TRANSPOWER

Keeping the energy flowing

ADDITIONAL INFORMATION

Date	30 July 2018
Prepared for	Customers and Stakeholders
Subject	RCP3 service performance measures: additional information on the proposed HVDC energy availability target

This memo provides additional information on the proposed allowances for scheduled outages and forced outages for the HVDC energy availability service target ('AP1') during RCP3.

To account for the planned Pole 2 life-extension programme of work in RCP3, Option A in our June engagement paper proposed to retain the same availability target of 98.5% with an adjustment to 97.8% for the three of the five years affected by this work.

This adjusted target would allow:
- 1.7% unavailability for scheduled outages, and
- 0.5% unavailability for forced outages.

Scheduled outages

The unavailability for scheduled outages would account for both the Pole 2 project and routine maintenance. The expected duration of outages necessary for the Pole 2 work and routine maintenance for both Pole 2 and Pole 3 is 12 days in each of the three years during RCP3, comprising: 8 days for Pole 2, 2 days for the bi-pole, and 2 days for Pole 3.

Forced outages

The 0.5% unavailability for forced outages corresponds to:
- a bi-pole outage lasting for 43.8 hours

  or
- a Pole 3 outage lasting for 75 hours

  or
- a Pole 2 outage lasting for 105 hours.

Table 1 shows the records for forced outages since 2010. Looking at this table, the 0.5% target could be perceived as being high compared to historical data. However, many of our forced outages can end up being classified as scheduled outages if we can defer the outage to fix the problem by 24 hours or more.

The 0.5% target also takes into account the risk of a HILP (high impact low probability) event, such as Cook Strait cable failure. For example, a single Cook Strait cable outage for a year would correspond to a forced unavailability of 16.67% for that year. If this event is spread across 30 years that would correspond to a forced unavailability of 0.55% per year.

To see how Transpower HVDC availability compares to HVDC links elsewhere in the world, we have attached a series of Cigre reports on international HVDC availability. Please note: the Cigre recorded availability is per calendar year, whereas Transpower's reported availability in Table 1 is for each financial year (July to June).

Table 1: Reported availability by financial year

Year	Target Availability	Availability Achieved	Pole 2 Forced Unavailability	Pole 3 Forced Unavailability	Comment
2010/11	92.0%	84.9%	0.09%	N/A	Pole 2 only as Pole 1 was stood down. HAY-OTB reconductoring affected Pole 2 availability.
2011/12	82.5%	83.6%	0.11%	N/A	Pole 2 only as Pole 1 was stood down. HAY-OTB reconductoring affected Pole 2 availability.
2012/13	82.5%	90.3%	0.68%	N/A	Pole 2 only as Pole 1 was stood down. HAY-OTB reconductoring and Pole 3 project work affected Pole 2 availability.
2013/14	86.9%	80.8%	0.09%	0.06%	Pole 3 was commissioned in May 2013. Pole 2 controls were replaced August-October.
2014/15	97.0%	97.7%	0.15%	0.08%	First year of normal Pole 2 and Pole 3 operation.
2015/16	98.5%	98.9%	0.06%	0.06%	First year monetary incentives were tied to AP1 availability.
2016/17	98.5%	98.6%	0.007%	0.097%	Additional planned/unplanned outages were required to replace insulators on HAY-OTB.

Attachments

21, rue d'Artois, F-75008 PARIS
http: //www.cigre.org

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A SURVEY OF THE RELIABILITY OF HVDC SYSTEMS THROUGHOUT THE WORLD DURING 2013 – 2014

By

M.G. BENNETT* **N.S.DHALIWAL**

On behalf of Study Committee B4

SUMMARY

CIGRE Advisory Group B4.04 collects data annually on the reliability performance of HVDC systems in operation throughout the world. This report is a summary of the reliability performance of HVDC systems in operation worldwide during 2013 and 2014. The summary was developed through data prepared by utilities that operate the HVDC systems and submitted to Advisory Group B4.04 of CIGRE Study Committee B4 (HVDC and Power Electronic Equipment). The report contains data on energy availability, energy utilization, forced and scheduled outages and other data in accordance with a reporting protocol developed by the Advisory Group. The report contains statistics on the frequency and duration of forced outages for the years 2013 and 2014 combined with previous data to present a cumulative average of forced outages by frequency and duration covering the years 1988 to 2014. The categories for the cumulative averages are back-to-back stations and two terminal and multi-terminal stations with one and two or more converters per pole.

The data in this report, together with that published in previous reports; provide a continuous record of reliability performance for the majority of HVDC systems in the world since they first went into operation. This now constitutes over 800 system-years of data on thyristor and IGBT valve systems.

KEYWORDS

Survey - Reliability - HVDC Systems

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mbennett@teshmont.com

Background

Advisory Group B4.04 was formed specifically to assemble and publish data on the reliability and operational experience of HVDC systems in service around the world. The Advisory Group developed definitions for the reliability terms and parameters of prime interest at that time and prepared a protocol for use in collecting and compiling the data.

The protocol has been revised periodically as experience was gained in collecting and interpreting the data [1]. The latest revision was modified to allow reporting from both Line Commutated Converters (LCC) and Voltage sourced Converters (VSC) [1].

Utilities that operate the HVDC systems collect the data for their systems in accordance with the protocol and prepare a report for each year of operation. These reports are submitted to the Advisory Group where they are compiled into a summary report.

The data were first collected in 1968, covering four dc systems utilizing mercury-arc valves. Data on the first thyristor valve system were compiled in 1972. For this paper full reports were received on 37 LCC systems and one VSC systems for 2013, and 39 LCC systems and two VSC systems for 2014.

The data contained in this survey report cover operation during 2013 and 2014. Data for earlier years can be found in previous reports [2] [3] and in the list of references given in those reports. The data in this report, together with that of the previous years, provide a continuous record of reliability performance of thyristor HVDC systems for the past 43 years.

HVDC System Reliability Performance

The overall reliability statistics for all systems for which reports were received for 2013 and 2014 are given in Table I. Thirteen of the systems are back-to-back systems and the remainder are point-to-point transmission systems utilizing overhead line and/or cable systems.

Al Fadhili, Adani, BritNed, Caprivi (VSC), EstLink 1 (VSC) and EstLink 2 provided reports for the first time.

Table I shows the year of commissioning, the maximum continuous transmission capacity, energy availability, energy utilization and energy unavailability for the HVDC systems covered by this report.

Energy Availability is a measure of the amount of energy that could have been transmitted over the HVDC system, except as limited by forced and scheduled outages of converter station equipment and dc transmission lines or cables. Energy Utilization is a measure of the amount of energy actually transmitted. Both parameters are expressed as a percentage based on the maximum continuous capacity of the HVDC system.

It can be seen in Table I that some systems operate at very low energy utilization, i.e. they are used primarily for standby capacity, and other systems at a very high level of energy utilization, i.e. approaching maximum rated capacity.

Forced Energy Unavailability (FEU) is the amount of energy that could not have been transmitted over the dc system due to forced outages. Only converter station equipment outages are considered, i.e. transmission line and cable outages are excluded.

Scheduled Energy Unavailability (SEU) is the amount of energy that could not have been transmitted over the dc system due to scheduled outages. Although transmission line and cable scheduled outages are included in the data in Table I, it is believed that in most cases the scheduled energy unavailability shown closely approximates that for converter stations only, since most scheduled maintenance on transmission lines and cables is generally conducted concurrently with station maintenance.

Scheduled outages have less impact on the performance of the power system than forced outages since planned outages can usually be taken during periods of reduced system load or when some reduction in transmission capacity can be accepted. Hence scheduled energy unavailability can vary substantially from system to system due to differences in utility maintenance practices and policies, and the requirement for transmission capacity.

Table I - System Energy Availability, Energy Utilization and Converter Station Energy Unavailability

System	Year Commis-sioned	Maximum Continuous Capacity MW	Energy Availability percent		Energy Utilization percent (1)		Forced Energy Unavailability percent (2)		Scheduled Energy Unavailability percent	
			2013	2014	2013	2014	2013	2014	2013	2014
Square Butte	1977	550	76.6	95.6	69.0	71.3	1.11	0.59	22.32	3.75
Nelson River BP1	1973//04	1855	95.3	95.5	67.4	65.7	0.82	1.09	3.86	3.38
Nelson River BP2	1978/83	2000	96.5	96.2	75.8	75.8	0.23	0.41	3.28	3.43
Hokkaido-Honshu	1979/93	600	94.7	97.9	17.1	17.4	0.05	0.00	5.25	2.09
CU	1979	1138	98.0	95.3	81.9	82.7	0.06	0.07	1.92	4.62
Gotland 2 & 3	1983/87	320	97.4	99.6	20.6	25.8	2.02	0.07	0.55	0.33
Itaipu BP1	1984/85	3150	92.5	76.6	75.8	66.2	0.67	18.84	6.82	2.52
Itaipu BP2	1987	3150	95.4	95.9	75.8	66.2	0.03	1.55	4.62	2.53
Highgate	1985	225	97.6	97.6	89.5	80.7	0.07	0.03	2.31	2.35
Virginia Smith	1988	200	94.2	86.4	6.7	6.2	0.00	6.70	5.81	6.94
Vindhyachal	1989	500	97.5	98.4	46.1	57.1	0.40	0.23	2.10	1.34
McNeill (3)	1989	150	97.4	39.2	42.5	16.8	0.08	1.80	2.50	59.05
Fenno-Skan 1	1990	500	58.9	71.5	40.5	68.2	0.53	0.74	11.11	2.76
Fenno-Skan 2	2011	830	92.4	98.2	59.8	84.7	0.21	0.01	7.37	1.40
Rihand-Dadri	1991	1650	97.0	97.5	69.2	74.4	1.02	0.42	1.98	2.08
SACOI (4, 5)	1992	300/300/50	87.0	85.2	82.7	65.1	1.57	0.16	11.41	9.08
New Zealand Pole 2 (6)	1992	500	63.2	97.7	32.1	41.5	0.34	0.12	36.10	2.13
New Zealand Pole 3	2013	700	-	91.7	-	28.7	-	0.05	-	8.28
Sakuma	1965/93	300	98.8	98.8	0.3	0.0	0.00	0.00	1.22	1.23
Kontek	1998	600	96.8	96.1	70.8	73.3	0.02	0.00	3.17	3.87
Chandrapur	1998	1000	99.6	99.6	91.1	94.4	0.01	0.15	0.35	0.30
Minami-Fukumitsu	1999	300	95.7	96.0	9.3	9.8	0.00	0.00	4.34	4.02
SwePol	2000	600	96.9	94.6	33.9	60.9	0.19	0.51	2.93	4.87
Vizag I East-South	2000	500	99.9	90.9	49.9	49.4	0.02	4.55	0.09	4.55
Vizag II East-South	2005	500	100.0	99.8	51.3	60.2	0.00	0.00	0.00	0.18
Kii Channel	2000	1400	98.4	98.6	73.3	72.4	0.00	0.00	1.61	1.40
Malaysia-Thailand	2001	300	98.1	96.6	10.4	61.5	0.35	2.35	1.54	0.98
Grita (7)	2001	500	72.6	46.9	39.6	32.9	0.03	0.24	26.40	52.90
Talcher-Kolar	2003	2000	99.3	99.3	90.1	90.4	0.23	0.01	0.48	0.70
Sasaram	2003	500	99.8	99.8	30.6	58.6	0.02	0.18	0.20	0.00
Higashi-Shimizu	2006	300	99.9	95.1	29.3	26.8	0.03	0.00	0.11	4.92
Basslink	2006	500	97.5	98.2	65.1	71.7	2.28	0.23	0.19	1.62
EstLink 1	2007	350	94.9	91.4	54.4	17.6	0.90	7.79	4.17	0.79
EstLink 2	2013	450	-	84.4	-	53.0	-	0.15	-	11.70
NorNed	2008	700	82.1	96.8	71.9	90.7	14.20	0.21	3.70	3.00
Al Fadhili	2009	1800	-	97.8	-	6.2	-	1.04	-	1.14
SAPEI	2009	1000	95.7	98.1	37.5	41.4	0.81	1.01	3.50	0.93
Caprivi	2009	300	96.9	97.4	14.9	16.8	0.07	0.16	2.99	2.33
Ballia-Bhiwadi	2010	2500	99.6	98.1	87.2	15.7	0.07	0.62	0.37	0.75
Adani	2011	2500	99.0	99.5	49.5	76.7	0.17	0.02	0.80	0.53
BritNed	2011	1000	96.9	96.1	75.0	91.0	0.49	0.03	2.66	3.89

(1) Based on maximum continuous capacity (2) Converter station outages only (3) SEU 2014 control upgrade
(4) Three terminal monopole system (5) Capacity reduced to 150 MW due to cable faults up to 2013 Dec (6) SEU due to Pole 3 testing
(7) SEU due cable repair

Forced Outage Data

Data on forced outages are given in Tables II to V inclusive. In Table II, the data on forced outages are classified into six categories as follows:

AC and Auxiliary Equipment (AC-E)
Valves (V)
Control and Protection (C&P)
DC Equipment (DC-E)
Other (O)
Transmission Line or Cable (TL)

The number of forced outage events and the equivalent forced outage hours within each category, together with the totals for each dc system are shown in Table IIA for 2013 and Table IIB for 2014. Equivalent forced outage hours is the sum of the actual forced outage hours after the outage duration has been adjusted for the percentage of reduction in capacity due to the outage. For example, for an outage of one pole of a bipole system (50% loss of capacity) that lasted two hours, the equivalent outage hours would be one hour.

Table II A - Number of Forced Outages and Equivalent Outage Hours - 2013

System	AC-E		V		C & P		DC-E		O		TL		TOTAL	
	No.	Hours	No.	Hours	No.	Hours	No.	Hours	No.	Hours	No.	Hours	No.	Hours
Square Butte	10	70.0	1	4.3	0	0.0	2	7.9	2	14.8	0	0.0	15	96.9
Nelson River BP1	6	10.8	2	0.8	6	7.1	12	35.2	8	17.8	0	0.0	34	71.8
Nelson River BP2	4	3.2	7	9.2	0	0.0	5	6.1	2	1.5	0	0.0	18	20.0
Hokkaido-Honshu	1	2.0	0	0.0	1	2.7	0	0.0	0	0.0	0	0.0	2	4.7
CU	1	4.7	0	0.0	0	0.0	0	0.0	1	0.1	0	0.0	2	4.9
Gotland 2 & 3	2	171.7	0	0.0	1	5.4	1	0.1	0	0.0	0	0.0	4	177.1
Itaipu BP1	4	46.9	5	10.2	0	0.0	0	0.0	3	1.8	0	0.0	12	58.9
Itaipu BP2	1	2.3	0	0.0	0	0.0	0	0.0	1	0.1	1	0.1	3	2.5
Highgate	1	0.8	3	5.6	0	0.0	0	0.0	0	0.0	0	0.0	4	6.4
Virginia Smith	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Vindhyachal	9	30.8	0	0.0	5	3.6	0	0.0	1	0.2	0	0.0	15	34.6
McNeill	0	0.0	0	0.0	0	0.0	0	0.0	1	6.6	0	0.0	1	6.6
Fenno-Skan 1 (1)	4	16.8	0	0.0	1	0.1	1	16.4	2	12.7	2	2580.9	10	2626.9
Fenno-Skan 2	1	0.6	0	0.0	2	5.2	1	12.4	1	0.1	0	0.0	5	18.2
Rihand-Dadri	3	86.3	1	2.5	1	0.3	0	0.0	1	0.5	4	1.3	10	90.9
SACOI	5	18.9	2	21.6	5	97.0	0	0.0	0	0.0	0	0.0	12	137.6
New Zealand Pole 2	0	0.0	0	0.0	16	29.7	1	0.3	0	0.0	5	27.7	22	57.7
Sakuma	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Kontek	0	0.0	0	0.0	1	1.4	0	0.0	0	0.0	0	0.0	1	1.4
Chandrapur	6	0.9	0	0.0	1	0.1	0	0.0	0	0.0	0	0.0	7	1.0
Minami-Fukumitsu	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
SwePol	7	11.6	0	0.0	2	4.9	0	0.0	1	0.5	0	0.0	10	17.0
Vizag I East-South	1	0.2	1	1.5	0	0.0	0	0.0	0	0.0	0	0.0	2	1.6
Vizag II East-South	1	0.3	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	1	0.3
Kii Channel	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Malaysia-Thailand	1	0.2	1	3.1	0	0.0	2	27.3	0	0.0	2	3.8	6	34.3
Grita	1	0.9	0	0.0	1	2.1	0	0.0	0	0.0	1	88.3	3	91.4
Talcher-Kolar	2	2.7	1	16.6	0	0.0	1	1.2	0	0.0	0	0.0	4	20.6
Sasaram	2	0.5	1	1.5	0	0.0	0	0.0	0	0.0	0	0.0	3	1.9
Higashi-Shimizu	0	0.0	0	0.0	1	3.0	0	0.0	0	0.0	0	0.0	1	3.0
Basslink	1	0.8	0	0.0	0	0.0	2	197.5	1	1.6	0	0.0	4	199.9
EstLink 1	4	76.3	0	0.0	0	0.0	0	0.0	1	2.2	0	0.0	5	78.4
NorNed (2)	0	0.0	1	1243.8	0	0.0	0	0.0	0	0.0	0	0.0	1	1243.8
SAPEI	3	71.3	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	3	71.3
Caprivi	1	1.7	1	3.2	0	0.0	2	0.8	0	0.0	3	7.8	7	13.6
Ballia-Bhiwadi	2	2.3	6	3.7	1	0.3	1	0.1	0	0.0	0	0.0	10	6.3
Adani	9	13.3	0	0.0	0	0.0	1	0.4	1	1.1	0	0.0	11	14.7
BritNed	5	40.3	1	2.6	0	0.0	0	0.0	0	0.0	0	0.0	6	42.9

(1) Major time caused by cable failure and capacity reduction (2) Damage to valve caused by damage to roof during storm

The protocol makes a distinction for reporting events that caused a reduction in transmission capacity but did not lead to a forced trip of the HVDC equipment. Table IIC summarizes the number of capacity reductions included in the statistics reported in Table IIA and Table IIB. Capacity reductions are not included in the values reported in Tables III to V, as these outages did not lead to a forced trip of equipment.

Table II B - Number of Forced Outages and Equivalent Outage Hours - 2014

System	AC-E		V		C & P		DC-E		O		TL		TOTAL	
	No.	Hours	No.	Hours	No.	Hours	No.	Hours	No.	Hours	No.	Hours	No.	Hours
Square Butte	4	28.7	3	8.3	0	0.0	4	15.0	0	0.0	1	3.8	12.0	55.7
Nelson River BP1	9	6.5	3	1.4	2	1.8	15	73.6	9	11.9	0	0.0	38	95.1
Nelson River BP2	5	2.3	4	0.3	7	17.8	2	11.0	6	4.1	2	0.2	26	35.6
Hokkaido-Honshu	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
CU	2	5.8	0	0.0	1	0.1	0	0.0	1	0.2	0	0.0	4	6.0
Gotland 2 & 3	0	0.0	0	0.0	4	5.9	0	0.0	0	0.0	0	0.0	4	5.9
Itaipu BP1 (1)	0	0.0	10	1648.2	1	0.0	0	0.0	1	1.7	5	179.4	17	1829.4
Itaipu BP2	0	0.0	4	40.0	1	0.1	1	96.0	1	0.0	0	0.0	7	136.1
Highgate	3	2.3	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	3	2.3
Virginia Smith	4	32.3	2	158.6	1	56.9	0	0.0	2	339.6	0	0.0	9	587.3

System	AC-E		V		C & P		DC-E		O		TL		TOTAL	
	No.	Hours	No.	Hours	No.	Hours	No.	Hours	No.	Hours	No.	Hours	No.	Hours
Vindhyachal	1	3.7	0	0.0	16	16.6	0	0.0	0	0.0	0	0.0	17	20.3
McNeill	1	59.2	0	0.0	2	7.0	0	0.0	3	91.8	0	0.0	6	158.0
Fenno-Skan 1 (2)	6	24.1	0	0.0	2	17.8	0	0.0	1	22.5	1	2190.0	10	2254.4
Fenno-Skan 2	0	0.0	0	0.0	3	0.8	0	0.0	0	0.0	3	31.5	6	32.3
Rihand-Dadri	0	0.0	4	37.2	0	0.0	0	0.0	0	0.0	0	0.0	4	37.2
SACOI	2	6.3	0	0.0	4	7.6	0	0.0	0	0.0	6	491.2	12	505.2
New Zealand Pole 2	2	4.1	1	3.9	1	0.5	1	2.3	0	0.0	2	7.6	7	18.5
New Zealand Pole 3	0	0.0	0	0.0	0	0.0	1	3.5	1	1.1	1	0.1	3	4.6
Sakuma	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Kontek	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Chandrapur	5	3.7	1	4.9	1	4.4	0	0.0	0	0.0	0	0.0	7	13.0
Minami-Fukumitsu	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
SwePol	5	19.6	0	0.0	2	24.9	0	0.0	0	0.0	0	0.0	7	44.5
Vizag I East-South	1	0.4	3	398.6	0	0.0	0	0.0	0	0.0	0	0.0	4	399.0
Vizag II East-South	1	0.4	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	1	0.4
Kii Channel	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Malaysia-Thailand	3	16.5	4	13.5	4	175.9	0	0.0	0	0.0	9	2.2	20	208.2
Grita	2	7.9	0	0.0	2	13.2	0	0.0	0	0.0	0	0.0	4	21.1
Talcher-Kolar	0	0.0	2	0.4	1	0.8	1	0.1	0	0.0	0	0.0	4	1.3
Sasaram	2	13.0	0	0.0	2	3.2	0	0.0	0	0.0	0	0.0	4	16.2
Higashi-Shimizu	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Basslink	1	2.7	5	17.4	0	0.0	0	0.0	0	0.0	0	0.0	6	20.0
EstLink 1	2	17.9	7	664.7	0	0.0	0	0.0	0	0.0	0	0.0	9	682.6
EstLink 2	1	2.1	0	0.0	2	10.7	0	0.0	0	0.0	2	325.7	5	338.5
NorNed	1	5.9	0	0.0	0	0.0	0	0.0	1	12.2	0	0.0	2	18.1
Al Fadhili	24	8.4	4	82.6	0	0.0	0	0.0	0	0.0	0	0.0	28	91.0
SAPEI	7	70.4	0	0.0	1	18.4	0	0.0	0	0.0	0	0.0	8	88.8
Caprivi	0	0.0	0	0.0	4	7.3	1	7.0	0	0.0	4	8.0	9	22.3
Ballia-Bhiwadi	10	35.5	9	15.5	5	2.1	1	0.5	1	0.7	4	45.4	30	99.6
Adani	3	1.9	0	0.0	0	0.0	0	0.0	1	0.2	0	0.0	4	2.1
BritNed	2	1.0	0	0.0	1	1.5	0	0.0	0	0.0	0	0.0	3	2.5

(1) Major time caused by valve failure (2) Major time caused by cable capacity reduction

Table II C - Number of Capacity Reductions and Equivalent Outage Hours (1)

System	2013		2014	
	No.	Hours	No.	Hours
Fenno-Skan 1	2	1196.7	1	2190.0
Fenno-Skan 2	-	-	3	0.8
SACOI	5	114.9	4	437.8
New Zealand Pole 3	-	-	1	0.1
SwePol	-	-	2	24.9
SAPEI	1	64.9	6	66.2

(1) Outage statistics included in Tables II A and II B.

88.1 Average of System FEU Hours

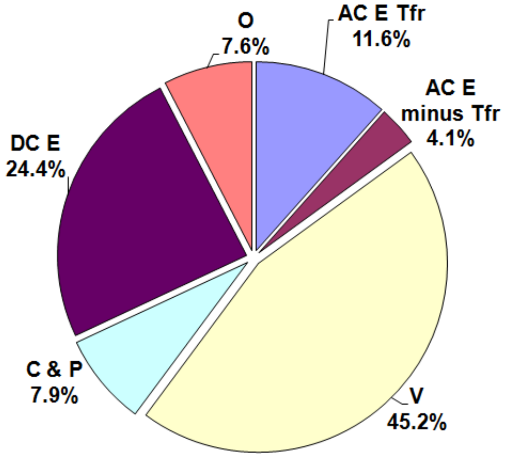

Figure 1
Breakdown of Average FEU by Equipment Category of All Reporting LCC and VSC HVDC Systems (2013-2014)

264.3 Average of System FEU Hours

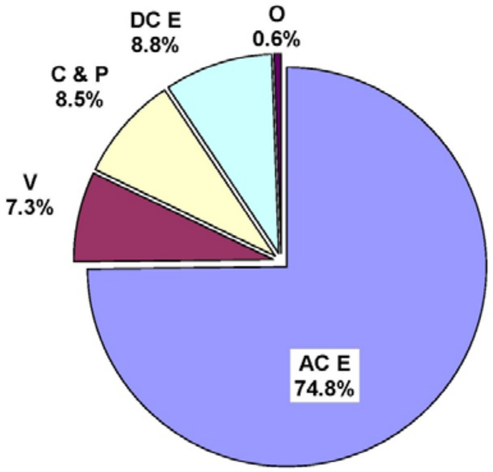

Figure 2
Breakdown of Average FEU by Equipment Category of All Reporting LCC HVDC Systems (1983-2012)

Figure 1 shows a summary of the average FEU of all reporting systems for 2013 and 2014 on the basis of the major equipment categories as reported in Table IIA and Table IIB but excluding outages due to transmission lines/cables. In Figure 1 the major AOH was associated with a valve hall fire in one system. Figure 1 can be compared to Figure 2 that shows the average FEU by category of all reporting systems from 1983 to 2012. The contribution to FEU by converter transformer failures is significantly reduced over this reporting period as compared to past results. Reports on converter transformer failures are available through CIGRE [4, 5, 6].

Table III gives data for each of the dc systems on the number of forced outages that have occurred and the average duration of the outages. It should be noted that the durations are given in actual lapsed time, i.e. the capacity lost during the outage is not considered. Some outages may be converter (valve group) outages, some pole outages and others bipole outages.

Table III - Average Actual Outage Duration for Converter Station Forced Outages

System	2013		2014	
	No. of Outages (1)	**Average Duration Hours**	**No. of Outages (1)**	**Average Duration Hours**
Square Butte	15	12.0	11	8.8
Nelson River BP1	34	10.2	38	13.8
Nelson River BP2	18	4.0	24	4.5
Hokkaido-Honshu	2	4.6	0	0.0
CU	2	2.5	4	2.0
Gotland 2 & 3	4	88.5	4	2.9
Itaipu BP1	12	19.3	12	549.3
Itaipu BP2	2	4.6	7	50.3
Highgate	4	1.6	3	0.8
Virginia Smith	0	0.0	9	65.3
Vindhyachal	15	4.6	17	1.4
McNeill	1	6.6	6	26.3
Fenno-Skan 1	7	6.6	9	7.2
Fenno-Skan 2	5	3.6	0	0.0
Rihand-Dadri	6	29.7	4	18.6
SACOI	7	3.2	5	2.4
New Zealand Pole 2	17	1.8	5	2.2
New Zealand Pole 3	-	-	2	2.3
Sakuma	0	0.0	0	0.0
Kontek	1	1.4	0	0.0
Chandrapur	7	0.3	7	3.7
Minami-Fukumitsu	0	0.0	0	0.0
SwePol	10	1.7	5	3.9
Vizag I East-South	2	0.8	4	99.7
Vizag II East-South	1	0.3	1	0.4
Kii Channel	0	0.0	0	0.0
Malaysia-Thailand	4	7.6	11	18.7
Grita	2	1.5	4	5.3
Talcher-Kolar	4	10.0	4	0.6
Sasaram	3	0.6	4	4.0
Higashi-Shimizu	1	3.0	0	0.0
Basslink	4	50.0	6	3.3
EstLink 1	5	15.7	9	75.8
EstLink 2	-	-	3	4.3
NorNed	1	1243.7	2	9.0
Al Fadhili	-	-	28	9.7
SAPEI	2	4.4	2	13.4
Caprivi	4	1.4	5	2.8
Ballia-Bhiwadi	10	1.2	26	4.1
Adani	11	2.7	4	1.1
BritNed	6	13.5	3	1.7

(1) Excludes capacity reduction

Table IV shows the number of bipole, pole and converter forced outages that occurred in 2013 and 2014 for all the bipolar systems. The total number of all outages for each of the systems is also shown.

Table IV - Number of Forced Outages by Severity

System	Number of Forced Outages							
	2013				2014			
	All Outages	Bipole Outages	Pole Outages	Converter Outages	All Outages	Bipole Outages	Pole Outages	Converter Outages
Square Butte	15	3	12	0	11	2	9	0
Nelson River BP1	34	1	7	26	38	0	6	32
Nelson River BP2	18	1	2	15	24	0	7	17
Hokkaido-Honshu	2	0	2	0	0	0	0	0
CU	2	1	1	0	4	1	3	0
Gotland 2 & 3	4	0	4	0	4	0	4	0
Itaipu BP1	12	0	1	11	12	0	1	11
Itaipu BP2	2	0	1	1	7	0	1	6
Rihand-Dadri	6	2	4	0	4	0	4	0
Kii Channel	0	0	0	0	0	0	0	0
Talcher-Kolar	4	1	3	0	4	0	4	0
SAPEI	2	0	2	0	2	1	1	0
Ballia-Bhiwadi	10	1	9	0	26	3	23	0
Adani	11	0	11	0	4	0	4	0
BritNed	6	2	4	0	3	0	3	0

Table V shows the frequency and duration of forced outages for 2013 and 2014 and the cumulative average of this data from 1988 to 2012. The table is presented in three parts: (A) covers back-to-back converter stations, (B) covers systems with one converter per pole, and (C) covers systems with two or more series-connected converters per pole. The data for systems reporting operation of less than one full year has been adjusted in these tables to an annual basis for the year, but the cumulative average is calculated for the actual total reporting period.

Table V(A) shows the average frequency (number) and average duration of station outages for back-to-back converter stations on a "per block" basis.

Tables V(B) and V(C) show the average frequency and duration of converter, pole and bipole outages for two-terminal and multi-terminal systems. The frequency of outages is given on a per terminal basis.

It is believed that the data in Table V will be useful to planning engineers involved with reliability studies of HVDC systems.

Table V – Frequency and Duration of Forced Outages

(A) Back-to-Back Converter Stations

System	Blocks	2013		2014		Average to 2014		
		f_s	d_s	f_s	d_s	Years	f_s	d_s
Highgate	1	4.00	1.6	3.00	0.8	26	2.35	5.3
Virginia Smith	1	0.00	0.0	9.00	65.3	25	5.72	45.0
Vindhyachal	2	7.50	4.6	8.50	1.4	18	5.19	9.6
McNeill	1	1.00	6.6	6.00	26.3	21	6.62	7.5
Sakuma	1	0.00	0.0	0.00	0.0	21.5	0.47	24.8
Chandrapur	2	3.50	0.3	3.50	3.7	11.3	4.76	31.6
Minami-Fukumitsu	1	0.00	0.0	0.00	0.0	8	0.00	0.0
Vizag I East-South	1	2.00	0.8	4.00	99.7	11	5.00	81.4
Vizag II East-South	1	1.00	0.3	1.00	0.4	7.8	1.53	4.1
Sasaram	1	3.00	0.6	4.00	4.0	8	4.75	1.7
Higashi-Shimizu	1	1.00	3.0	0.00	0.0	8	0.25	2.4
Al Fadhili	3	-	-	9.33	9.7	1	9.33	9.7

(B) 2 Terminal Systems - 1 Converter per Pole

System	2013				2014				Average to 2014				
	Pole		Bipole		Pole		Bipole		Years	Pole		Bipole	
	f_p	d_p	f_b	d_b	f_p	d_p	f_b	d_b		f_p	d_p	f_b	d_b
Square Butte	3.00	13.6	1.50	5.4	2.25	10.0	1.00	3.6	24	2.71	10.8	0.65	4.3
CU	0.25	0.2	0.50	4.7	0.75	1.2	0.50	4.1	24	1.58	5.1	0.27	2.1
Gotland 2 & 3	1.00	88.5	0.00	0.0	1.00	2.9	0.00	0.0	26	0.40	36.3	0.21	1.7
Fenno-Skan 1 (1)	3.50	6.6	-	-	4.50	7.2	-	-	25	2.66	25.7	-	-
Fenno-Skan 2 (1)	2.50	3.6	-	-	0.00	0.0	-	-	3	1.17	6.3	-	-
Rihand-Dadri	1.00	44.3	1.00	0.5	1.00	18.6	0.00	0.0	18.6	3.14	57.4	0.78	1.2
SACOI (2)	2.33	3.2	-	-	1.67	2.4	-	-	22	4.11	2.8	-	-
New Zealand Pole 2 (3)	8.50	1.8	-	-	2.50	2.2	-	-	23	1.98	3.1	-	-
New Zealand Pole 3 (3)	-	-	-	-	1.00	2.3	-	-	1	1.00	2.3	-	-

System	2013				2014				Average to 2014				
	Pole		Bipole		Pole		Bipole		Years	Pole		Bipole	
	f_p	d_p	f_b	d_b	f_p	d_p	f_b	d_b		f_p	d_p	f_b	d_b
Kontek (1)	0.50	1.4	-	-	0.00	0.0	-	-	12	1.08	8.3	-	-
SwePol (1)	5.00	1.7	-	-	2.50	3.9	-	-	12	3.83	17.8	-	-
Kii Channel	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	14	0.11	123.2	0.00	0.0
Malaysia-Thailand (1)	2.00	7.6	-	-	5.50	18.7	-	-	7.3	4.21	10.6	-	-
Grita (1)	1.00	1.5	-	-	2.00	5.3	-	-	11	2.32	25.9	-	-
Talcher-Kolar	0.75	12.9	0.50	1.2	1.00	0.6	0.00	0.0	9	3.00	6.3	0.22	7.5
EstLink 1 (1)	2.50	15.7	-	-	4.50	75.8	-	-	2	3.50	54.4	-	-
EstLink 2 (1)	-	-	-	-	1.50	4.3	-	-	1	1.50	4.3	-	-
NorNed (1)	0.50	1243.7	-	-	1.00	9.0	-	-	6	1.42	94.7	-	-
SAPEI	0.50	4.4	0.00	0.0	0.25	8.4	0.50	18.4	2	0.38	5.7	0.25	18.4
Caprivi (1)	4.00	1.4	-	-	5.00	2.8	-	-	2	4.50	2.2	-	-
Ballia-Bhiwadi	2.25	1.3	0.50	0.3	5.75	4.6	1.50	0.4	3	3.42	3.1	0.67	0.4
Adani	2.75	2.7	0.00	0.0	1.00	1.1	0.00	0.0	2	1.88	2.2	0.00	0.0
BritNed	1.00	19.2	1	2.1	0.75	1.7	0	0.0	2	0.88	11.7	0.50	2.1

(1) Monopolar System (2) Three Terminal Monopolar System (3) One Pole

(C) 2 Terminal Systems - Two or More Converters per Pole

System	Converter		Pole		Bipole	
	f_c	d_c	f_p	d_p	f_b	d_b
2013						
Nelson River BP1	2.17	12.0	1.75	4.8	0.50	3.1
Nelson River BP2	1.88	4.4	0.50	3.1	0.50	0.3
Hokkaido-Honshu	0.00	0.0	0.50	4.6	0.00	0.0
Itaipu BP1	1.38	20.8	0.25	3.3	0.00	0.0
Itaipu BP2	0.13	9.1	0.25	0.2	0.00	0.0
2014						
Nelson River BP1	2.67	15.6	1.50	4.0	0.00	0.0
Nelson River BP2	2.13	4.5	1.75	4.7	0.00	0.0
Hokkaido-Honshu	0.00	0.0	0.00	0.0	0.00	0.0
Itaipu BP1	1.38	598.4	0.25	8.7	0.00	0.0
Itaipu BP2	0.75	26.7	0.25	192.1	0.00	0.0

System	Years	Average to 2014					
		f_c	d_c	f_p	d_p	f_b	d_b
Nelson River BP1	19 (2)	2.14	96.0	1.53	2.5	0.15	5.7
Nelson River BP2	26	3.67	15.7	1.81	2.6	0.19	2.8
Hokkaido-Honshu (1)	26 (3)	0.02	23.4	0.37	13.1	0.05	163.1
Itaipu BP1	22	1.22	47.7	0.55	6.8	0.14	1.3
Itaipu BP2	22	1.05	63.3	0.83	7.6	0.09	2.1

(1) Two converters in first pole, one in second pole (2) 10 years bipolar operation (3) 21.8 years bipolar operation

Notes to Table V

f_s = number of station outages per block for back-to-back converter stations per year
f_c = number of converter outages per converter per terminal per year
f_p = number of pole outages per pole per terminal per year
f_b = number of bipole outages per bipole per terminal per year
d_s = average duration of station outages in hours
d_c = average duration of converter outages in hours
d_p = average duration of pole outages in hours
d_b = average duration of bipole outages in hours
block = one independent back-to-back converter circuit consisting of one rectifier and one inverter

Thyristor and IGBT Valve Performance

Data on thyristor and IGBT failure rates are given in Table VI. The table shows the total number of thyristor/IGBT devices in a system, and the number of failed devices and the associated failure rate in 2013 and 2014 for each of the dc systems for the device failure rate indicates the inherent failure rate of the thyristors and their associated circuitry and the IGBTs.

A device is an individual thyristor (with its associated auxiliary circuits) or IGBT. A number of thyristor or IGBT levels are connected in series to form a valve.

The device failure rate is the ratio of the number of device failures to the total number of thyristors or IGBTs in the system, expressed in percent.

As indicated in Table VI, in most cases, the device failure rate is well below 0.5 percent.

Table VI - Thyristor and IGBT Calendar Failure Rate

System	Total Devices	Number of Failed Devices		Device Failure Rate percent/year	
		2013	2014	2013	2014
Square Butte	6912	13	15	0.19	0.22
Nelson River BP1 (1)	4680	95	1201	2.03	25.7
Nelson River BP2	18432	28	22	0.15	0.12
Hokkaido-Honshu	4008	0	0	0.00	0.00
CU	8640	21	8	0.24	0.09
Gotland 2 & 3	864	0	0	0.00	0.00
Itaipu BP1 (2)	9216	4	176	0.04	1.91
Itaipu BP2	9216	6	0	0.07	0.00
Highgate	432	5	1	1.16	0.23
Virginia Smith	960	0	0	0.00	0.00
Vindhyachal	1152	0	8	0.00	0.69
McNeill	276	1	2	0.36	0.72
Fenno-Skan 1	1584	0	0	0.00	0.00
Fenno-Skan 2	1560	0	0	0.00	0.00
Rihand-Dadri	4608	2	1	0.04	0.02
SACOI (3)	1344	4	1	0.30	0.07
New Zealand Pole 2	1584	0	0	0.00	0.00
New Zealand Pole 3	1248	-	0	-	0.00
Sakuma	672	0	0	0.00	0.00
Kontek	1728	0	0	0.00	0.00
Chandrapur	2592	7	6	0.27	0.23
Minami-Fukumitsu	672	0	0	0.00	0.00
SwePol	792	0	0	0.00	0.00
Vizag I East-South	1296	0	82	0.00	6.33
Vizag II East-South	864	0	0	0.00	0.00
Kii Channel	2016	0	0	0.00	0.00
Malaysia-Thailand	1152	1	27	0.09	2.34
Grita	1440	0	0	0.00	0.00
Talcher-Kolar	3888	0	3	0.00	0.08
Higashi-Shimizu	672	0	0	0.00	0.00
Basslink	1440	0	1	0.00	0.07
EstLink 1	3672	13	16	0.35	0.44
EstLink 2	1536	-	0	-	0.00
NorNed	2880	25	0	0.87	0.00
Al Fadhili	2592	-	15	-	0.58
SAPEI	3456	0	0	0.00	0.00
Caprivi	2184	6	0	0.27	0.00
Ballia-Bhiwadi	3600	1	11	0.03	0.31
Adani	3600	6	3	0.17	0.08
BritNed	3360	0	4	0.00	0.12

(1) Failures due high leakage current (2) 173 failed as a result of one event (3) Suvereto and Codrongianos terminals only

Commutation Failure Start Rate

A parameter of interest in assessing LCC valve and control system performance is the number of commutation failure starts (CFS). A CFS is the initiation of a distinct and separate commutation failure event. CFS are usually caused by ac system voltage disturbances but may also be caused by events internal to the converter station. CFS are associated with LCC systems. The number of recordable ac faults is an indication of the number of system disturbances. More frequent CFS could be indicative of valve and control system problems. The protocol calls for the inverter end commutation failures to be reported when the ac bus voltage drops below 90 percent.

Table VII records the recordable ac faults, the CFS caused by ac system faults (external) and those initiated by control problems, switching events or other causes (internal) for 2013 and 2014.

Table VII - Recordable AC Faults and Number of Commutation Failure Starts for LCC Systems

System	2013			2014		
	Recordable AC Faults	**Number of CFS External**	**Number of CFS Internal**	**Recordable AC Faults**	**Number Of CFS External**	**Number of CFS Internal**
Square Butte	23	23	29	15	11	28
Nelson River BP1	9	9	52	15	15	162
Nelson River BP2	9	9	0	15	15	0
Hokkaido-Honshu	17	6	0	19	4	0
CU	18	17	11	6	3	8
Gotland 2 & 3	3	0	2	8	8	0
Virginia Smith	0	0	0			
Vindhyachal	0	0	0	0	0	0
Fenno-Skan 1	-	-	-	0	0	0
Fenno-Skan 2	0	0	0	0	0	0
Rihand-Dadri	20	20	0	13	13	0
SACOI	-	94	-	-	36	-
New Zealand Pole 2	2	1	1	1	-	-
New Zealand Pole 3	-	-	-	1	1	0
Kontek	0	0	0	3	3	0
Minami-Fukumitsu	-	4	0	-	17	0
SwePol		14	0		12	0
Kii Channel	13	13	0	14	16	0
Malaysia-Thailand	1	1	0	0	0	0
Talcher-Kolar	52	95	0	89	157	0
Higashi-Shimizu		3	0		6	0
Basslink	9	9	0	21	21	0
NorNed	0	1	0	0	3	0
SAPEI	-	-	-	-	55	-
Adani	43	43	-	80	80	-

(1) Suvereto and Codrongianos terminals

Acknowledgement

The Advisory Group wishes to thank the System Correspondents for providing the annual reports that form the basis for the data in this paper and for their valuable comments and suggestions on improvements to the reporting procedure.

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21, rue d'Artois, F-75008 PARIS
http: //www.cigre.org

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CIGRE 2014

A SURVEY OF THE RELIABILITY OF HVDC SYSTEMS THROUGHOUT THE WORLD DURING 2011 – 2012

By

M.G. BENNETT* **N.S.DHALIWAL** **A. LEIRBUKT**

On behalf of Study Committee B4

SUMMARY

CIGRE Advisory Group B4.04 collects data annually on the reliability performance of HVDC systems in operation throughout the world. This report is a summary of the reliability performance of HVDC systems in operation worldwide during 2011 and 2012. The summary was developed through data prepared by utilities that operate the HVDC systems and submitted to Advisory Group B4.04 of CIGRE Study Committee B4 (HVDC and Power Electronic Equipment). The report contains data on energy availability, energy utilization, forced and scheduled outages and other data in accordance with a reporting protocol developed by the Advisory Group. The report contains statistics on the frequency and duration of forced outages for the years 2011 and 2012 combined with previous data to present a cumulative average of forced outages by frequency and duration covering the years 1988 to 2012. The categories for the cumulative averages are back-to-back stations and two terminal and multi-terminal stations with one and two or more converters per pole.

The data in this report, together with that published in previous reports; provide a continuous record of reliability performance for the majority of HVDC systems in the world since they first went into operation. This now constitutes about 770 system-years of data on thyristor valve systems.

KEYWORDS

Survey - Reliability - HVDC Systems

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mbennett@teshmont.com

Background

Advisory Group B4.04 was formed specifically to assemble and publish data on the reliability and operational experience of HVDC systems in service around the world. The Advisory Group developed definitions for the reliability terms and parameters of prime interest at that time and prepared a protocol for use in collecting and compiling the data.

The protocol has been revised periodically as experience was gained in collecting and interpreting the data [1].

Utilities that operate the HVDC systems collect the data for their systems in accordance with the protocol and prepare a report for each year of operation. These reports are submitted to the Advisory Group where they are compiled into a summary report.

The data were first collected in 1968, covering four dc systems utilizing mercury-arc valves. Data on the first thyristor valve system were compiled in 1972. For this paper full reports were received on 34 thyristor valve systems for 2011 and 36 thyristor valve systems for 2012.

The data contained in this survey report cover operation during 2011 and 2012. Data for earlier years can be found in previous reports [2] [3] and in the list of references given in those reports. The data in this report, together with that of the previous years, provide a continuous record of reliability performance of thyristor HVDC systems for the past 41 years.

HVDC System Reliability Performance

The overall reliability statistics for all systems for which reports were received for 2011 and 2012 are given in Table I. Thirteen of the systems are back-to-back systems and the remainder are point-to-point transmission systems utilizing overhead line and/or cable systems.

Fenno-Skan 2 and Ballia-Bhiwadi provided reports for the first time for the year 2012.

Table I shows the year of commissioning, the maximum continuous transmission capacity, energy availability, energy utilization and energy unavailability for the HVDC systems covered by this report.

Energy Availability is a measure of the amount of energy that could have been transmitted over the HVDC system, except as limited by forced and scheduled outages of converter station equipment and dc transmission lines or cables. Energy Utilization is a measure of the amount of energy actually transmitted. Both parameters are expressed as a percentage based on the maximum continuous capacity of the HVDC system.

It can be seen in Table I that some systems operate at very low energy utilization, i.e. they are used primarily for standby capacity, and other systems at a very high level of energy utilization, i.e. approaching maximum rated capacity.

Table I - System Energy Availability, Energy Utilization and Converter Station Energy Unavailability

System	Year Commis-sioned	Maximum Continuous Capacity MW	Energy Availability percent		Energy Utilization percent (1)		Forced Energy Unavailability percent (2)		Scheduled Energy Unavailability percent	
			2011	2012	2011	2012	2011	2012	2011	2012
Skagerrak 1 & 2	1976/77	550	94.9	93.3	59.6	56.9	0.07	0.19	4.88	6.45
Skagerrak 3	1993	500	94.7	95.2	71.8	73.0	0.43	0.18	4.88	4.59
Square Butte	1977	550	93.6	94.0	78.6	81.5	1.07	0.28	4.25	4.80
Shin-Shinano 1	1977	300	97.7	95.4	20.0	4.4	0.00	0.00	2.26	4.60
Shin-Shinano 2	1992	300	97.0	93.6	53.6	56.9	0.03	0.01	2.95	6.34
Nelson River BP1	1973//04	1855	96.2	95.5	71.9	63.0	0.84	1.10	2.90	3.43
Nelson River BP2	1978/83	2000	96.0	95.4	76.6	68.0	1.41	0.39	2.58	4.23
Hokkaido-Honshu	1979/93	600	97.5	88.2	67.3	24.7	0.04	0.15	2.47	1.67
CU	1979	1138	93.7	98.5	79.3	85.3	0.35	0.46	4.71	1.05
Gotland 2 & 3	1983/87	320	99.4	98.8	20.2	18.9	0.32	0.20	0.30	0.30
Itaipu BP1	1985/86	3150	97.2	96.5	74.9	73.4	0.03	0.09	2.79	3.38
Itaipu BP2	1985/86	3150	98.1	94.6	74.9	73.4	0.03	1.27	1.92	2.79
Highgate	1985	200	97.8	88.8	86.7	82.4	0.04	0.12	2.12	11.13
Virginia Smith	1988	200	94.6	84.1	27.0	9.2	0.01	0.00	5.38	15.94
Konti Skan 2	1988	300	-	95.5	-	70.8	-	0.00	-	3.44
Vindhyachal	1989	500	100.0	99.1	51.8	44.8	0.00	0.27	0.00	0.64
McNeill	1989	150	96.4	97.0	44.7	40.2	0.14	0.00	3.50	3.00
Fenno-Skan 1	1990	500	92.2	62.3	59.6	45.3	2.95	24.66	4.86	13.06
Fenno-Skan 2	2011	830	-	81.0	-	52.2	-	0.30	-	0.10
Rihand-Dadri	1991	1650	99.4	96.8	64.9	64.3	0.43	0.02	0.14	3.18
SACOI (3, 4)	1992	300/300/50	91.4	68.0	80.4	58.2	0.57	0.27	7.12	5.81
New Zealand Pole 2	1992	500	79.2	85.3	43.1	36.8	0.12	0.11	20.64	14.55
Sakuma	1965/93	300	99.9	97.4	21.7	0.4	0.00	0.00	0.12	2.59
Kontek	1998	600	96.2	-	63.2	-	0.04	-	3.77	-
Chandrapur	1998	1000	99.4	99.3	84.4	81.9	0.46	0.14	0.11	0.54
Minami-Fukumitsu	1999	300	100.0	99.8	17.7	16.2	0.00	0.00	0.02	0.17
Vizag I East-South	2000	500	99.9	100.0	34.4	33.5	0.13	0.01	0.00	0.01
Vizag II East-South	2005	500	99.4	99.7	16.9	28.3	0.39	0.08	0.16	0.18
Kii Channel	2000	1400	98.1	96.7	78.4	76.8	0.00	1.38	1.91	1.96
Grita (5)	2001	500	63.5	92.3	50.9	65.2	0.04	0.13	32.12	7.58
Talcher-Kolar	2003	2000	99.1	99.6	91.4	93.5	0.28	0.13	0.67	0.27
Sasaram	2003	500	100.0	99.0	5.9	16.7	0.00	0.05	0.00	0.97
Higashi-Shimizu	2006	300	95.4	100.0	20.8	5.4	0.00	0.00	4.58	0.00
Basslink	2006	500	98.6	99.7	53.4	64.7	0.11	0.07	1.25	0.22
NorNed	2008	700	87.2	97.0	81.6	93.3	0.09	0.38	0.00	2.63
Storebaelt	2010	600	97.5	92.9	46.8	45.8	0.20	0.08	2.30	7.07
Ballia-Bhiwadi	2010	2500	-	98.0	-	17.2	-	0.04	-	1.94

(1) Based on maximum continuous capacity (2) Converter station outages only (3) Three terminal monopole system
(4) Capacity reduced to 150 MW due to cable faults (5) Scheduled outage largely due to cables

Forced Energy Unavailability (FEU) is the amount of energy that could not have been transmitted over the dc system due to forced outages. Only converter station equipment outages are considered, i.e. transmission line and cable outages are excluded.

Scheduled Energy Unavailability (SEU) is the amount of energy that could not have been transmitted over the dc system due to scheduled outages. Although transmission line and cable scheduled outages are included in the data in Table I, it is believed that in most cases the scheduled energy unavailability shown closely approximates that for converter stations only, since most scheduled maintenance on transmission lines and cables is generally conducted concurrently with station maintenance.

Scheduled outages have less impact on the performance of the power system than forced outages since planned outages can usually be taken during periods of reduced system load or when some reduction in transmission capacity can be accepted. Hence scheduled energy unavailability can vary substantially from system to system due to differences in utility maintenance practices and policies, and the requirement for transmission capacity.

Forced Outage Data

Data on forced outages are given in Tables II to V inclusive. In Table II, the data on forced outages are classified into six categories as follows:

AC and Auxiliary Equipment (AC-E)
Valves (V)
Control and Protection (C&P)
DC Equipment (DC-E)
Other (O)
Transmission Line or Cable (TL)

The number of forced outage events and the equivalent forced outage hours within each category, together with the totals for each dc system are shown in Table IIA for 2011 and Table IIB for 2012. Equivalent forced outage hours is the sum of the actual forced outage hours after the outage duration has been adjusted for the percentage of reduction in capacity due to the outage. For example, for an outage of one pole of a bipole system (50% loss of capacity) that lasted two hours, the equivalent outage hours would be one hour.

Table II A - Number of Forced Outages and Equivalent Outage Hours - 2011

System	AC-E		V		C & P		DC-E		O		TL		TOTAL	
	No.	Hours	No.	Hours	No.	Hours	No.	Hours	No.	Hours	No.	Hours	No.	Hours
Skagerrak 1 & 2	2	0.2	0	0.0	0	0.0	3	4.3	1	1.7	1	13.9	7	20.1
Skagerrak 3	5	37.4	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	5	37.4
Square Butte	6	26.0	4	24.2	0	0.0	1	41.8	2	2.1	3	96.7	16	190.7
Shin-Shinano 1	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Shin-Shinano 2	0	0.0	1	2.7	0	0.0	0	0.0	0	0.0	0	0.0	1	2.7
Nelson River BP1	7	40.9	13	4.9	6	3.2	2	3.1	4	21.7	4	4.0	36	77.8
Nelson River BP2	3	9.1	15	91.0	4	21.7	2	1.7	2	0.2	1	0.1	27	123.8
Hokkaido-Honshu	0	0.0	0	0.0	1	3.5	0	0.0	0	0.0	0	0.0	1	3.5
CU	2	7.9	1	1.5	0	0.0	1	20.5	2	0.4	1	105.6	7	135.8
Gotland 2 & 3	1	21.3	0	0.0	2	6.6	0	0.0	1	0.1	0	0.0	4	28.0
Itaipu BP1	2	0.1	2	2.2	0	0.0	0	0.0	1	0.0	0	0.0	5	2.4
Itaipu BP2	0	0.0	3	3.0	0	0.0	0	0.0	0	0.0	0	0.0	3	3.0
Highgate	2	2.3	0	0.0	0	0.0	0	0.0	2	1.4	0	0.0	4	3.7
Virginia Smith	0	0.0	0	0.0	0	0.0	0	0.0	1	1.3	0	0.0	1	1.3
Vindhyachal	0	0.0	0	0.0	1	0.1	0	0.0	0	0.0	0	0.0	1	0.1
McNeill	0	0.0	0	0.0	2	6.0	0	0.0	1	6.5	0	0.0	3	12.4
Fenno-Skan 1	1	164.8	0	0.0	10	89.6	0	0.0	2	3.9	0	0.0	13	258.2
Rihand-Dadri	1	37.3	0	0.0	1	0.1	0	0.0	1	0.6	2	0.7	5	38.7
SACOI	7	42.1	0	0.0	3	7.9	0	0.0	0	0.0	10	80.1	20	130.2
New Zealand Pole 2	1	2.7	0	0.0	2	7.6	1	0.3	0	0.0	0	0.0	4	10.7
Sakuma	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Kontek	2	1.1	1	1.4	1	0.9	0	0.0	0	0.0	0	0.0	4	3.3
Chandrapur	8	5.5	2	0.1	12	34.9	0	0.0	0	0.0	0	0.0	22	40.4
Minami-Fukumitsu	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Vizag I East-South	1	1.2	3	10.4	0	0.0	0	0.0	0	0.0	0	0.0	4	11.6
Vizag II East-South	1	0.6	1	33.8	0	0.0	0	0.0	0	0.0	0	0.0	2	34.4
Kii Channel	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Grita (1)	0	0.0	0	0.0	1	3.3	0	0.0	0	0.0	1	377.9	2	381.2
Talcher-Kolar	1	4.0	2	1.0	0	0.0	2	19.3	0	0.0	2	0.4	7	24.7
Sasaram	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Higashi-Shimizu	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Basslink	1	2.5	1	7.1	0	0.0	0	0.0	0	0.0	0	0.0	2	9.7
NorNed (1)	0	0.0	0	0.0	0	0.0	1	7.9	0	0.0	1	1110.2	2	1118.1
Storebaelt	0	0.0	2	2.6	3	15.1	0	0.0	0	0.0	0	0.0	5	17.7

(1) Major time caused by cable failure

The protocol makes a distinction for reporting events that caused a reduction in transmission capacity but did not lead to a forced trip of the HVDC equipment. Table IIC summarizes the number of capacity reductions included in the statistics reported in Table IIA and Table IIB. Capacity reductions are not included in the values reported in Tables III to V, as these outages did not lead to a forced trip of equipment.

Table II B - Number of Forced Outages and Equivalent Outage Hours - 2012

System	AC-E		V		C & P		DC-E		O		TL		TOTAL	
	No.	Hours	No.	Hours	No.	Hours	No.	Hours	No.	Hours	No.	Hours	No.	Hours
Skagerrak 1 & 2	1	0.3	1	1.8	2	14.5	0	0.0	0	0.0	1	1.8	5	18.4
Skagerrak 3	1	6.8	2	4.0	0	0.0	0	0.0	3	5.3	1	2.3	7	18.4
Square Butte	13	22.2	1	1.5	0	0.0	0	0.0	2	1.0	1	78.2	17	102.8
Shin-Shinano 1	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Shin-Shinano 2	1	1.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	1	1.0
Nelson River BP1	11	65.6	10	4.7	9	15.5	9	8.8	6	1.6	2	0.2	47	96.3
Nelson River BP2	3	10.7	9	14.0	6	9.2	0	0.0	1	0.1	4	0.3	23	34.2
Hokkaido-Honshu (1)	0	0.0	0	0.0	1	13.4	0	0.0	0	0.0	2	877.8	3	891.2
CU	1	0.2	1	38.7	1	1.1	0	0.0	2	0.1	0	0.0	5	40.0
Gotland 2 & 3	0	0.0	0	0.0	1	17.2	0	0.0	0	0.0	1	57.7	2	74.8
Itaipu BP1	1	1.6	6	2.6	0	0.0	2	3.3	0	0.0	0	0.0	9	7.5
Itaipu BP2	1	0.1	0	0.0	2	3.6	2	107.6	0	0.0	1	113.3	6	224.6
Highgate	2	6.4	0	0.0	1	1.1	0	0.0	1	2.8	0	0.0	4	10.2
Virginia Smith	1	0.1	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	1	0.1
Konti Skan 2	1	0.3	0	0.0	0	0.0	0	0.0	0	0.0	1	91.8	2	92.0
Vindhyachal	9	23.6	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	9	23.6
McNeill	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Fenno-Skan 1 (2)	2	26.6	1	2069.0	5	14.4	1	50.6	0	0.0	0	0.0	9	2160.5
Fenno-Skan 2 (1)	0	0.0	0	0.0	2	0.4	1	23.7	1	1.8	2	1633.6	6	1659.5
Rihand-Dadri	1	0.9	0	0.0	2	0.8	0	0.0	0	0.0	0	0.0	3	1.7
SACOI (1)	1	1.6	0	0.0	1	21.9	0	0.0	0	0.0	7	2271.2	9	2294.6
New Zealand Pole 2	0	0.0	0	0.0	1	1.6	2	7.7	0	0.0	0	0.0	3	9.3
Sakuma	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Chandrapur	12	6.2	1	2.2	7	3.6	0	0.0	0	0.0	0	0.0	20	12.0
Minami-Fukumitsu	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Vizag I East-South	1	0.6	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	1	0.6
Vizag II East-South	1	7.4	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	1	7.4
Kii Channel	0	0.0	1	120.8	0	0.0	0	0.0	0	0.0	0	0.0	1	120.8
Grita	1	0.9	4	6.4	2	4.5	0	0.0	0	0.0	0	0.0	7	11.8
Talcher-Kolar	3	4.5	3	5.2	2	1.4	1	0.1	0	0.0	0	0.0	9	11.1
Sasaram	8	4.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	8	4.0
Higashi-Shimizu	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Basslink	3	6.2	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	3	6.2
NorNed	2	15.2	0	0.0	1	12.2	1	5.8	0	0.0	0	0.0	4	33.2
Storebaelt	0	0.0	0	0.0	9	6.8	0	0.0	0	0.0	0	0.0	9	6.8
Ballia-Bhiwadi	2	0.2	3	2.5	3	0.3	1	0.6	0	0.0	0	0.0	9	3.7

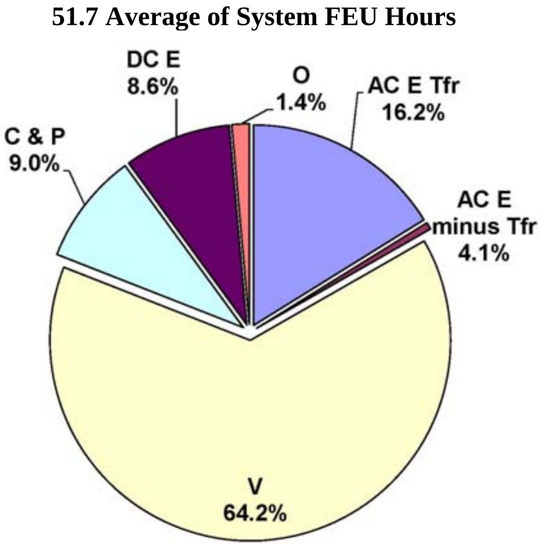
(1) Major time caused by cable failure (2) Major time caused by fire in valve hall

Table II C - Number of Capacity Reductions and Equivalent Outage Hours (1)

System	2012	
	No.	Hours
Fenno-Skan 2	2	0.4
NorNed	1	9.4
Storebaelt	2	0.2

(1) Outage statistics included in Tables II A and II B.

Figure 1 shows a summary of the average FEU of all reporting systems for 2011 and 2012 on the basis of the major equipment categories as reported in Table IIA and Table IIB but excluding outages due to transmission lines/cables. In Figure 1 the major AOH was associated with a valve hall fire in one system. Figure 1 can be compared to Figure 2 that shows the average FEU by category of all reporting systems from 1983 to 2010. The contribution to FEU by converter transformer failures is significantly reduced over this reporting period as compared to past results. Reports on converter transformer failures are available through CIGRE [4, 5].


51.7 Average of System FEU Hours

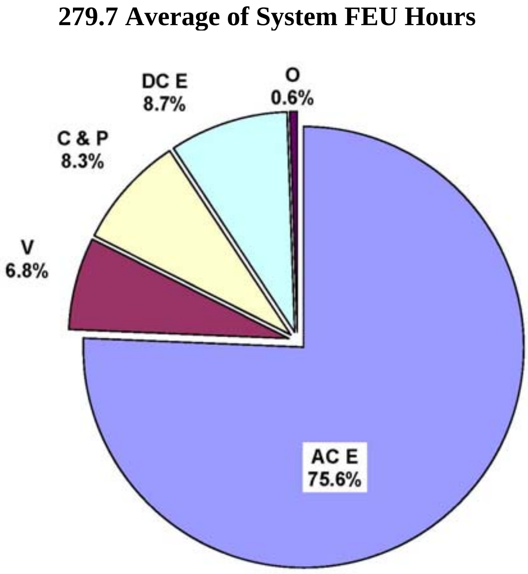

279.7 Average of System FEU Hours

Figure 1
Breakdown of Average FEU By Equipment Category of All Reporting Thyristor HVDC Systems (2011-2012)

Figure 2
Breakdown of Average FEU By Equipment Category of All Reporting Thyristor HVDC Systems (1983-2010)

Table III gives data for each of the dc systems on the number of forced outages that have occurred and the average duration of the outages. It should be noted that the durations are given in actual lapsed time, i.e. the capacity lost during the outage is not considered. Some outages may be converter (valve group) outages, some pole outages and others bipole outages.

Table III - Average Actual Outage Duration for Converter Station Forced Outages

System	2011		2012	
	No. of Outages (1)	Average Duration Hours	No. of Outages (1)	Average Duration Hours
Skagerrak 1 & 2	6	2.1	4	7.3
Skagerrak 3	5	7.5	6	2.7
Square Butte	13	9.9	16	2.9
Shin-Shinano 1	0	0.0	0	0.0
Shin-Shinano 2	1	2.7	1	1.0
Nelson River BP1	32	13.3	45	12.4
Nelson River BP2	26	17.3	19	6.0
Hokkaido-Honshu	1	7.0	1	26.7
CU	6	10.1	5	16.0
Gotland 2 & 3	4	13.2	1	34.3
Itaipu BP1	5	1.9	9	3.2
Itaipu BP2	3	4.0	5	44.4
Highgate	4	0.9	4	2.6
Virginia Smith	1	1.2	1	0.0
Konti Skan 2	-	-	1	0.2
Vindhyachal	1	0.2	9	5.2
McNeill	3	4.1	0	0.0
Fenno-Skan 1	13	19.9	9	240.1
Fenno-Skan 2	-	-	2	12.8
Rihand-Dadri	3	25.1	3	1.1
SACOI	10	6.1	2	11.7
New Zealand Pole 2	4	2.7	3	3.1
Sakuma	0	0.0	0	0.0
Kontek	4	0.8	-	-
Chandrapur	22	3.6	20	1.2

System	2011		2012	
	No. of Outages (1)	Average Duration Hours	No. of Outages (1)	Average Duration Hours
Minami-Fukumitsu	0	0.0	0	0.0
Vizag I East-South	4	2.9	1	0.6
Vizag II East-South	2	17.2	1	7.4
Kii Channel	0	0.0	1	241.5
Grita	1	3.3	7	1.7
Talcher-Kolar	5	6.2	9	2.5
Sasaram	0	0.0	8	0.5
Higashi-Shimizu	0	0.0	0	0.0
Basslink	2	4.8	3	2.1
NorNed	1	7.9	3	8.0
Storebaelt	5	3.5	7	1.0
Ballia-Bhiwadi	-	-	9	0.8

(1) Excludes capacity reduction

Table IV shows the number of bipole, pole and converter forced outages that occurred in 2011 and 2012 for all the bipolar systems. The total number of all outages for each of the systems is also shown.

Table IV - Number of Forced Outages by Severity

System	Number of Forced Outages							
	2011				2012			
	All Outages	Bipole Outages	Pole Outages	Converter Outages	All Outages	Bipole Outages	Pole Outages	Converter Outages
Skagerrak 1 & 2	6	0	6	-	4	1	3	-
Square Butte	13	7	6	-	16	2	14	-
Nelson River BP1	32	0	3	29	45	0	8	37
Nelson River BP2	26	0	5	21	19	1	3	15
Hokkaido-Honshu	1	0	1	0	1	0	1	0
CU	6	0	6	-	5	0	5	-
Gotland 2 & 3	4	1	3	-	1	0	1	-
Itaipu BP1	5	0	0	5	9	0	2	7
Itaipu BP2	3	0	0	3	5	1	3	1
Rihand-Dadri	3	1	2	-	3	0	3	-
Kii Channel	0	0	0	-	1	0	1	-
Talcher-Kolar	5	1	4	-	9	0	9	-
Ballia-Bhiwadi	-	-	-	-	9	0	9	-

Table V shows the frequency and duration of forced outages for 2011 and 2012 and the cumulative average of this data from 1988 to 2012. The table is presented in three parts: (A) covers back-to-back converter stations, (B) covers systems with one converter per pole, and (C) covers systems with two or more series-connected converters per pole. The data for systems reporting operation of less than one full year has been adjusted in these tables to an annual basis for the year, but the cumulative average is calculated for the actual total reporting period.

Table V(A) shows the average frequency (number) and average duration of station outages for back-to-back converter stations on a "per block" basis.

Tables V(B) and V(C) show the average frequency and duration of converter, pole and bipole outages for two-terminal and multi-terminal systems. The frequency of outages is given on a per terminal basis.

It is believed that the data in Table V will be useful to planning engineers involved with reliability studies of HVDC systems.

Table V – Frequency and Duration of Forced Outages

(A) Back-to-Back Converter Stations

System	Blocks	2011		2012		Average to 2012		
		f_s	d_s	f_s	d_s	Years	f_s	d_s
Shin-Shinano 1	1	0.00	0.0	0.00	0.0	23	0.48	0.9
Shin-Shinano 2	1	1.00	2.7	1.00	1.0	19.6	0.31	0.7
Highgate	1	4.00	0.9	4.00	2.6	24	2.25	5.9
Virginia Smith	1	1.00	1.2	1.00	0.0	23	5.83	43.6
Vindhyachal	2	0.50	0.2	4.50	5.2	16	4.84	11.0
McNeill	1	3.00	4.1	0.00	0.0	19	6.95	6.6
Sakuma	1	0.00	0.0	0.00	0.0	19.5	0.51	24.8
Chandrapur	2	11.00	3.6	0.00	0.0	9.3	5.03	36.0
Minami-Fukumitsu	1	0.00	0.0	0.00	0.0	6.0	0.00	0.0
Vizag I East-South	1	4.00	2.9	1.00	0.6	9.0	5.44	83.1
Vizag II East-South	1	2.00	17.2	1.00	7.4	5.8	1.71	4.9
Sasaram	1	0.00	0.0	8.00	0.5	6	5.17	1.5
Higashi-Shimizu	1	0.00	0.0	0.00	0.0	6	0.17	1.9

(B) 2 Terminal Systems - 1 Converter per Pole

System	2011				2012				Average to 2012				
	Pole		Bipole		Pole		Bipole		Years	Pole		Bipole	
	f_p	d_p	f_b	d_b	f_p	d_p	f_b	d_b		f_p	d_p	f_b	d_b
Skagerrak 1 & 2	1.50	2.1	0.00	0.0	0.75	8.4	0.50	4.0	24	1.50	15.1	0.15	1.4
Skagerrak 3 (1)	2.50	7.5	-	-	3.00	2.7	-	-	19	1.82	325.7	-	-
Square Butte	1.50	11.5	3.50	8.5	3.50	3.1	1.00	1.4	22	2.72	10.7	0.59	4.2
CU	1.50	10.1	0.00	0.0	1.25	16.0	0.00	0.0	22	1.68	5.2	0.25	1.7
Gotland 2 & 3	0.75	16.6	0.50	3.0	0.25	34.3	0.00	0.0	24	0.35	34.1	0.23	1.7
Konti Skan 2 (1)	-	-	-	-	0.50	0.2	-	-	17	2.71	3.6	-	-
Fenno-Skan 1 (1)	6.50	19.9	-	-	4.50	240.1	-	-	23	2.54	28.3	-	-
Fenno-Skan 2 (1)	-	-	-	-	1.00	12.8	-	-	1	1.00	12.8	-	-
Rihand-Dadri	0.50	37.4	0.50	0.6	0.75	1.1	0.00	0.0	16.6	3.40	58.3	0.81	1.3
SACOI (2)	3.33	6.1	-	-	0.67	11.7	-	-	20	4.32	2.8	-	-
New Zealand Pole 2 (3)	2.00	2.7	-	-	1.50	3.1	-	-	21	1.64	3.5	-	-
Kontek (1)	2.00	0.8	-	-	-	-	-	-	10	1.25	8.6	-	-
Kii Channel	0.00	0.0	0.00	0.0	0.25	241.5	0.00	0.0	12	0.13	123.2	0.00	0.0
Grita (1)	0.50	3.3	-	-	3.50	1.7	-	-	9	2.50	28.9	-	-
Talcher-Kolar	1.00	3.3	0.50	17.8	2.25	2.5	0.00	0.0	7	3.61	6.3	0.21	9.5
NorNed (1)	0.50	7.9	-	-	1.50	8.0	-	-	4	1.75	24.9	-	-
Storebaelt (1)	2.50	3.5	-	-	3.50	1.0	-	-	2.33	2.57	2.0	-	-
Ballia-Bhiwadi (4)	-	-	-	-	2.25	0.8	0.00	0.0	1.0	2.25	0.8	0.00	0.0

(1) Monopolar System (2) Three Terminal Monopolar System (3) One Pole (4) 0.5 years one pole; 0.5 years bipole

(C) 2 Terminal Systems - Two or More Converters per Pole

System	Converter		Pole		Bipole	
	f_c	d_c	f_p	d_p	f_b	d_b
2011						
Nelson River BP1	2.42	14.4	0.75	2.7	0.00	0.0
Nelson River BP2	2.63	19.3	1.25	8.9	0.00	0.0
Hokkaido-Honshu	0.00	0.0	0.25	7.0	0.00	0.0
Itaipu BP1	0.63	1.9	0.00	0.0	0.00	0.0
Itaipu BP2	0.38	4.0	0.00	0.0	0.00	0.0
2012						
Nelson River BP1	3.08	14.8	2.00	1.1	0.00	0.0
Nelson River BP2	1.88	6.5	0.75	4.9	0.50	2.2
Hokkaido-Honshu	0.00	0.0	0.25	26.7	0.00	0.0
Itaipu BP1	0.88	3.9	0.50	0.6	0.00	0.0
Itaipu BP2	0.13	0.3	0.75	73.6	0.50	0.8

System	Years	Average to 2012					
		f_c	d_c	f_p	d_p	f_b	d_b
Nelson River BP1	17 (2)	2.10	107.1	1.51	2.2	0.12	6.9
Nelson River BP2	24	3.81	16.2	1.86	2.5	0.19	3.1
Hokkaido-Honshu (1)	24 (3)	0.02	23.4	0.39	13.6	0.05	163.1
Itaipu BP1	20	1.20	17.7	0.58	6.8	0.15	1.3
Itaipu BP2	20	1.11	64.8	0.89	5.2	0.10	2.1

(1) Two converters in first pole, one in second pole (2) 8 years bipolar operation (3) 19.8 years bipolar operation

Notes to Table V

f_s = number of station outages per block for back-to-back converter stations per year
f_c = number of converter outages per converter per terminal per year
f_p = number of pole outages per pole per terminal per year
f_b = number of bipole outages per bipole per terminal per year
d_s = average duration of station outages in hours
d_c = average duration of converter outages in hours
d_p = average duration of pole outages in hours
d_b = average duration of bipole outages in hours
block = one independent back-to-back converter circuit consisting of one rectifier and one inverter

Thyristor Valve Performance

Data on thyristor failure rates are given in Table VI. The table shows the number of thyristor levels, the number of thyristor cells and the number of failed cells in 2011 and 2012 for each of the dc systems for which data were provided.

A thyristor cell is an individual thyristor (with its associated auxiliary circuits) whereas a thyristor level is the assembly of one or more thyristor cells connected in parallel including the associated circuits. A number of thyristor levels are connected in series to form a valve.

The thyristor cell failure rate is the ratio of the number of cell failures to the total number of cells in the system, expressed in percent. The thyristor cell failure rate indicates the inherent failure rate of the thyristors and their associated circuitry.

As indicated in Table VI, in most cases, the thyristor cell failure rate is well below 0.5 percent.

Table VI - Thyristor Calendar Failure Rate

System	Total Levels	Total Cells	Number of Failed Cells		Thyristor Cell Failure Rate percent/year	
			2011	2012	2011	2012
Skagerrak 1 & 2	6912	6912	21	20	0.30	0.29
Skagerrak 3	1440	1440	1	0	0.07	0.00
Square Butte	6912	6912	22	11	0.32	0.16
Shin-Shinano 1	3744	5184	0	0	0.00	0.00
Shin-Shinano 2	672	672	0	0	0.00	0.00
Nelson River BP1	4680	4680	5	22	0.11	0.47
Nelson River BP2	9216	18432	68	56	0.37	0.30
Hokkaido-Honshu	4008	4008	1	1	0.02	0.02
CU	8640	8640	29	198 (2)	0.34	2.29
Gotland 2 & 3	864	864	0	0	0.00	0.00
Highgate	432	432	0	2	0.00	0.46
Virginia Smith	960	960	0	0	0.00	0.00
Konti Skan 2	1152	1152	-	0	-	0.00
Vindhyachal	1152	1152	0	0	0.00	0.00
McNeill	276	276	13	6	4.71	2.17
Fenno-Skan 1	1584	1584	0	0	0.00	0.00
Fenno-Skan 2	1560	1560	-	0	-	0.00
Rihand-Dadri	4608	4608	5	4	0.11	0.09
SACOI (1)	1344	1344	0	1	0.00	0.07
New Zealand Pole 2	1584	1584	0	0	0.00	0.00
Sakuma	672	672	0	0	0.00	0.00
Chandrapur	2592	2592	4	7	0.15	0.27
Minami-Fukumitsu	672	672	0	0	0.00	0.00
Vizag I East-South	1296	1296	5	0	0.39	0.00
Vizag II East-South	864	864	0	0	0.00	0.00
Kii Channel	2016	2016	0	5	0.00	0.25
Grita	1440	1440	0	1	0.00	0.07
Talcher-Kolar	3888	3888	8	2	0.21	0.05
Sasaram	1200	1200	0	8	0.00	0.67

System	Total Levels	Total Cells	Number of Failed Cells		Thyristor Cell Failure Rate percent/year	
			2011	2012	2011	2012
Higashi-Shimizu	672	672	0	0	0.00	0.00
Basslink	1440	1440	0	0	0.00	0.00
NorNed	2880	2880	0	0	0.00	0.00
Storebaelt	1440	1440	2	1	0.14	0.07
Ballia-Bhiwadi	3600	3600	-	2	-	0.06

(1) Suvereto and Codrongianos terminals only (2) Failed as a result of one event

Commutation Failure Start Rate

A parameter of interest in assessing valve and control system performance is the number of commutation failure starts (CFS). A CFS is the initiation of a distinct and separate commutation failure event. CFS are usually caused by ac system voltage disturbances but may also be caused by events internal to the converter station. The number of recordable ac faults is an indication of the number of system disturbances. More frequent CFS could be indicative of valve and control system problems. The protocol calls for the inverter end commutation failures to be reported when the ac bus voltage drops below 90 percent.

Table VII records the recordable ac faults, the CFS caused by ac system faults (external) and those initiated by control problems, switching events or other causes (internal) for 2011 and 2012.

Table VII - Recordable AC Faults and Number of Commutation Failure Starts (CFS)

System	2011			2012		
	Recordable AC Faults	Number of CFS External	Number of CFS Internal	Recordable AC Faults	Number Of CFS External	Number of CFS Internal
Skagerrak 1 & 2	3	13	1	0	19	5
Skagerrak 3	3	10	0	0	13	1
Square Butte	5	9	5	26	37	14
Shin-Shinano 1	5	2	0	2	1	0
Shin-Shinano 2	22	9	0	10	4	0
Nelson River BP1	17	16	104	18	18	512
Nelson River BP2	17	16	0	18	18	0
Hokkaido-Honshu	15	1	0	32	3	0
CU	4	6	1	8	9	3
Gotland 2 & 3	5	5	0	8	8	0
Highgate	40	32	8	-	-	-
Virginia Smith	0	0	0	0	0	0
Konti Skan 2	-	-	-	0	0	0
Vindhyachal	0	0	0	0	0	0
McNeill	0	0	0	-	-	-
Fenno-Skan 1	0	0	0	0	0	0
Fenno-Skan 2	-	-	-	0	0	0
Rihand-Dadri	66	66	0	-	-	-
SACOI (1)	-	-	45	-	-	61
New Zealand Pole 2	3	2	8	-	-	-
Sakuma	1	1	0	0	0	0
Chandrapur	-	0	0	-	0	0
Minami-Fukumitsu	-	1	0	-	2	0
Kii Channel	11	11	1	26	26	7
Talcher-Kolar	57	113	0	86	157	0
Higashi-Shimizu	0	0	0	0	0	0
Basslink	4	4	0	8	8	0
NorNed	0	8	0	0	7	0
Storebaelt	0	21	0	0	9	0

(1) Suvereto and Codrongianos terminals

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