European Network of
Transmission System Operators
for Electricity

NORDIC AND BALTIC HVDC UTILISATION AND UNAVAILABILITY STATISTICS 2016

10.11.2017

REGIONAL GROUP NORDIC

Table of Contents

1 SUMMARY

This report presents the availability and utilisation of HVDC links connected to the Nordic and Baltic power system in 2016, with an emphasis on disturbance outages.

This report presents methods and definitions and statistics for 2016: An overview of availability and utilisation for all links, a closer look on the disturbances and separate presentations of the performance of each HVDC link.

In 2016, 50.9 TWh of electric energy was transmitted through the Nordic and Baltic HVDC links. The total number of disturbance outages registered was 69, preventing 1.4 TWh of potential energy transmission.

Maintenance outages reduced the potential transmission by 2.8 TWh and limitations reduced it by 2.9 TWh.

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

2 INTRODUCTION AND BACKGROUND

The total HVDC power transmission capacity connected to the Nordic and Baltic power systems is 10240 MW. Most of this capacity connects the Nordic synchronous system to other systems but Fenno-Skan 1 and Fenno-Skan 2 HVDC links connect Finland and Sweden as Figure 2.1 shows and provide the transmission capacity of 1200 MW.

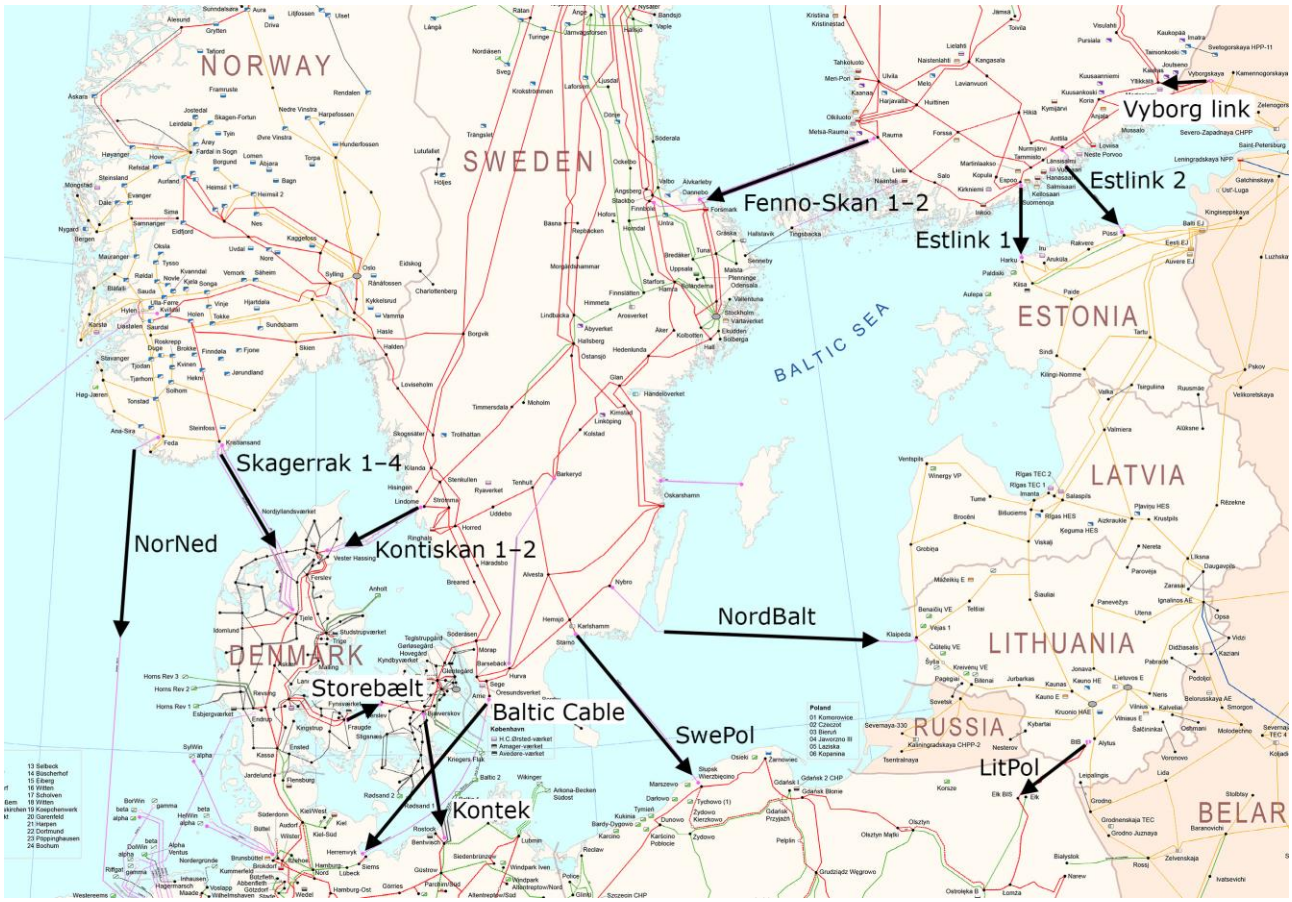

FIGURE 2.1 PART OF THE NORDIC GRID MAP SHOWING THE HVDC LINKS [1]. THE ARROWS INDICATES THE DIRECTION OF EXPORT USED IN THIS REPORT.

The total annual HVDC transmission capacity is 90.9 TWh. This makes the HVDC links important components for the stable operation of the Nordic and Baltic power system while supporting the commercial power trade in the European energy markets. Hence, the advantages of keeping HVDC links in operation as much of the time as possible are obvious.

Schematic presentations of the HVDC links and their converter stations, both for line commutated converters (LCC) and voltage source converters (VSC) are presented in Appendix A.

Disturbances do happen, but high-quality hardware components, thorough installation routines, and fault analysis combined with preventive maintenance are means to limit the number of such unfortunate events. Planned outages and limitations due to maintenance work are necessary, but should be planned and conducted as efficient as possible. The result is more available capacity for energy transmission through HVDC links.

Therefore, mapping the available capacity, including the reasons for unavailability, is of vital interest for the utilisation of this infrastructure. Furthermore, the utilisation of the links is of interest since this is the action that realises the value through energy trade.

3 SCOPE

The scope of these statistics differs from the scope of the CIGRÉ HVDC statistics, which concentrate on the outages, faults and disturbances of the HVDC links, including the converter stations.

The main interest of this HVDC statistics is a macro view on the *availability* and *utilisation* of the HVDC links, including total outages and limitations. Disturbance outages are more thoroughly examined than other events.

The macro view of these statistics includes only links that were commissioned before the statistical year in question or were available for the electricity market the whole year.

3.1 CONTACT PERSONS

Each country is represented by at least one contact person, responsible for the statistical information of the corresponding country. The contact person can provide additional information concerning the HVDC availability and utilisation statistics. The relevant contact information is given in Appendix B.

4 METHODS, DEFINITIONS AND CALCULATIONS

This chapter explains the availability and utilisation categories of the HVDC statistics. Interesting details in the collected data will be emphasized.

The utilisation of HVDC link capacities can be calculated by using the data received from SCADA, grid operation, market departments, Urgent Market Messages (UMMs) of the Nord Pool Spot and measurements on each side of a link.

The process of collecting and sorting data for these statistics will be described in the guidelines of this report. This chapter describes how the collected data is defined and used in the calculations.

The technical capacity (E_{max}) of the HVDC link is the maximum energy that can be transmitted from the AC grid to the converter station on the exporting side, excluding all HVDC link losses and ignoring outages and limitations. The technical capacity is thereby calculated:

$$E_{\max} = P_{\mathrm{R}} \cdot 24 \cdot d, \qquad (4.1)$$

where P_R is the rated power capacity and d is the number of days in the reported time period (month or year). The column in Figure 4.1 describes the nine main categories of these statistics, as well as aggregated categories used for simplified presentations.

In Figure 4.1, technical capacity (E_{max}) is represented as the total height of the column. This section explains the mutual exclusivity and mathematical consistence of all categories used in the HVDC statistics.

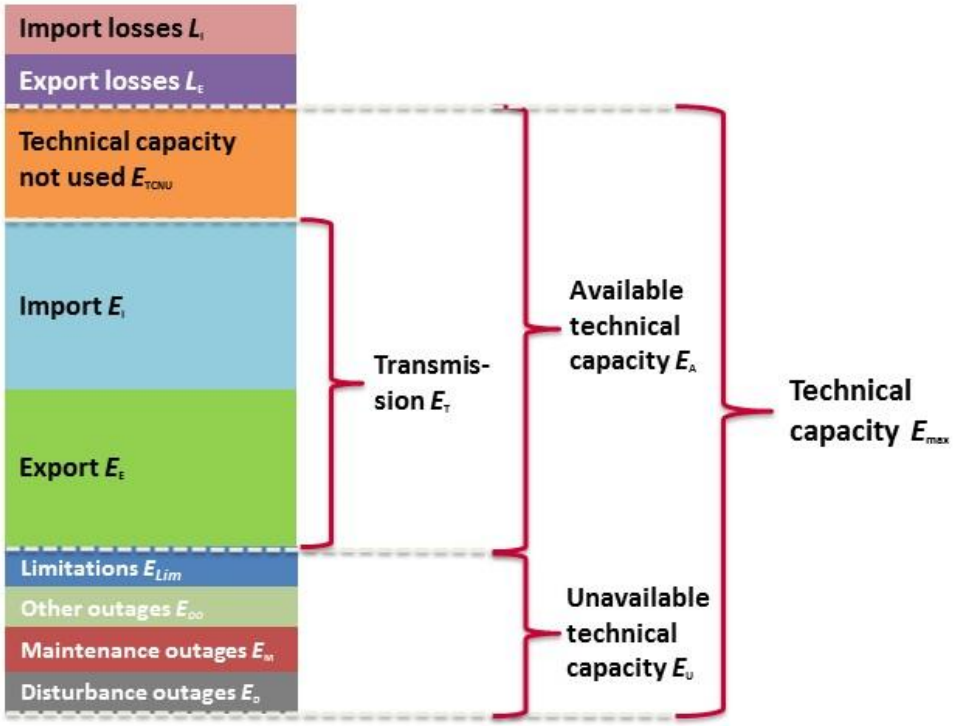

FIGURE 4.1 THE AVAILABILITY AND UTILISATION CATEGORIES USED IN THE HVDC STATISTICS. THE DEFINITIONS AND CALCULATIONS ARE EXPLAINED IN CHAPTER 4. EVERY VALUE IS AN ENERGY VALUE AND REPRESENTS A PART OF THE AVAILABLE OR UNAVAILABLE TECHNICAL CAPACITY. THE NINE CATEGORIES OF THE COLUMN TO THE LEFT ARE INTERNALLY EXCLUSIVE AND THEIR SUM AMOUNTS TO THE TOTAL TECHNICAL CAPACITY.

The technical capacity of the link is a theoretical value and can be divided into **available technical capacity (E_A) and unavailable technical capacity (E_U)**. The unavailable technical capacity E_U is due to outages or limitations.

The capacity used for transmission (E_T) is the sum of exported and imported energy:

$$E_T = E_E + E_I, \quad (4.2)$$

where **Imported energy** (E_I) is the energy transferred from the HVDC link to the importing AC side. It does not include **import losses (L_I)**, i.e. the energy losses in any of the HVDC link components during import, which are calculated by subtracting the received energy from the transferred energy. **The exported energy (E_E)** and **export losses (L_E)** are explained likewise, with an opposite point of view. Exported energy E_E from one side of the link equals imported energy E_I considered from the opposite side of the link. It should be noted that these values are measurements and therefore considered factual.

An **outage** is when a component is partially or fully disconnected from the system and the transfer capacity is reduced to zero. There are different types of outages:

- **Disturbance outages (E_D)** are *total outages* due to a fault on the HVDC link or in the AC grid causing a *total outage* of the link. This could be a forced outage or an automatic trip.
- **Maintenance outages (E_M)** are *total outages* due to all technically motivated actions on the HVDC link or in the AC grid intended to retain an entity in, or restore it to, a state where it can perform its required function.
- **Other outages (E_{OO})** are *total outages* due to any other reason except those mentioned above. This could be for example when the markets do not need the transmission capacity of the link and the link is disconnected.

The energy transfer made unavailable due to disturbance, maintenance and other outages are calculated by multiplying the **rated power (P_R)** by the **disturbance outage duration (h_D)**, **maintenance outage duration (h_M)**, and **other outage duration (h_{OO})** in the following way:

$$E_D = P_R \cdot h_D, \quad (4.3)$$

$$E_M = P_R \cdot h_M, \quad (4.4)$$

$$E_{OO} = P_R \cdot h_{OO}. \quad (4.5)$$

A limitation (E_{Lim}) is a condition when the transmission capacity of an HVDC link is limited, i.e. the power transmission capacity of the link is less than the rated power. The limitation is always motivated from a technical perspective, but not always concerning the link itself. The most common causes of limitations are:

- faults on any HVDC link component as long as they do not cause a total outage;
- faults, congestions or outages in the AC grid causing a limitation in the transmission capacity of the link;
- seasonal variations on the transmission capacity of the HVDC link;[1]

[1] The transmission capacity of some links is limited during the summer season due to a decreased convection of heat from transmission losses. The full capacity is as rated by the manufacturer, and is given for all links in Table 5.1.

- link capacity reserved as power reserves.

Limitations lasting less than ten minutes should not be reported. In the scope of this statistics report, these limitations are too small to have an actual significance on the presented data. Hence, short ramping limitations and commutation failures are not cases included in this category.

Limitations are calculated by multiplying the **limited power capacity (P_{Lim})** by the **duration of the limitation in hours (h_{Lim})**:

$$E_{\mathrm{Lim}} = P_{\mathrm{Lim}} \cdot h_{\mathrm{Lim}}. \tag{4.6}$$

The limited power capacity (P_{Lim}) describes the amount of power reduced from the rated power.

Now it is possible to define the mathematical description of the unavailable technical capacity (E_U) as the part of technical capacity that is *not* available for transmission due to outages (disturbance, maintenance, other) and limitations:

$$E_{\mathrm{U}} = E_{\mathrm{D}} + E_{\mathrm{M}} + E_{\mathrm{OO}} + E_{\mathrm{Lim}} = P_{\mathrm{R}}(h_{\mathrm{D}} + h_{\mathrm{M}} + h_{\mathrm{OO}}) + P_{\mathrm{Lim}} \cdot h_{\mathrm{Lim}}. \tag{4.7}$$

The counterpart to unavailable technical capacity (E_U) is the available technical capacity (E_A), which consists of the remaining of the technical capacity (E_{max}). The available technical capacity equals **the capacity used for transmission (E_T)** and **technical capacity not used E_{TCNU}**.

$$E_{\mathrm{A}} = E_{\mathrm{max}} - E_{\mathrm{U}} = E_{\mathrm{T}} + E_{\mathrm{TCNU}}. \tag{4.8}$$

Technical capacity not used (E_{TCNU}) can now be calculated:

$$\begin{aligned} E_{\mathrm{TCNU}} &= E_{\mathrm{max}} - E_{\mathrm{U}} - E_{\mathrm{T}} \\ &= E_{\mathrm{max}} - [P_{\mathrm{R}}(h_{\mathrm{D}} + h_{\mathrm{M}} + h_{\mathrm{OO}}) + P_{\mathrm{Lim}} \cdot h_{\mathrm{Lim}}] - [E_{\mathrm{E}} + E_{\mathrm{I}}]. \end{aligned} \tag{4.9}$$

However, there is an exception when calculating the technical capacity not used. If the **transmission (E_T)** and **unavailable technical capacity (E_U)** equals more than 90 % of the total **technical capacity (E_{max})**, then all of the remaining capacity is categorised as **limitations (E_{Lim})**. If this is not the case, no limitations are recorded and the remaining capacity is categorised as **technical capacity not used (E_{TCNU})**. That is:

$$\begin{aligned} E_{\mathrm{Lim}} &= E_{\mathrm{max}} - E_{\mathrm{D}} - E_{M} - E_{OO} - E_{\mathrm{T}}, \quad if\ E_{max} \cdot 0.9 \leq E_T + E_U \\ E_{TCNU} &= E_{\mathrm{max}} - E_{\mathrm{D}} - E_{M} - E_{OO} - E_{\mathrm{T}}, \quad otherwise. \end{aligned} \tag{4.10}$$

Technical capacity not used (E_{TCNU}) and limitations (E_{Lim}) are what remains when all other categories are mapped and calculated. The content of this category is complex and consists of both technical and market related details. The most important of these are:

- When bidding differences between the markets on each side of the HVDC link are too small to promote transmission, in spite of technical availability. The link is still available and can be used for balancing or transmitting emergency power, and hence not disconnected.
- Any limitations lasting less than ten minutes (does not include total outages):

- Ramping time: When the power flow is changed the capacity is fully released to the market. Note that, depending on the type of converter technology, the nominal voltage, and hence the full transmission capacity, may not be obtained immediately.
- Commutation failures may interrupt the power transmission. In the CIGRÉ statistics, commutation failures are categorized as 'transient disturbances'.
- Emergency power is not usually used for more than ten minutes for a given event. Longer lasting disturbances will be registered as outages or limitations.

5 TECHNICAL DETAILS OF THE HVDC LINKS

Table 5.1 presents the main properties of the HVDC links while Table 5.2 presents the technical properties of the HVDC lines. The defined export directions are also presented in Figure 2.1.

TABLE 5.1 MAIN PROPERTIES OF THE HVDC LINKS

Name of the link	Commissioning year	Market connection (Y/N)	Type of HVDC converter	Rated power, mono-polar (MW)	Parallel monopolar capacity (MW)	Bipolar capacity (MW)	Defined export direction (N–S, E–W)
Baltic Cable	1994	Y	LCC	600			N–S
Estlink 1	2006	Y	VSC	350	1000		N–S
Estlink 2	2014	Y	LCC	650			N–S
Fenno-Skan 1	1989	Y	LCC	400	1200	1200	E–W
Fenno-Skan 2	2011	Y	LCC	800			E–W
Kontek	1986	Y	LCC	600			N–S
Konti-Skan 1	2008	Y	LCC	370	740		E–W
Konti-Skan 2	1988	Y	LCC	370			E–W
LitPol Link	2015	Y	LCC	500			E–W
NordBalt	2016	Y	VSC	700			N–S
NorNed	2008	Y	LCC	700			N–S
Skagerrak 1	1976–1977	Y	LCC	250	1000	1000	N–S
Skagerrak 2		Y	LCC	250			N–S
Skagerrak 3	1993	Y	LCC	500			N–S
Skagerrak 4	2014	Y	VSC	700			N–S
Storebaelt	2010	Y	LCC	600			E–W
SwePol	2000	Y	LCC	600			N–S
Vyborg Link[1)]	1981, 1982, 1984, 2000		LCC	1400			E–W

1) Each commissioning included a capacity of 350 MW

TABLE 5.2 TECHNICAL DETAILS OF THE HVDC LINES

Name of the link	Total length of the link (km)	Length of mass cable (km)	Length of PEX cable (km)	Length of DC overhead line (km)	Length of DC back-to-back connection (km)
Baltic Cable	262	250		12	
Estlink 1	105		210 (2 × 105 km)		
Estlink 2	171	157		14	
Fenno-Skan 1	233	200		33	
Fenno-Skan 2	299	196		103	
Kontek	160		160		
Konti-Skan 1	150	89		61	
Konti-Skan 2	150	89		61	
LitPol Link	< 1				< 1
NordBalt	450				
NorNed	580	580			
Skagerrak 1	212.5	133.6		78.5	
Skagerrak 2	211.4	132.9		78.5	
Skagerrak 3	212.9	134.4		78.5	
Skagerrak 4	226	226			
Storebaelt	57		57		
SwePol	254	254			
Vyborg Link	< 1				< 1

6 PRESENTATION OF THE RESULTS FOR 2016

6.1 INTRODUCTION

During 2016 there were 69 disturbance outages affecting the HVDC links connected to the Nordic power systems. The disturbances caused a capacity reduction that corresponds to 1.4 TWh (1.5 %) of the total technical HVDC transmission capacity.

Maintenance outages amounted to 2.8 TWh (3.0 %), and limitations reduced the transmission capacity by 2.9 TWh (3.2 %) of the total technical HVDC transmission capacity.

Section 6.2 provides an overview of the HVDC links and Section 6.3 presents the availability and utilisation of each HVDC link. The unavailable technical capacity (E_U) due to disturbance outages, the origins that triggered the events, and the performance of all the HVDC links connected to the Nordic and Baltic power system in 2016 are presented and explained.

6.2 OVERVIEW

Figure 6.2.1 presents the overview of the availability and utilisation of HVDC statistics at an aggregated level. This enables a comparison between the connections. It should be noted that the usages of the links show big variations. Most links are market dependent, some are mostly used only in one direction, and some are used for technical reasons to control power flow for system stability according to agreements.

Appendix C shows the overviews of the HVDC links using the same values as Figure 6.2.1 but ranked according to the highest unavailable technical capacity, according to the highest transmission, and according to the highest technical capacity not used.

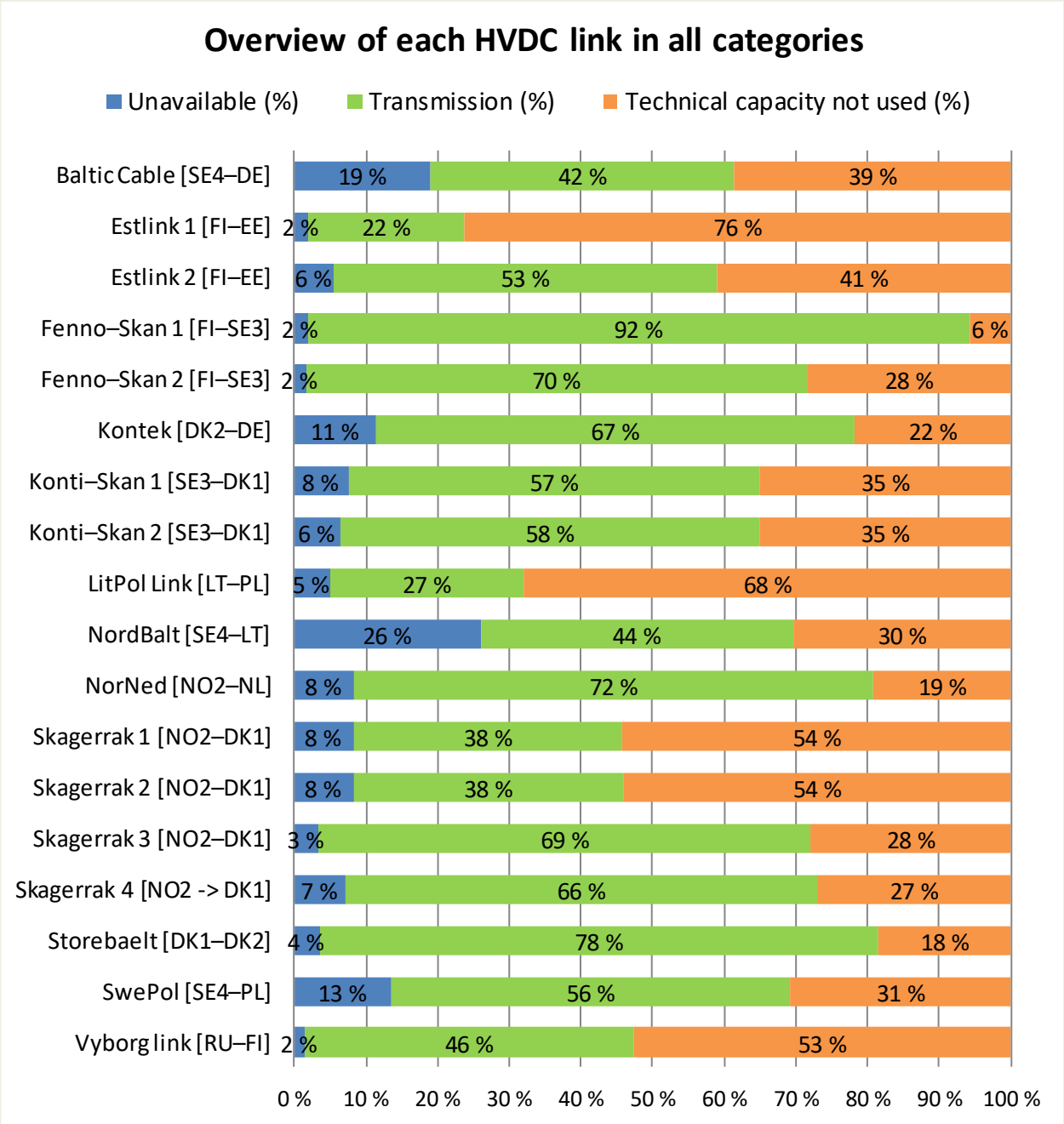

FIGURE 6.2.1 ANNUAL OVERVIEW OF THE AVAILABILITY AND UTILISATION OF EACH HVDC LINK IN 2016. THE CATEGORIES USED REFER TO THE METHODS, DEFINITIONS AND CALCULATIONS DEFINED IN CHAPTER 4.

Figure 6.2.2 presents the percentage unavailable technical capacity (E_U) of the annual technical capacity (E_{max}) due to the disturbance outages. The comments are added below the figure.

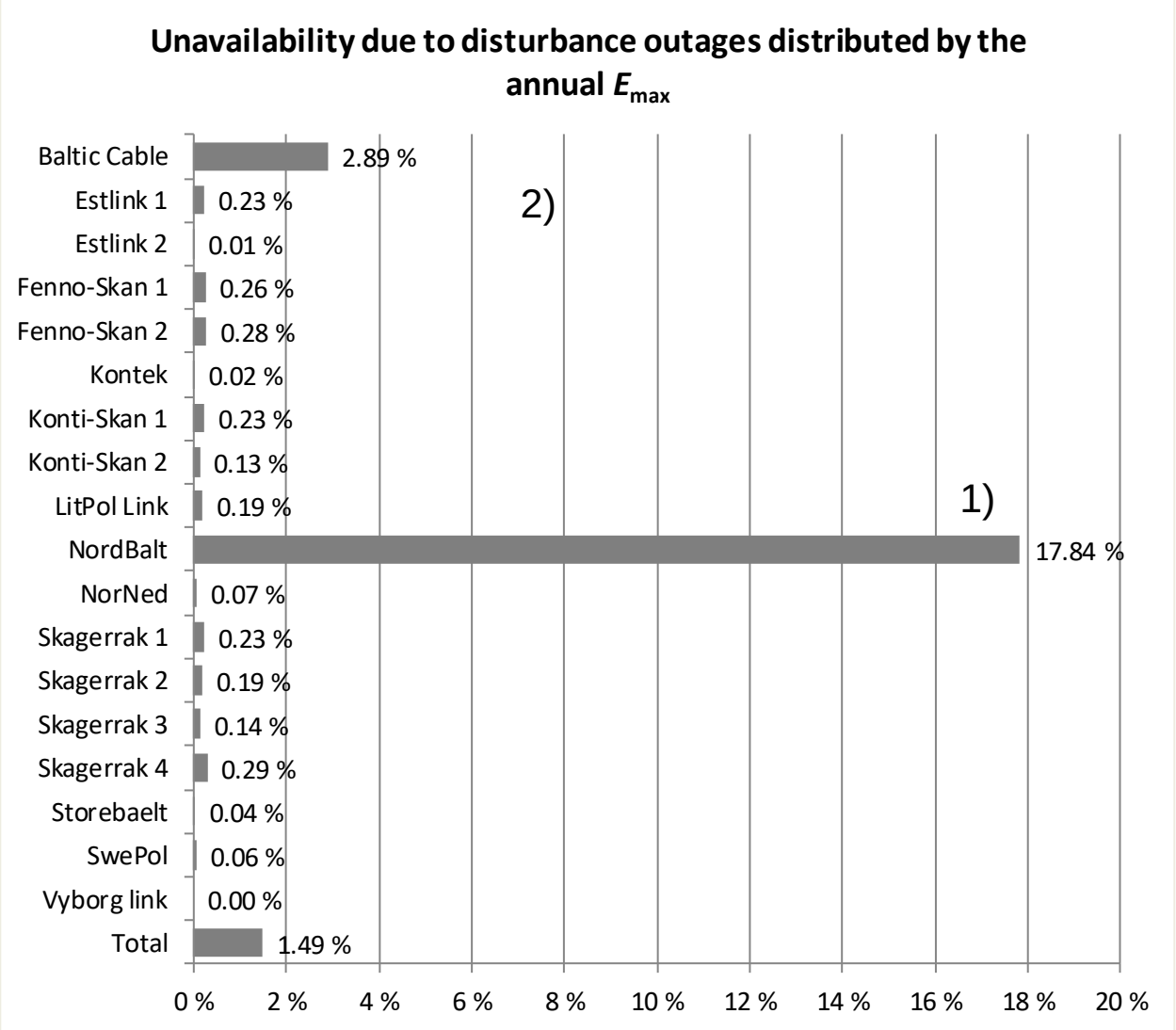

FIGURE 6.2.2 PERCENTAGE DISTRIBUTION OF UNAVAILABLE TECHNICAL CAPACITY E_U DUE TO DISTURBANCE OUTAGES FOR EACH LINK IN 2016

1) NordBalt had a disturbance outage in July which was caused by two capacitors exploding. The fault occurred in Klaipeda converter station in one of the arms of the BR2 filter capacitor bank and finally resulted in five destroyed units. Furthermore, NordBalt had six disturbance outages due to faults in the land DC cable joints.

2) Baltic Cable had a fault that originated from the DC electrode cable in April

Figure 6.2.3 presents the number of all disturbance, maintenance and other outages.

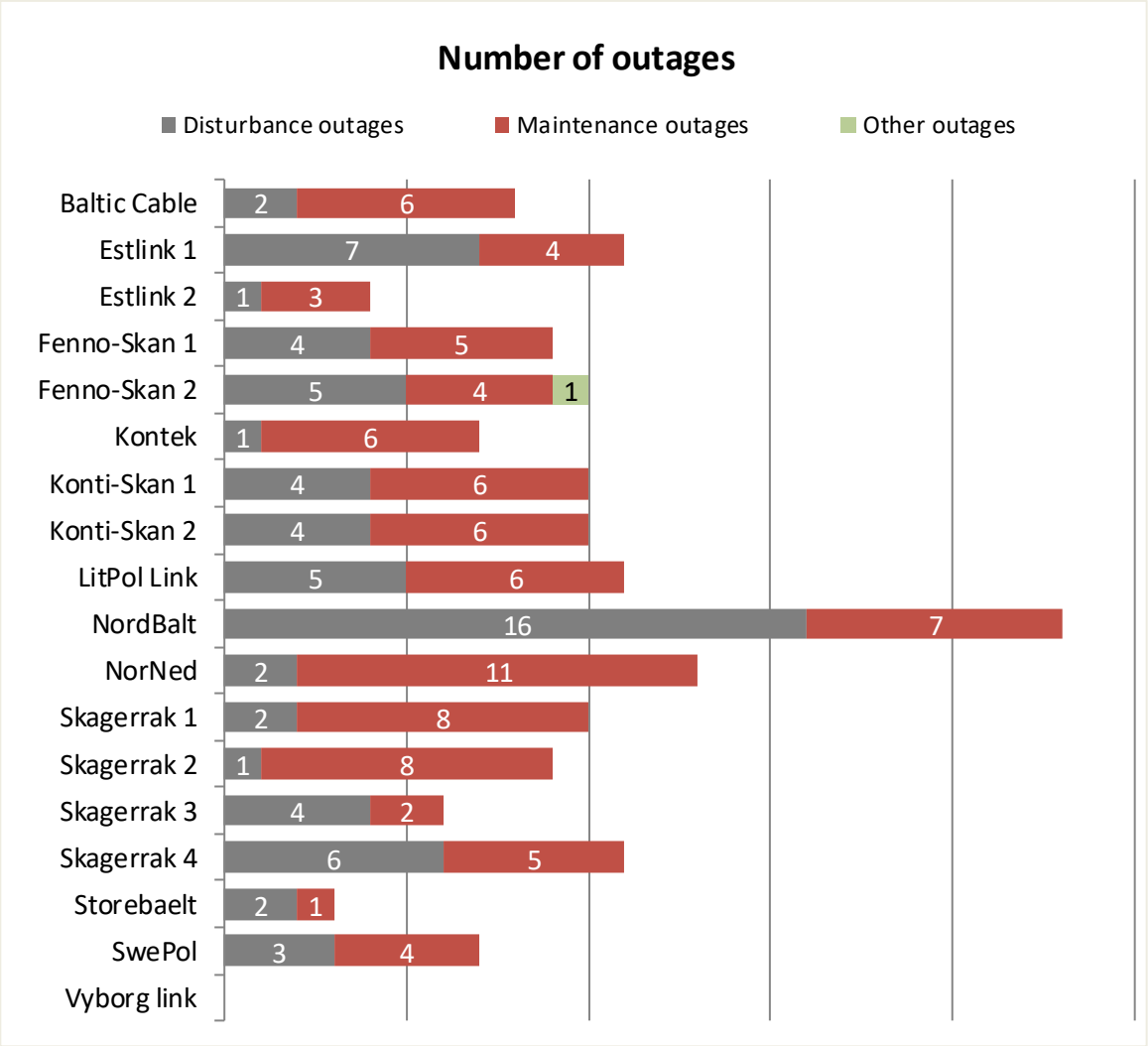

FIGURE 6.2.3 THE NUMBER OF DISTURBANCE, MAINTENANCE AND OTHER OUTAGES FOR EACH LINK IN 2016

6.3 INDIVIDUAL PRESENTATIONS OF ALL LINKS

This section presents the performance of each HVDC link. The categories used in the following presentations of each separate HVDC link are presented and defined in Chapter 4.

Note that the sums in the tables for each link may show a technical capacity E_{max} higher than the E_{max} stated in the diagram. This is due to power flow over the rated technical power capacity of the links. Other times, when power flow is under the rated technical capacity (and there is no limitation reported), the difference is registered in the category 'technical capacity not used'.

6.3.1 BALTIC CABLE

Figure 6.3.1 presents the availability and utilisation of Baltic Cable for 2016. Baltic Cable is connected between southern Sweden (bidding zone SE4) and Germany (bidding zone DE-TenneT). The operations started in 1994 and the transmission capacity is 600 MW.

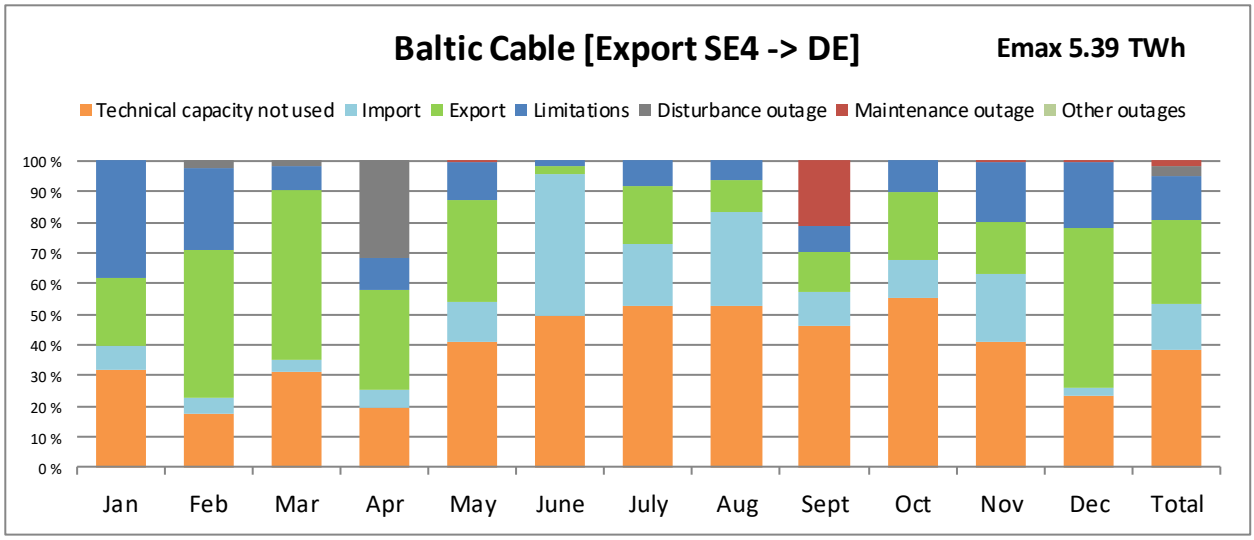

FIGURE 6.3.1 PERCENTAGE DISTRIBUTION OF THE AVAILABILITY AND UTILISATION CATEGORIES DEFINED IN CHAPTER 4 ACCORDING TO MONTH FOR THE BALTIC CABLE IN 2016

In 2016, Baltic Cable had an available technical capacity of 80.9 %. The technical capacity not used was 38.6 %. Totally, 1.5 TWh (27.5 % of the technical capacity) was exported from Sweden to Germany and 800 GWh (14.8 % of the technical capacity) was imported to Sweden. Table 6.3.1 presents the numerical values behind Figure 6.3.1.

The annual maintenance lasted 4 days in September and there were two disturbances on Baltic Cable of which the most severe originated from the DC electrode cable in April.

TABLE 6.3.1 MONTHLY DISTRIBUTION OF THE TECHNICAL CAPACITY E_{MAX} FOR THE BALTIC CABLE IN 2016

Baltic Cable [Export SE4 -> DE]	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	% (of Emax)
Import losses [MWh]	726	485	377	574	1201	4605	2034	3109	1221	1306	2197	234	0.3
Export losses [MWh]	4901	5490	7045	4477	4630	2146	4082	3303	3768	4205	3074	6210	1.0
Technical capacity not used [MWh]	145205	74906	142236	86780	188150	219442	241963	241965	203126	253876	182529	105968	38.6
Import [MWh]	34569	22074	17220	24353	57220	202862	90405	138776	49323	55284	96068	12231	14.8
Export [MWh]	101359	205801	252520	144448	154675	11974	88721	46781	58619	103435	76258	239644	27.5
Limitations [MWh]	176427	115990	37752	47475	54489	8522	36471	30038	37095	45580	86151	99130	14.3
Disturbance outage [MWh]	0	9269	7217	139744	0	0	0	0	0	0	0	0	2.9
Maintenance outage [MWh]	0	0	0	0	3025	0	0	0	94637	0	1794	586	1.9
Other outages [MWh]	0	0	0	0	0	0	0	0	0	0	0	0	0.0
P_r (600 MW)	457560	428040	456945	442800	457560	442800	457560	457560	442800	458175	442800	457560	100.0

6.3.2 ESTLINK 1

Figure 6.3.2 presents the availability and utilisation of Estlink 1 for 2016. Estlink 1 has been in operation since 2006 and is the first HVDC connection between Finland and Estonia. In Finland (bidding zone FI), it is connected to Espoo substation and in Estonia (bidding zone EE) it is connected to Harku substation. The transmission capacity is 350 MW.

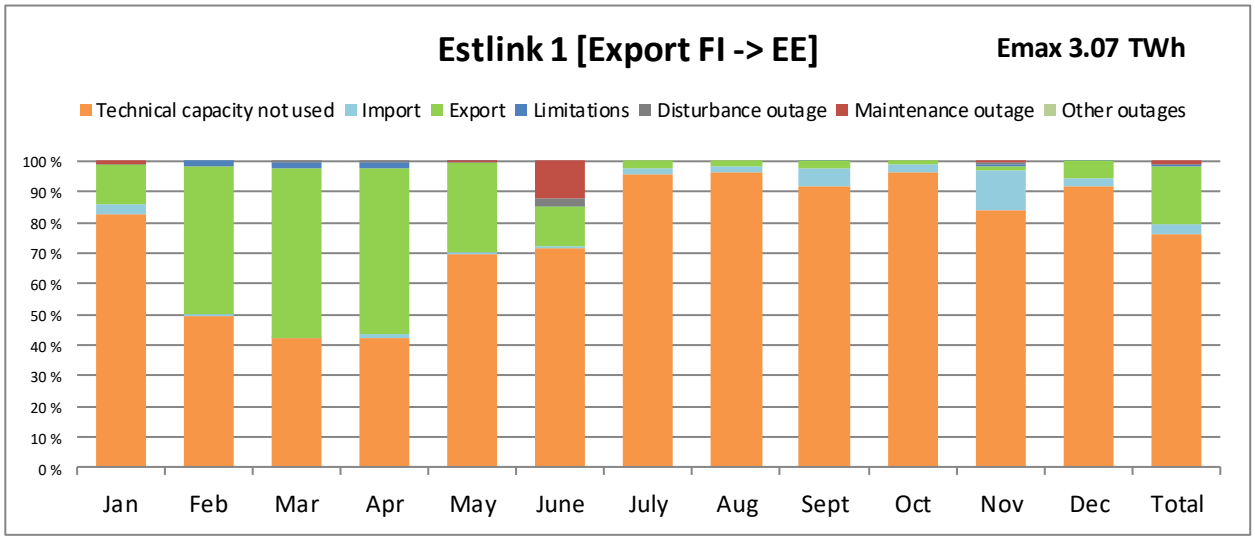

FIGURE 6.3.2 PERCENTAGE DISTRIBUTION OF THE AVAILABILITY AND UTILISATION CATEGORIES DEFINED IN CHAPTER 4 ACCORDING TO MONTH FOR ESTLINK 1 IN 2016

In 2016, Estlink 1 had an available technical capacity of 98 %. The technical capacity not used was 76 %. Totally, 577 GWh (18.8 % of the technical capacity) was exported from Finland to Estonia and 91 GWh (3.0 % of the technical capacity) was imported to Finland. Table 6.3.2 presents the numerical values behind Figure 6.3.2.

The annual maintenance outage lasted three days in June and there were seven minor disturbances on Estlink 1.

TABLE 6.3.2 MONTHLY DISTRIBUTION OF THE TECHNICAL CAPACITY E_{MAX} FOR ESTLINK 1 IN 2016

Estlink 1 [Export FI -> EE]	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	% (of E_{max})
Import losses [MWh]	658	373	324	291	527	563	782	814	919	868	1328	808	0.3
Export losses [MWh]	1236	3032	3681	3594	2107	1182	737	694	664	651	499	896	0.6
Technical capacity not used [MWh]	215828	120227	109589	105656	181054	179584	248756	250702	232008	251299	211297	239226	76.3
Import [MWh]	7578	1240	587	4046	2066	2119	6253	5911	14002	6361	33754	7169	3.0
Export [MWh]	33448	118405	144193	136890	75841	33280	5392	3787	5894	3090	2581	13751	18.8
Limitations [MWh]	243	3727	5265	5075	1107	508	0	0	95	0	2125	254	0.6
Disturbance outage [MWh]	0	0	416	332	0	5726	0	0	0	0	598	0	0.2
Maintenance outage [MWh]	3302	0	0	0	332	30783	0	0	0	0	1704	0	1.2
Other outages [MWh]	0	0	0	0	0	0	0	0	0	0	0	0	0.0
P_r (350 MW)	260400	243600	260050	252000	260400	252000	260400	260400	252000	260750	252058	260400	100.0

6.3.3 ESTLINK 2

Figure 6.3.3 presents the availability and utilisation of Estlink 2 for 2016. Estlink 2 was commissioned in Feb 2014 and is the second HVDC connection between Finland and Estonia. In Finland (bidding zone FI), it is connected to Anttila substation and in Estonia (bidding zone EE) it is connected to Püssi substation. The transmission capacity is 650 MW.

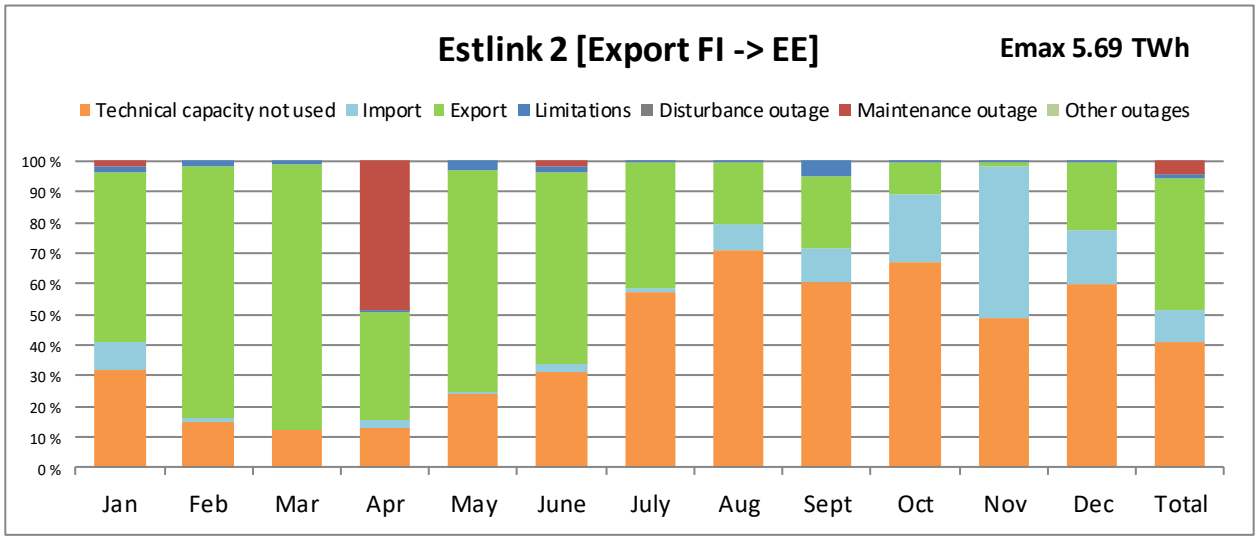

FIGURE 6.3.3 PERCENTAGE DISTRIBUTION OF THE AVAILABILITY AND UTILISATION CATEGORIES DEFINED IN CHAPTER 4 ACCORDING TO MONTH FOR ESTLINK 2 IN 2016

In 2016, Estlink 2 had an available technical capacity of 94 %. The technical capacity not used was 41.0 %. Totally, 2.4 TWh (42.8 % of the technical capacity) was exported from Finland to Estonia and 605 GWh (10.6 % of the technical capacity) was imported to Finland. Table 6.3.3 presents the numerical values behind Figure 6.3.3.

The annual maintenance lasted two weeks in April and there was only one disturbance on Estlink 2.

TABLE 6.3.3 MONTHLY DISTRIBUTION OF THE TECHNICAL CAPACITY E_{MAX} FOR ESTLINK 2 IN 2016

Estlink 2 [Export FI -> EE]	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	% (of E_{max})
Import losses [MWh]	423	41	2	100	28	107	84	447	482	982	2214	784	0.1
Export losses [MWh]	2635	3957	4453	1726	3624	2966	1811	944	1065	484	85	1050	0.4
Technical capacity not used [MWh]	152293	67917	58131	59877	115936	145293	276980	343344	283439	324356	227845	288641	41.0
Import [MWh]	46559	4492	2	11496	2600	11712	6939	41926	52861	107171	233017	86652	10.6
Export [MWh]	267490	373514	418681	166295	351958	294719	199049	97716	107464	52267	6556	107580	42.8
Limitations [MWh]	8960	6612	6294	2845	13156	8889	638	681	24288	539	1377	788	1.3
Disturbance outage [MWh]	0	0	0	711	0	0	0	0	0	0	0	0	0.0
Maintenance outage [MWh]	8320	0	0	226822	0	7401	0	0	0	0	0	0	4.2
Other outages [MWh]	0	0	0	0	0	0	0	0	0	0	0	0	0.0
P_r (650 MW)	483621	452535	483107	468046	483650	468013	483605	483667	468052	484334	468795	483661	100.0

6.3.4 FENNO-SKAN 1

Figure 6.3.4 presents the availability and utilisation of Fenno-Skan 1 for 2016. Fenno-Skan 1 has been in operation since 1989 and is the first HVDC connection between Finland and Sweden. In Finland (bidding zone FI), Fenno-Skan 1 is connected to Rauma and in Sweden to Dannebo (bidding zone SE3). The transmission capacity used to be 500 MW during summer and 550 MW during winter but was permanently decreased to 400 MW in 1.7.2014 after detailed investigations were completed. The investigations were started after a cable issue in 12.2.2013.

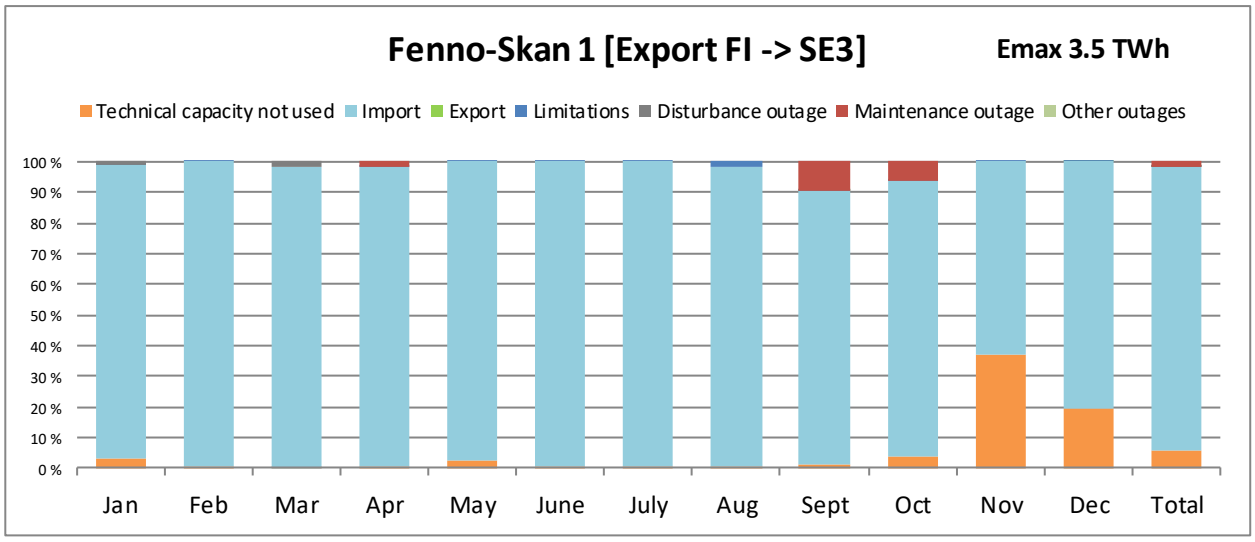

FIGURE 6.3.4 PERCENTAGE DISTRIBUTION OF THE AVAILABILITY AND UTILISATION CATEGORIES DEFINED IN CHAPTER 4 ACCORDING TO MONTH FOR FENNO-SKAN 1 IN 2016

In 2016, Fenno-Skan 1 had an available technical capacity of 98 %. The technical capacity not used was 5.8 %. Totally, 3 MWh (0.0 % of the technical capacity) was exported from Finland to Sweden and 3.3 TWh (92.4 % of the technical capacity) was imported to Finland. Table 6.3.4 presents the numerical values behind Figure 6.3.4.

The annual maintenance was between 28.9–2.10 and there were four minor disturbances on Fenno-Skan 1.

TABLE 6.3.4 MONTHLY DISTRIBUTION OF THE TECHNICAL CAPACITY E_{MAX} FOR FENNO-SKAN 1 IN 2016

Fenno-Skan 1 [Export FI -> SE3]	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	% (of E_{max})
Import losses [MWh]	7210	6878	7259	7183	7458	7802	7902	7785	6728	7798	4776	6447	2.4
Export losses [MWh]	0	0	0	0	0	0	0	0	1	0	0	2	0.0
Technical capacity not used [MWh]	10010	1429	181	1616	6540	1424	594	1700	2678	11639	106334	58259	5.8
Import [MWh]	284445	277432	292168	282745	291513	286997	297345	291684	257787	268025	181553	239809	92.4
Export [MWh]	0	0	0	0	0	0	0	0	1	0	0	2	0.0
Limitations [MWh]	125	24	0	42	102	48	119	4395	1	628	237	94	0.2
Disturbance outage [MWh]	3453	0	5602	0	0	0	0	0	0	0	0	0	0.3
Maintenance outage [MWh]	0	0	0	4095	0	0	0	0	27999	18031	0	0	1.4
Other outages [MWh]	0	0	0	0	0	0	0	0	0	0	0	0	0.0
P_r (400 MW)	298033	278885	297952	288498	298155	288468	298057	297779	288466	298323	288124	298164	100.0

6.3.5 FENNO-SKAN 2

Figure 6.3.5 presents the availability and utilisation of Fenno-Skan 2 for 2016. Fenno-Skan 2 has been in operation since 2011 and is the second HVDC connection between Finland and Sweden. In Finland (bidding zone FI) Fenno-Skan 2 is connected to Rauma and in Sweden to Finnböle (bidding zone SE3). The transmission capacity is 800 MW.

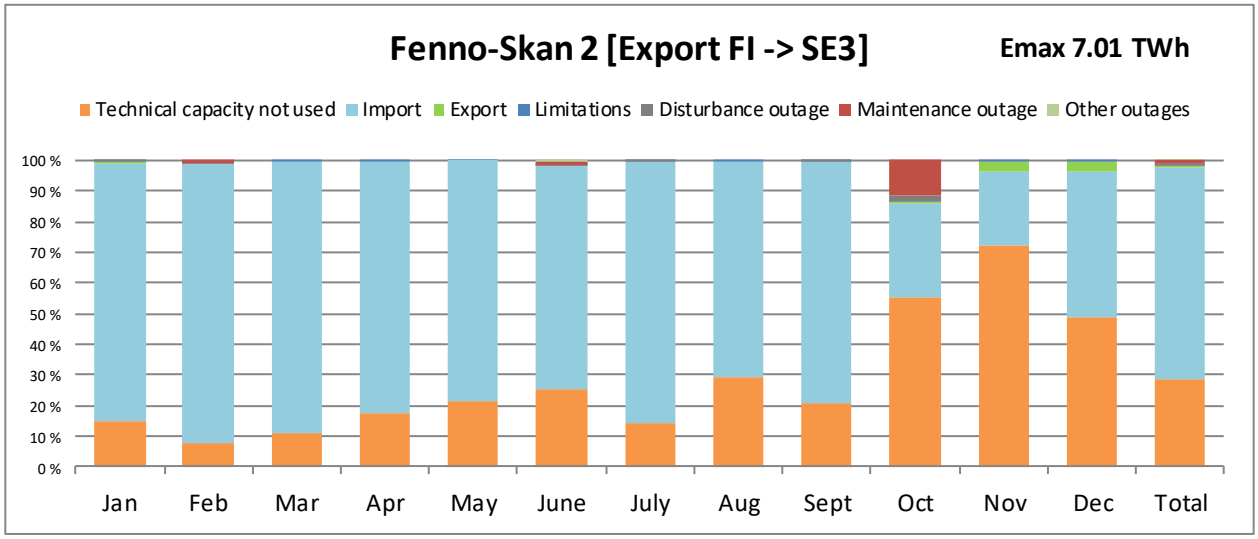

FIGURE 6.3.5 PERCENTAGE DISTRIBUTION OF THE AVAILABILITY AND UTILISATION CATEGORIES DEFINED IN CHAPTER 4 ACCORDING TO MONTH FOR FENNO-SKAN 2 IN 2016

In 2016, Fenno-Skan 2 had an available technical capacity of 98 %. The technical capacity not used was 28 %. Totally, 48 GWh (0.7 % of the technical capacity) was exported from Finland to Sweden and 4.9 TWh (69.2 % of the technical capacity) was imported to Finland. Table 6.3.5 presents the numerical values behind Figure 6.3.5.

The annual maintenance was in the beginning of October and there were five disturbances on Fenno-Skan 2.

TABLE 6.3.5 MONTHLY DISTRIBUTION OF THE TECHNICAL CAPACITY E_{MAX} FOR FENNO-SKAN 2 IN 2016

Fenno-Skan 2 [Export FI -> SE3]	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	% (of E_{max})
Import losses [MWh]	11110	11468	11720	10485	10629	8943	11493	9141	10381	3549	2797	6030	1.5
Export losses [MWh]	52	0	0	0	0	0	0	0	0	19	440	444	0.0
Technical capacity not used [MWh]	88894	43700	65980	100953	127877	144662	83889	175283	118307	330211	431840	301615	28.4
Import [MWh]	503434	506214	526926	474121	467046	420867	508234	417913	453968	184425	143543	292604	69.2
Export [MWh]	2529	0	0	0	0	0	0	0	0	1131	22068	22551	0.7
Limitations [MWh]	1261	579	1647	1153	530	1875	443	2185	656	535	670	1153	0.2
Disturbance outage [MWh]	1705	0	0	0	0	0	2817	0	3233	12111	0	0	0.3
Maintenance outage [MWh]	0	6394	0	0	0	8000	0	0	0	68800	0	0	1.2
Other outages [MWh]	0	0	0	0	0	724	0	0	0	0	0	0	0.0
P_r (800 MW)	597823	556887	594554	576226	595453	576128	595383	595381	576164	597212	598121	617922	100.0

6.3.6 KONTEK

Figure 6.3.6 presents the availability and utilisation of Kontek for 2016. Kontek has been in operation since 1986. In Denmark it is connected to Bjaeverskov (bidding zone DK2) and in Germany to Bentwisch (bidding zone DE-TenneT). The transmission capacity is 600 MW.

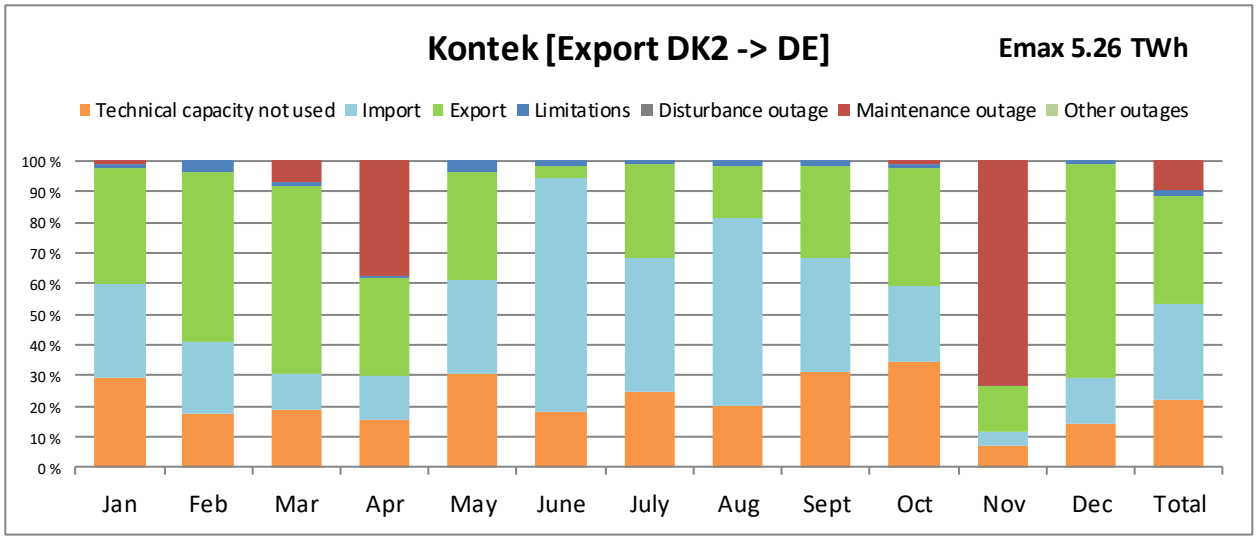

FIGURE 6.3.6 PERCENTAGE DISTRIBUTION OF THE AVAILABILITY AND UTILISATION CATEGORIES DEFINED IN CHAPTER 4 ACCORDING TO MONTH FOR KONTEK IN 2016

In 2016, Kontek had an available technical capacity of 87 %. The technical capacity not used was 21.8 %. Totally, 1.9 TWh (35.6 % of the technical capacity) was exported from Denmark to Germany and 1.6 TWh (31.2 % of the technical capacity) was imported to Denmark. Table 6.3.6 presents the numerical values behind Figure 6.3.6.

The annual maintenance lasted ten days in April and there was an additional maintenance outage in November due to an upgrade to the control system. Kontek suffered only one minor disturbance during 2016.

TABLE 6.3.6 MONTHLY DISTRIBUTION OF THE TECHNICAL CAPACITY E_{MAX} FOR KONTEK IN 2016

Kontek [Export DK2 -> DE]	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	% (of E_{max})
Import losses [MWh]	2903	2135	1067	1310	2821	7075	4156	5840	3329	2301	448	1388	0.7
Export losses [MWh]	3270	4484	5392	2772	3106	335	2756	1500	2600	3433	1256	6229	0.7
Technical capacity not used [MWh]	131563	71686	84485	66241	136815	77895	108498	90458	135467	152969	29126	63763	21.8
Import [MWh]	135652	98098	50150	62389	136537	329270	196988	273639	160075	112829	22130	67585	31.2
Export [MWh]	169724	231302	275344	139095	157554	17710	135145	74650	129836	171957	62522	309646	35.6
Limitations [MWh]	4028	16515	3829	3000	15494	7124	5769	7654	6622	4187	1671	5407	1.5
Disturbance outage [MWh]	1102	0	0	0	0	0	0	0	0	0	0	0	0.0
Maintenance outage [MWh]	4331	0	31992	161276	0	0	0	0	0	5059	316551	0	9.9
Other outages [MWh]	0	0	0	0	0	0	0	0	0	0	0	0	0.0
P_r (600 MW)	446400	417600	445800	432000	446400	432000	446400	446400	432000	447000	432000	446400	100.0

6.3.7 KONTI-SKAN 1

Figure 6.3.7 presents the availability and utilisation of Konti-Skan 1 for 2016. In south-western Sweden it is connected to Lindome (bidding zone SE3) and in Denmark to Vester Hassing (bidding zone DK1). It has been in operation since 1965. Today the transmission capacity is 370 MW and the upgraded converter stations were commissioned in 2008.

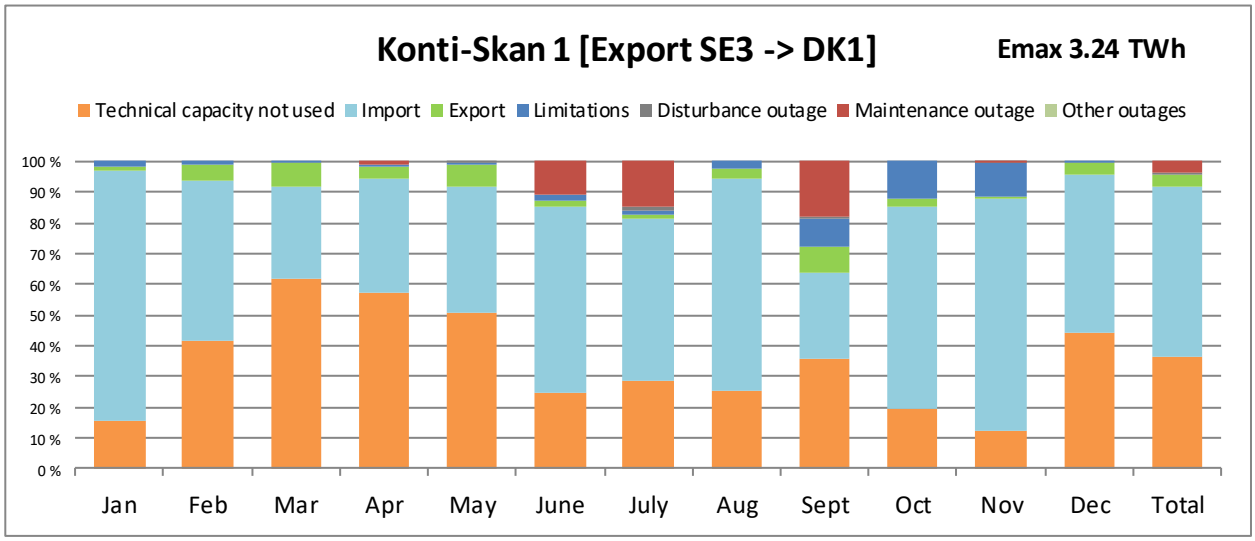

FIGURE 6.3.7 PERCENTAGE DISTRIBUTION OF THE AVAILABILITY AND UTILISATION CATEGORIES DEFINED IN CHAPTER 4 ACCORDING TO MONTH FOR KONTI-SKAN 1 IN 2016

In 2016, Konti-Skan 1 had an available technical capacity of 92 % and the technical capacity not used was 35.0 %. Totally, 0.1 TWh (3.9 % of the technical capacity) was exported from Sweden to Denmark and 1.8 TWh (53.4 % of the technical capacity) was imported to Sweden. The available technical capacity of the link was 25 percentage points higher in comparison with 2015. Table 6.3.7 presents the numerical values behind Figure 6.3.7.

The annual maintenance lasted six days in September and there was also one longer maintenance in Vester Hassing in Juny–July due to replacement of gaskets in valve hall water cooling system. Konti-Skan 1 suffered four minor disturbances during 2016.

TABLE 6.3.7 MONTHLY DISTRIBUTION OF THE TECHNICAL CAPACITY E_{MAX} FOR KONTI-SKAN 1 IN 2016

Konti-Skan 1 [Export SE3 -> DK1]	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	% (of E_{max})
Import losses [MWh]	58	223	381	191	324	104	70	167	454	90	35	186	0.1
Export losses [MWh]	6345	3713	2258	2608	3154	4630	4014	5580	2269	5076	5640	3806	1.5
Technical capacity not used [MWh]	42993	112537	183376	159486	150129	66224	80284	72412	103288	55613	32958	126153	35.0
Import [MWh]	227810	141908	89412	101711	121182	165594	147427	195644	81935	185447	202712	147054	53.4
Export [MWh]	3662	13327	23092	11136	20280	5999	3840	9432	23551	6445	1878	10279	3.9
Limitations [MWh]	4749	3111	2122	1463	2957	4322	3169	7224	27245	34590	28948	2074	3.6
Disturbance outage [MWh]	0	0	0	0	1012	0	4037	0	1366	0	1368	0	0.2
Maintenance outage [MWh]	0	0	0	3740	0	30260	40393	0	52566	0	414	0	3.8
Other outages [MWh]	0	0	0	0	0	0	0	0	0	0	0	0	0.0
P_r (370 MW)	279214	270884	298002	277536	295560	272399	279150	284712	289951	282095	268278	285559	100.0

6.3.8 KONTI-SKAN 2

Figure 6.3.8 presents the availability and utilisation of Konti-Skan 2 for 2016. Konti-Skan 2 is connected between Sweden and Denmark in parallel to Konti-Skan 1. It has a transmission capacity of 370 MW and has been in operation since 1988.

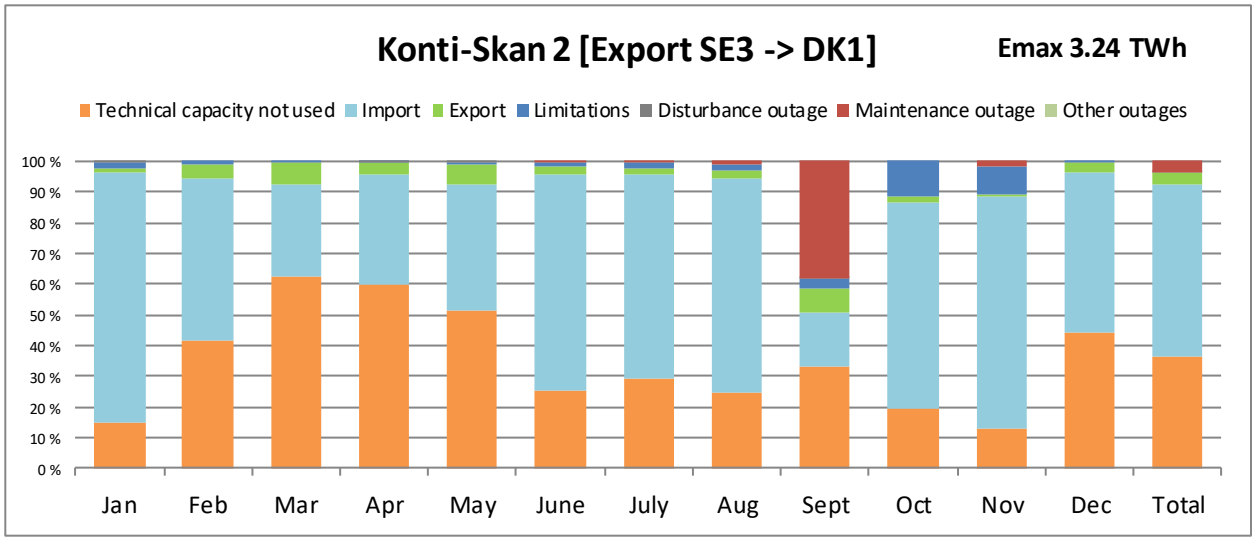

FIGURE 6.3.8 PERCENTAGE DISTRIBUTION OF THE AVAILABILITY AND UTILISATION CATEGORIES DEFINED IN CHAPTER 4 ACCORDING TO MONTH FOR KONTI-SKAN 2 IN 2016

In 2016, Konti-Skan 2 had an available technical capacity of 93 % and the technical capacity not used was 35.1 %. Totally, 0.1 TWh (3.7 % of the technical capacity) was exported from Sweden to Denmark and 1.8 TWh (54.7 % of the technical capacity) was imported to Sweden. The available technical capacity of the link was 3 percentage points lower in comparison with 2015. The annual maintenance lasted thirteen days in September. Konti-Skan 2 suffered four minor disturbances during 2016.

Table 6.3.8 presents the numerical values behind Figure 6.3.8.

The annual maintenance lasted thirteen days in September. Konti-Skan 2 suffered four minor disturbances during 2016.

TABLE 6.3.8 MONTHLY DISTRIBUTION OF THE TECHNICAL CAPACITY E_{MAX} FOR KONTI-SKAN 2 IN 2016

Konti-Skan 2 [Export SE3 -> DK1]	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	% (of E_{max})
Import losses [MWh]	85	296	504	223	446	134	129	223	568	117	35	241	0.1
Export losses [MWh]	6005	3562	2106	2373	3022	5538	5301	5446	1326	4927	5301	3590	1.4
Technical capacity not used [MWh]	42268	112863	184089	164489	150741	68346	82546	70703	94398	55483	33825	125959	35.1
Import [MWh]	226297	142306	89302	100369	121672	193085	186023	197311	52092	188390	203172	148399	54.7
Export [MWh]	3690	12528	21347	9547	18832	5672	4791	8974	21657	5895	1474	9854	3.7
Limitations [MWh]	5073	2453	1595	864	2031	3357	5809	4115	9445	32281	25856	1077	2.8
Disturbance outage [MWh]	1916	0	0	754	1020	0	0	0	674	0	0	0	0.1
Maintenance outage [MWh]	0	0	0	0	0	2010	1099	3764	109820	0	4080	0	3.6
Other outages [MWh]	0	0	0	0	0	0	0	0	0	0	0	0	0.0
P_r (370 MW)	279244	270149	296332	276022	294295	272470	280268	284867	288086	282050	268407	285289	100.0

6.3.9 LITPOL LINK

Figure 6.3.9 presents the availability and utilisation of LitPol Link for 2016. LitPol Link has been in operation since the end of 2015 even if though it went through trail operation up until 1 February 2016. In Lithuania, it is connected to Alytus (bidding zone LT) and in Poland to Ełk (bidding zone PL). The transmission capacity is 500 MW.

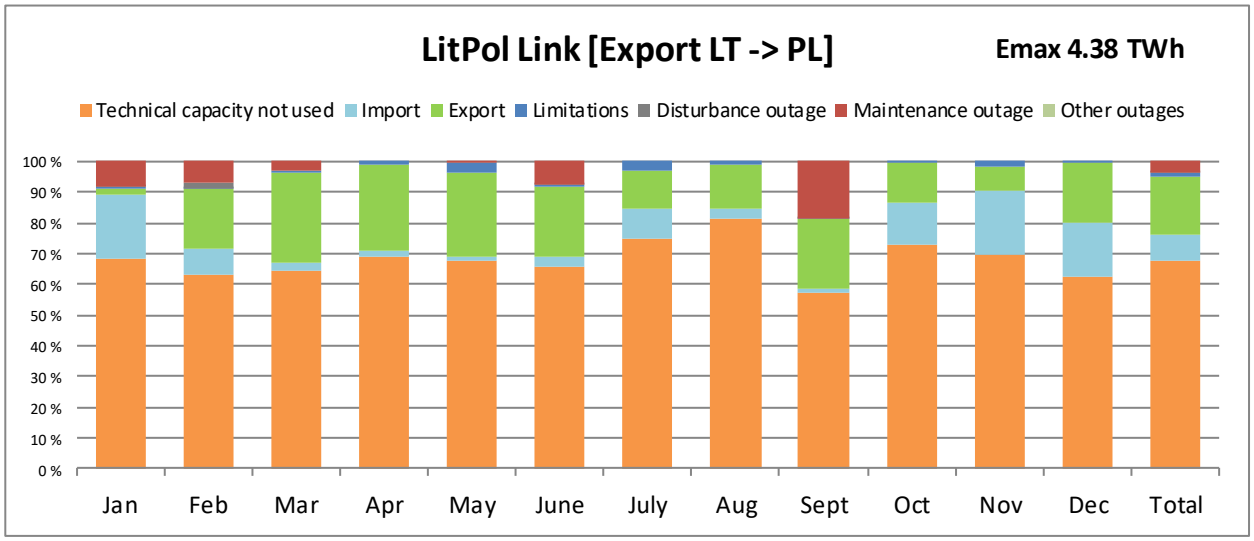

FIGURE 6.3.9 PERCENTAGE DISTRIBUTION OF THE AVAILABILITY AND UTILISATION CATEGORIES DEFINED IN CHAPTER 4 ACCORDING TO MONTH FOR LITPOL LINK IN 2016

In 2016, LitPol Link had had an available technical capacity of 95 %. The technical capacity not used was 67.9 %. Totally, 1.0 TWh (19.0 % of the technical capacity) was exported from Lithuania to Poland and 0.4 TWh (8.1 % of the technical capacity) was imported to Lithuania.

LitPol link had five maintenance outages to remove minor defects in equipment and to install insulation. There were five disturbance outages on LitPol Link with minor significance.

Table 6.3.9 presents the numerical values behind Figure 6.3.9.

TABLE 6.3.9 MONTHLY DISTRIBUTION OF THE TECHNICAL CAPACITY E_{MAX} FOR LITPOL LINK IN 2016

LitPol Link [Export LT -> PL]	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	% (of E_{max})
Import losses [MWh]	3131	1104	457	390	294	533	1330	632	259	1670	2130	2079	0.3
Export losses [MWh]	269	1789	3199	3009	2904	2348	1222	1374	2340	1347	746	1995	0.4
Technical capacity not used [MWh]	257503	271034	339702	345988	346264	307278	318516	353879	266301	313585	273231	289906	67.9
Import [MWh]	80882	37491	12372	9985	6452	14179	41190	13621	5339	57415	80640	80501	8.1
Export [MWh]	6582	81712	153741	140634	137894	107744	54224	63115	106450	57520	30899	92704	19.0
Limitations [MWh]	2015	626	2851	4027	16002	2000	12294	4500	2663	1500	6129	1593	1.0
Disturbance outage [MWh]	114	9902	0	0	0	544	0	0	0	0	0	0	0.2
Maintenance outage [MWh]	31486	28947	16574	0	3282	36000	0	0	85697	0	0	0	3.7
Other outages [MWh]	0	0	0	0	0	0	0	0	0	0	0	0	0.0
P_r (500 MW)	378582	429712	525241	500634	509894	467744	426224	435115	466450	430020	390899	464704	100.0

6.3.10 NORDBALT

Figure 6.3.10 presents the availability and utilisation of NordBalt for 2016. NordBalt has been in operation since 2016. However, it still underwent system tests until 16 February and trail operation until 22 June. In Sweden, it is connected to Nybro (bidding zone SE4) and in Lithuania to Klaipeda (bidding zone LT). The transmission capacity is 700 MW.

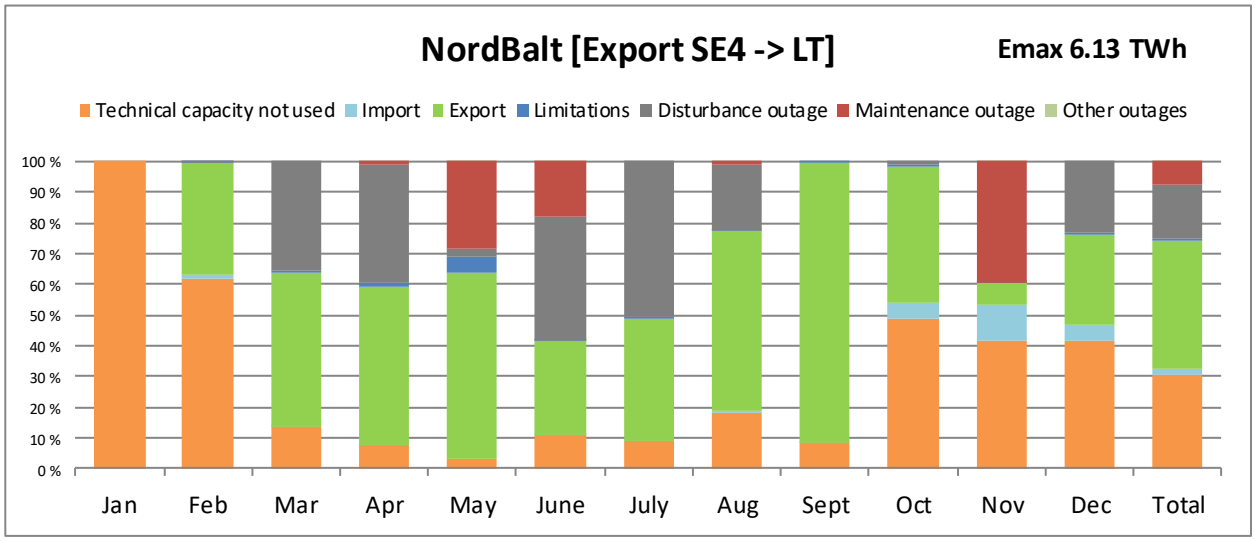

FIGURE 6.3.10 PERCENTAGE DISTRIBUTION OF THE AVAILABILITY AND UTILISATION CATEGORIES DEFINED IN CHAPTER 4 ACCORDING TO MONTH FOR NORDBALT IN 2016

In 2016, NordBalt had had an available technical capacity of 74 %. The technical capacity not used was 30.4 %. Totally, 2.6 TWh (41.6 % of the technical capacity) was exported from Sweden to Lithuania and 0.1 TWh (2.0 % of the technical capacity) was imported to Sweden. Table 6.3.10 presents the numerical values behind Figure 6.3.10.

The annual maintenance lasted ten days in November and there were 16 disturbances on NordBalt, of which one was severe. It was caused by two capacitors exploding in July.

TABLE 6.3.10 MONTHLY DISTRIBUTION OF THE TECHNICAL CAPACITY E_{MAX} FOR NORDBALT IN 2016

NordBalt [Export SE4 -> LT]	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	% (of E_{max})
Import losses [MWh]	0	169	42	18	0	43	23	62	2	1128	2212	1024	0.1
Export losses [MWh]	0	7765	11555	11571	13956	6495	9356	13286	20907	9771	1222	6130	1.8
Technical capacity not used [MWh]	520800	302453	70637	39781	15847	55266	47669	95431	43331	254295	207931	216139	30.4
Import [MWh]	0	4829	139	113	0	261	125	595	12	28198	59865	27839	2.0
Export [MWh]	0	177046	259281	257917	317029	154099	207278	306455	456954	231306	35709	153876	41.6
Limitations [MWh]	0	776	3248	8286	26418	1209	1755	2156	3705	2055	1233	1683	0.9
Disturbance outage [MWh]	0	2097	186798	190980	13130	200749	263982	110600	0	5647	1558	121262	17.8
Maintenance outage [MWh]	0	0	0	6937	148378	92493	0	5565	0	0	197705	0	7.3
Other outages [MWh]	0	0	0	0	0	0	0	0	0	0	0	0	0.0
P_t (700 MW)	520800	487200	520102	504013	520802	504077	520809	520801	504001	521501	504001	520800	100.0

6.3.11 NorNed

Figure 6.3.11 presents the availability and utilisation of NorNed for 2016. NorNed has been in operation since 2008, and is, with a length of 580 km, the longest HVDC link connected to the Nordic power system. In Norway on the south-western coast (bidding zone NO2) it is connected to Feda substation and in Netherlands to Eems-haven (bidding zone APX NL). The transmission capacity is 700 MW.

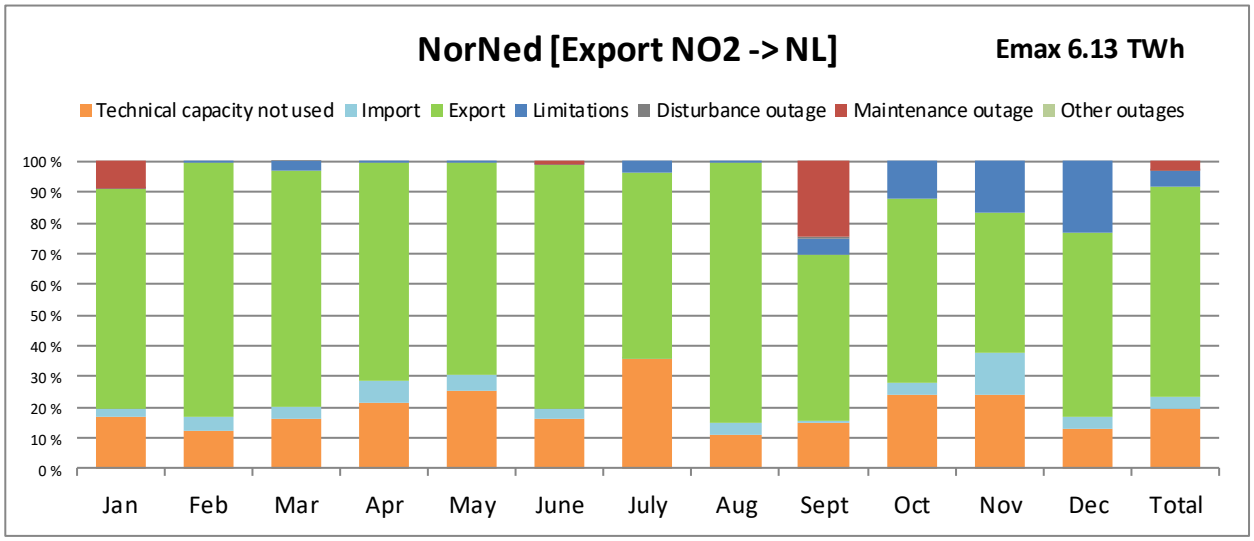

Figure 6.3.11 Percentage distribution of the availability and utilisation categories defined in Chapter 4 according to month for NorNed in 2016

In 2016, NorNed had had an available technical capacity of 92 %. The technical capacity not used was 19.2 %. Totally, 4.2 TWh (68.1 % of the technical capacity) was exported from Norway to the Netherlands and 0.3 TWh (4.4 % of the technical capacity) was imported to Norway.

Table 6.3.11 presents the numerical values behind Figure 6.3.11.

The annual maintenance lasted seven days in September and there were two minor disturbances on NorNed.

Table 6.3.11 Monthly distribution of the technical capacity E_{MAX} for NorNed in 2016

NorNed [Export NO2 -> NL]	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	% (of E_{max})
Import losses [MWh]	527	790	714	1429	1115	558	61	693	168	827	2560	718	0.2
Export losses [MWh]	14486	15743	15081	13749	13744	15542	9699	17508	10148	10621	6919	9433	2.5
Technical capacity not used [MWh]	88604	58540	85149	106873	130431	81063	185239	58567	73631	123854	122249	66502	19.2
Import [MWh]	12994	22405	18741	36565	28229	16013	1573	17384	4132	22882	68322	19632	4.4
Export [MWh]	373668	406381	401825	359175	361080	403059	313799	445832	273152	311953	230445	315061	68.1
Limitations [MWh]	1549	1123	14859	2396	1942	1129	20605	1004	26476	63310	82984	119606	5.5
Disturbance outage [MWh]	0	0	525	0	0	0	0	0	3616	0	0	0	0.1
Maintenance outage [MWh]	44888	0	0	0	0	4069	0	0	123761	0	0	0	2.8
Other outages [MWh]	0	0	0	0	0	0	0	0	0	0	0	0	0.0
P_r (700 MW)	521703	488449	521099	505009	521682	505334	521215	522787	504769	521999	504000	520800	100.0

6.3.12 SKAGERRAK 1

Figure 6.3.12 presents the availability and utilisation of Skagerrak 1 for 2016. Skagerrak 1 and Skagerrak 2 have been in operation since 1976 and are the oldest HVDC links in operation in the Nordic countries. In Norway, the links are connected to Kristiansand on the southern coast (bidding zone NO2) and in Denmark to Tjele (bidding zone DK1), approximately 15 km east of the town of Viborg in the northern part of Jutland. The transmission capacity is 236 MW at the receiving end.

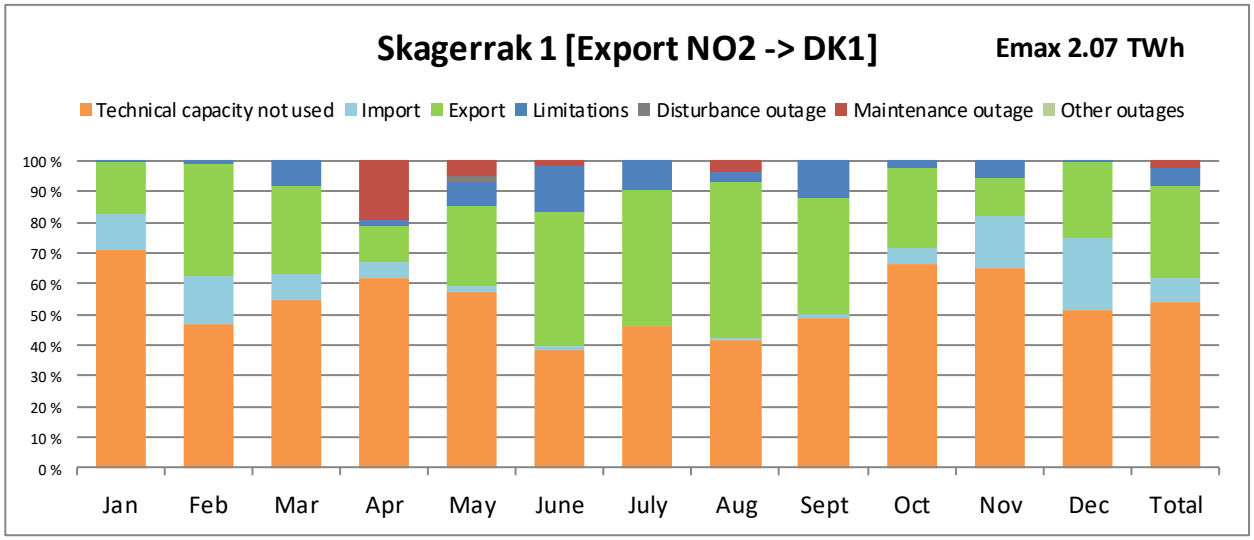

FIGURE 6.3.12 PERCENTAGE DISTRIBUTION OF THE AVAILABILITY AND UTILISATION CATEGORIES DEFINED IN CHAPTER 4 ACCORDING TO MONTH FOR SKAGERRAK 1 IN 2016

In 2016, Skagerrak 1 had an available technical capacity of 92 %. The technical capacity not used was 54.1 %. Totally, 0.6 TWh (29.9 % of the technical capacity) was exported from Norway to the Denmark and 0.2 TWh (7.6 % of the technical capacity) was imported to Norway. Table 6.3.12 presents the numerical values behind Figure 6.3.12.

The annual maintenance lasted five days in the end of April and there were two minor disturbances on Skagerrak 1. Furthermore, there were two additional maintenance outages in August to reconstruct the electrode lines.

TABLE 6.3.12 MONTHLY DISTRIBUTION OF THE TECHNICAL CAPACITY E_{MAX} FOR SKAGERRAK 1 IN 2016

Skagerrak 1 [Export NO2 -> DK1]	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	% (of E_{max})
Import losses [MWh]	1034	1342	790	456	154	99	17	63	126	511	1468	2228	0.4
Export losses [MWh]	1397	3091	2346	945	2007	3359	3456	4452	3155	2207	880	2218	1.4
Technical capacity not used [MWh]	124942	77018	95844	104878	100864	64763	80428	72999	82979	116291	110815	90389	54.1
Import [MWh]	20291	25171	14771	8881	3030	2230	410	1386	2594	9844	28250	41289	7.6
Export [MWh]	29684	60149	50070	20193	45447	74808	78148	88645	63305	45920	20978	43179	29.9
Limitations [MWh]	667	1963	14694	2810	13955	25286	16598	5681	21043	3877	9904	769	5.7
Disturbance outage [MWh]	0	0	0	826	3902	0	0	0	0	0	0	0	0.2
Maintenance outage [MWh]	0	0	0	32332	8386	2832	0	6874	0	0	0	0	2.4
Other outages [MWh]	0	0	0	0	0	0	0	0	0	0	0	0	0.0
P_r (250 MW)	175584	164301	175378	169920	175584	169920	175584	175584	169921	175933	169946	175625	100.0

6.3.13 SKAGERRAK 2

Figure 6.3.13 presents the availability and utilisation of Skagerrak 2 for 2016. Skagerrak 1 and Skagerrak 2 have been in operation since 1976 and are the oldest HVDC links in operation in the Nordic countries. In Norway, the links are connected to Kristiansand on the southern coast (bidding zone NO2) and in Denmark to Tjele (bidding zone DK1), approximately 15 km east of the town of Viborg in the northern part of Jutland. The transmission capacity is 236 MW at the receiving end.

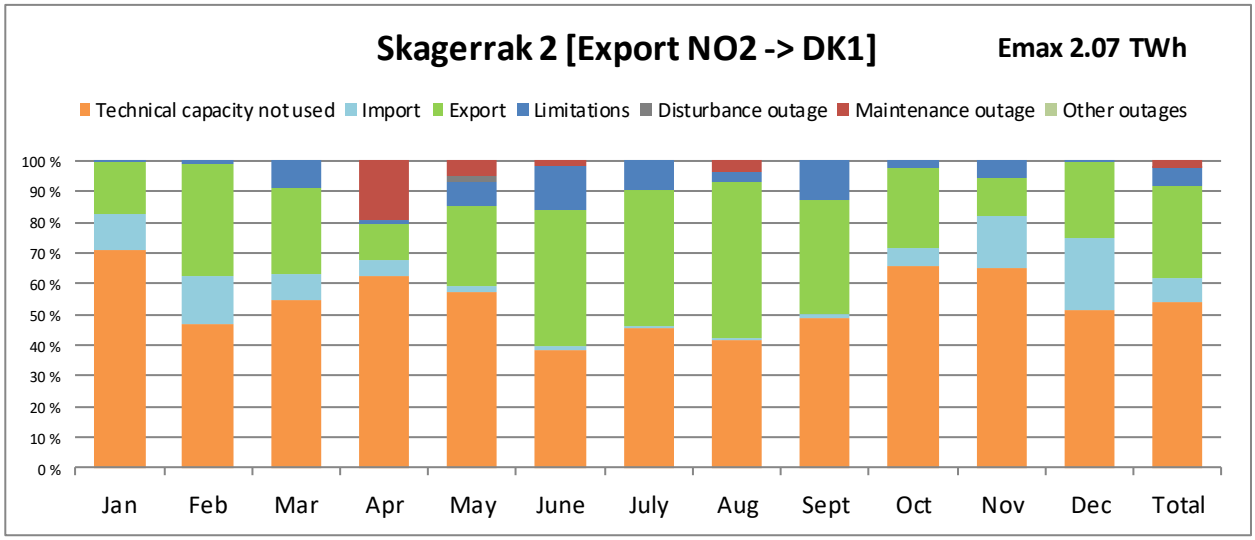

FIGURE 6.3.13 PERCENTAGE DISTRIBUTION OF THE AVAILABILITY AND UTILISATION CATEGORIES DEFINED IN CHAPTER 4 ACCORDING TO MONTH FOR SKAGERRAK 2 IN 2016

In 2016, Skagerrak 2 had an available technical capacity of 92 %. The technical capacity not used was 54.0 %. Totally, 0.6 TWh (30.0 % of the technical capacity) was exported from Norway to the Denmark and 0.1 TWh (7.7 % of the technical capacity) was imported to Norway. Table 6.3.13 presents the numerical values behind Figure 6.3.13.

The annual maintenance lasted five days in the end of April and there was one minor disturbance on Skagerrak 2. Furthermore, there were two additional maintenance outages in August to reconstruct the electrode lines.

TABLE 6.3.13 MONTHLY DISTRIBUTION OF THE TECHNICAL CAPACITY E_{MAX} FOR SKAGERRAK 2 IN 2016

Skagerrak 2 [Export NO2 -> DK1]	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	% (of E_{max})
Import losses [MWh]	1044	1354	795	459	156	100	17	66	128	518	1494	2245	0.4
Export losses [MWh]	1412	3093	2356	947	2011	3342	3439	4886	3151	2238	883	2226	1.4
Technical capacity not used [MWh]	124714	77002	95301	105605	100940	64975	80263	72829	82407	115576	110633	90387	54.0
Import [MWh]	20399	25268	14811	8936	3042	2240	415	1406	2619	9895	28399	41490	7.7
Export [MWh]	29866	60181	50173	20296	45322	74875	78412	89026	63317	46250	21158	43290	30.0
Limitations [MWh]	623	1894	15123	2751	13988	25002	16495	5449	21578	4227	9830	598	5.7
Disturbance outage [MWh]	0	0	0	0	3912	0	0	0	0	0	0	0	0.2
Maintenance outage [MWh]	0	0	0	32332	8380	2828	0	6874	0	0	0	0	2.4
Other outages [MWh]	0	0	0	0	0	0	0	0	0	0	0	0	0.0
P_r (236 MW)	175601	164345	175407	169921	175584	169920	175585	175584	169921	175948	170019	175765	100.0

6.3.14 SKAGERRAK 3

Figure 6.3.14 presents the availability and utilisation of Skagerrak 3 for 2016. Skagerrak 3 has been in operation since 1993. In Norway, it is connected to Kristiansand (bidding zone NO2) and in Denmark to Tjele (bidding zone DK1). The transmission capacity is 478 MW at the receiving end.

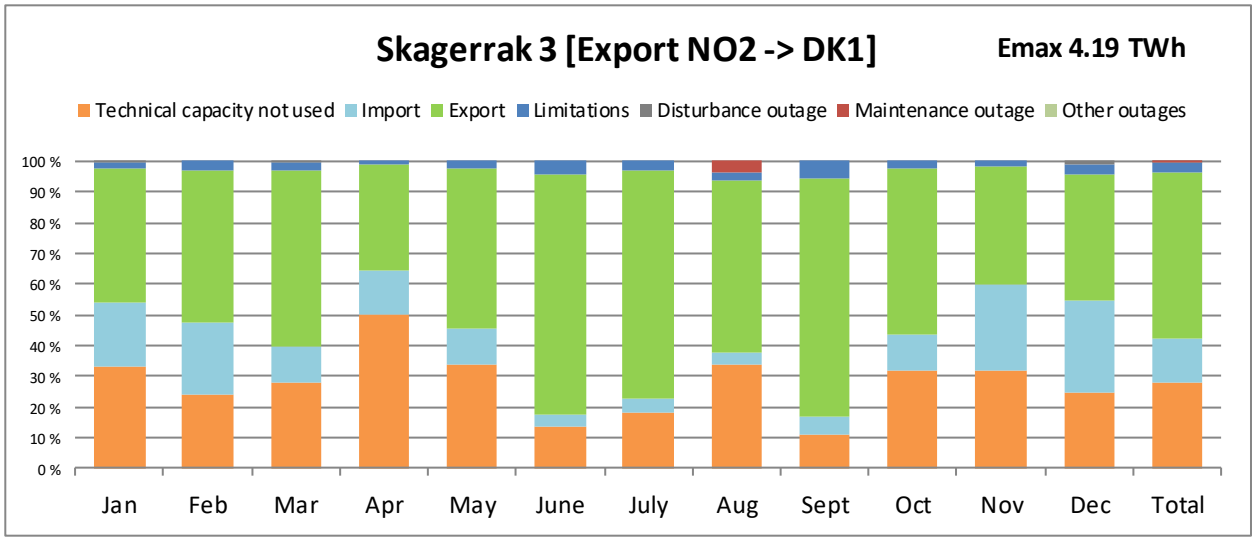

FIGURE 6.3.14 PERCENTAGE DISTRIBUTION OF THE AVAILABILITY AND UTILISATION CATEGORIES DEFINED IN CHAPTER 4 ACCORDING TO MONTH FOR SKAGERRAK 3 IN 2016

In 2016, Skagerrak 3 had an available technical capacity of 97 %. The technical capacity not used was 27.9 %. Totally, 2.3 TWh (54.5 % of the technical capacity) was exported from Norway to Denmark and 0.6 TWh (14.1 % of the technical capacity) was imported to Norway. Table 6.3.14 presents the numerical values behind Figure 6.3.14.

Skagerrak 3 had two maintenance outages in August to reconstruct the electrode lines and four minor disturbances in 2016.

TABLE 6.3.14 MONTHLY DISTRIBUTION OF THE TECHNICAL CAPACITY E_{MAX} FOR SKAGERRAK 3 IN 2016

Skagerrak 3 [Export NO2 -> DK1]	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	% (of E_{max})
Import losses [MWh]	2003	2118	1201	1359	1082	386	394	354	536	1097	2619	3085	0.4
Export losses [MWh]	3701	4067	5058	2834	4689	6939	6880	4763	6848	4794	3138	3603	1.4
Technical capacity not used [MWh]	118467	80783	98168	172567	121047	46828	64655	120750	38275	112816	108584	88167	27.9
Import [MWh]	73081	77636	42495	49546	41054	14030	15847	13046	20218	41569	98235	106496	14.1
Export [MWh]	155147	164339	204365	117291	184841	267612	263244	198453	265357	194076	130455	144516	54.5
Limitations [MWh]	7662	9952	9430	4770	8706	15734	11932	9471	20349	8063	6937	12578	3.0
Disturbance outage [MWh]	1291	0	717	0	0	0	0	0	0	0	0	3925	0.1
Maintenance outage [MWh]	0	0	0	0	0	0	0	13939	0	0	0	0	0.3
Other outages [MWh]	0	0	0	0	0	0	0	0	0	0	0	0	0.0
P_r (478 MW)	355647	332709	355176	344175	355648	344204	355680	355659	344198	356524	344210	355682	100.0

6.3.15 SKAGERRAK 4

Figure 6.3.15 presents the availability and utilisation of Skagerrak 4 for 2016. Skagerrak 4 has been in commercial operation since 29 December 2014. In Norway, it is connected to Kristiansand (bidding zone NO2) and in Denmark to Tjele (bidding zone DK1). The transmission capacity is 682 MW at the receiving end.

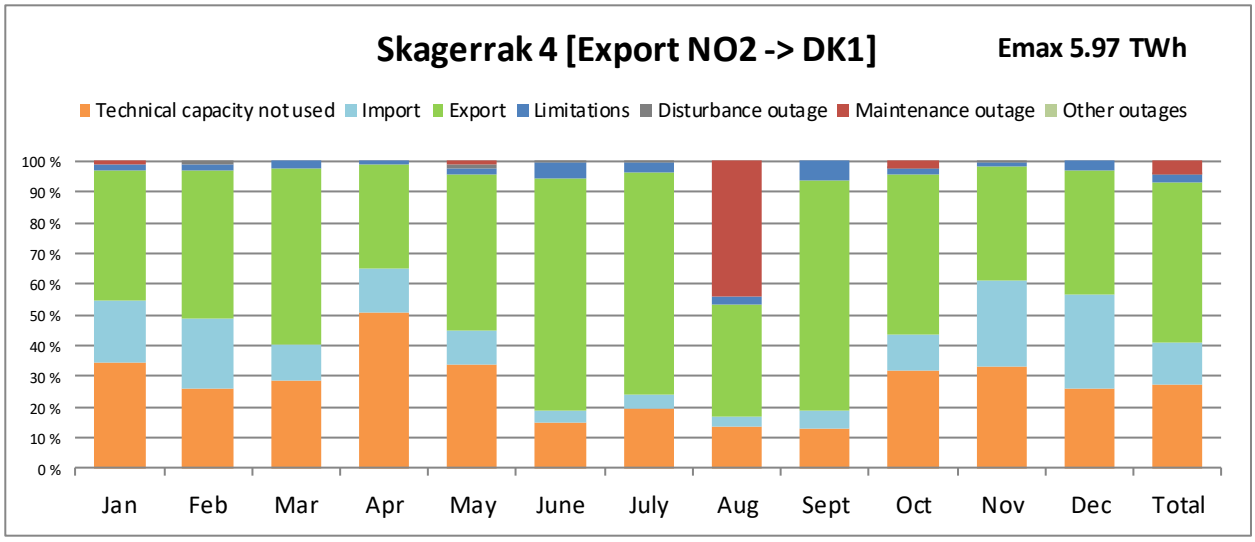

FIGURE 6.3.15 PERCENTAGE DISTRIBUTION OF THE AVAILABILITY AND UTILISATION CATEGORIES DEFINED IN CHAPTER 4 ACCORDING TO MONTH FOR SKAGERRAK 4 IN 2016

In 2016, Skagerrak 4 had an available technical capacity of 93 %. The technical capacity not used was 27.0 %. Totally, 3.1 TWh (51.7 % of the technical capacity) was exported from Norway to the Denmark and 0.8 TWh (14.0 % of the technical capacity) was imported to Norway. Table 6.3.15 presents the numerical values behind Figure 6.3.15.

Skagerrak 4 had one major maintenance outage in August to reconstruct the electrode lines and four other minor maintenance outages. There were also six minor disturbance outages.

TABLE 6.3.15 MONTHLY DISTRIBUTION OF THE TECHNICAL CAPACITY E_{MAX} FOR SKAGERRAK 4 IN 2016

Skagerrak 4 [Export NO2 -> DK1]	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	% (of E_{max})
Import losses [MWh]	2530	2639	1513	1902	1436	484	526	435	688	1442	3311	3850	0.3
Export losses [MWh]	3953	4296	5416	3094	4851	7077	7003	3432	6961	4971	3385	3835	1.0
Technical capacity not used [MWh]	173433	121986	145659	249125	170897	72579	98788	67870	62479	162212	163324	130869	27.0
Import [MWh]	102922	108667	59917	71122	57664	19845	22421	17533	28355	58517	135800	156874	14.0
Export [MWh]	215753	228993	288369	164678	255431	372481	365903	186507	370140	265389	182014	203814	51.7
Limitations [MWh]	9379	11070	12787	6115	11770	23392	19081	12702	30067	9673	8225	15851	2.8
Disturbance outage [MWh]	0	3955	0	0	6863	2743	1215	0	0	1194	1678	0	0.3
Maintenance outage [MWh]	5921	0	0	0	4782	0	0	222796	0	11601	0	0	4.1
Other outages [MWh]	0	0	0	0	0	0	0	0	0	0	0	0	0.0
P_r (682 MW)	507408	474672	506732	491040	507408	491040	507408	507408	491040	508586	491040	507408	100.0

6.3.16 STOREBAELT

Figure 6.3.16 presents the availability and utilisation of Storebaelt for 2016. Storebaelt has been in operation since 2010. It connects the western part of the Danish system, which belongs to the Continental European synchronous system (Jutland and the island of Fynen), with the eastern part, belonging to the Nordic synchronous system (Zealand). The link is connected to Fraugde on Fynen (bidding zone DK1) and to Herslev on Zealand (bidding zone DK2). The transmission capacity is 600 MW.

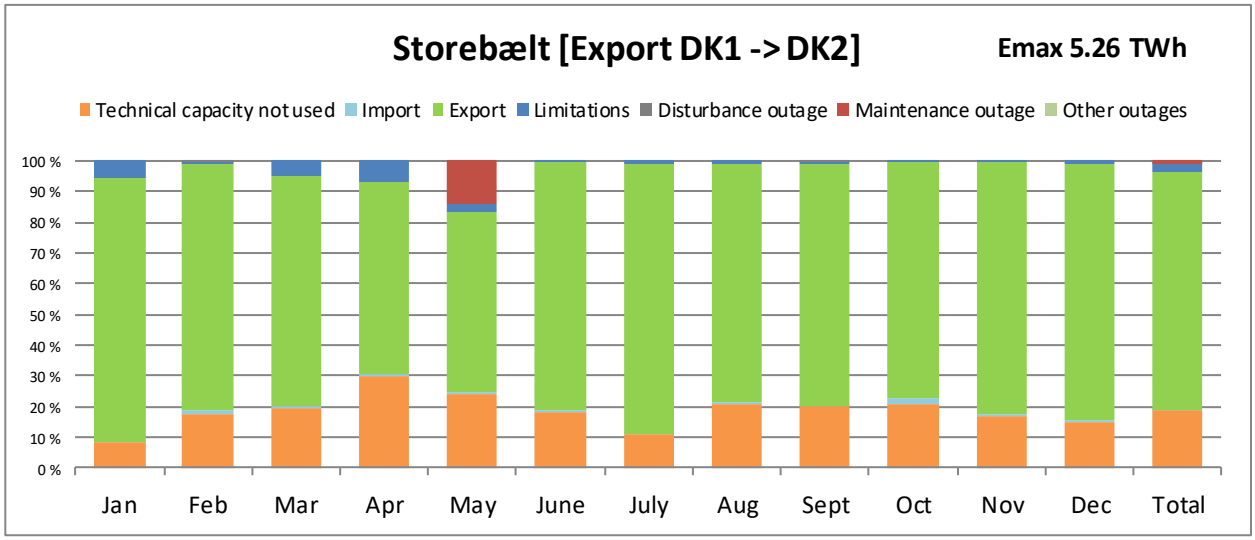

FIGURE 6.3.16 PERCENTAGE DISTRIBUTION OF THE AVAILABILITY AND UTILISATION CATEGORIES DEFINED IN CHAPTER 4 ACCORDING TO MONTH FOR STOREBELT IN 2016

In 2016, Storebaelt had an available technical capacity of 96 %. The technical capacity not used was 18.5 %. Totally, 4.1 TWh (77.4 % of the technical capacity) was exported from Jutland to Zealand and 31 GWh (0.6 % of the technical capacity) was imported to Jutland. Table 6.3.16 presents the numerical values behind Figure 6.3.16.

The annual maintenance lasted four days in May and two minor disturbances on Storebaelt.

TABLE 6.3.16 MONTHLY DISTRIBUTION OF THE TECHNICAL CAPACITY E_{MAX} FOR IN 2016

Storebælt [Export DK1 -> DK2]	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	% (of E_{max})
Import losses [MWh]	7	55	48	72	70	31	7	25	21	151	32	46	0.0
Export losses [MWh]	6520	5670	5550	4355	4376	5919	6739	5945	5809	5874	6044	6329	1.3
Technical capacity not used [MWh]	37607	74027	86943	127789	106958	78431	49871	93703	86228	92695	72520	67738	18.5
Import [MWh]	315	3207	2642	3781	3773	1586	390	844	913	8985	1911	2507	0.6
Export [MWh]	383984	334945	334894	269621	260894	349252	391914	347680	339599	342723	355452	370849	77.4
Limitations [MWh]	25003	4586	21543	30922	10982	3195	4721	4658	4712	3026	2573	5827	2.3
Disturbance outage [MWh]	0	1171	0	0	0	0	0	0	887	0	0	0	0.0
Maintenance outage [MWh]	0	0	0	0	64015	0	0	0	0	0	0	0	1.2
Other outages [MWh]	0	0	0	0	0	0	0	0	0	0	0	0	0.0
P_t (600 MW)	446908	417935	446022	432113	446622	432463	446895	446884	432338	447429	432456	446921	100.0

6.3.17 SWEPOL

Figure 6.3.17 presents the availability and utilisation of SwePol for 2016. SwePol Link has been in operation since 2000 and it connects the Swedish and Polish transmission grids. In south-eastern Sweden (bidding zone SE4) it is connected to Stärnö and in Poland (bidding zone PL) to Slupsk. The transmission capacity is 600 MW.

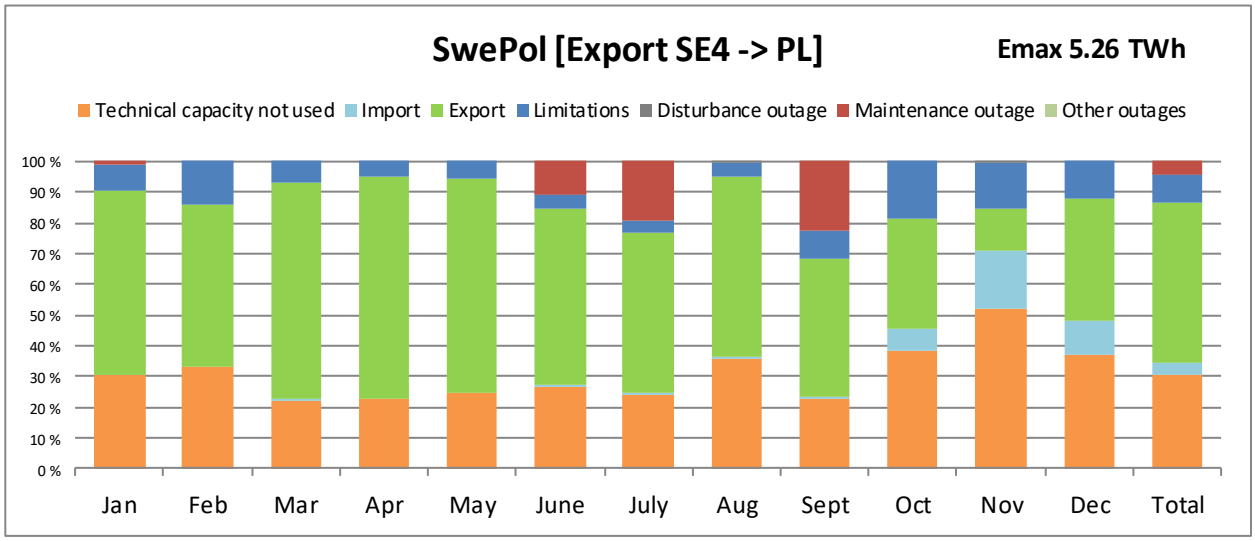

FIGURE 6.3.17 PERCENTAGE DISTRIBUTION OF THE AVAILABILITY AND UTILISATION CATEGORIES DEFINED IN CHAPTER 4 ACCORDING TO MONTH FOR SWEPOL IN 2016

In 2016, SwePol had an available technical capacity of 87 %. The technical capacity not used was 25 %. Totally, 2.8 TWh (52.4 % of the technical capacity) was exported from Sweden to Poland and 0.2 TWh (3.3 % of the technical capacity) was imported to Sweden. Table 6.3.17 presents the numerical values behind Figure 6.3.17.

There were two longer maintenance outages on SwePol and three minor disturbances in 2016. The first was in June to maintain a transformer in Stärnö and the second was in September due to annual maintenance.

TABLE 6.3.17 MONTHLY DISTRIBUTION OF THE TECHNICAL CAPACITY E_{MAX} FOR SWEPOL IN 2016

SwePol [Export SE4 -> PL]	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	% (of E_{max})
Import losses [MWh]	18	0	53	0	0	79	57	39	47	763	1690	1066	0.1
Export losses [MWh]	7322	5771	9003	8967	8886	7142	6710	7495	5377	3998	1581	4977	1.5
Technical capacity not used [MWh]	135479	137464	99501	96934	110452	115106	107315	159763	98399	170063	225442	164402	30.7
Import [MWh]	655	0	2226	0	0	3339	2244	1608	2097	34161	80044	49154	3.3
Export [MWh]	269028	220937	313862	313335	309353	248168	234083	263323	194479	157992	60474	178578	52.4
Limitations [MWh]	35088	59200	30211	21731	26595	18093	16961	20564	40791	84784	64806	54265	9.0
Disturbance outage [MWh]	0	0	0	0	0	787	0	1160	0	0	1234	0	0.1
Maintenance outage [MWh]	6150	0	0	0	0	46506	85800	0	96307	0	0	0	4.5
Other outages [MWh]	0	0	0	0	0	0	0	0	0	0	0	0	0.0
P_r (600 MW)	446400	417600	445800	432000	446400	432000	446403	446418	432073	447000	432000	446400	100.0

6.3.18 VYBORG LINK

Figure 6.3.18 presents the availability and utilisation of the Vyborg Link for 2016. The Vyborg Link is a back-to-back HVDC connection between Russia and Finland. The HVDC substation is situated in Vyborg, Russia. The 400 kV lines from Vyborg are connected to substations Yllikkälä and Kymi in southern Finland. The commissioning years were 1981, 1982, 1984, and 2000. Each commissioning included a capacity of 350 MW. The total technical capacity today is 4 × 350 MW and the commercial transmission capacity is 1.3 GW. Fingrid Oyj, the Finnish transmission system operator, allocates 100 MW for reserves. Earlier, the direction of transmission has been only to Finland but during September 2014, one 350 MW unit was successfully tested to be able to export electricity to Russia. The possibility of commercial trade from Finland to Russia started on 1 December 2014.

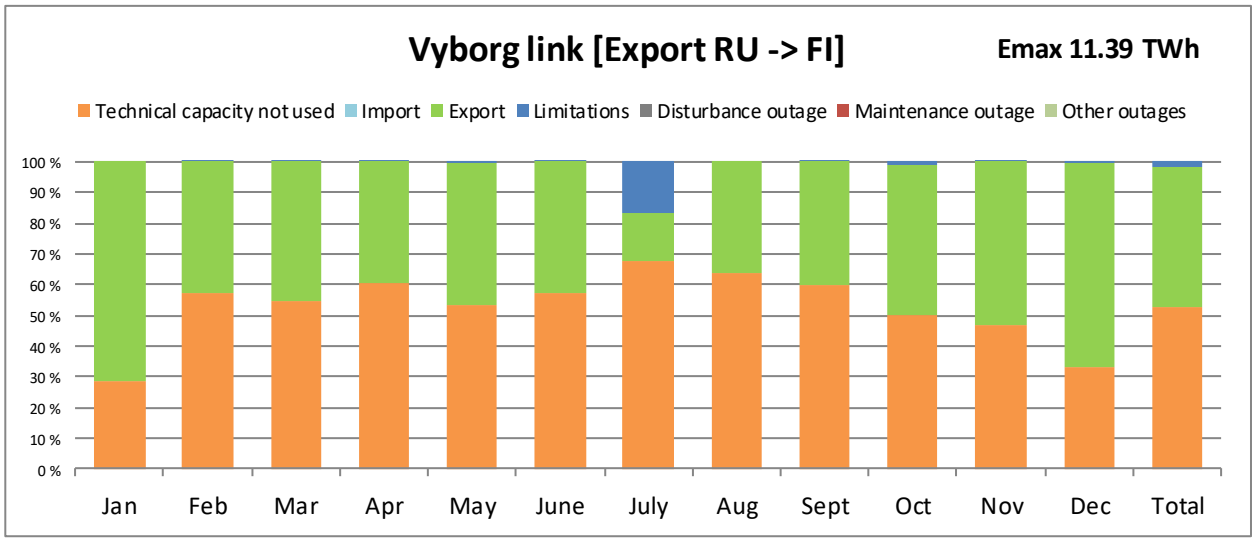

FIGURE 6.3.18 PERCENTAGE DISTRIBUTION OF THE AVAILABILITY AND UTILISATION CATEGORIES DEFINED IN CHAPTER 4 ACCORDING TO MONTH FOR VYBORG LINK IN 2016

In 2016, the Vyborg Link had an available technical capacity of 98 %. The technical capacity not used was 52.7 %. Totally, 5.2 TWh (45.8 % of the technical capacity) was exported from Russia to Finland and none was imported to Russia. Table 6.3.18 presents the numerical values behind Figure 6.3.18.

There were no total (4 x 350 MW) disturbance or maintenance outages that affected the Vyborg link in 2016. The limitation in July was caused by maintenance.

TABLE 6.3.18 MONTHLY DISTRIBUTION OF THE TECHNICAL CAPACITY E_{MAX} FOR VYBORG LINK IN 2016

Vyborg link [Export RU -> FI]	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	% (of E_{max})
Import losses [MWh]	0	0	0	0	0	0	0	0	0	0	0	0	0.0
Export losses [MWh]	20768	11623	13181	11113	13531	11951	4533	10515	11326	14181	14909	19293	1.4
Technical capacity not used [MWh]	274941	517295	526020	565500	514524	537500	655380	616702	558280	484583	438444	323084	52.7
Import [MWh]	0	0	0	0	0	0	0	0	0	0	0	0	0.0
Export [MWh]	692259	387419	439380	370425	451020	398364	151114	350498	377530	472689	496956	643116	45.8
Limitations [MWh]	0	86	500	75	1656	136	160706	0	190	11228	600	1000	1.5
Disturbance outage [MWh]	0	0	0	0	0	0	0	0	0	0	0	0	0.0
Maintenance outage [MWh]	0	0	0	0	0	0	0	0	0	0	0	0	0.0
Other outages [MWh]	0	0	0	0	0	0	0	0	0	0	0	0	0.0
P_r (1300 MW)	967200	904800	965900	936000	967200	936000	967200	967200	936000	968500	936000	967200	100.0

7 REFERENCES

[1] ENTSO-E, “The ENTSO-E Interconnected System Grid Map,” [Online]. Available: https://www.entsoe.eu/publications/order-maps-and-publications/electronic-grid-maps/Pages/default.aspx. [Accessed 4 May 2017].

Appendix A SCHEMATIC PRESENTATION OF HVDC LINKS

Figure A-1 shows a schematic presentation of an HVDC link with line commutated converters (LCC) and Figure A-3 shows a similar presentation of a link with voltage source converters (VSC). Figure A-2 and Figure A-4, show the converter stations for HVDC links having line commutated converters and voltage source converters, respectively. All the figures also show definitions for the origin of an event. The origin of each event is used for categorizing a disturbance or a limitation for statistical purposes. The figures also show how the terms 'local' and 'remote' are defined and the locations of the circuit breakers and measurement points for transferred energy on a link.

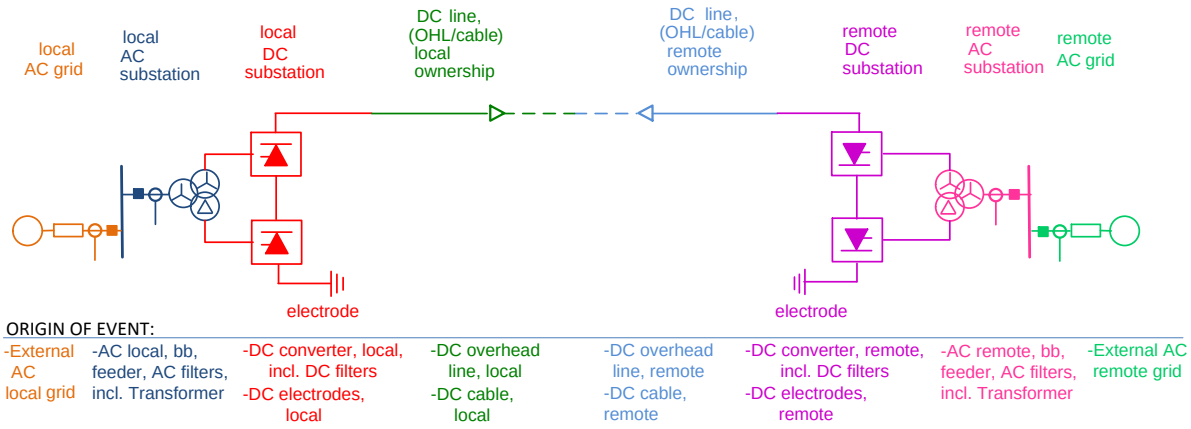

FIGURE A-1 A SCHEMATIC PRESENTATION OF A HVDC LINK WITH LINE COMMUTATED CONVERTERS (LCC)

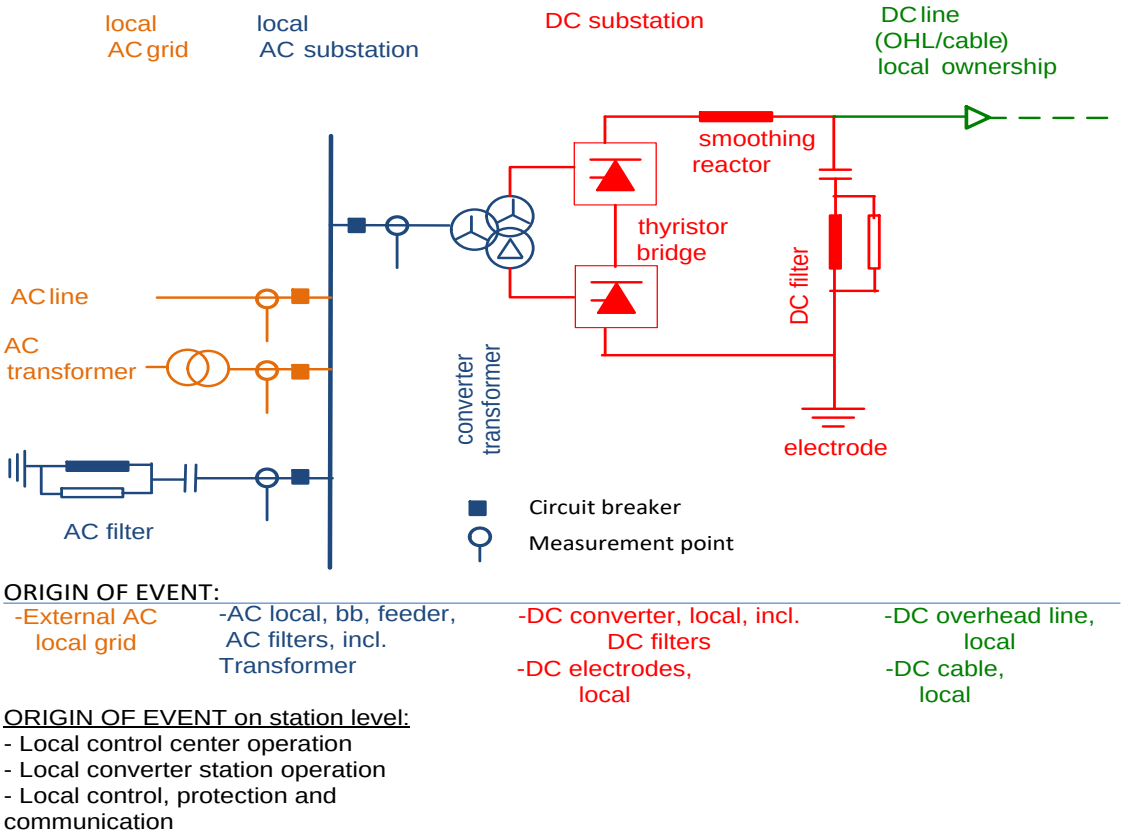

FIGURE A-2 A CONVERTER STATION OF A LINE COMMUTATED CONVERTER HVDC LINK WITH THE CONNECTION TO THE AC GRID

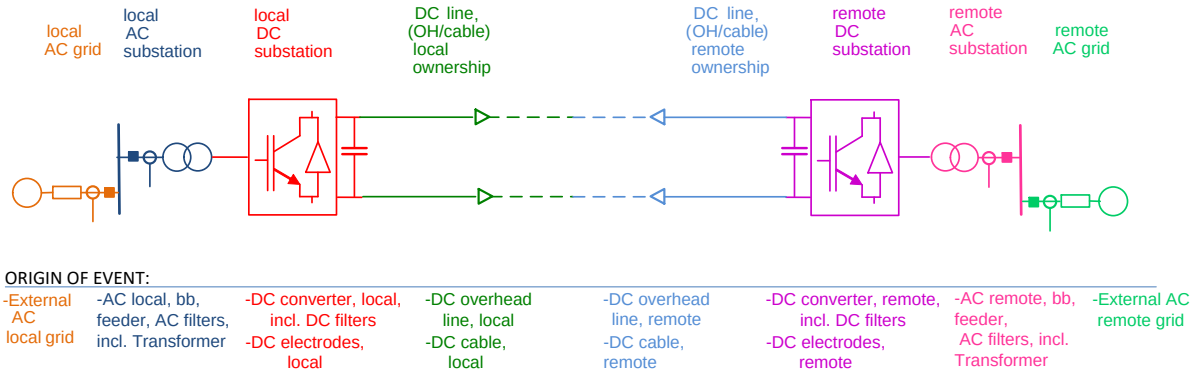

FIGURE A-3 A SCHEMATIC PRESENTATION OF A HVDC LINK WITH VOLTAGE SOURCE CONVERTERS (VSC)

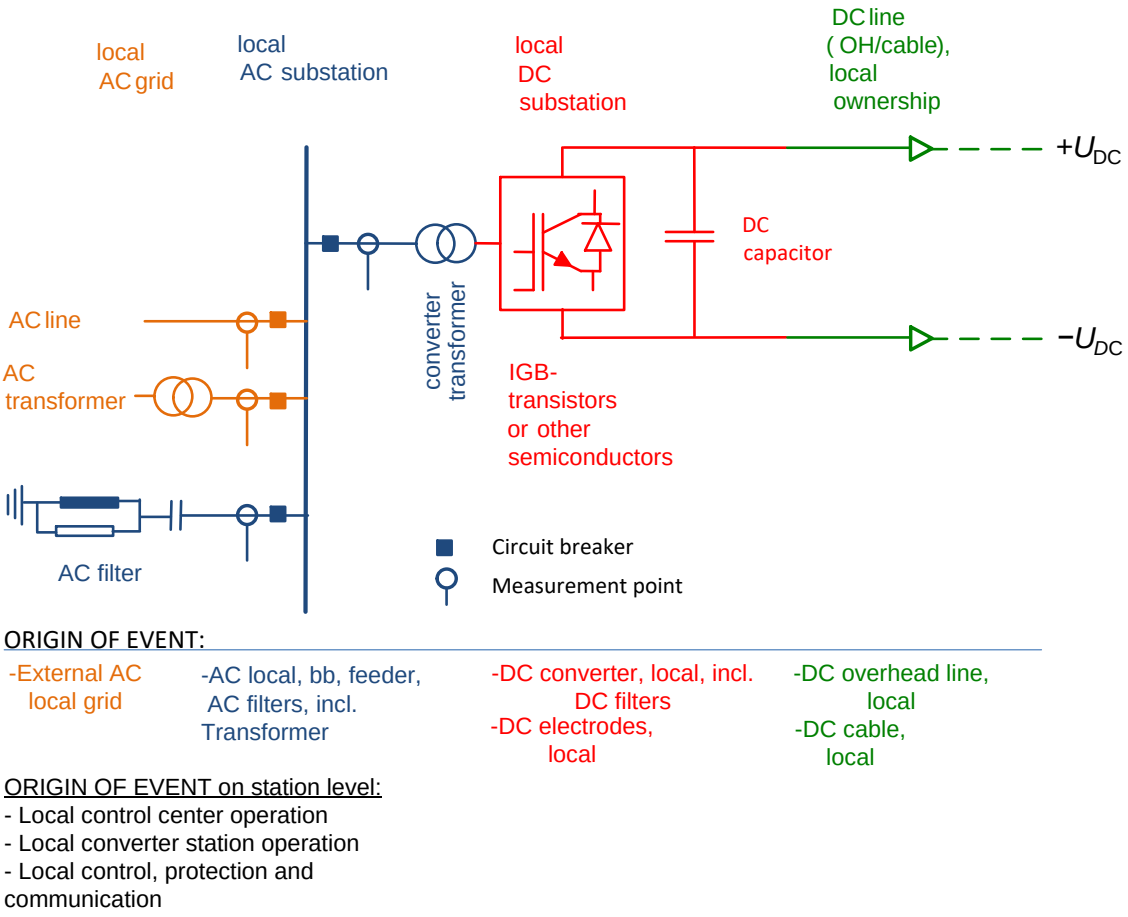

FIGURE A-4 A CONVERTER STATION OF A VOLTAGE SOURCE CONVERTER HVDC LINK WITH THE CONNECTION TO THE AC GRID

Appendix B CONTACT PERSONS

Denmark:	Energinet Tonne Kjærsvej 65, DK-7000 Fredericia
	Anders Bratløv Tel. +45 51 38 01 31 E-mail: anv@energinet.dk
Estonia:	Elering AS Kadaka tee 42, Tallinn, Estonia
	Kaur Krusell Tel. +372 5648 6011 E-mail: kaur.krusell@elering.ee
Finland:	Fingrid Oyj Läkkisepäntie 21, P.O. Box 530, FI-00101 Helsinki
	Markku Piironen Tel. +358 30 395 4172, Mobile +358 40 351 1718 E-mail: markku.piironen@fingrid.fi
Lithuania:	Litgrid AB A.Juozapavičiaus g. 13, LT-09311, Vilnius
	Valdas Tarvydas Tel. +370 707 02207 E-mail: valdas.tarvydas@litgrid.eu
	Vytautas Šatinskis Tel. +370 707 02196 E-mail: vytautas.satinskis@litgrid.eu
Norway:	Statnett SF Nydalen allé 33, PB 4904 Nydalen, NO-0423 Oslo
	Jørn Schaug-Pettersen Tel. +47 23 90 35 55 E-mail: jsp@statnett.no
Sweden:	Svenska kraftnät Sturegatan 1, P.O. Box 1200, SE-172 24 Sundbyberg
	Hampus Bergquist Tel. +46 10 475 84 48, Mobile: +46 72 515 90 70 E-mail: hampus.bergquist@svk.se
	Tarek Tallberg Tel. +46 10 475 86 79, Mobile: Tel. +46 72 244 96 97 E-mail: tarek.tallberg@svk.se
Production of report:	Hillner Consulting
	Henrik Hillner Tel. +358 41 505 7004 E-mail: henrik.hillner@hillner.fi

Appendix C ANNUAL OVERVIEW OF ALL HVDC DATA WITH SORTED CATEGORIES

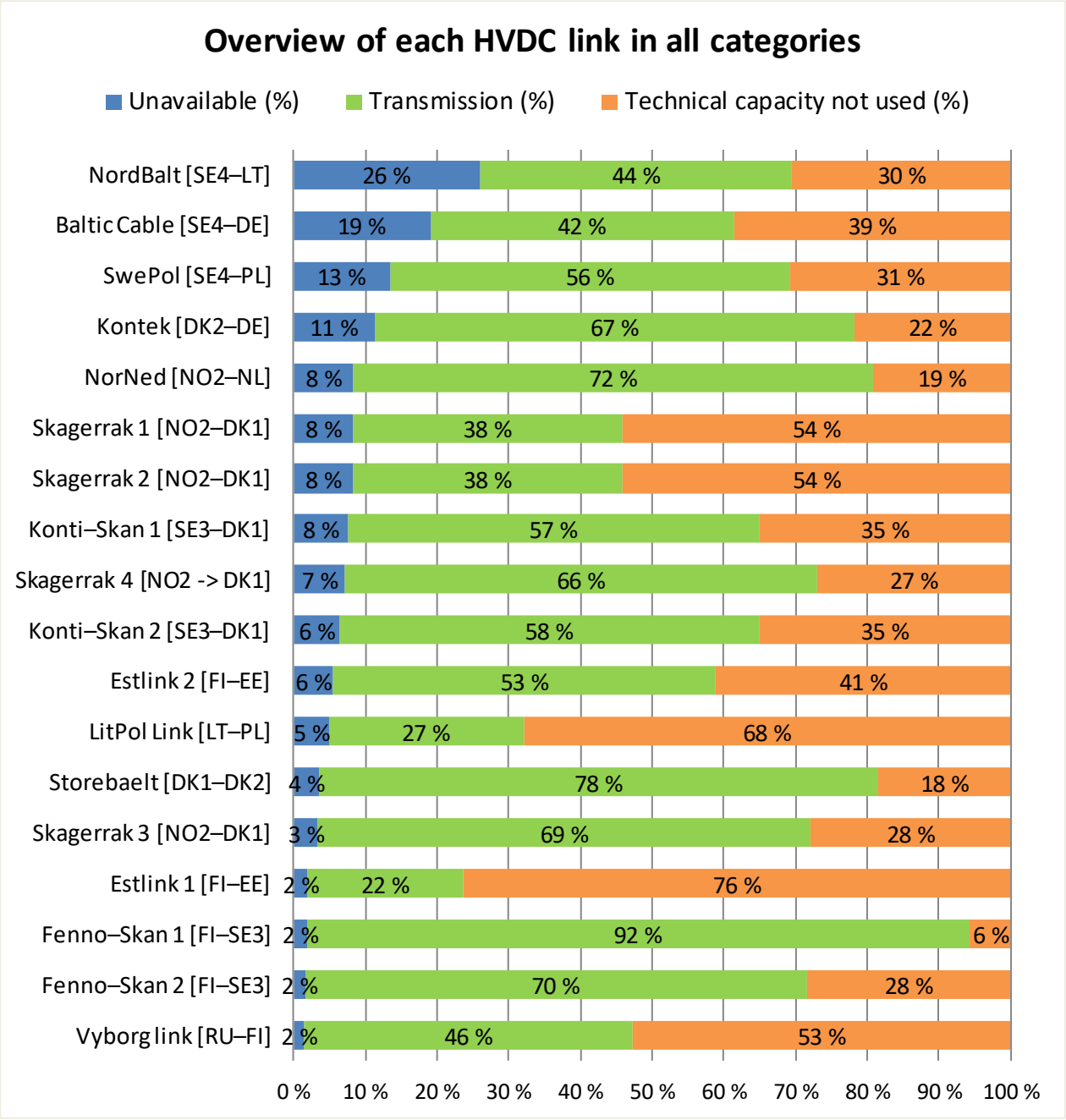

FIGURE C-1 ANNUAL OVERVIEW OF EACH HVDC LINK SORTED BY DESCENDING UNAVAILABLE TECHNICAL CAPACITY (E_U) IN 2016

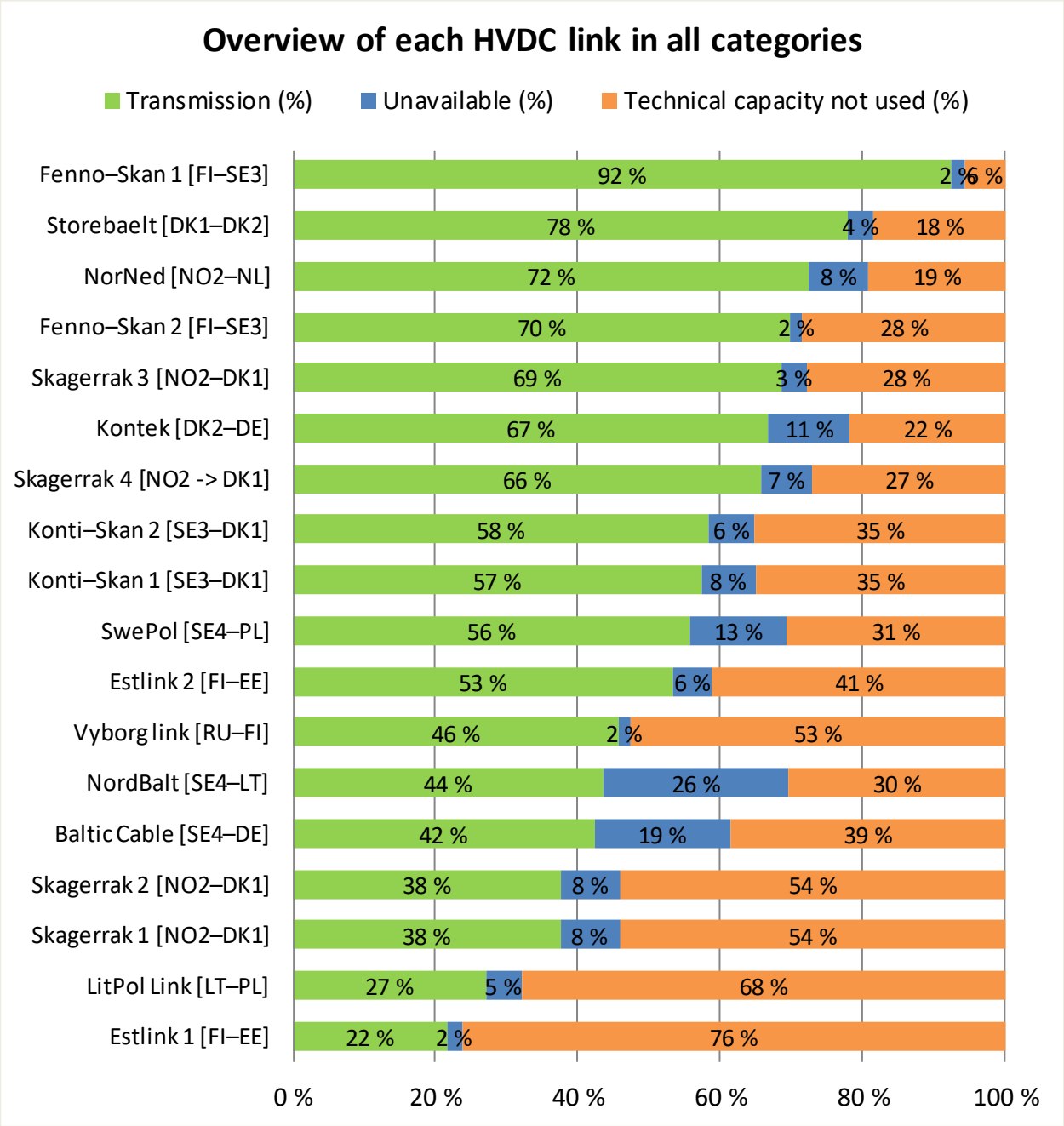

FIGURE C-2 ANNUAL OVERVIEW OF EACH HVDC LINK SORTED BY DESCENDING TRANSMISSION (E_T) IN 2016

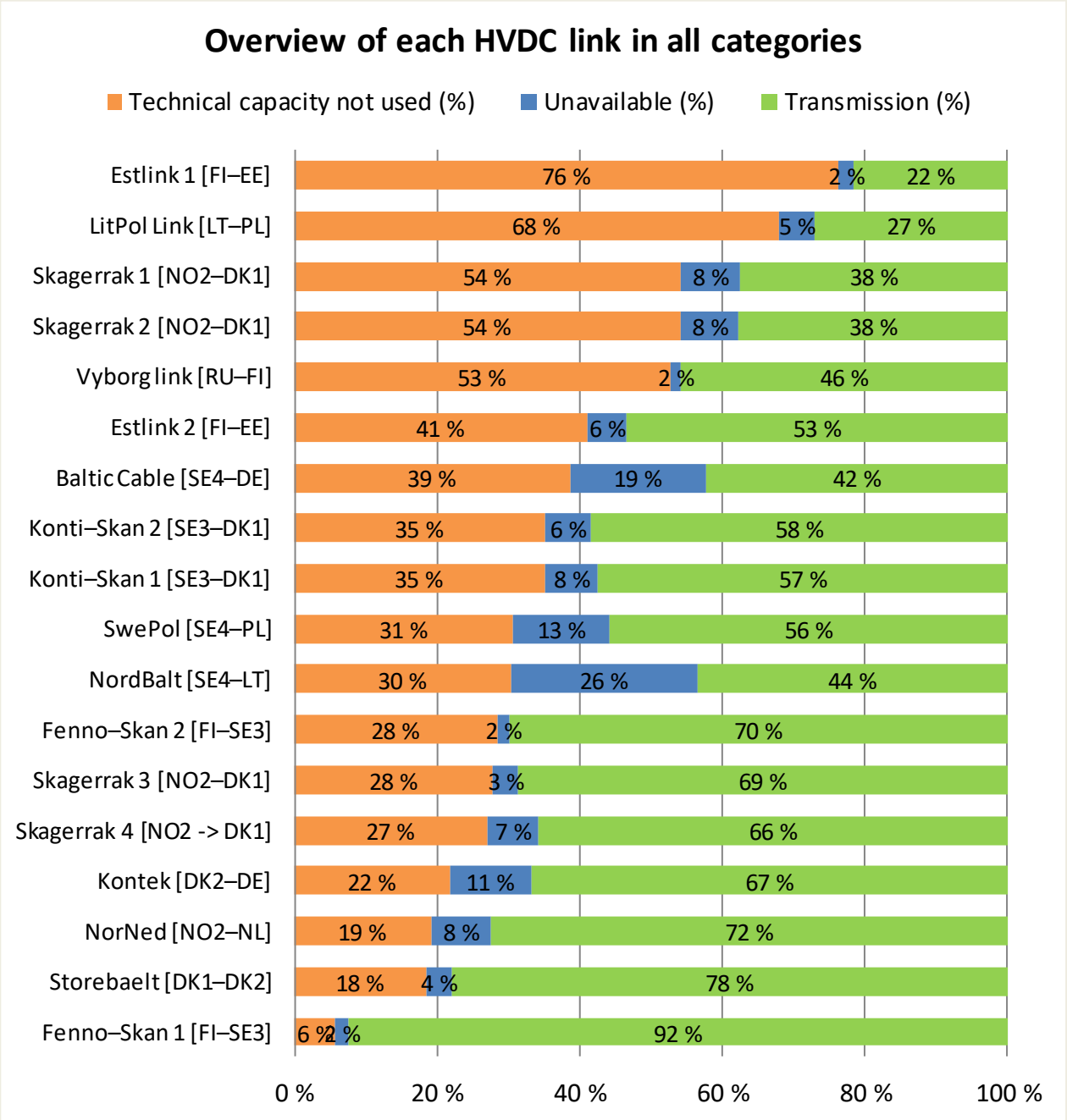

FIGURE C-3 ANNUAL OVERVIEW OF EACH HVDC LINK SORTED BY DESCENDING TECHNICAL CAPACITY NOT USED (E_{TCNU}) IN 2016