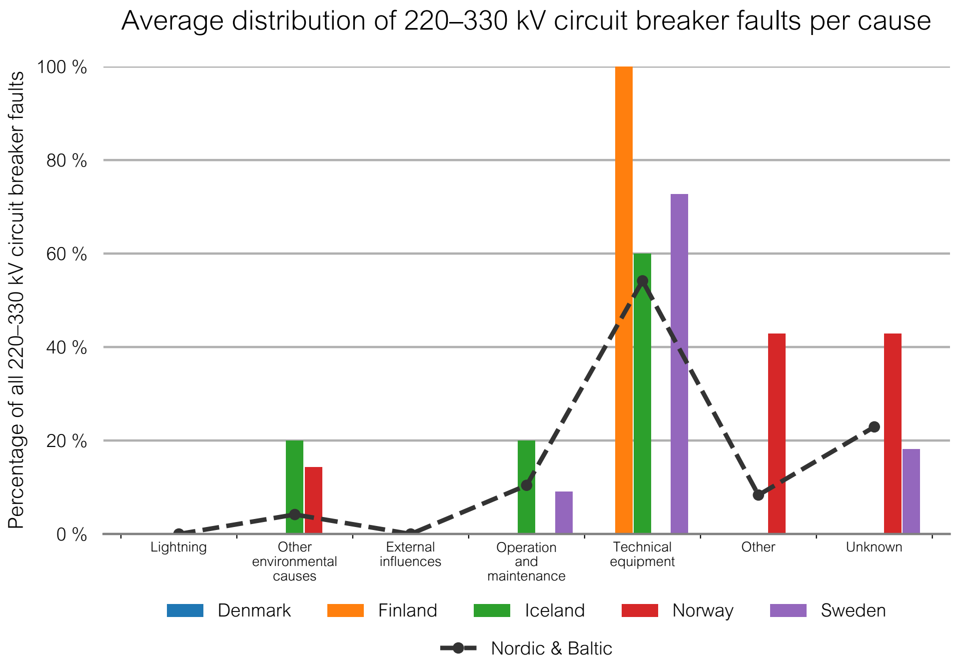


Figure 6.6.8: Average distribution of 220–330 kV circuit breaker faults per cause during 2008–2017 in each Nordic country.

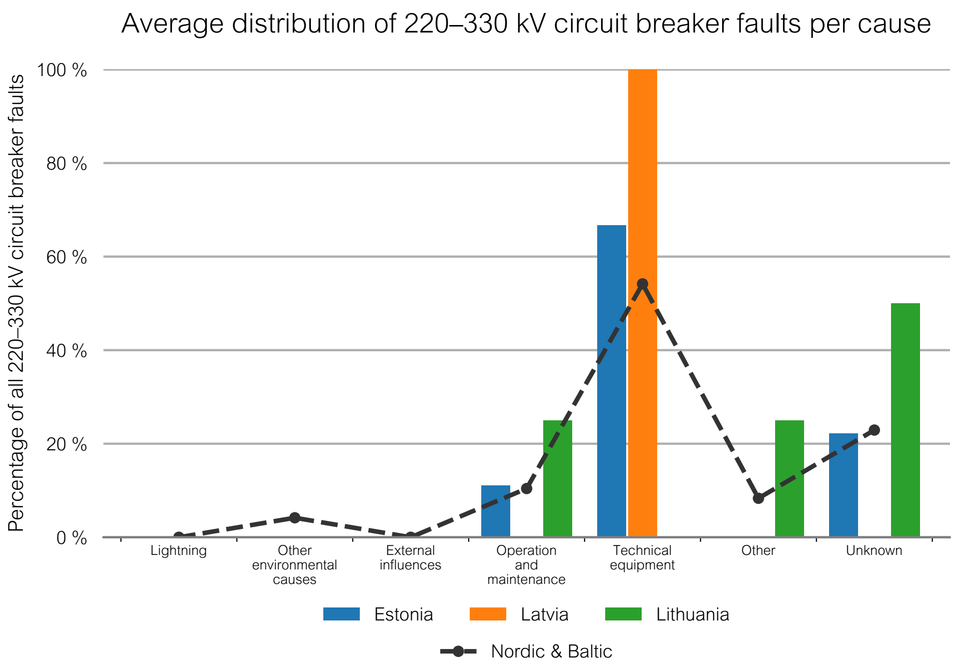


Figure 6.6.9: Average distribution of 220–330 kV circuit breaker faults per cause during 2008–2017 in Estonia and during 2012–2017 in Latvia and Lithuania.

### 6.6.3 100–150 kV circuit breakers

This section presents fault statistics for 100–150 kV circuit breakers. This includes a table with an overview of circuit breaker faults and figures with the annual number of faults and faults according to cause in 2017 and the average during 2008–2017. The fault causes used in these statistics are presented in Chapter 1.4.1.

Table 6.6.3 shows the number of 100–150 kV circuit breakers and the number of faults for 100–150 kV circuit breakers. Furthermore, the amount of ENS caused by the faults is presented. The data consists of the values for the year 2017 and for the period 2008–2017.

Table 6.6.3: Overview of faults for 100–150 kV circuit breakers.

| | Devices | Faults | Faults per 100 devices | | ENS (MWh) | |
|---|---|---|---|---|---|---|
| Country | 2017 | 2017 | 2017 | 2008–2017 | 2017 | 2008–2017 |
| Denmark | 965 | 8 | 0.83 | 0.34 | 4.0 | 2.1 |
| Estonia | 599 | 3 | 0.50 | 0.78 | 0.9 | 2.8 |
| Finland | 2721 | 7 | 0.26 | 0.17 | 54.8 | 11.1 |
| Iceland | 176 | 5 | 2.84 | 1.06 | 1.4 | 37.4 |
| Latvia[1] | 611 | 2 | 0.33 | 0.44 | 0.0 | 0.3 |
| Lithuania[1] | 859 | 5 | 0.58 | 0.94 | 0.3 | 1.0 |
| Norway | 2491 | 21 | 0.84 | 0.39 | 16.0 | 24.5 |
| Sweden | 2417 | 2 | 0.08 | 0.17 | 12.0 | 55.8 |
| Nordic | 8770 | 43 | 0.49 | 0.27 | 88.2 | 131.0 |
| Baltic | 2069 | 10 | 0.48 | 0.75 | 1.2 | 4.0 |
| Nordic & Baltic | 10839 | 53 | 0.49 | 0.34 | 89.4 | 135.0 |

[1] The average values of Latvia and Lithuania use the period 2012–2017.

Figure 6.6.10 and Figure 6.6.11 present the annual number of 100–150 kV circuit breaker faults per 100 devices during 2008–2017 and the average for the period 2008–2017 in the Nordic and Baltic countries, respectively.

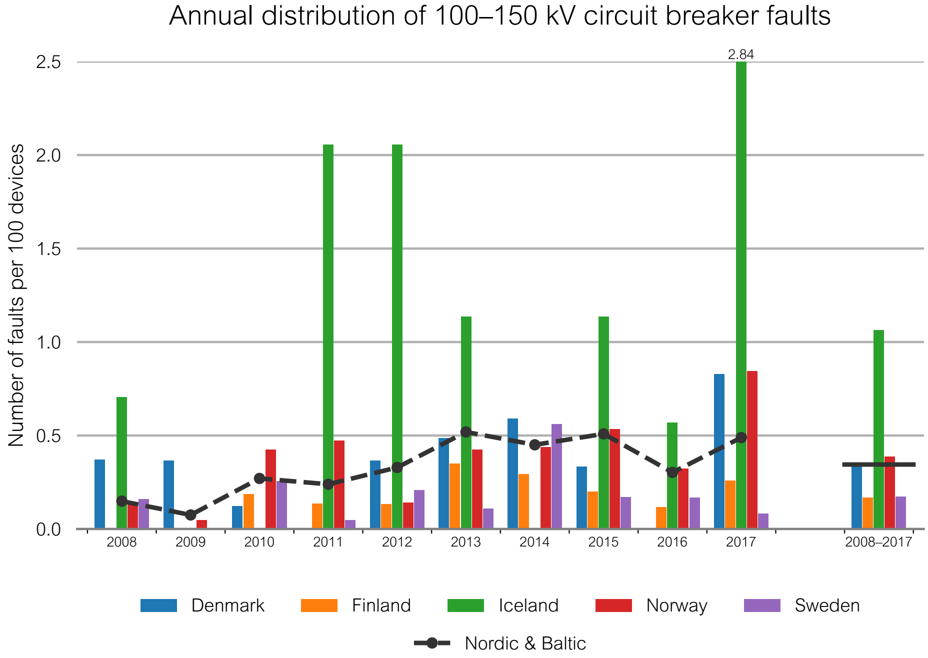


Figure 6.6.10: Annual distribution of 100–150 kV circuit breaker faults and the average during 2008–2017 in each Nordic country.

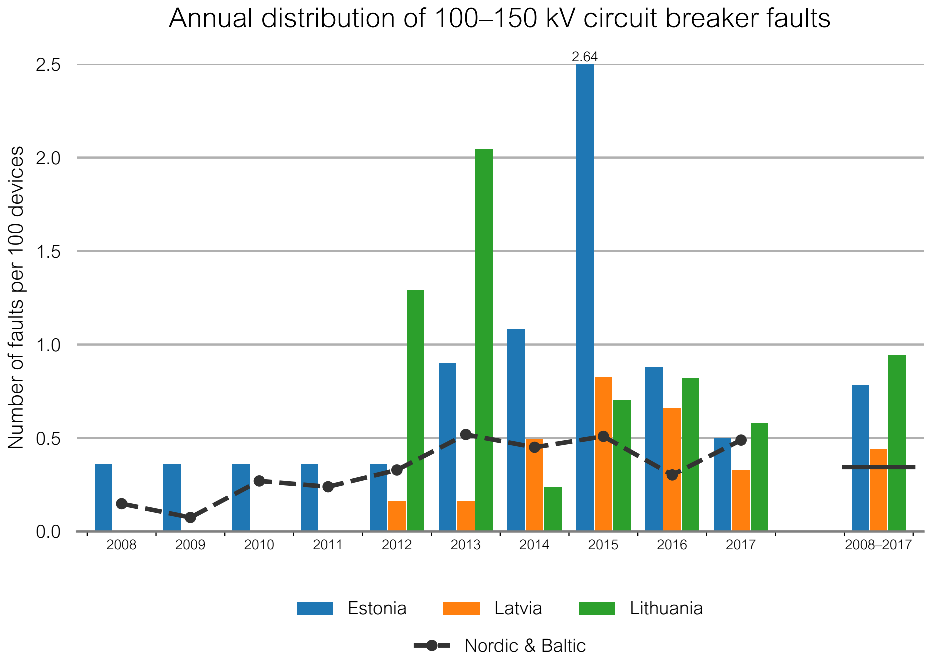


Figure 6.6.11: Annual distribution of 100–150 kV circuit breaker faults and the average during 2008–2017 in Estonia and during 2012–2017 in Latvia and Lithuania.

Figure 6.6.12 and Figure 6.6.13 present the number of 100–150 kV circuit breaker faults per cause in 2017 in the Nordic and Baltic countries.

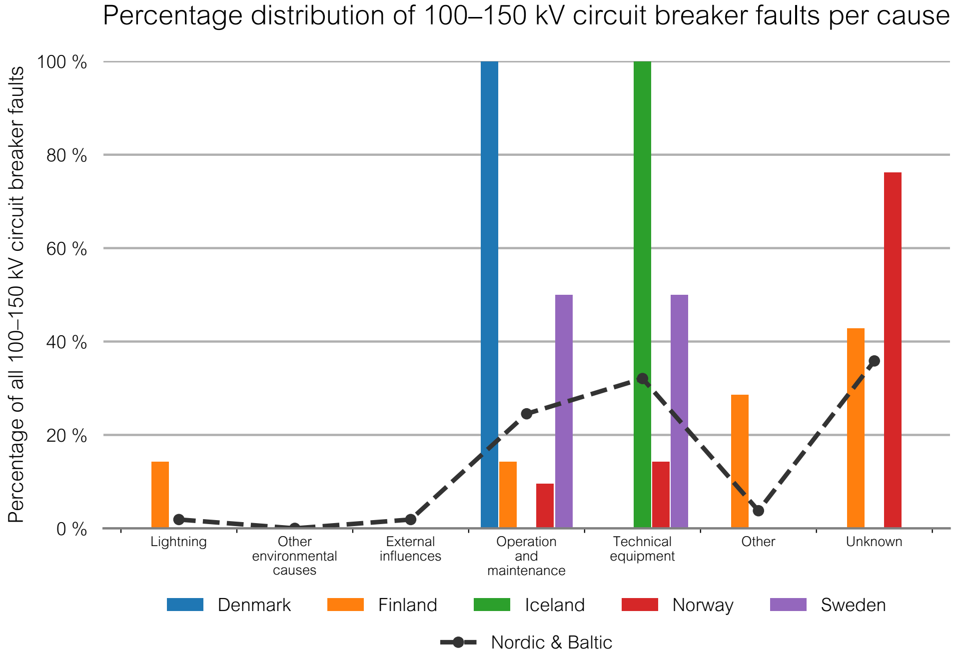


Figure 6.6.12: Percentage distribution of 100–150 kV circuit breaker faults per cause in 2017 in each Nordic country.

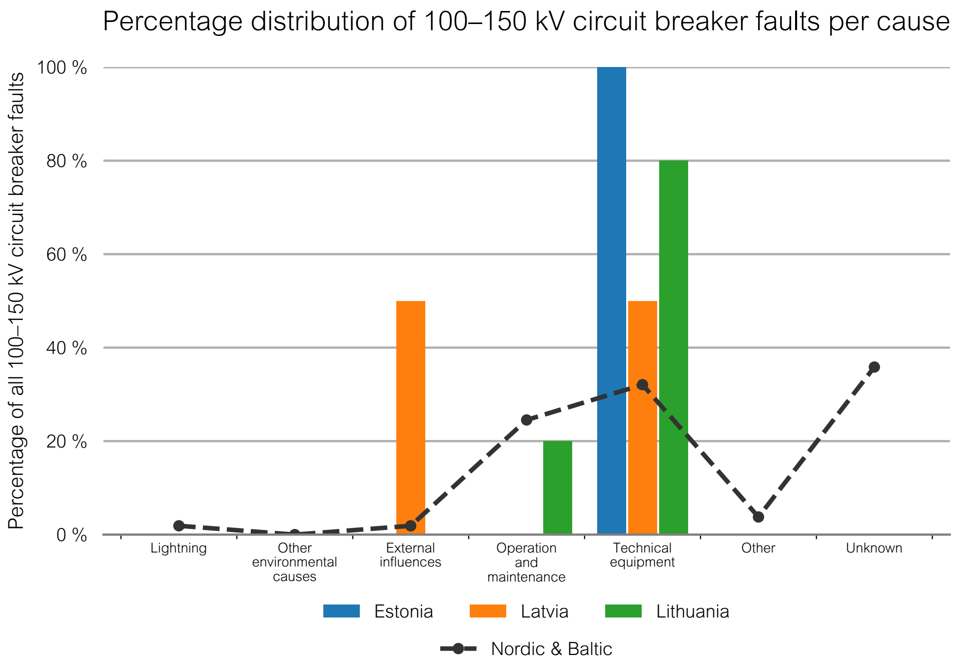


Figure 6.6.13: Percentage distribution of 100–150 kV circuit breaker faults per cause in 2017 in each Baltic country.

Figure 6.6.14 and Figure 6.6.15 present the average number of 100–150 kV circuit breaker faults per cause during 2008–2017 in the Nordic countries and Estonia and during 2012–2017 in Latvia and Lithuania.

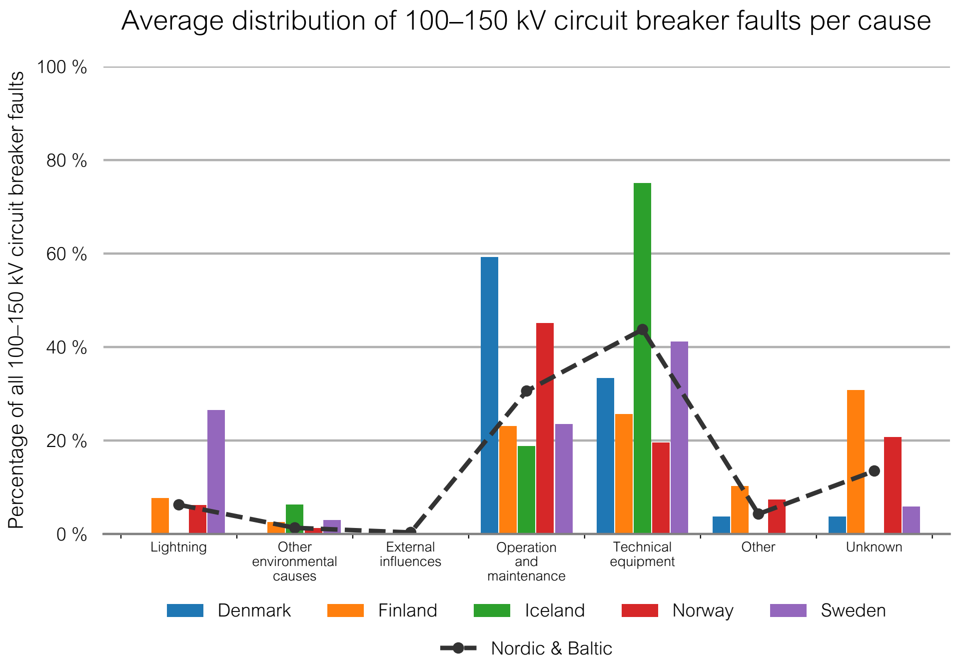


Figure 6.6.14: Average distribution of 100–150 kV circuit breaker faults per cause during 2008–2017 in each Nordic country.

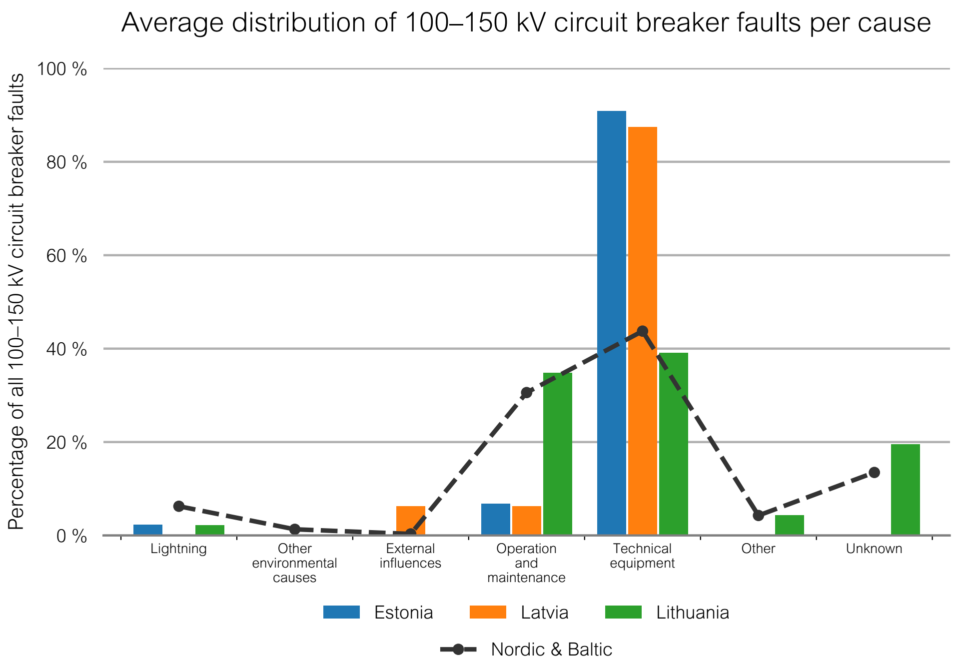


Figure 6.6.15: Average distribution of 100–150 kV circuit breaker faults per cause during 2008–2017 in Estonia and during 2012–2017 in Latvia and Lithuania.

## 6.6.4 Fault trends for circuit breakers

The figures in this section present fault trends for circuit breakers at the voltage levels 100–150 kV, 220–330 kV and 380–420 kV. The Nordic countries use a 5-year rolling average, that is calculated by dividing the sum of the faults by the total number of devices for each 5-year period. The rolling average for the Baltic countries is calculated similarly, but with 3-year periods. The trend curves are proportioned to the number of circuit breakers in order to get comparable results between countries.

Figure 6.6.16 presents 380–420 kV fault trends for Denmark, Finland, Lithuania, Norway and Sweden, Figure 6.6.17 presents the Nordic 220–330 kV fault trends, Figure 6.6.18 presents the Baltic 220–330 kV fault trends, Figure 6.6.19 presents the Nordic 100–150 kV fault trends and Figure 6.6.20 presents the Baltic 100–150 kV fault trends.

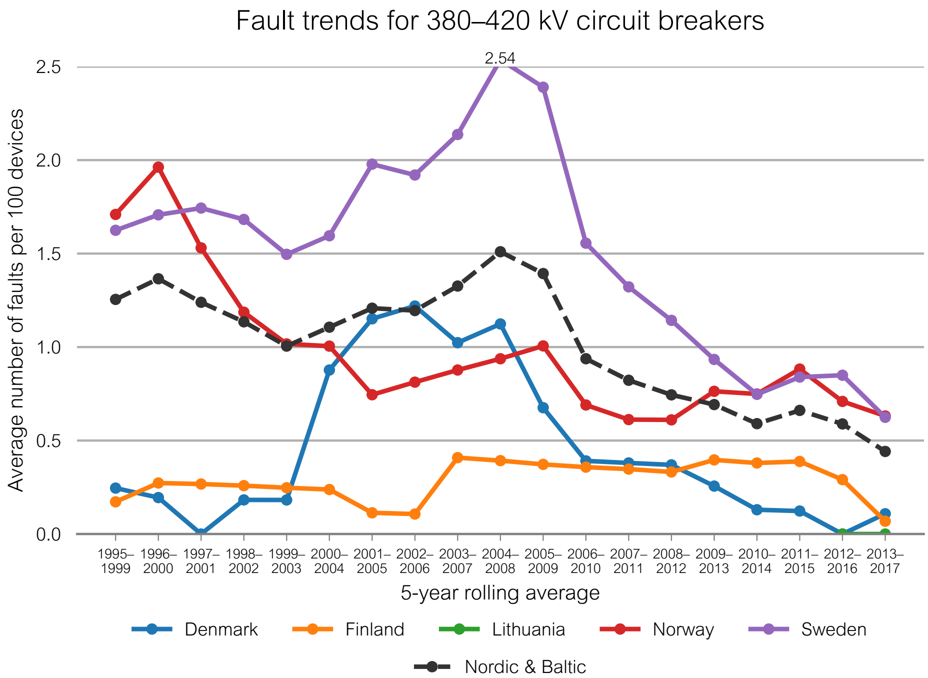


Figure 6.6.16: Fault trends as 5-year rolling averages for 380–420 kV circuit breakers in Denmark, Finland, Lithuania, Norway and Sweden. This figure has the following remarks:

- Lithuania had no faults in their 380–420 kV circuit breakers.
- For Sweden, the breaker failures at the 380–420 kV voltage level most often occurred in breakers that are used to switch the reactors. Furthermore, a reactor breaker is operated significantly more often than a line breaker, which in turn causes the high number of circuit breaker faults in Sweden.

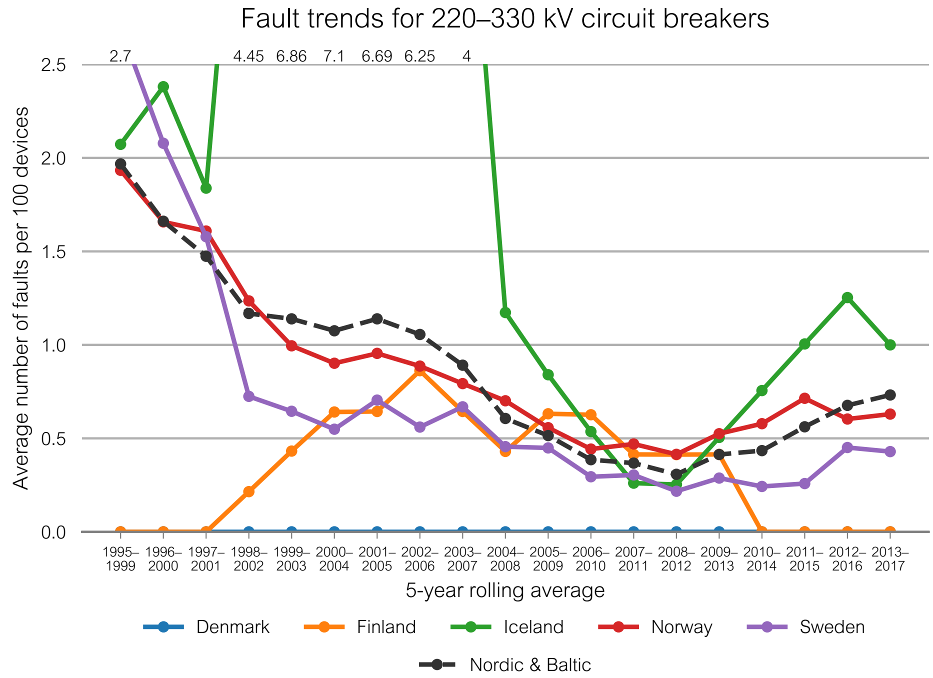


Figure 6.6.17: Fault trends as 5-year rolling averages for 220–330 kV circuit breakers in each Nordic country. This figure has the following remarks:

- 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. Furthermore, two new substations were installed adding 18 more circuit breakers to the grid (from 56 breakers to 74 breakers in total).

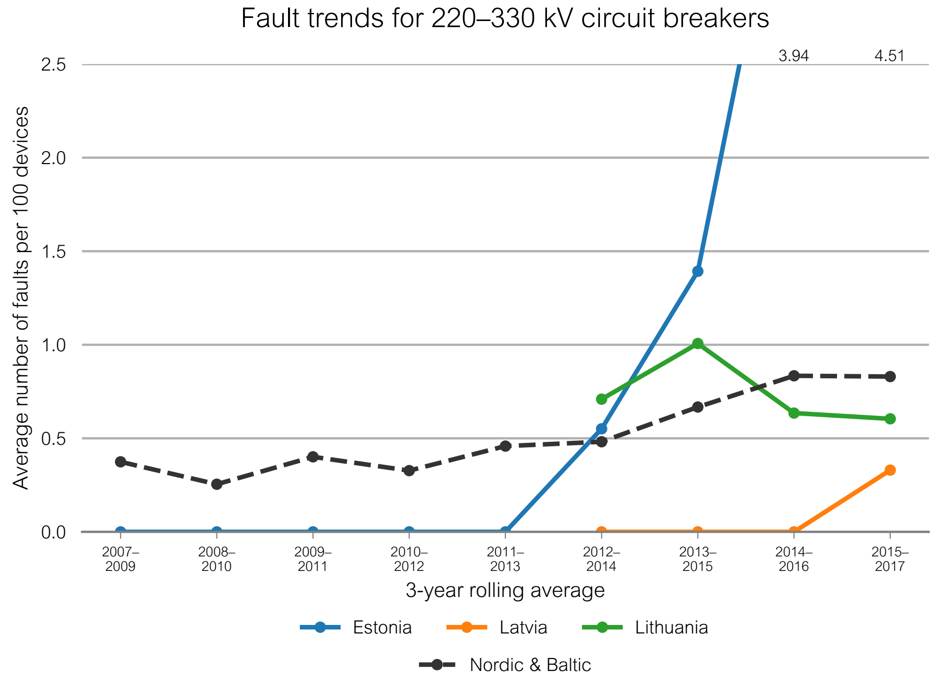


Figure 6.6.18: Fault trends as 3-year rolling averages for 220–330 kV circuit breakers in each Baltic country. This figure has the following remarks:

- Estonia's high values are caused by a relatively small number of faults (~4) in a small grid (121 220–330 kV circuit breakers).

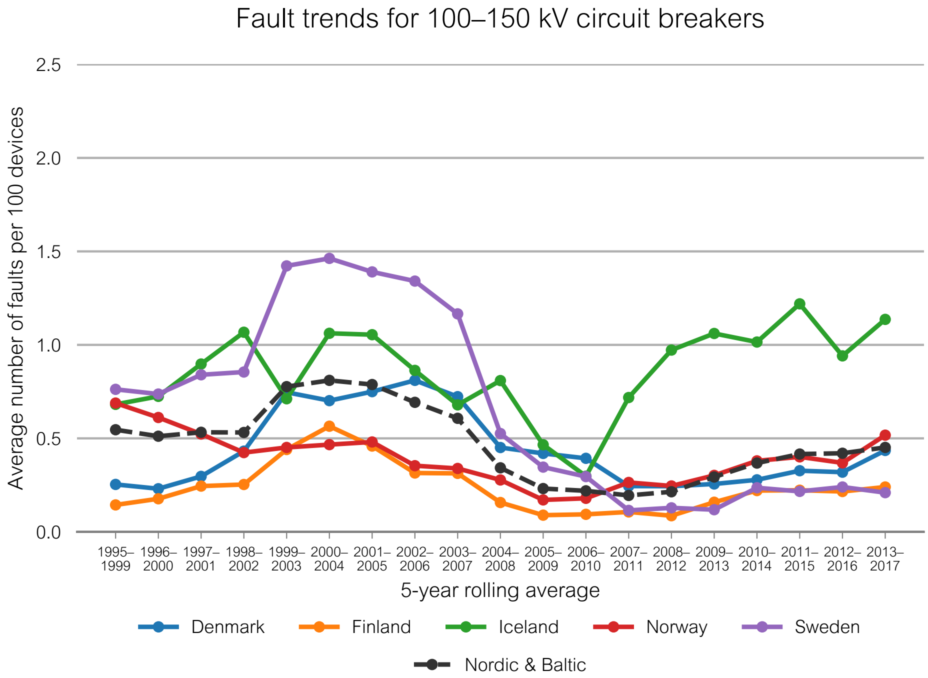


Figure 6.6.19: Fault trends as 5-year rolling averages for 100–150 kV circuit breakers in each Nordic country.

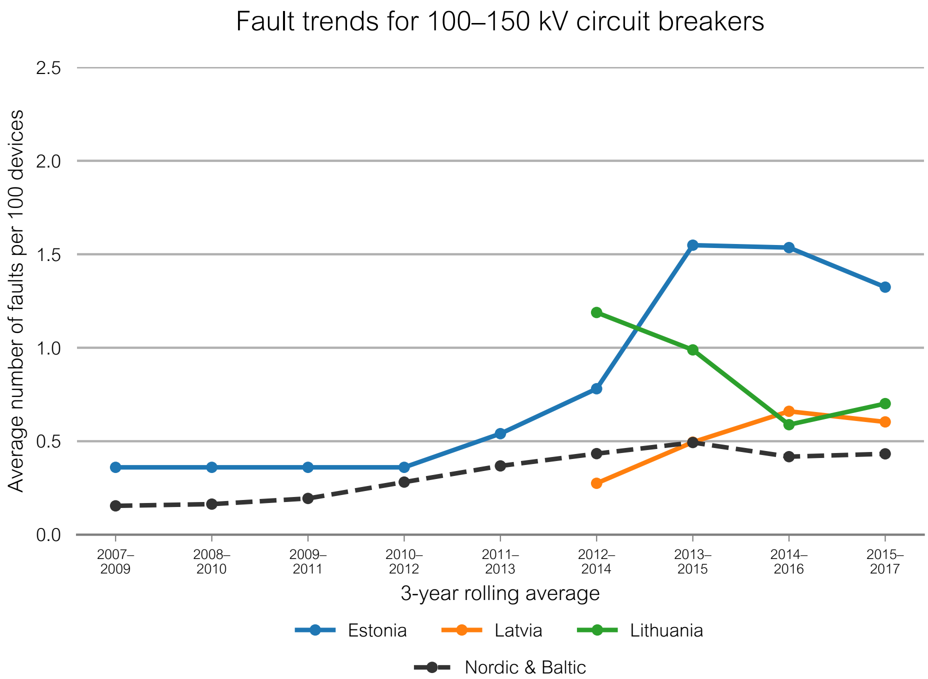


Figure 6.6.20: Fault trends as 3-year rolling averages for 100–150 kV circuit breakers in each Baltic country.

## 6.7 Faults in control equipment

The tables and figures in this section present control equipment faults in 2017 and during 2008–2017 at the voltage levels 100–150 kV, 220–330 kV and 380–420 kV. Control equipment are the components that help the grid owner to monitor their power grid. However, control equipment integrated in other components are not included in this category.

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.

Chapter 6.7.1 presents fault statistics for 380–420 kV control equipment, Chapter 6.7.2 for 220–330 kV control equipment and Chapter 6.7.3 100–150 kV control equipment. The figures and tables present the number of control equipment faults per 100 devices in 2017 as well as the average values during 2008–2017 in the Nordic countries and Estonia and during 2012–2017 in Latvia and Lithuania. Furthermore, faults according to the cause categories, defined in Chapter 1.4.1, are presented. Finally, Chapter 6.7.4 presents trend figures for the number of faults per 100 devices. The trends are calculated by 5-year moving averages for the Nordic countries during 1995–2017 and by 3-year moving averages for the Baltic countries during 2007–2017. With the help of the trend curve, it may be possible to estimate the number of faults in the future.

### 6.7.1 380–420 kV control equipment

This section presents fault statistics for 380–420 kV control equipment. This includes a table with an overview of control equipment faults and figures with the annual number of faults and faults according to cause in 2017 and the average during 2008–2017. The fault causes used in these statistics are presented in Chapter 1.4.1.

Table 6.7.1 shows the number of 380–420 kV control equipment and the number of faults for 380–420 kV control equipment. Furthermore, the amount of ENS caused by the faults is presented. The data consists of the values for the year 2017 and for the period 2008–2017.

It should be noted, that only Denmark, Finland, Lithuania, Norway and Sweden own 380–420 kV equipment. Therefore, only these countries are presented in the figures in this section.

Table 6.7.1: Overview of faults for 380–420 kV control equipment.

| | Devices | Faults | Faults per 100 devices | | ENS (MWh) | |
|---|---|---|---|---|---|---|
| Country | 2017 | 2017 | 2017 | 2008–2017 | 2017 | 2008–2017 |
| Denmark | 227 | 5 | 2.20 | 1.10 | 0.0 | 0.0 |
| Estonia | 0 | 0 | 0.00 | 0.00 | 0.0 | 0.0 |
| Finland | 352 | 2 | 0.57 | 2.70 | 0.0 | 11.7 |
| Iceland | 0 | 0 | 0.00 | 0.00 | 0.0 | 0.0 |
| Latvia | 0 | 0 | 0.00 | 0.00 | 0.0 | 0.0 |
| Lithuania[1] | 5 | 0 | 0.00 | 0.00 | 0.0 | 0.0 |
| Norway | 453 | 18 | 3.97 | 3.78 | 19.1 | 21.6 |
| Sweden | 592 | 14 | 2.36 | 4.01 | 0.0 | 0.0 |
| Nordic | 1624 | 39 | 2.40 | 3.30 | 19.1 | 33.3 |
| Baltic | 5 | 0 | 0.00 | 0.00 | 0.0 | 0.0 |
| Nordic & Baltic | 1629 | 39 | 2.39 | 3.30 | 19.1 | 33.3 |

[1] Lithuania started operating its first 380–420 kV control equipment in 2016.

Figure 6.7.1 presents the annual number of 380–420 kV control equipment faults per 100 devices during 2008–2017 and the average for the period 2008–2017 in Denmark, Finland, Lithuania, Norway and Sweden.

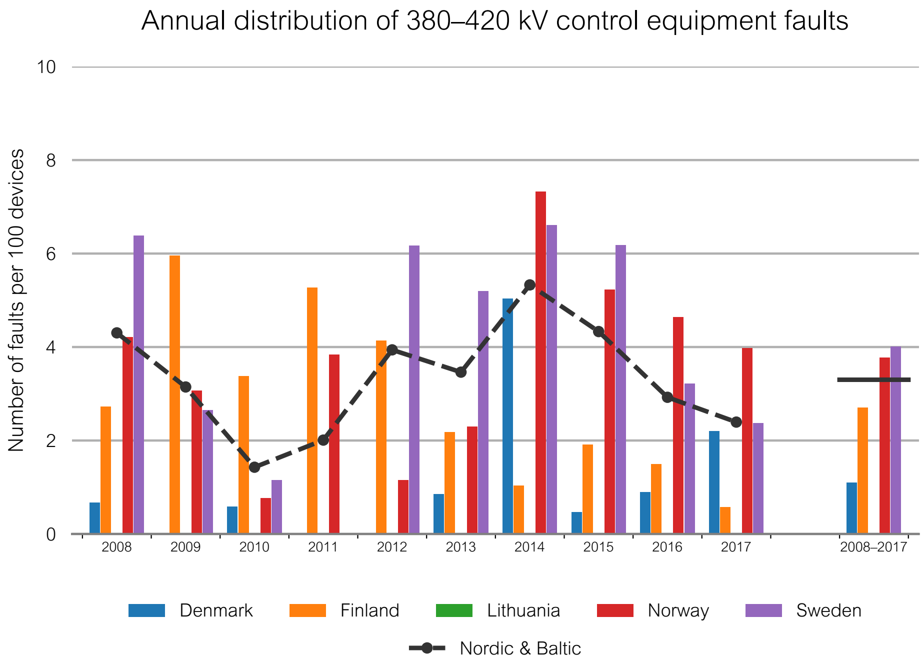


Figure 6.7.1: Annual distribution of 380–420 kV control equipment faults and the average during 2008–2017 in Denmark, Finland, Lithuania, Norway and Sweden. Lithuania had no faults in their 380–420 kV circuit breakers.

Figure 6.7.2 presents the number of 380–420 kV control equipment faults per cause in 2017 in Denmark, Finland, Lithuania, Norway and Sweden.

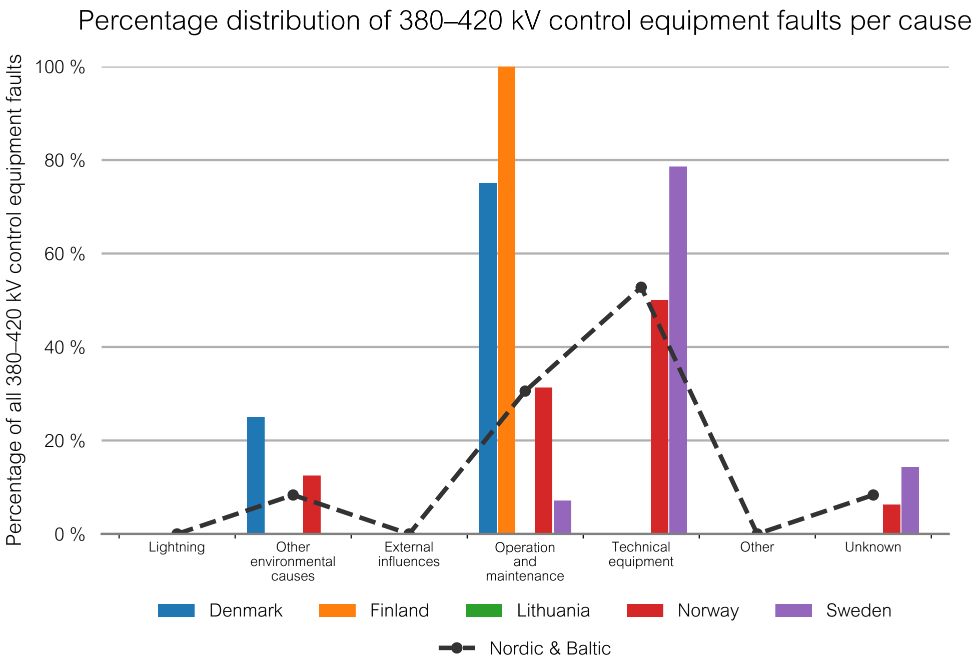


Figure 6.7.2: Percentage distribution of 380–420 kV control equipment faults per cause in 2017 in Denmark, Finland, Lithuania, Norway and Sweden. Lithuania had no faults in their 380–420 kV circuit breakers.

Figure 6.7.3 presents the average number of 380–420 kV control equipment faults per cause during 2008–2017 in Denmark, Finland, Lithuania, Norway and Sweden.

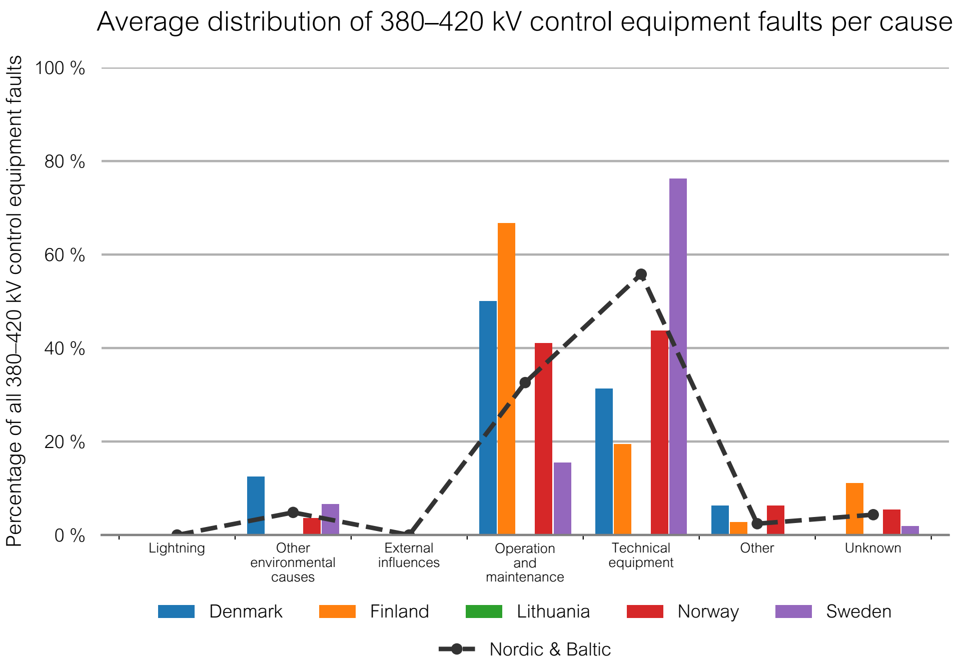


Figure 6.7.3: Average distribution of 380–420 kV control equipment faults per cause during 2008–2017 in Denmark, Finland, Lithuania, Norway and Sweden. Lithuania had no faults in their 380–420 kV circuit breakers.

### 6.7.2 220–330 kV control equipment

This section presents fault statistics for 220–330 kV control equipment. This includes a table with an overview of control equipment faults and figures with the annual number of faults and faults according to cause in 2017 and the average during 2008–2017. The fault causes used in these statistics are presented in Chapter 1.4.1.

Table 6.7.2 shows the number of 220–330 kV control equipment and the number of faults for 220–330 kV control equipment. Furthermore, the amount of ENS caused by the faults is presented. The data consists of the values for the year 2017 and for the period 2008–2017.

Table 6.7.2: Overview of faults for 220–330 kV control equipment.

| | Devices | Faults | Faults per 100 devices | | ENS (MWh) | |
|---|---|---|---|---|---|---|
| Country | 2017 | 2017 | 2017 | 2008–2017 | 2017 | 2008–2017 |
| Denmark | 17 | 0 | 0.00 | 1.32 | 0.0 | 0.0 |
| Estonia | 121 | 0 | 0.00 | 0.54 | 0.0 | 0.0 |
| Finland | 78 | 0 | 0.00 | 2.91 | 0.0 | 5.3 |
| Iceland | 80 | 9 | 11.25 | 4.65 | 945.9 | 155.2 |
| Latvia[1] | 97 | 1 | 1.03 | 2.61 | 0.0 | 0.2 |
| Lithuania[1] | 113 | 2 | 1.77 | 1.79 | 0.0 | 0.0 |
| Norway | 730 | 20 | 2.74 | 2.76 | 1.7 | 35.2 |
| Sweden | 342 | 10 | 2.92 | 2.47 | 0.1 | 32.4 |
| Nordic | 1247 | 39 | 3.13 | 2.80 | 947.7 | 228.1 |
| Baltic | 331 | 3 | 0.91 | 1.42 | 0.0 | 0.2 |
| Nordic & Baltic | 1578 | 42 | 2.66 | 2.58 | 947.7 | 228.3 |

[1] The average values of Latvia and Lithuania use the period 2012–2017.

Figure 6.7.4 and Figure 6.7.5 present the annual number of 220–330 kV control equipment faults per 100 devices during 2008–2017 and the average for the period 2008–2017 in the Nordic and Baltic countries, respectively.

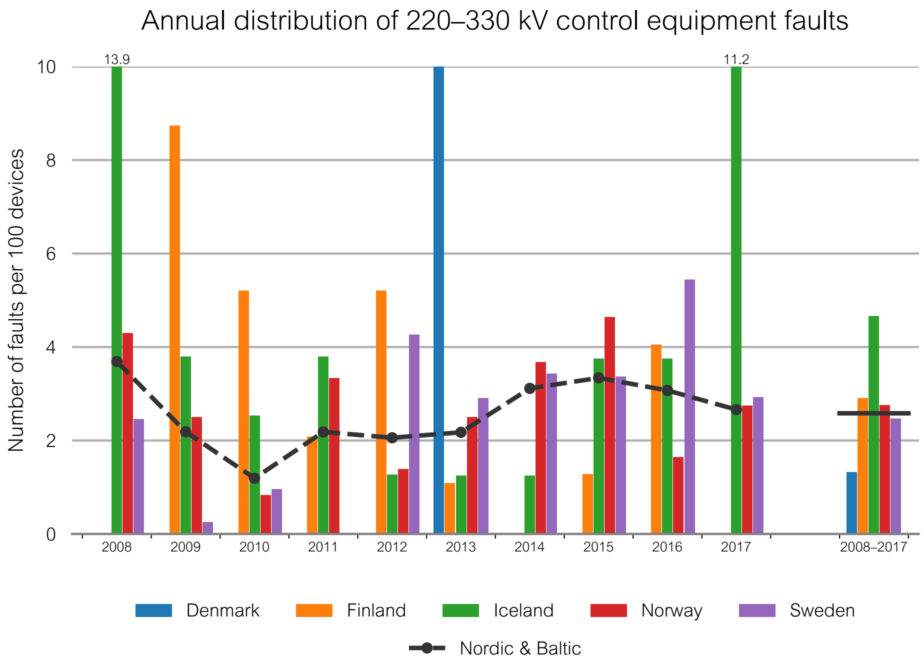


Figure 6.7.4: Annual distribution of 220–330 kV control equipment faults and the average during 2008–2017 in each Nordic country.

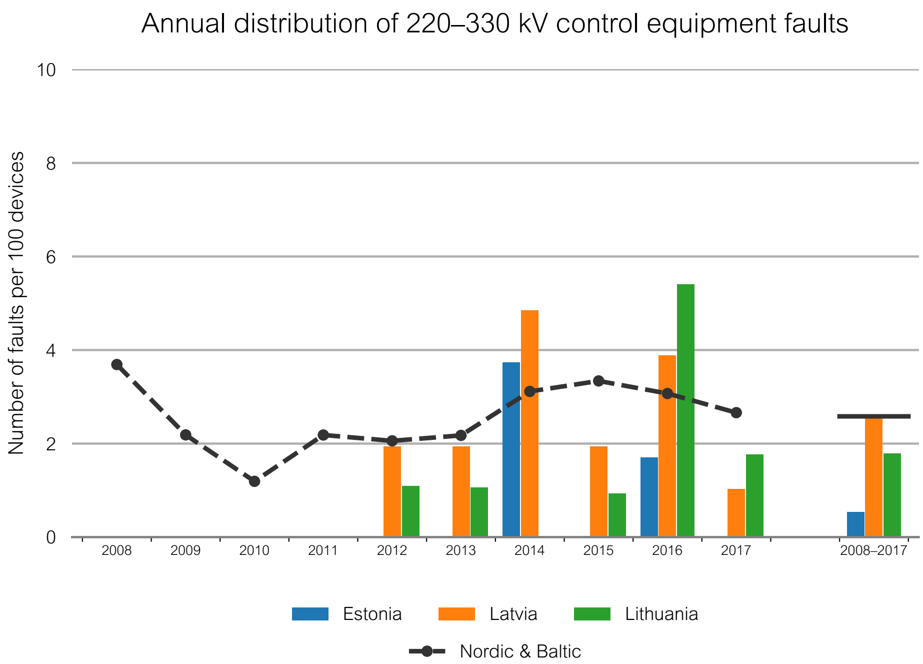


Figure 6.7.5: Annual distribution of 220–330 kV control equipment faults and the average during 2008–2017 in Estonia and during 2012–2017 it Latvia and Lithuania.

Figure 6.7.6 and Figure 6.7.7 present the number of 220–330 kV control equipment faults per cause in 2017 in the Nordic and Baltic countries.

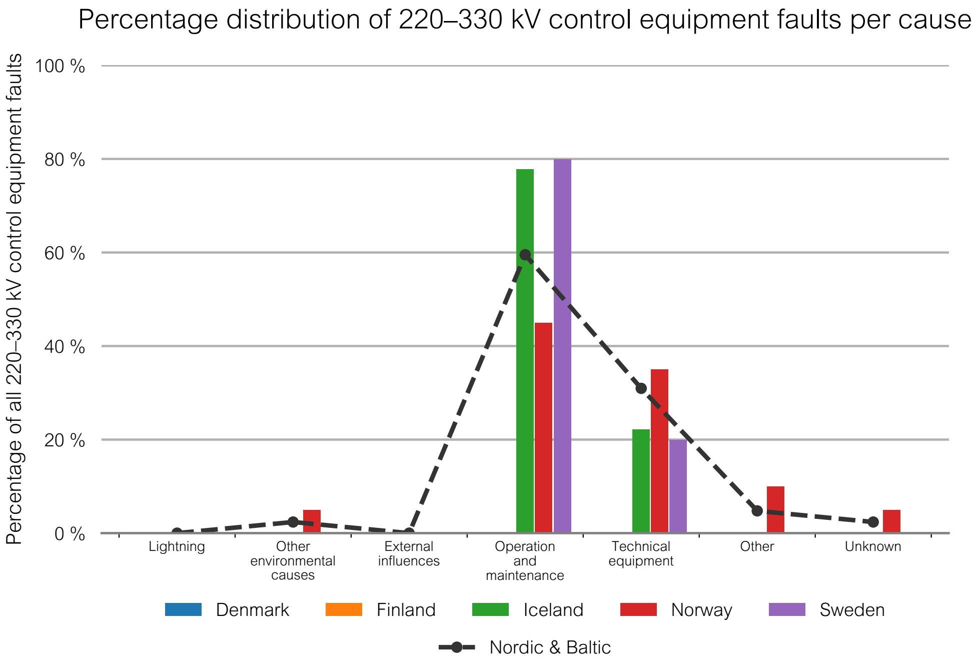


Figure 6.7.6: Percentage distribution of 220–330 kV control equipment faults per cause in 2017 in each Nordic country.

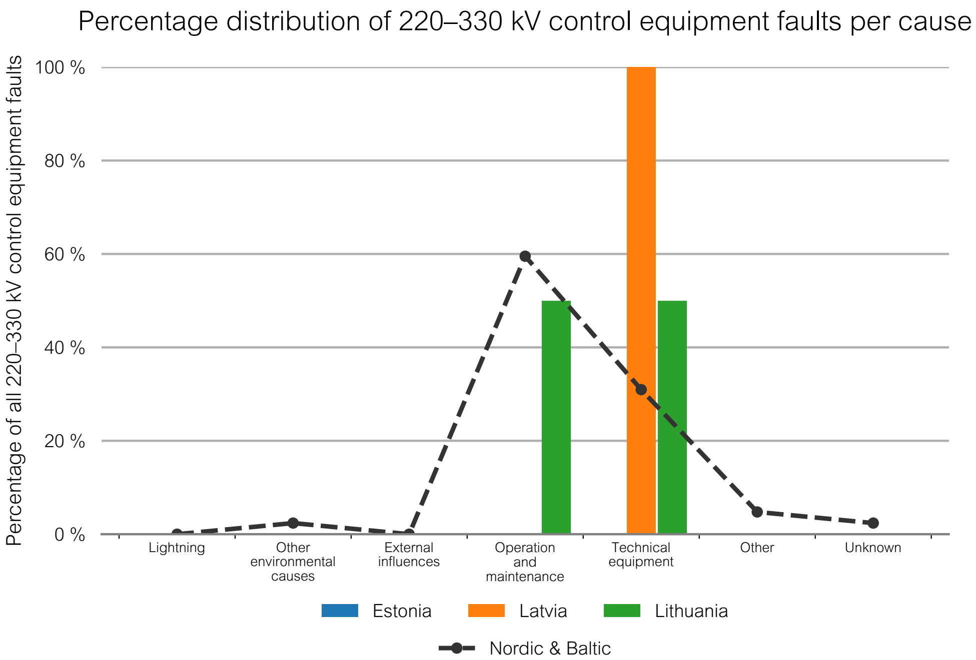


Figure 6.7.7: Percentage distribution of 220–330 kV control equipment faults per cause in 2017 in each Baltic country.

Figure 6.7.8 and Figure 6.7.9 present the average number of 220–330 kV control equipment faults per cause during 2008–2017 in the Nordic countries and Estonia and during 2012–2017 in Latvia and Lithuania.

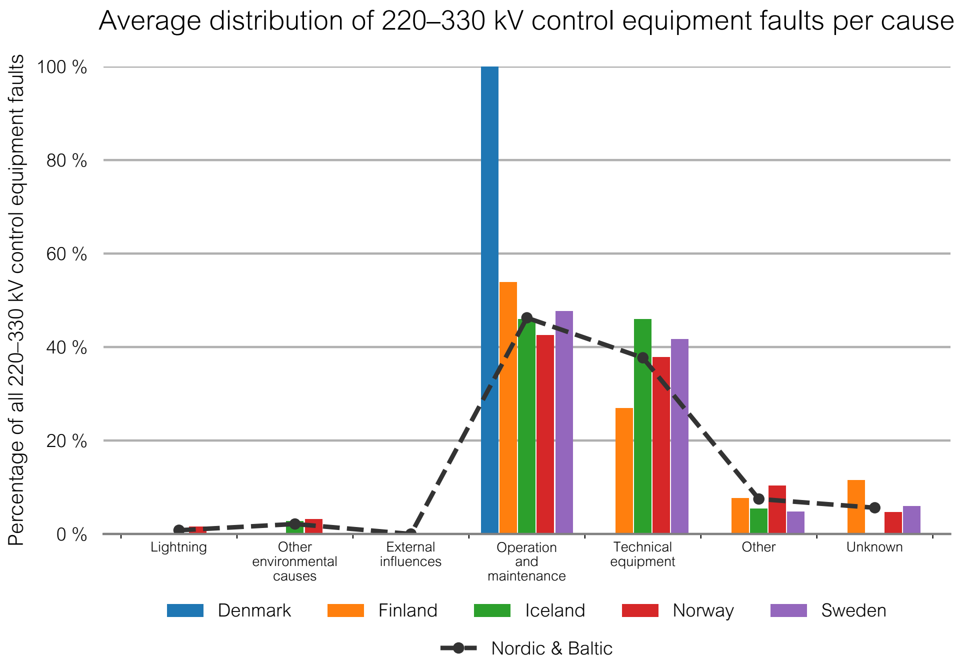


Figure 6.7.8: Average distribution of 220–330 kV control equipment faults per cause during 2008–2017 in each Nordic country.

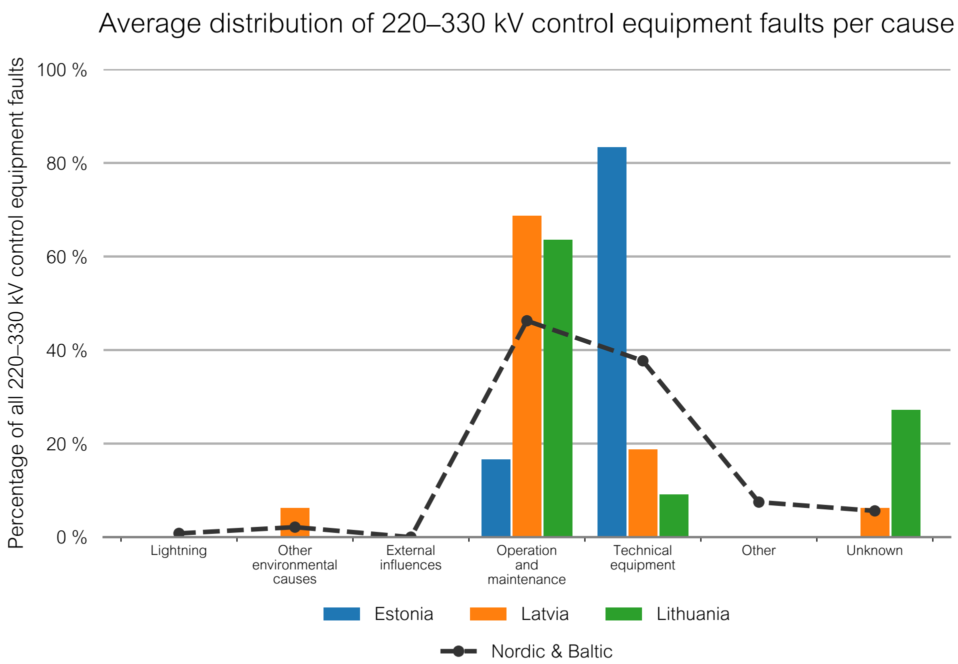


Figure 6.7.9: Average distribution of 220–330 kV control equipment faults per cause during 2008–2017 in Estonia and during 2012–2017 in Latvia and Lithuania.

### 6.7.3 100–150 kV control equipment

This section presents fault statistics for 100–150 kV control equipment. This includes a table with an overview of control equipment faults and figures with the annual number of faults and faults according to cause in 2017 and the average during 2008–2017. The fault causes used in these statistics are presented in Chapter 1.4.1.

Table 6.7.3 shows the number of 100–150 kV control equipment and the number of faults for 100–150 kV control equipment. Furthermore, the amount of ENS caused by the faults is presented. The data consists of the values for the year 2017 and for the period 2008–2017.

Table 6.7.3: Overview of faults for 100–150 kV control equipment.

| | Devices | Faults | Faults per 100 devices | | ENS (MWh) | |
|---|---|---|---|---|---|---|
| Country | 2017 | 2017 | 2017 | 2008–2017 | 2017 | 2008–2017 |
| Denmark | 965 | 3 | 0.31 | 0.89 | 0.0 | 2.0 |
| Estonia | 599 | 1 | 0.17 | 0.78 | 0.0 | 2.1 |
| Finland | 2721 | 15 | 0.55 | 1.20 | 9.0 | 26.1 |
| Iceland | 176 | 7 | 3.98 | 3.33 | 10.9 | 15.2 |
| Latvia[1] | 611 | 23 | 3.76 | 3.16 | 15.8 | 17.4 |
| Lithuania[1] | 859 | 15 | 1.75 | 1.61 | 50.8 | 14.8 |
| Norway | 2491 | 29 | 1.16 | 1.29 | 57.0 | 221.0 |
| Sweden | 2417 | 19 | 0.79 | 0.41 | 101.7 | 38.8 |
| Nordic | 8770 | 73 | 0.83 | 1.03 | 178.6 | 303.0 |
| Baltic | 2069 | 39 | 1.88 | 1.68 | 66.6 | 34.3 |
| Nordic & Baltic | 10839 | 112 | 1.03 | 1.13 | 245.2 | 337.4 |

[1] The average values of Latvia and Lithuania use the period 2012–2017.

Figure 6.7.10 and Figure 6.7.11 present the annual number of 100–150 kV control equipment faults per 100 devices during 2008–2017 and the average for the period 2008–2017 in the Nordic and Baltic countries, respectively.

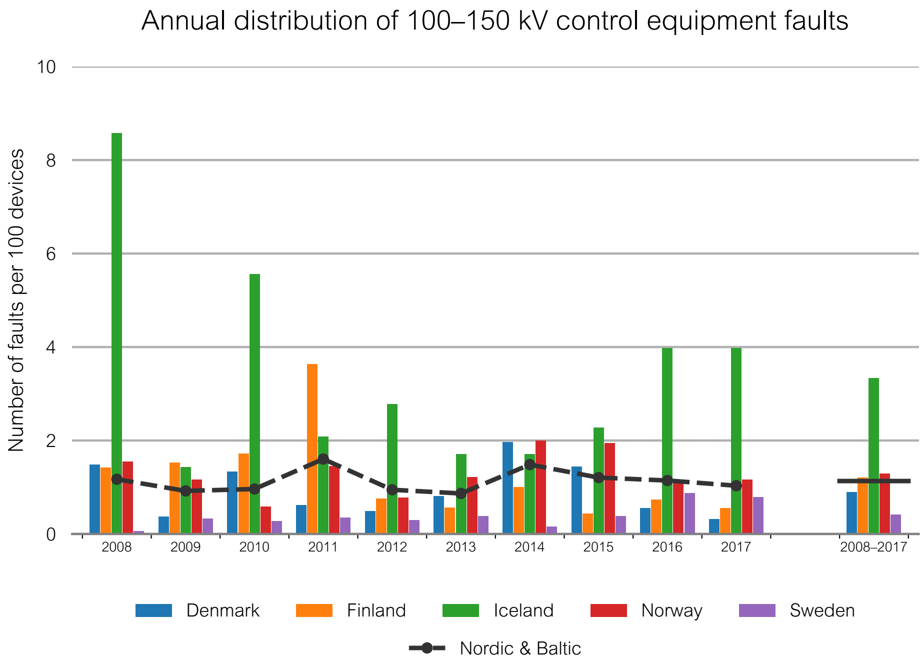


Figure 6.7.10: Annual distribution of 100–150 kV control equipment faults and the average during 2008–2017 in each Nordic country.

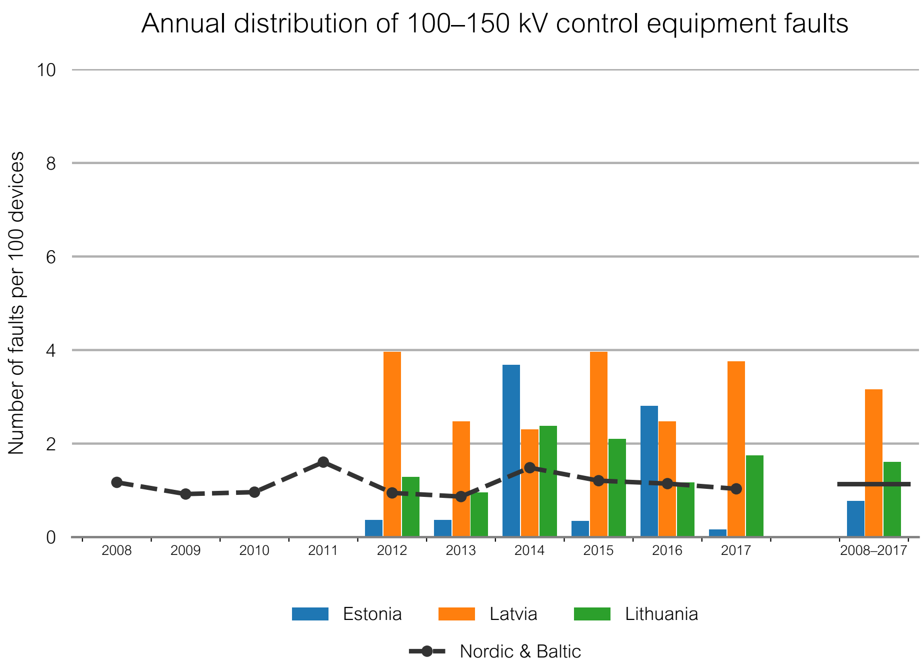


Figure 6.7.11: Annual distribution of 100–150 kV control equipment faults and the average during 2008–2017 in Estonia and during 2012–2017 in Latvia and Lithuania.

Figure 6.7.12 and Figure 6.7.13 present the number of 100–150 kV control equipment faults per cause in 2017 in the Nordic and Baltic countries.

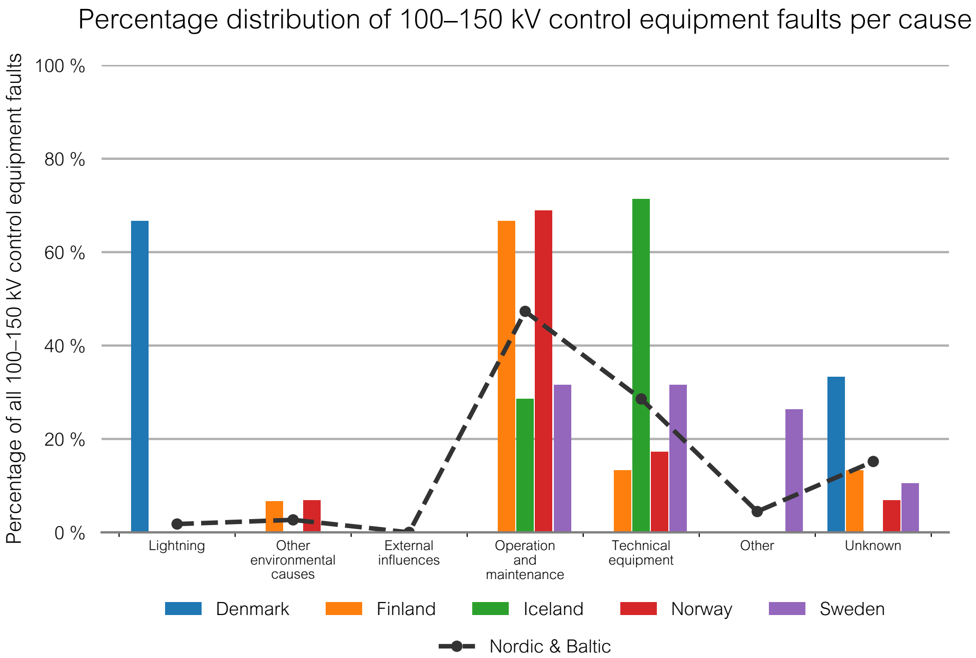


Figure 6.7.12: Percentage distribution of 100–150 kV control equipment faults per cause in 2017 in each Nordic country.

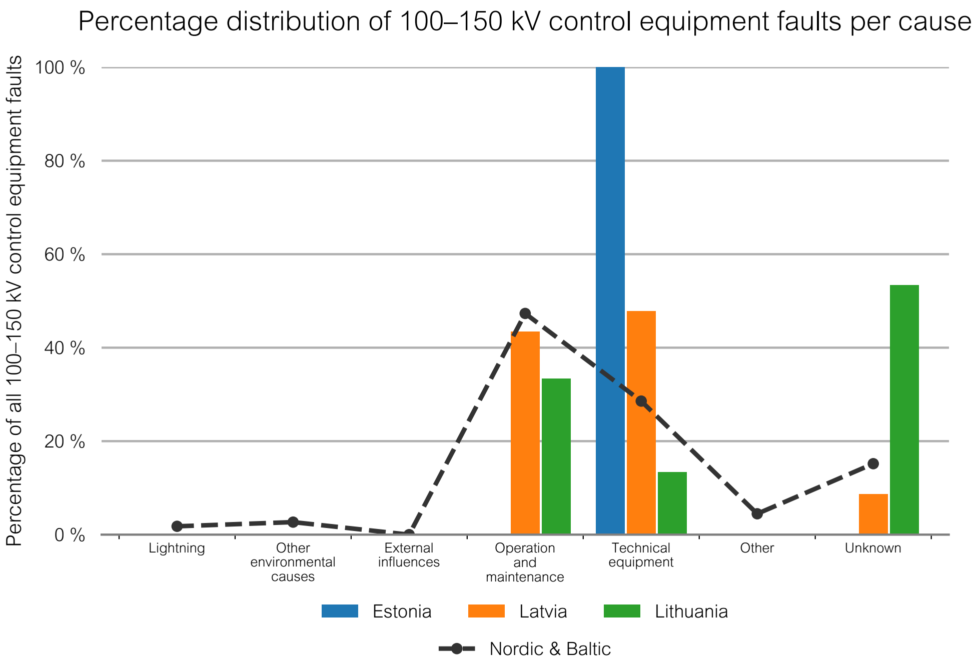


Figure 6.7.13: Percentage distribution of 100–150 kV control equipment faults per cause in 2017 in each Baltic country.

Figure 6.7.14 and Figure 6.7.15 present the average number of 100–150 kV control equipment faults per cause during 2008–2017 in the Nordic countries and Estonia and during 2012–2017 in Latvia and Lithuania.

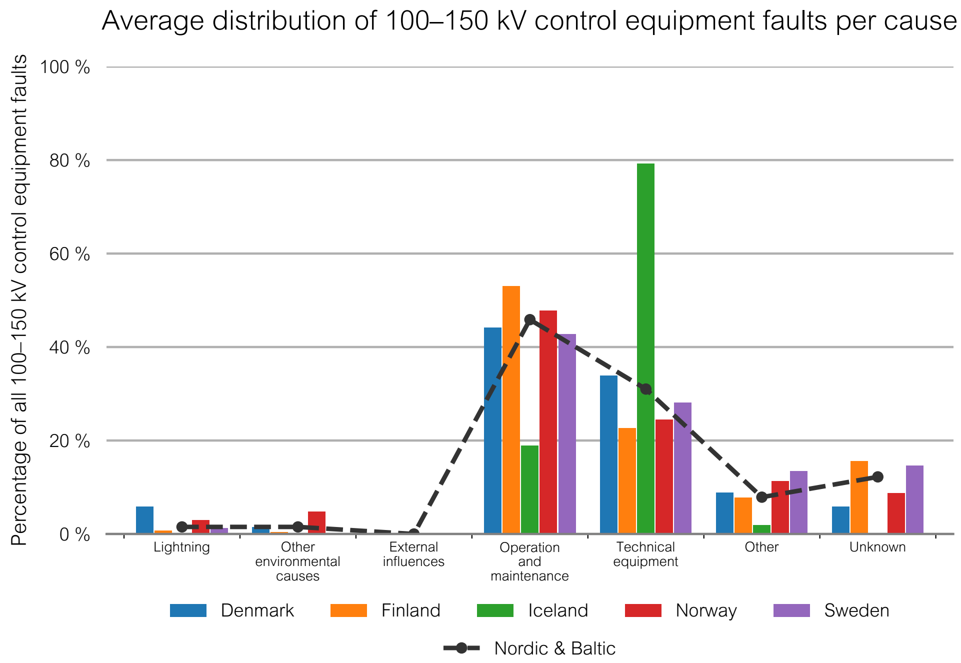


Figure 6.7.14: Average distribution of 100–150 kV control equipment faults per cause during 2008–2017 in each Nordic country.

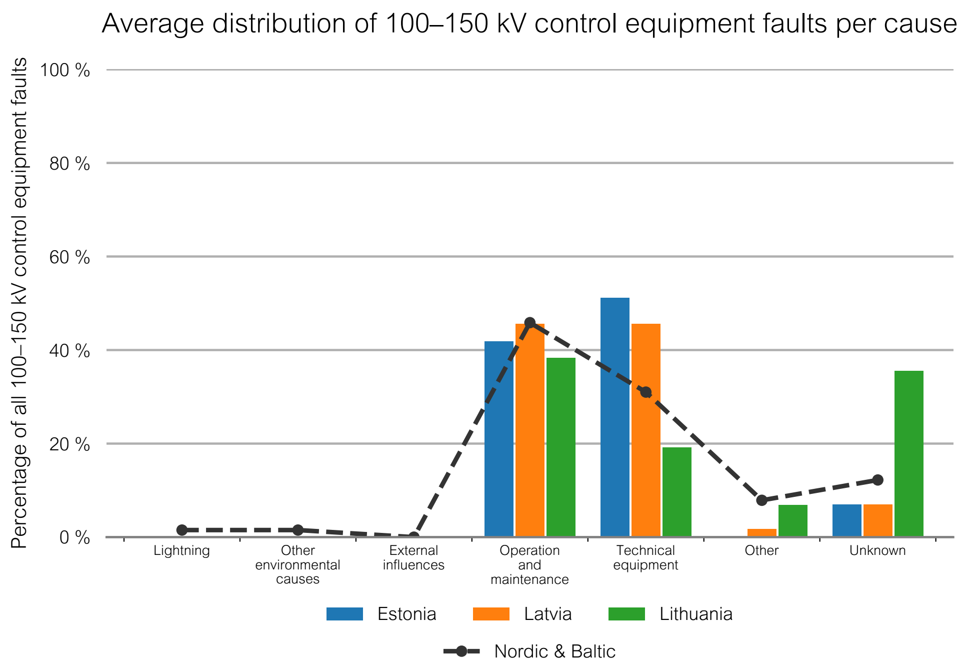


Figure 6.7.15: Average distribution of 100–150 kV control equipment faults per cause during 2008–2017 in Estonia and during 2012–2017 in Latvia and Lithuania.

### 6.7.4 Fault trends for control equipment

The figures in this section present fault trends for control equipment at the voltage levels 100–150 kV, 220–330 kV and 380–420 kV. The Nordic countries use a 5-year rolling average, that is calculated by dividing the sum of the faults by the total number of devices for each 5-year period. The rolling average for the Baltic countries is calculated similarly, but with 3-year periods. The trend curves are proportioned to the number of control equipment in order to get comparable results between countries.

Figure 6.7.16 presents 380–420 kV fault trends for Denmark, Finland, Lithuania, Norway and Sweden, Figure 6.7.17 presents the Nordic 220–330 kV fault trends, Figure 6.7.18 presents the Baltic 220–330 kV fault trends, Figure 6.7.19 presents the Nordic 100–150 kV fault trends and Figure 6.7.20 presents the Baltic 100–150 kV fault trends.

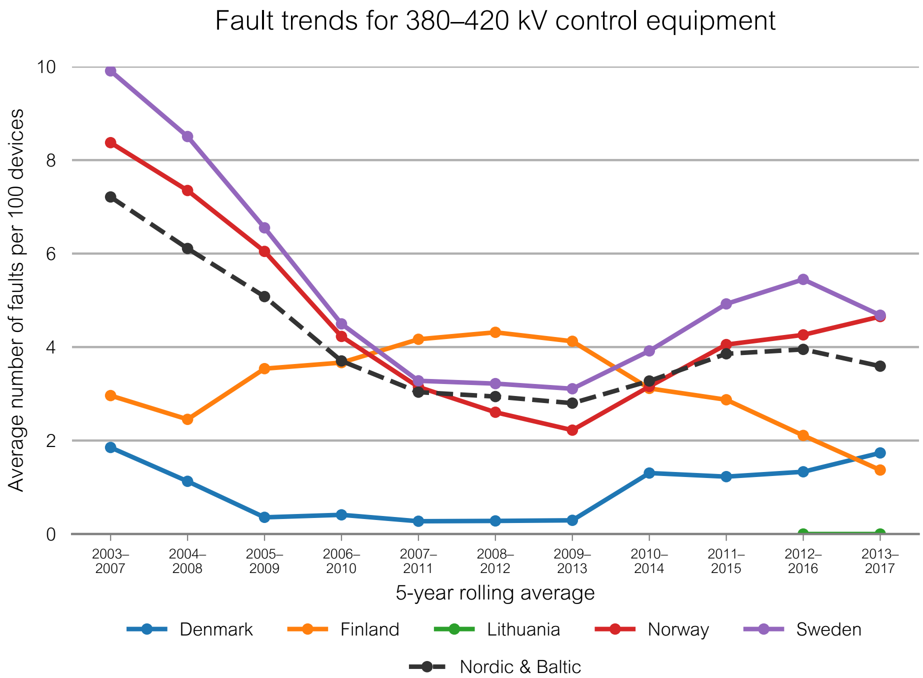


Figure 6.7.16: Fault trends as 5-year rolling averages for 380–420 kV control equipment in Denmark, Finland, Lithuania, Norway and Sweden. Lithuania had no faults in their 380–420 kV control equipment.

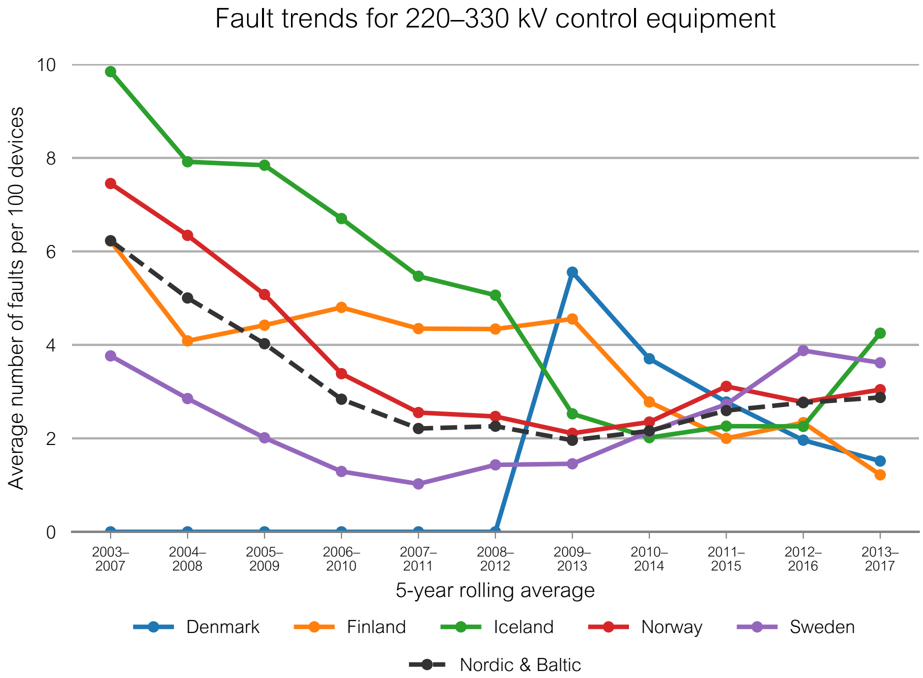


Figure 6.7.17: Fault trends as 5-year rolling averages for 220–330 kV control equipment in each Nordic country.

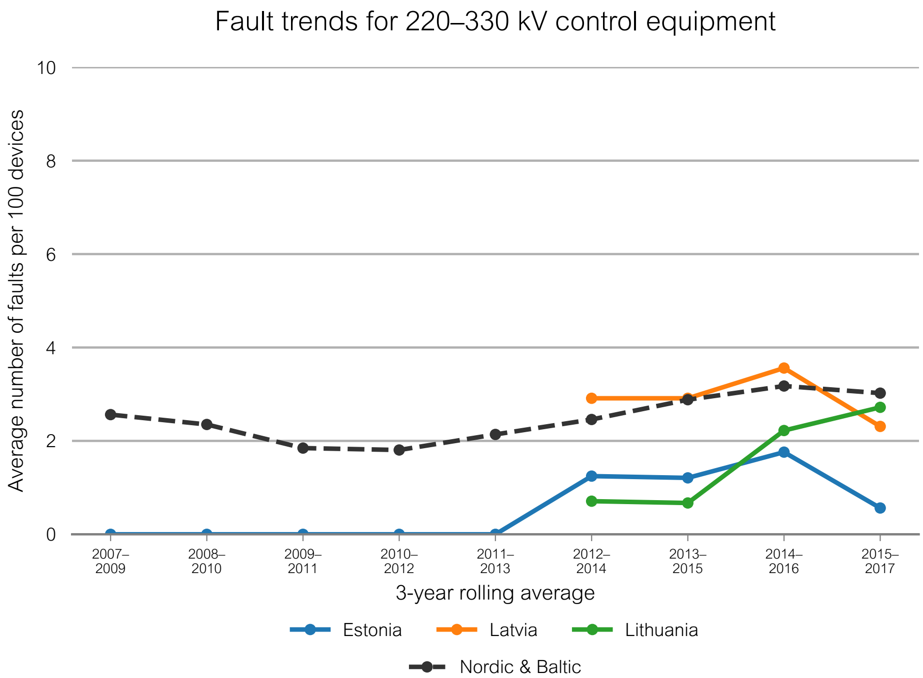


Figure 6.7.18: Fault trends as 3-year rolling averages for 220–330 kV control equipment in each Baltic country.

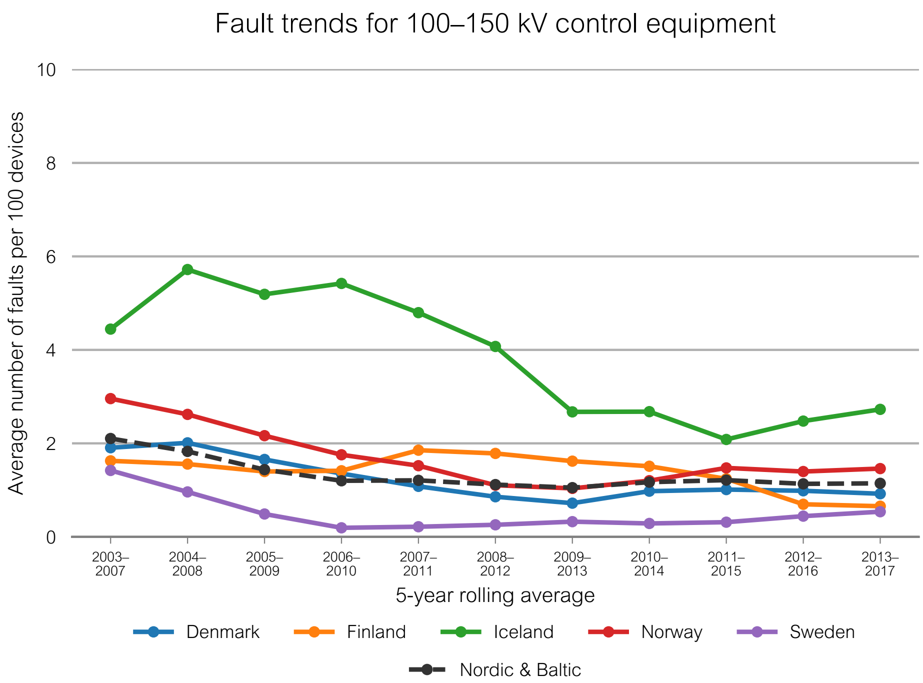


Figure 6.7.19: Fault trends as 5-year rolling averages for 100–150 kV control equipment in each Nordic country.

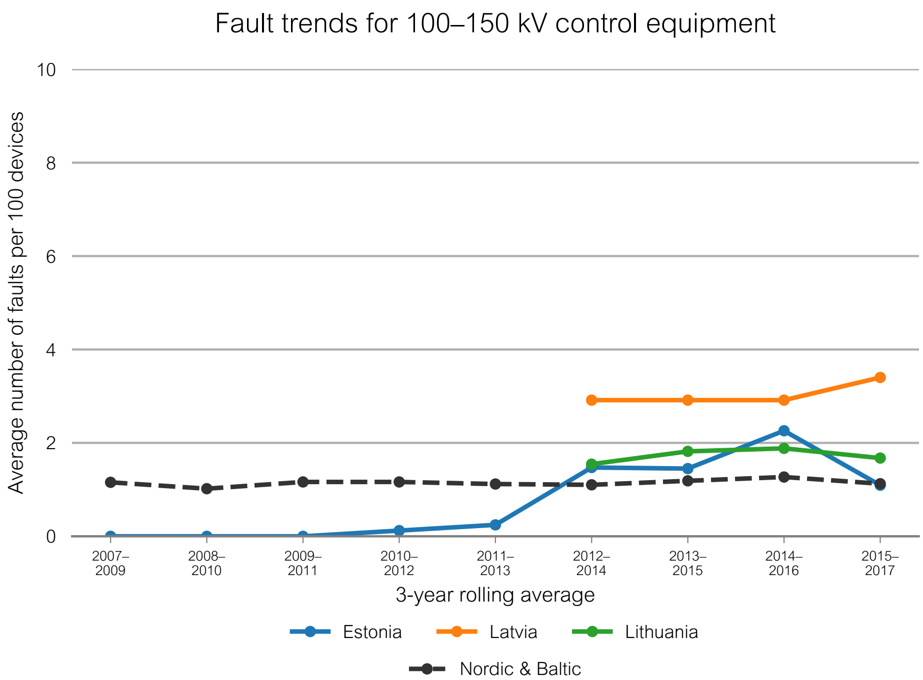


Figure 6.7.20: Fault trends as 3-year rolling averages for 100–150 kV control equipment in each Baltic country.

# 6.8 Faults in compensation devices

The sections in this chapter present fault statistics for compensation devices. Compensation devices are used to reduce reactive and capacitive power and for stabilizing voltage and frequency in the power system. The following compensation devices are presented in this chapter: reactors, series capacitors, shunt capacitors and SVC devices. The statistics include the number of devices and faults in 2017, number of faults per 100 devices and ENS in 2017 and 2008–2017.

## 6.8.1 Faults in reactors

Reactors add reactance to the power grid and limit short circuit currents. Table 6.8.1 presents the number of reactors and faults in 2017, the number of faults per 100 devices and the amount of ENS in 2017 and 2008–2017.

Table 6.8.1: Overview of reactor faults

| | Devices | Faults | Faults per 100 devices | | ENS (MWh) | |
|---|---|---|---|---|---|---|
| Country | 2017 | 2017 | 2017 | 2008–2017 | 2017 | 2008–2017 |
| Denmark | 84 | 0 | 0.00 | 1.46 | 0.0 | 0.2 |
| Estonia | 27 | 2 | 7.41 | 9.00 | 0.0 | 0.0 |
| Finland[2] | 72 | 0 | 0.00 | 0.28 | 0.0 | 1.0 |
| Iceland | 0 | 0 | 0.00 | 0.00 | 0.0 | 0.0 |
| Latvia[1] | 16 | 3 | 18.75 | 7.29 | 0.0 | 0.0 |
| Lithuania[1] | 2 | 0 | 0.00 | 0.00 | 0.0 | 0.0 |
| Norway | 36 | 1 | 2.78 | 2.50 | 0.0 | 0.0 |
| Sweden | 78 | 6 | 7.69 | 11.14 | 0.0 | 0.0 |
| Nordic | 270 | 7 | 2.59 | 4.37 | 0.0 | 1.2 |
| Baltic | 45 | 5 | 11.11 | 7.21 | 0.0 | 0.0 |
| Nordic & Baltic | 315 | 12 | 3.81 | 4.62 | 0.0 | 1.2 |

[1] The average values of Latvia and Lithuania use the period 2012–2017.
[2] 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.

## 6.8.2 Faults in series capacitors

Series capacitors compensate for the inductance created by long transmission lines. This reduces voltage drop and transmission losses, increases the transmission capacity and improves voltage stability. Table 6.8.2 presents the number of series capacitors and faults in 2017, the number of faults per 100 devices and the amount of ENS in 2017 and 2008–2017.

Table 6.8.2: Overview of series capacitor faults

| | Devices | Faults | Faults per 100 devices | | ENS (MWh) | |
|---|---|---|---|---|---|---|
| Country | 2017 | 2017 | 2017 | 2008–2017 | 2017 | 2008–2017 |
| Denmark | 0 | 0 | 0.00 | 0.00 | 0.0 | 0.0 |
| Estonia | 0 | 0 | 0.00 | 0.00 | 0.0 | 0.0 |
| Finland | 11 | 5 | 45.45 | 58.06 | 0.0 | 1.9 |
| Iceland | 1 | 0 | 0.00 | 10.00 | 0.0 | 0.0 |
| Latvia[1] | 0 | 0 | 0.00 | 0.00 | 0.0 | 0.0 |
| Lithuania[1] | 0 | 0 | 0.00 | 0.00 | 0.0 | 0.0 |
| Norway | 3 | 0 | 0.00 | 3.33 | 0.0 | 0.0 |
| Sweden | 8 | 3 | 37.50 | 150.00 | 0.0 | 0.0 |
| Nordic | 23 | 8 | 34.78 | 90.46 | 0.0 | 1.9 |
| Baltic | 0 | 0 | 0.00 | 0.00 | 0.0 | 0.0 |
| Nordic & Baltic | 23 | 8 | 34.78 | 90.46 | 0.0 | 1.9 |

[1] The average values of Latvia and Lithuania use the period 2012–2017.

## 6.8.3 Faults in shunt capacitors

Shunt capacitors provide the grid with reactive power to the grid, thus decreasing transmission losses and increasing transmission capacity. Table 6.8.3 presents the number of shunt capacitors and faults in 2017, the number of faults per 100 devices and the amount of ENS in 2017 and 2008–2017.

Table 6.8.3: Overview of shunt capacitor faults

| | Devices | Faults | Faults per 100 devices | | ENS (MWh) | |
|---|---|---|---|---|---|---|
| Country | 2017 | 2017 | 2017 | 2008–2017 | 2017 | 2008–2017 |
| Denmark | 26 | 0 | 0.00 | 0.49 | 0.0 | 0.0 |
| Estonia | 14 | 10 | 71.43 | 7.14 | 29.6 | 3.0 |
| Finland | 62 | 0 | 0.00 | 2.87 | 0.0 | 0.0 |
| Iceland | 13 | 2 | 15.38 | 9.57 | 0.0 | 9.9 |
| Latvia[1] | 2 | 0 | 0.00 | 0.00 | 0.0 | 0.0 |
| Lithuania[1] | 2 | 0 | 0.00 | 0.00 | 0.0 | 0.0 |
| Norway | 194 | 8 | 4.12 | 1.60 | 0.0 | 0.0 |
| Sweden | 182 | 1 | 0.55 | 0.85 | 0.0 | 7.0 |
| Nordic | 477 | 11 | 2.31 | 1.61 | 0.0 | 16.9 |
| Baltic | 18 | 10 | 55.56 | 6.10 | 29.6 | 3.0 |
| Nordic & Baltic | 495 | 21 | 4.24 | 1.76 | 29.6 | 19.9 |

[1] The average values of Latvia and Lithuania use the period 2012–2017.

### 6.8.4 Faults in SVC devices

SVCs, or static VAR compensators, provide the power grid with fast and dynamic reactive power to stabilize the voltage levels, the power factor and harmonics. However, 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.

Table 6.8.4 presents the number of shunt capacitors and faults in 2017, the number of faults per 100 devices and the amount of ENS in 2017 and 2008–2017.

Table 6.8.4: Overview of SVC device faults

| | Devices | Faults | Faults per 100 devices | | ENS (MWh) | |
|---|---|---|---|---|---|---|
| Country | 2017 | 2017 | 2017 | 2008–2017 | 2017 | 2008–2017 |
| Denmark | 1 | 0 | 0.00 | 20.00 | 0.0 | 0.0 |
| Estonia | 0 | 0 | 0.00 | 0.00 | 0.0 | 0.0 |
| Finland | 5 | 1 | 20.00 | 16.00 | 0.0 | 0.0 |
| Iceland | 2 | 0 | 0.00 | 20.00 | 0.0 | 0.0 |
| Latvia[1] | 0 | 0 | 0.00 | 0.00 | 0.0 | 0.0 |
| Lithuania[1] | 11 | 2 | 18.18 | 3.77 | 0.0 | 0.0 |
| Norway | 25 | 8 | 32.00 | 83.53 | 0.0 | 0.0 |
| Sweden | 3 | 8 | 266.67 | 333.33 | 0.0 | 0.0 |
| Nordic | 36 | 17 | 47.22 | 102.04 | 0.0 | 0.0 |
| Baltic | 11 | 2 | 18.18 | 3.77 | 0.0 | 0.0 |
| Nordic & Baltic | 47 | 19 | 40.43 | 84.56 | 0.0 | 0.0 |

[1] The average values of Latvia and Lithuania use the period 2012–2017.

# References

[1] International Electrotechnical Commission. *International Electrotechnical Vocabulary*. IEC 60050-191:1990. Note that the IEC standard 60050-191 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. Chap. 191: Dependability and quality of service.

[2] DISTAC. *Guidelines for the Classification of Grid Disturbances above 100 kV*. English. Technical report. ENTSO-E, Aug. 2017. URL: https://docstore.entsoe.eu/Documents/Publications/SOC/Nordic/HVAC_guidelines_2017_04_13.pdf.

[3] DISTAC. *Nordic and Baltic HVDC Utilisation and Unavailability Statistics*. English. Technical report. ENTSO-E, Sept. 2018. URL: https://www.entsoe.eu/publications/system-operations-reports/.

[4] ENTSO-E. *The ENTSO-E Interconnected System Grid Map*. URL: https://www.entsoe.eu/publications/order-maps-and-publications/electronic-grid-maps/Pages/default.aspx.

# Appendices

# A 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 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 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 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.

# B Policies for examining the cause of 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.

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# D Contact persons for the distribution network statistics

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

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

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# E Additional figures

This appendix was introduced to allow experimenting with new kinds of figures without affecting the rest of the report. Furthermore, it shows what kind of statistical data can be derived from the data collected by the DISTAC group.

Section E.1 shows fault trends for other environmental causes and operation and maintenance. Section E.2 shows fault trends for operation and maintenance faults for overhead lines.

## E.1 Trends of faults per cause

This section presents trend curves specifically for other environmental causes and operation and maintenance faults. This lets us see if either one of them is a dominating cause of faults in a country. Other environmental causes was selected because it is the main reason for higher maintenance costs and depends significantly on the weather conditions in a country. Furthermore, faults due to other environmental causes can be decreased through increased maintenance and by improving work procedures. Operation and maintenance was selected because it may be interesting to see whether changes in work procedures or investments in system upgrades have impacted the fault rates of the grid. Furthermore, trend curves for operation and maintenance might be connected to the increase in digital technology inside the substations and to the amount of work orders being performed in the grids. There are a total of 7 fault categories, which are defined in Chapter 1.4.1.

Figure E.1.1 and Figure E.1.2 show the trend curves for other environmental causes for the Nordic and Baltic countries respectively. Figure E.1.3 and Figure E.1.4 show the trend curves for other environmental causes for the Nordic and Baltic countries respectively.

The trends are calculated by 5-year moving averages for the Nordic countries during 1995–2017 and by 3-year moving averages for the Baltic countries during 2007–2017. The 380–420 kV trends are shown for Denmark, Finland, Lithuania, Norway and Sweden because they are the only countries that own 380–420 kV components. With the help of the trend curve, it may be possible to estimate the number of faults in the future.

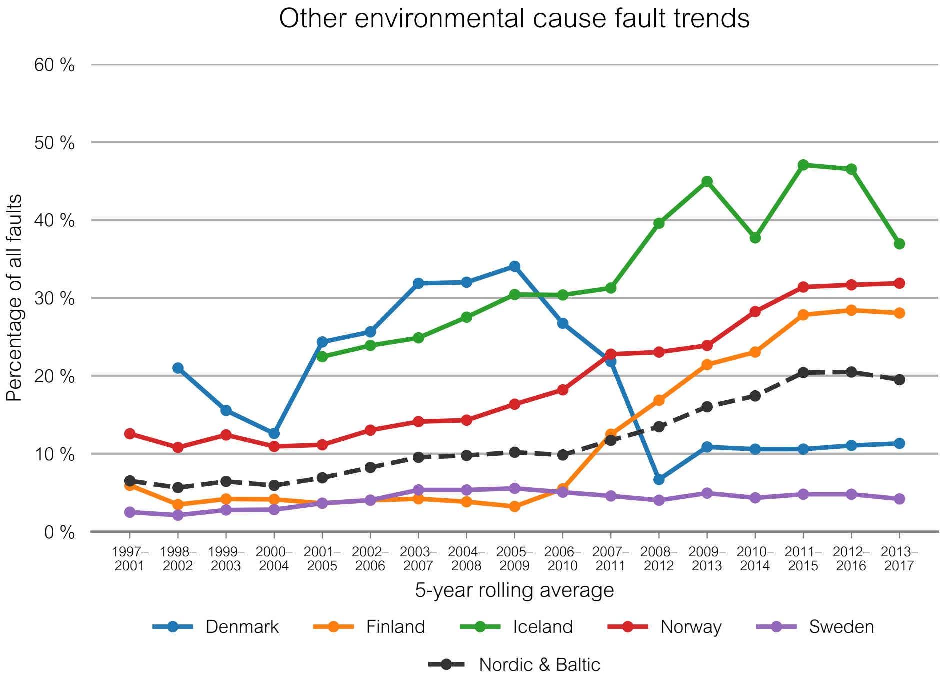


Figure E.1.1: Fault trends as 5-year rolling averages for other environmental faults in each Nordic country. Other environmental causes are the main reason for higher maintenance costs and depends significantly on the weather conditions in a country. Furthermore, faults due to other environmental causes can be decreased through increased maintenance and by improving work procedures.

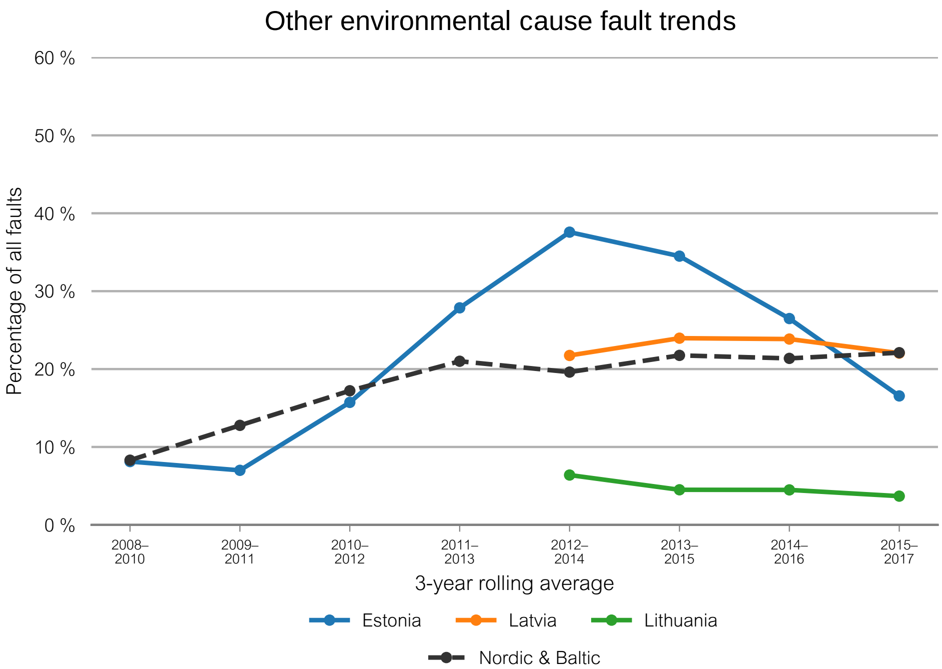


Figure E.1.2: Fault trends as 3-year rolling averages for other environmental faults in each Baltic country. Other environmental causes are the main reason for higher maintenance costs and depends significantly on the weather conditions in a country. Furthermore, faults due to other environmental causes can be decreased through increased maintenance and by improving work procedures.

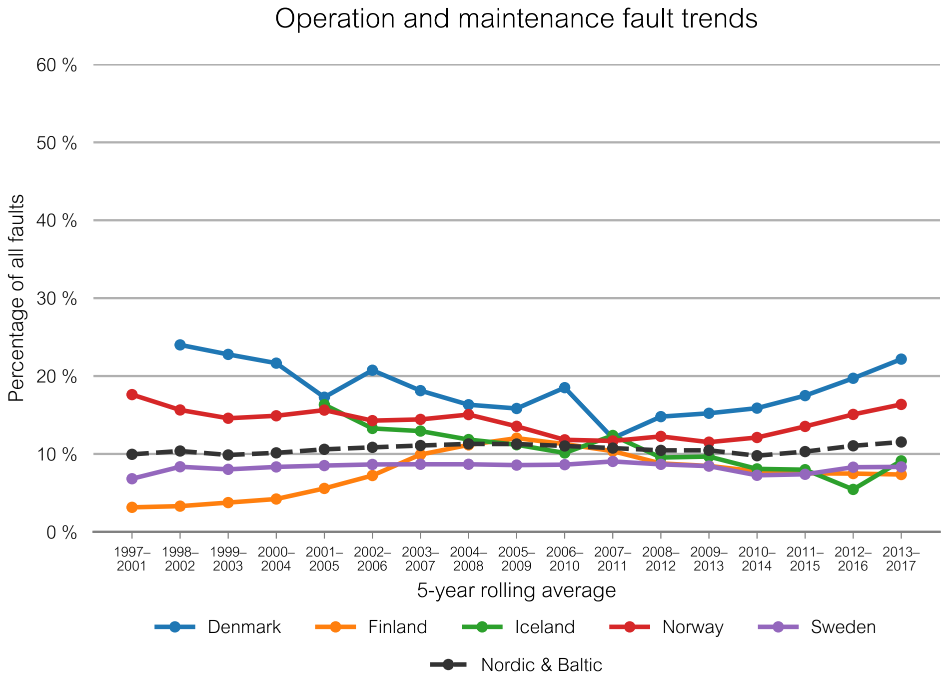


Figure E.1.3: Fault trends as 5-year rolling averages for operation and maintenance faults in each Nordic country. Operation and maintenance faults are directly connected to changes in work procedures and grid investments. Furthermore, trend curves for operation and maintenance might be connected to the increase in digital technology inside the substations and to the amount of work orders being performed in the grids.

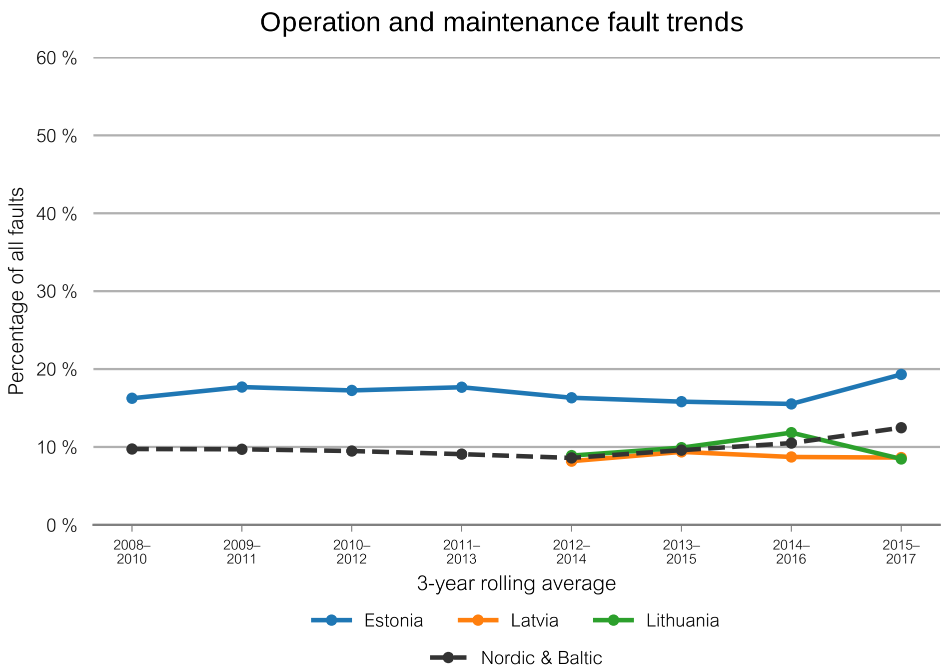


Figure E.1.4: Fault trends as 3-year rolling averages for operation and maintenance faults in each Baltic country. Operation and maintenance faults are directly connected to changes in work procedures and grid investments. Furthermore, trend curves for operation and maintenance might be connected to the increase in digital technology inside the substations and to the amount of work orders being performed in the grids.

# E.2 Overhead line fault trends per cause

This section presents trend curves for overhead line faults according to other environmental causes and operation and maintenance. This lets us see if either one of them is a dominating cause of faults in overhead lines in a country. Other environmental causes was selected because it is the main reason for higher maintenance costs and depends significantly on the weather conditions in a country. Furthermore, faults due to other environmental causes can be decreased through increased maintenance and by improving work procedures. Operation and maintenance was selected because it may be interesting to see whether changes in work procedures or investments in system upgrades have impacted the fault rates of the grid. Furthermore, trend curves for operation and maintenance might be connected to the increase in digital technology inside the substations and to the amount of work orders being performed in the grids. There are a total of 7 fault categories, which are defined in Chapter 1.4.1.

Overhead line fault trends for other environmental causes are shown per voltage level in Figure E.2.1, Figure E.2.2, Figure E.2.3, Figure E.2.4 and Figure E.2.5. Trends for overhead line operation and maintenance faults are shown per voltage level in Figure E.2.6, Figure E.2.7, Figure E.2.8, Figure E.2.9 and Figure E.2.10.

The trends are calculated by 5-year moving averages for the Nordic countries during 1995–2017 and by 3-year moving averages for the Baltic countries during 2007–2017. The 380–420 kV trends are shown for Denmark, Finland, Lithuania, Norway and Sweden because they are the only countries that own 380–420 kV components. With the help of the trend curve, it may be possible to estimate the number of faults in the future.

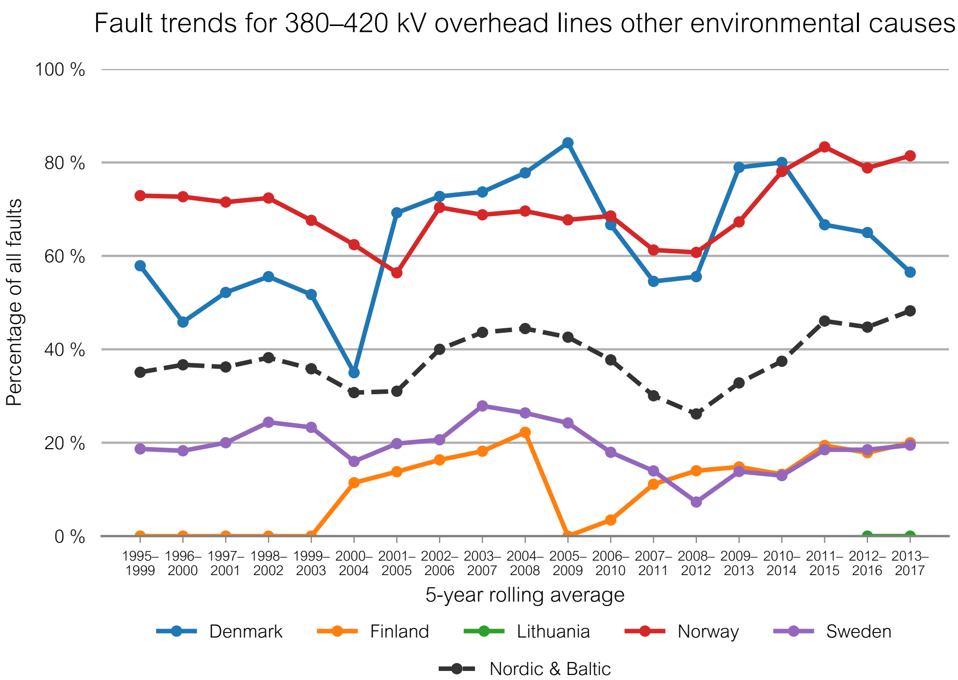


Figure E.2.1: Fault trends as 5-year rolling averages for 380–420 kV overhead line other environmental causes in Denmark, Finland, Lithuania, Sweden and Norway. Other environmental causes are the main reason for higher maintenance costs and depends significantly on the weather conditions in a country. Furthermore, faults due to other environmental causes can be decreased through increased maintenance and by improving work procedures.

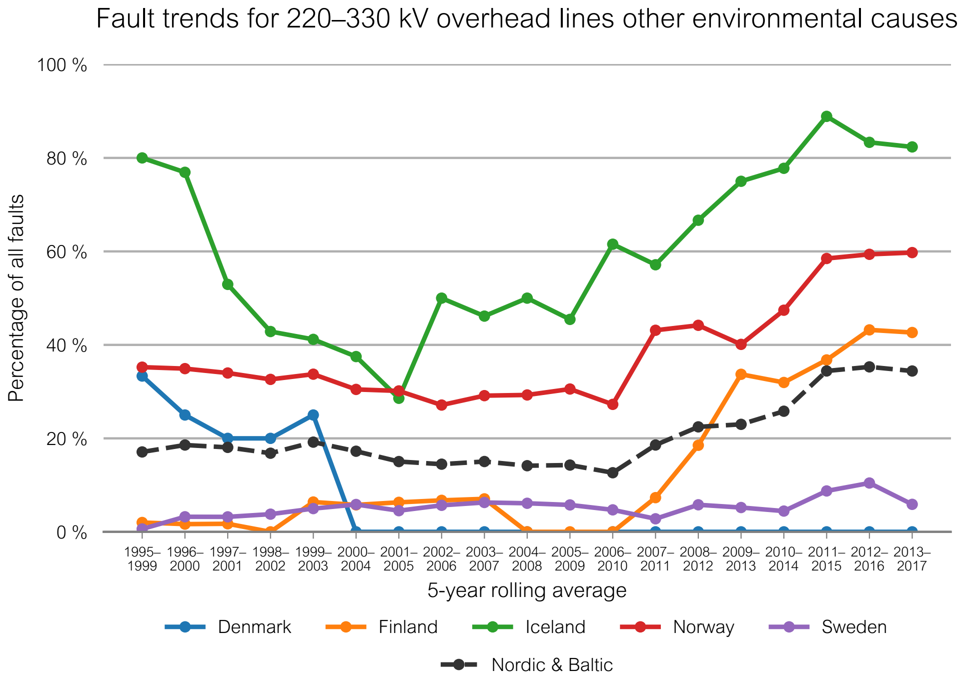


Figure E.2.2: Fault trends as 5-year rolling averages for 220–330 kV overhead line other environmental causes in each Nordic country. Other environmental causes are the main reason for higher maintenance costs and depends significantly on the weather conditions in a country. Furthermore, faults due to other environmental causes can be decreased through increased maintenance and by improving work procedures.

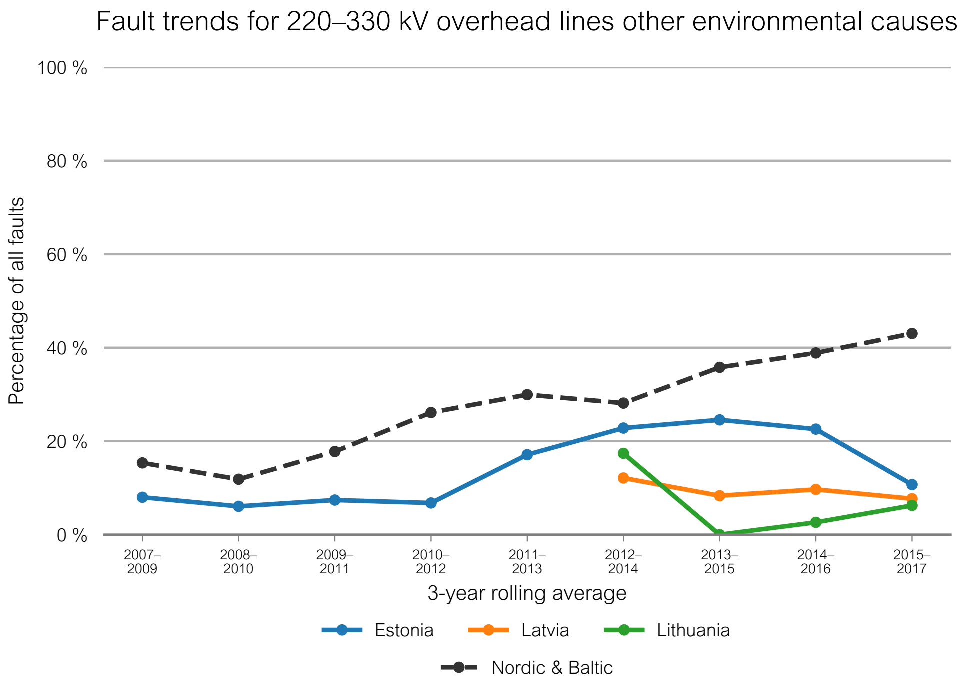


Figure E.2.3: Fault trends as 3-year rolling averages for 220–330 kV overhead line other environmental causes in each Baltic country. Other environmental causes are the main reason for higher maintenance costs and depends significantly on the weather conditions in a country. Furthermore, faults due to other environmental causes can be decreased through increased maintenance and by improving work procedures.

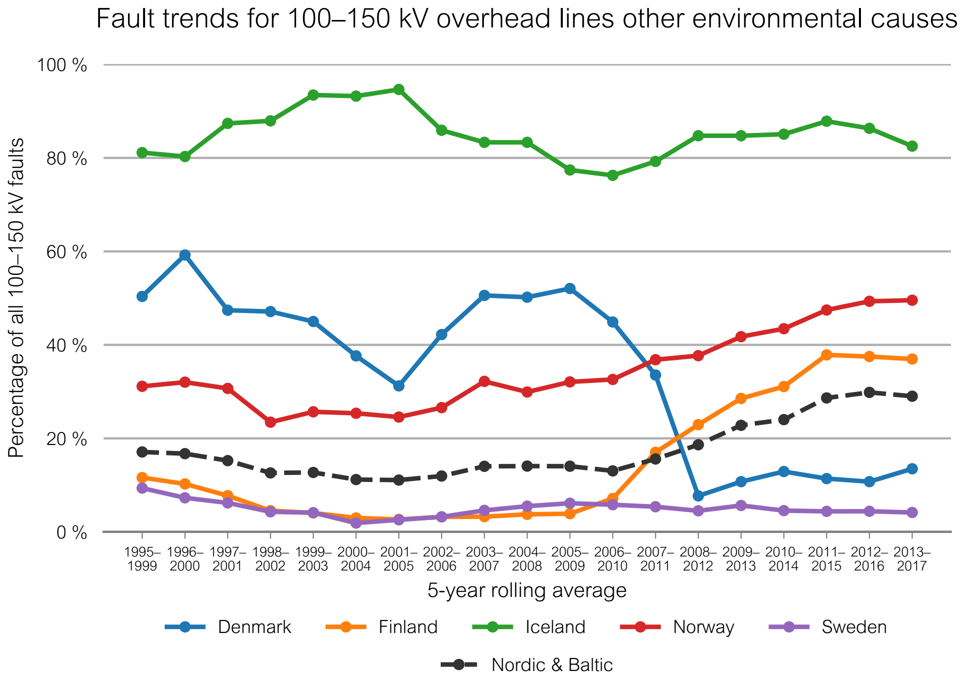


Figure E.2.4: Fault trends as 5-year rolling averages for 110–150 kV overhead line other environmental causes in each Nordic country. Other environmental causes are the main reason for higher maintenance costs and depends significantly on the weather conditions in a country. Furthermore, faults due to other environmental causes can be decreased through increased maintenance and by improving work procedures.

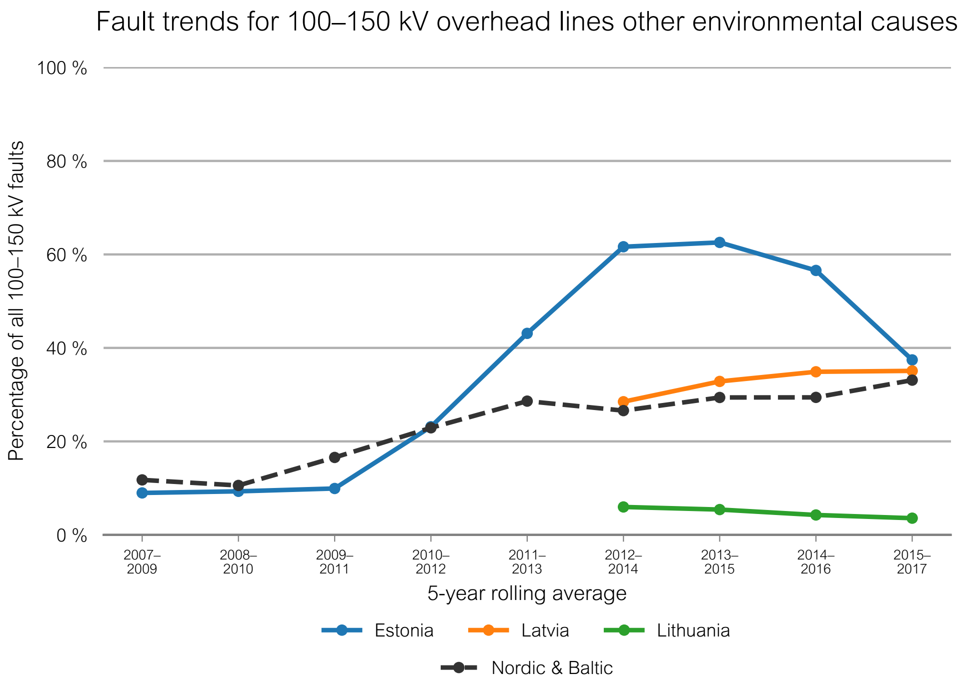


Figure E.2.5: Fault trends as 3-year rolling averages for 100–150 kV overhead line other environmental causes in each Baltic country. Other environmental causes are the main reason for higher maintenance costs and depends significantly on the weather conditions in a country. Furthermore, faults due to other environmental causes can be decreased through increased maintenance and by improving work procedures.

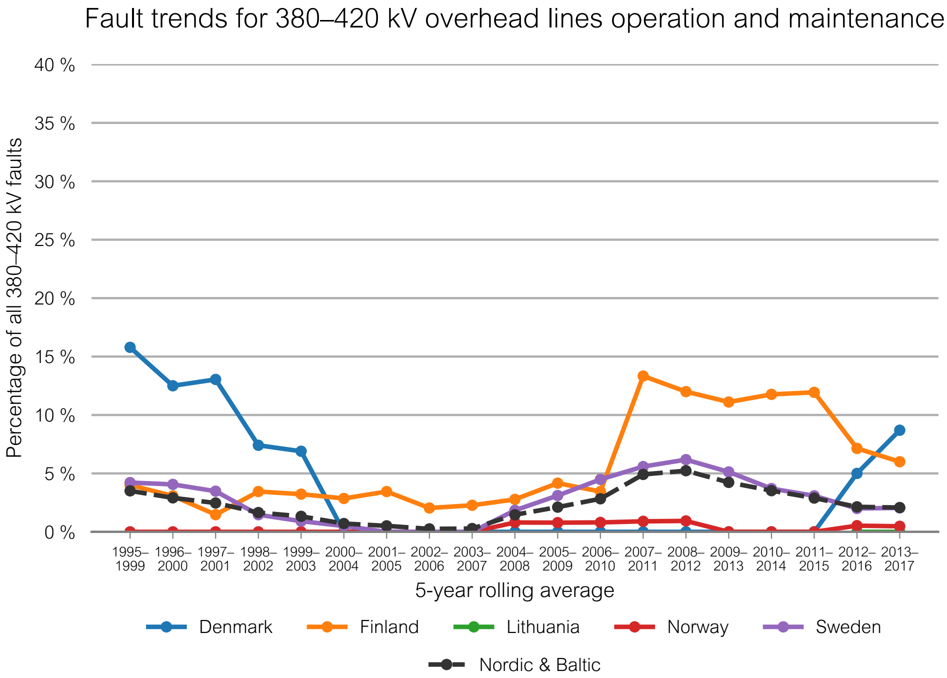


Figure E.2.6: Fault trends as 5-year rolling averages for 380–420 kV overhead line operation and maintenance faults in Denmark, Finland, Lithuania, Sweden and Norway. Operation and maintenance faults are directly connected to changes in work procedures and grid investments. Furthermore, trend curves for operation and maintenance might be connected to the increase in digital technology inside the substations and to the amount of work orders being performed in the grids.

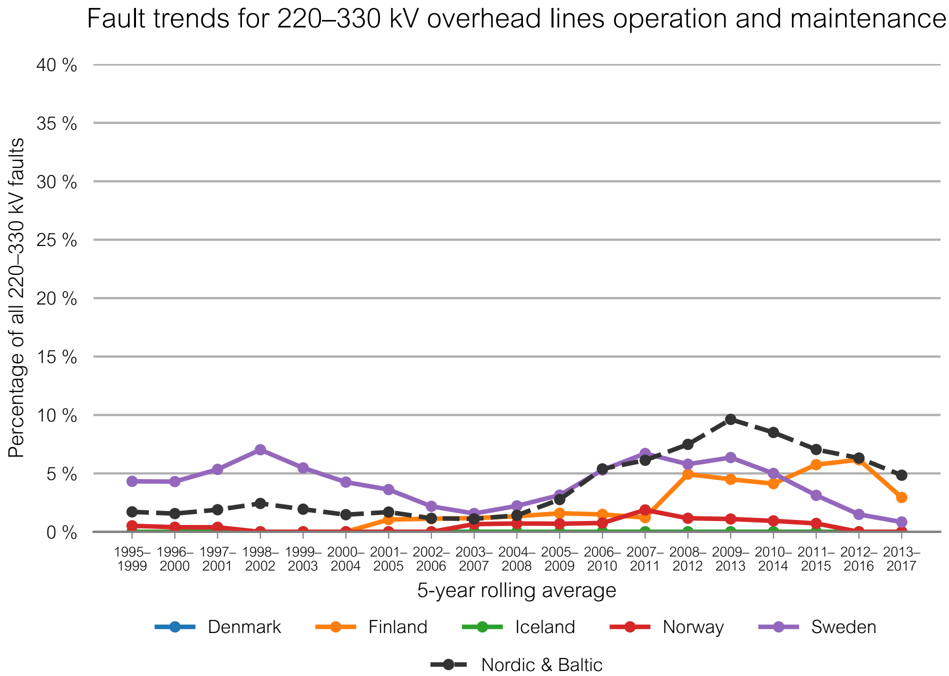


Figure E.2.7: Fault trends as 5-year rolling averages for 220–330 kV overhead line operation and maintenance faults in each Nordic country. Operation and maintenance faults are directly connected to changes in work procedures and grid investments. Furthermore, trend curves for operation and maintenance might be connected to the increase in digital technology inside the substations and to the amount of work orders being performed in the grids.

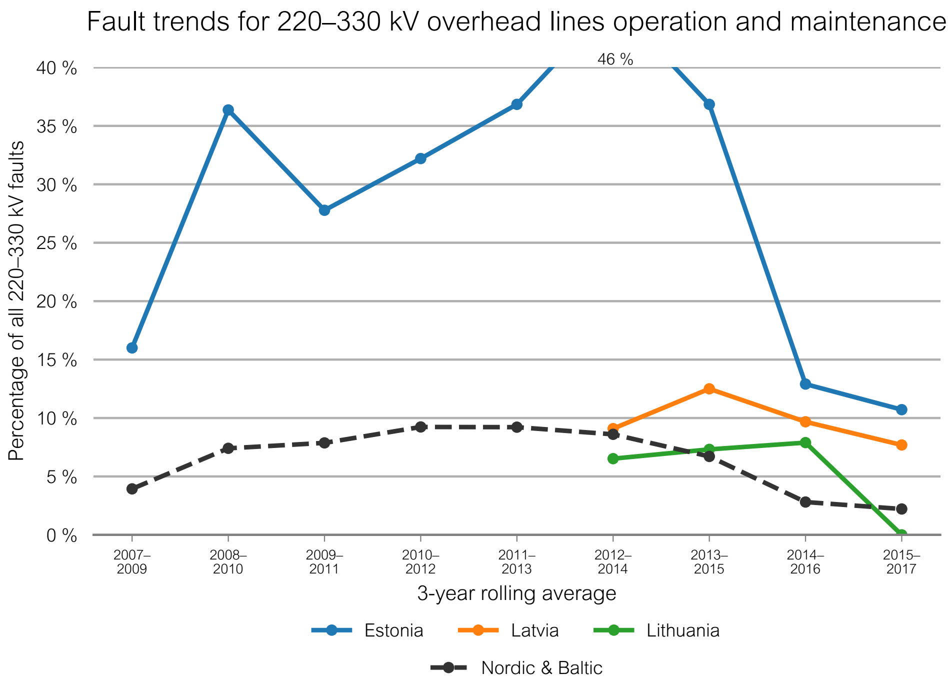


Figure E.2.8: Fault trends as 3-year rolling averages for 220–330 kV overhead line operation and maintenance faults in each Baltic country. Operation and maintenance faults are directly connected to changes in work procedures and grid investments. Furthermore, trend curves for operation and maintenance might be connected to the increase in digital technology inside the substations and to the amount of work orders being performed in the grids.

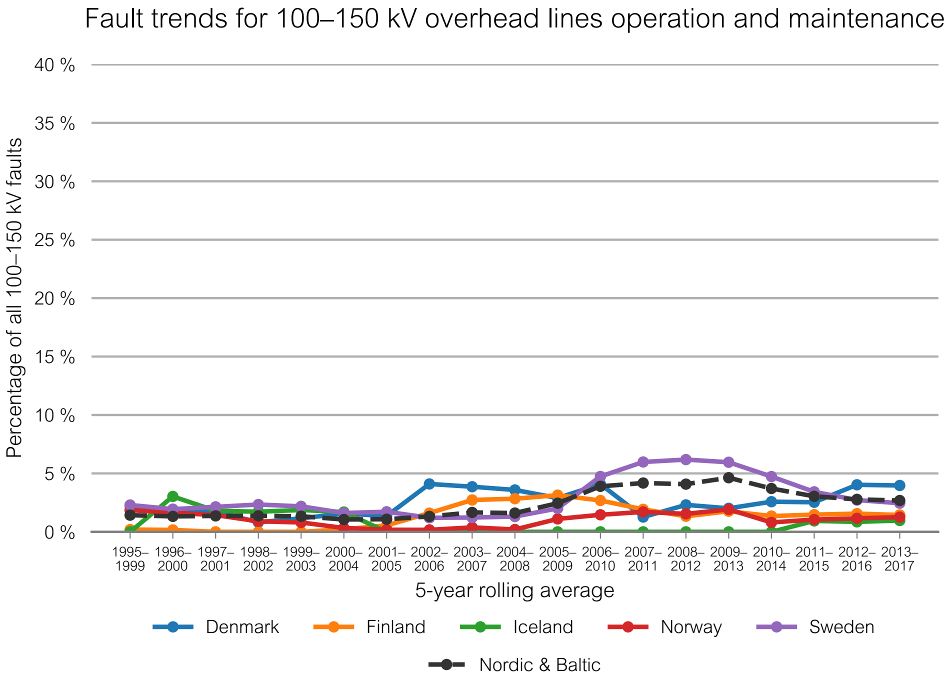


Figure E.2.9: Fault trends as 5-year rolling averages for 110–150 kV overhead line operation and maintenance faults in each Nordic country. Operation and maintenance faults are directly connected to changes in work procedures and grid investments. Furthermore, trend curves for operation and maintenance might be connected to the increase in digital technology inside the substations and to the amount of work orders being performed in the grids.

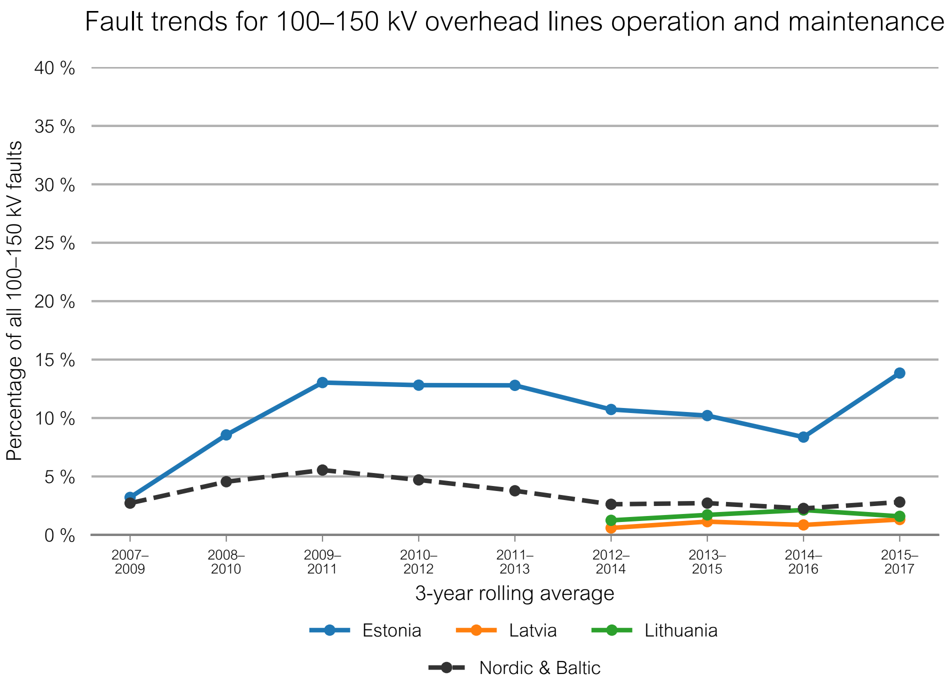


Figure E.2.10: Fault trends as 3-year rolling averages for 100–150 kV overhead line operation and maintenance faults in each Baltic country. Operation and maintenance faults are directly connected to changes in work procedures and grid investments. Furthermore, trend curves for operation and maintenance might be connected to the increase in digital technology inside the substations and to the amount of work orders being performed in the grids.