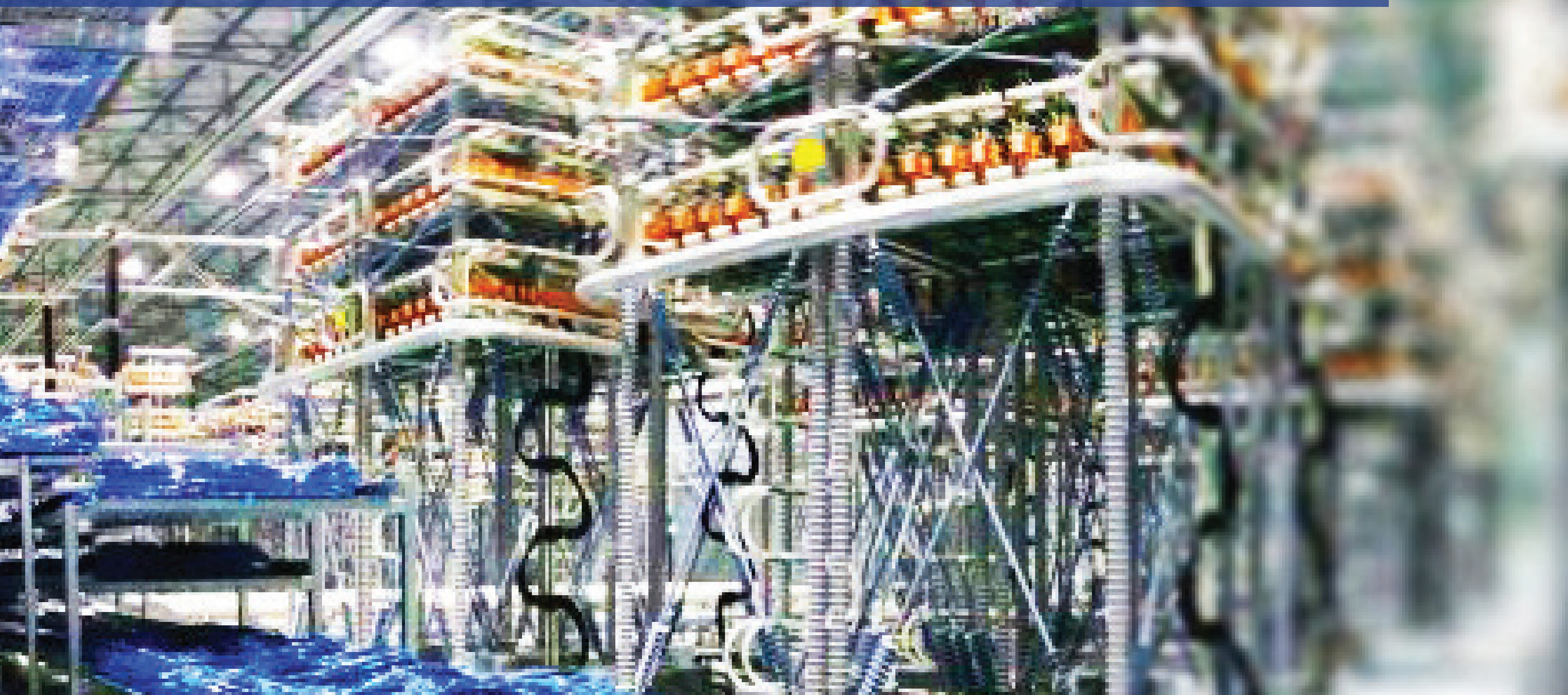
B4 TECHNICAL BROCHURE

DC systems and power electronics



HVDC transformer failure survey results from 2013 to 2020

Reference: 859

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For power system expertise

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TECHNICAL BROCHURE

HVDC transformer failure survey results from 2013 to 2020

AG B4.04

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Executive summary

CIGRE Study Committee B4, Advisory Group AG B4-04 collects data on the performance of HVDC systems around the world every year. This data is then analyzed and the results are presented in a paper at the biannual conference in Paris. The objective of the work is to provide system planners, HVDC designers and system operators with performance of HVDC system as a whole and the performance of various HVDC system components in terms of failure rate and duration. This Advisory Group also identifies the poor performance of any component and makes recommendations of any work that should be performed by the study committee B4, either on its own or jointly with other committees.

In early 1990, poor performance of converter transformers was identified as one such subject. In order to improve the performance of the converter transformers, a Joint task force JTF 12/14.10-01 was formed. The JTF 12/14.10-01 conducted a transformer failure survey for the years up to 1990 and published its results in 1994 [1] with several recommendations. Another Task force JTF B4.04/A2-1 was formed in 2000 to review if the performance of the transformers had improved. JTF B4.04/A2-1 conducted another survey of transformer failures from 1991 to 2002 and published its report in 2004 [2]. As per recommendation of TF B4.04/A2-1, Joint Working Group JWG A2/B4-28 was formed. One of the recommendations of the JWG was that AG B4-04 should continue to conduct transformer failure survey on a regular basis. AG B4-04 conducted five more surveys every two years between 2003 and 2012. The results of these surveys were published in CIGRE Technical Brochure 617, April 2015 [4].

AG B4-04 conducted four more surveys between 2013 and 2020. This report provides detailed information collected on converter transformer failures from 2013 to 2020. The report only provides the data and no specific recommendations are made.

The last two surveys also included reports from VSC systems whereas all previous surveys were related to LCC systems only.

Contents

Figures and Tables

1. Introduction

CIGRE Study Committee B4, Advisory Group (AG B4.04) collects reliability performance data on HVDC systems in commercial service every year. The information is compiled and presented at the CIGRE Paris biennial technical sessions and is used for planning, design, construction and operation of HVDC systems.

The results of the performance survey had shown that converter transformers failures were the largest contributor to the forced energy unavailability of the HVDC systems. The first joint task force formed to investigate the reasons for converter transformer failures was JTF 12/14.10-1. The JTF 12/14.10-1 conducted a survey of transformer failures up to 1990. The second task force TF B4.04/A2-1 to further monitor the performance of converter transformers was formed in 2000. This task force conducted a survey of transformer failures from 1991-2002. As per recommendation of TF B4.04/A2-1 a joint working group JWG A2/B4-28 was formed. AG B4-04 conducted three transformer failure surveys for JWG A2/B4-28 which included failures for the years 2003 to 2008 (results were included in JWG A2/B4-28 report [3]. AG B4-04 conducted five more surveys every two years between 2003 and 2012. The results of these surveys were published int CIGRE Technical Brochure 617, April 2015 [4].

AG B4-04 conducted four more surveys between 2013 and 2020. This technical brochure provides detailed information collected on HVDC transformer failures from 2013 to 2020.

The last two surveys also included reports from VSC systems whereas all previous surveys were related to LCC system only.

2. Failure surveys

The surveys were conducted by a questionnaire sent to each system owner. A copy of the latest questionnaire is included in Appendix A. This report only includes information collected in surveys conducted from 2013 to 2020. The details of the previous surveys can be found in references [1], [2], [3] and [4].

Apart from the general pertinent data, a description of the failure was requested, together with the apparent cause(s) as identified by the utility and/or by the manufacturer and the relationship, if any, with the factory type/routine tests performed on that unit. The survey did not cover external bushing flashovers related to pollution.

2.1 Failure definitons

For the purpose of the surveys, the failures were defined as actual and preventive.

Actual failure

A failure was considered to be actual, if removal of a unit from service was required due to the damage of the active part.

Prevent failure

A failure was considered as preventive if the unit did not actually fail but was taken out of service to repair active parts following diagnostic testing such as dissolved gas-in-oil analysis (DGA), high insulation power factor, or failure of similar unit(s).

2.2 Failure categories and causes

The JTF 12/14.10-01 report classified the failures in the category of failure with the most likely cause as follows:

Category of failure	**Most likely cause**
A- Bushings	1- Mechanical
B- Valve Windings	2- Dielectric
C- AC Winding	3- Thermal
D- Static Shield	4-Induced Current
E- On-Load Tap Changer (LTC)	5- Operational Error
F- Core and Magnetic Shields	6- Unknown
G-Internal Connections and Leads	

For purpose of consistency the subsequent reports followed the same format.

3. 2015 failure survey (Failures in 2013 and 2014)

This transformer failure survey was conducted in Mar, 2015. This was the eighth survey conducted on the failure of converter transformers. The users were requested to report all actual and prevent failures for the years 2013 and 2014 . A total of 37 systems reported.

The results of the survey were as following (Appendix B):

Number of system responses received	= 37
Number of system reporting no failures	= 34
Number of systems reporting actual failures	= 3
Number of systems reporting prevent failures	= 1
Number of systems reporting multiple failures	= 2
Number of actual failures of transformers	= 7
Number of prevent failures of transformers	= 3

Table 3-1 shows the summary of the failures.

3.1 Failure descriptions

All reporting systems were requested to submit descriptions of the failures, the outage time and the corrective action taken. The following describes the failures by category.

3.1.1 Bushings – 3 actual

Cross Channel- England: 3 Actual failures

The system continues to have Converter Transformer LV bushing failures. The bushing tap voltages are monitored to give an indication that the condenser foils are shorting due to electrical breakdown of the ERIP insulation. There have been three forced outages due to bushing insulation faults since November 2013.

3.1.2 Valve windings – 1 actual + 3 prevent

Itaipu: 1 Actual failures, 3 Prevent Failures

Inverter station (Ibiuna)

April 30, 2013

A 300 kV Converter transformer – Serial number #57857 was taken out of service due to a failure in the winding C2 (DC side);

Outage time - 72 hours.

In addition, as part of the ongoing refurbishing program, two 600 kV units were repaired at the rectifier station. One 300 kV unit was repaired at the inverter station.

Table 3-1 - Summary of Transformer Failures in 2013 and 2014

Summary of Transformer Failures 2013 - 2014							
Category →	**A Bushings**	**B Valve Wdgs**	**C AC Wdgs**	**D Static Shields**	**E LTC**	**F Core & Magn Shields**	**G Internal Conn**
Mech 2					1-Itaipu 1-UK		
Dielect 5+3P	3-UK	1-Itaipu 3P-Itaipu			1-Rihand-Dadri		
Thermal							
Ind. Curr							
Operator							
Unknown							
Total 7+3P	**3**	**1+3P**			**3**		

3.1.3 Tap changer – 3 actual

Itaipu Inverter station (Ibiuna) - 1 Actual Failure

300 kV Converter transformer – Serial number #7197233 - Failure of the converter transformer due to a problem in the on load tap changer.

Outage time - 72 hours

Cross Channel- England: 1 Actual failure

On load tap changer diverter/selector switch: One unit failed due to the failure of a drive shaft pin. The pin failed on the shaft between the common drive to the selector and the diverter after the take-off gearing mechanism for the diverter switch drive. The failure of this drive shaft caused the selector to continue to be moved with no subsequent diverter switch operation. A flashover occurred in the Selector compartment. The other 7 units on the Sellindge site had their drive pins checked and were verified as OK.

Rihand-Dadri: 1 Actual failure

July 25, 2013

One transformer failed due to tap changer diverter failure. Unit was replaced with spare.

Outage time: 159 hrs.

4. 2017 failure survey (failures in 2015 and 2016)

This survey was conducted in Mar, 2017. This was the ninth survey conducted on the failure of converter transformers. The users were requested to report all actual and prevent failures for the years 2015 and 2016.

The results of the survey were as following (Appendix C):

Number of system responses received	= 38
Number of system reporting no failures	= 29
Number of systems reporting actual failures	= 5
Number of systems reporting prevent failures	= 2
Number of systems reporting multiple failures	= 5
Number of actual failures of transformers	= 11
Number of prevent failures of transformers	= 4

Table 4-1 shows the summary of the failures.

4.1 Failure descriptions

All reporting systems were requested to submit descriptions of the failures, the outage time and the corrective action taken. The following describes the failures by category:

4.1.1 Bushings – 3 actual + 1 prevent

Nelson River 2: 1 Prevent failure

Sep 12, 2016 - Dorsey T32S was taken out of service to replace two valve side bushings due to high gassing levels.

Outage time: 91.70 Hours.

Square Butte: 1 Actual failure

Mar 3, 2016 - Transformer failed due to line side bushing failure.

Outage time: 2616 hours

Cahora Bassa - Apollo: 2 Actual Failures

June 24, 2015 - Red phase transformer failed due to DC side bushing failure.

Outage time: 216 hours.

Feb 29, 2016 - Blue phase transformer failed due to DC side bushing failure.

Outage time: 211 hours.

4.1.2 Valve windings : 1 actual + 3 prevent

Itaipu: 2 Prevent Failures

Rectifier (Foz)

One 300 kV transformer transformer was repaired.

Inverter (Ibiuna)

One 600kV transformer transformer was repaired.

The repairs consisted of new AC and DC windings.

Table 4-1- Summary of Transformer Failures in 2015 and 2016

Summary of Transformer Failures 2015 - 2016							
Category -→	A Bushings	B Valve Wdgs	C AC Wdgs	D Static Shields	E LTC	F Core & Magn Shields	G Internal Conn
Mech							
Dielect 9 + 2P	1-S.Butte 2-Apollo	1-R-Dadri 2P-Itaipu	2-Un Named 1-V. Chal 1-S.Butte		1-Apollo		
Thermal 2 + 2P	1P-NR2	1P-NR1					2-Chandra BtB
Ind. Curr							
Operator							
Unknown							
Total 11 + 4P	3 + 1P	1 + 3P	4		1		2

Rihand-Dadri: 1 Actual failure

One transformer failed due to failure of Delta valve winding. Unit was replaced with spare.

Outage time: 87 hrs.

Nelson River 1: 1 Prevent failure

Sep 24, 2016- Dorsey T12B was taken out of service due to high gassing levels and was replaced with spare.

Outage time: 882.33 hours

4.1.3 AC windings : 4 actual

Square Butte: 1 Actual failure

July 17, 2015 - Transformer failed due to failure of AC winding. It is suspected that metal pieces from a previous pump failure may have been embedded into the winding.

Outage time: 336 hours.

Vindhyachal: 1 Actual failure

One transformer failed due to failure of AC winding. Unit was replaced with spare.

Outage time: 283 hrs.

Un-named system (due to legal issues): 2 Actual failures

Two transformers failed due to failure of AC winding.

Outage time: 72 hours each.

4.1.4 Tap Changer : 1 Actual

Cahora Bassa - Apollo: 1 Actual Failure

July 9. 2016 - Blue phase transformer failed due to diverter switch failure.

Outage time: 65 hours.

4.1.5 Internal Connection : 2 Actual

Chandrapore BtB: 2 Actual failure

Two transformers failed due to failure of connection lead to bushing. Units were repaired.

Date	Time	Sr No of Unit
28/12/15	4:48	1622/04
02/12/16	5:35	1622/05

Outage time: 216 hrs each time.

5. 2019 failure survey (Failures in 2017 and 2018)

This transformer failure survey was conducted in Apr, 2019. The systems were requested to report all actual and prevent failures for the years 2017 and 2018.

This was the first survey that included both LCC and VSC systems.

The results of the survey are as following :

LCC Systems (Appendix D)

Number of system responses received	= 50
Number of systems reporting no failures	= 44
Number of systems reporting actual failures	= 6
Number of systems reporting prevent failures	= 0
Number of systems reporting multiple failures	= 0
Number of actual failures of transformers	= 6
Number of prevent failures of transformers	= 0

VSC Systems

Number of VSC responses received	= 15
Number of systems that reported failures	= 0

The following 15 VSC systems participated in the survey.

- Zambezi (Caprivi)
- EASTlINK 1
- France Spain INELFE 1 & 2
- NordBalt
- Troll_A
- Troll_B
- Troll_C
- Troll_D
- Borwin1
- Borwin2
- Dolwin1
- Dolwin2
- Helwin1
- Helwin2
- Sylwin1

Only failures in LCC systems were reported

Table 5-1 shows the summary of the failures in years 2017 and 2018 in LCC systems.

Table 5-1 - Summary of Transformer Failures in 2017 and 2018

Summary of Transformer Failures (LCC) 2017 - 2018							
Category -→	**A Bushings**	**B Valve Wdgs**	**C AC Wdgs**	**D Static Shields**	**E LTC**	**F Core & Magn Shields**	**G Internal Conn**
Mech							
Dielect 5	1 - IPP	1-R.Dadri	1-Vyborg 1-V. Chal 1-Skagrreak 2				
Thermal							
Ind. Curr							
Operator 1					1-Itaipu		
Unknown							
Total 6	**1**	**1**	**3**		**1**		

5.1 Failure Descriptions (LCC Systems)

There were 6 actual failures reported and no prevent failures reported. All failures were on systems that had been in service for more than 25 years. The following describes the failures by category:

5.1.1 Bushing : 1 Actual

IPP

On February 18, 2017, a transformer failure occurred in pole 2, phase C at the Adelanto station. The failure was on the AC bushing. This was one of the original transformers in operation since 1985.

The unit was replaced with spare.

5.1.2 Valve Windings : 1 Actual

Rihand -Dadri

Valve winding – Delta

Year 2018

During operation Pole-2 B phase converter transformer tripped on Gas relay and oil pressure trip. After tripping low voltage testing was carried out and found fault in Delta limb winding

Outage time: 92.33 hrs,

5.1.3 AC Windings : 3 Actual

Skagerrak 2

AC Winding - Short circuit to earth in phase L3

Inside the transformer there had been a flash over from the torus on the high voltage bushing L3 to the core. The transformer was repaired at site, energized and in operation again from 08.05.2018.

Failure date: 06.04.2018

Outage time – 32 days (768 hrs)

Vindhyachal

AC winding R- phase

Vindhyachal HVDC Block#2 tripped at 14:55 Hrs of 26.11.2017 on north side converter transformer B2T12 "Differential Protection Trip". On LV test, it was found that R-phase of transformer was drawing high magnetizing current.

No spare was available at the time of failure.

Outage time: 11376 hrs or 16 months

Vyborg

400 kV transformer TV-2 phase B short circuit occurred due to the breakdown of the transformer insulation during long-term operation

March 3, 2017 – AC winding

Outage time – 500 hours

5.1.4 Tap Changer – 1 Actual

ITAIPU BP1 – Ibiuna station : 1 Actual

Transformer #7197230 failed on March 17, 2017 at 08:01am.

Cause of failure: On load tap changer diverter/selector switch

This transformer has undergone repair service and had been in service since April 04, 2015.

Two metal rods required only for commissioning test after the repair service were found inside the on-load tap changer compartment.

Outage time: 376.35 Hours

6. 2021 failure survey (failures in 2019 and 2020)

This survey was conducted in Apr. 2021. This was the tenth survey conducted on the failure of HVDC transformers. The users were requested to report all actual and prevent failures for the years 2019 and 2020. This survey also included VSC systems.

The results of the survey are as following:

LCC Systems (Appendix E)

Number of system responses received	= 39
Number of systems reporting no failures	= 36
Number of systems reporting actual failures	= 3
Number of systems reporting prevent failures	= 0
Number of systems reporting multiple failures	= 1
Number of actual failures of transformers	= 4
Number of prevent failures of transformers	= 0

VSC Systems (Appendix F & G)

Number of VSC responses received	= 19
Number of systems that reported failures	= 0

No failure were reported on VSC systems

Table 6-1 shows the summary of the failures in years 2019 and 2020.

6.1 Failure descriptions (LCC SYSTEMS)

There were 4 actual failures reported and no prevent failures reported. Three failures were on systems that had been in service for more than 25 years. One failure was on a system installed in 2015

The following describes the failures by category

6.1.1 Bushings – 1 actual

Chandrapore BtB – 1 Actual

Year 2020 – Failure of HV Bushing

On 22nd Feb 2020 at 23:29 hrs, 400/93 kV, 234 MVA Pole 1 B phase GE make transformer tripped on inter zone protection due to failure of B phase HV bushing.

Neutral LA was damaged due to impact from failure of HV bushing. Two radiators were struck by porcelain from blasted HV bushing, thereby causing oil leakages.

Fire occurred due to failure of HV bushing and same was controlled by emulsifier / hydrant systems. All cables were damaged due to fire. Transformer MB and OLTC driving mechanism box was also damaged due to fire.

The unit was replaced by spare unit. The outage time was 11 days (264 hrs.)

Table 6-1 - Summary of Transformer Failures in 2019 and 2020

Summary of Transformer Failures (LCC) 2019 - 2020							
Category -→	**A Bushings**	**B Valve Wdgs**	**C AC Wdgs**	**D Static Shields**	**E LTC**	**F Core & Magn Shields**	**G Internal Conn**
Mech							
Dielect 3	1-Chandrapore BtB	1-R.Dadri	1-Chandrapore				
Thermal 1							1-Rio Madeira BP2
Ind. Curr							
Operator							
Unknown							
Total 4	**1**	**1**	**1**				**1**

6.1.2 Valve windings: 1 actual

Rihand -Dadri

Valve winding – Delta

Year 202

During operation Pole-2 B phase converter transformer tripped on Gas relay and oil pressure trip. After tripping low voltage testing was carried out and found fault in Delta limb winding.

The unit was replaced by spare.

Outage time: 102.42 hrs,

6.1.3 Ac windings : 1 actual

Chandrapore BtB – 1 Actual

Year 2019- Failure of AC Winding

On 15th December 2019 at 09:58 hrs, 400/93 kV, 234 MVA Alstom make, Pole 1 West Side "Y" Phase Convertor Transformer tripped on Differential, Instantaneous Phase Fault & PRD protection.

The Maximum current on HV side was observed as IHV = 6.191 kA. During Failure of converter transformer approx. 25-30kL oil spilled out through different cracked joints of main tank and discharged through underground sump. Both PRD operated however the tank body has cracked from different points and ruptured the top welded joint of Main tank on OLTC mechanism side.

The Header to cooler unit has shredded and came out from Main Tank gate valve Flange and Inspection window near OLTC mechanism side.

From the internal inspection it appeared that the fault has occurred in the HV winding and fault built up huge pressure in the transformer tank which resulted in bulging of Main Tank and cracking of vertical stiffeners.

OLTC leads were intact however divertor assembly has been displaced due to huge pressure inside the tank.

The unit was replaced by spare unit. The outage time was 21 days (494 hrs.)

6.1.4 Internal connection – 1 actual

Rio Madeira BP2 – Araraquara Station

Failure date: Jan 18 ,2019

Internal connection failure

The corona shield on the tank side of the AC line bushing had fallen from its mounting location and was hanging from the top edge of the lead cable (just below the cable connector with the bushing terminal). One of the two conductors of the lead cable has partially damaged due to medium energy discharges between the corona shield and the conductor.

The problem has been detected due to a substantial increase of acetylene gas in the unit's chromatographic analysis.

The failure was caused by an assembly error, in the type or routine tests it was not possible to identify that the bushing shield screws were loose.

Unit was repaired at site.

Outage time: 264 hours

7. Failure survey discussion

7.1 Introduction

This section provides analysis of the failure data reported for the failures between years 2013 and 2020.

The failure rate is calculated as follows:

$$FailureRate = \frac{Total\ Number\ of\ Units\ Failed}{\sum(Number\ of\ Units\ in\ Service \times Years\ in\ Service)}$$

Due to insufficient technical data made available in these surveys, for the purpose of this analysis it was not possible to determine the actual causes of individual failures nor was it possible to identify some general trends. The failures were classified as described in section 2.2.

Sections 7.2 to 7.7 summarize the failure rate as per following:

- Failure rate by survey reports
- Failure rate based on year of commissioning
- Failure rate based on transformer tank configuration.
- Failure rate by component
- Failure rate by cause
- Failure rate by transformer MVA rating.

7.2 Failure rate by survey reports

Figure 7-1 shows the Converter Transformer failure rate history based on the combined data of surveys carried out in the following periods:

- 1972 to 1990
- 1991 to 2002
- 2003 to 2004 (reported in 2005)
- 2005 to 2006 (reported in 2007)
- 2007 to 2008 (reported in 2009)
- 2009 to 2010 (reported in 2011)
- 2011 to 2012 (reported in 2013)
- 2013 to 2014 (reported in 2015)
- 2015 to 2016 (reported in 2017)
- 2017 to 2018 (reported in 2019)
- 2019 to 2020 (reported in 2021)

It can be observed in Figure 7-1 that following a reduced failure rate in the period from 1991 to 2002, there was a significant increase in the period from 2003 to 2006 (2005 and 2007 report). The failure rate in last three reports (2009 to 2019) decreased to same level as the rate recorded for the period 1991 to 2002. Failure rate in 2019 and 2021 reports is less than 0.006. In addition majority of these failures are on systems more than 25 years old.

This finding is encouraging, indicating a potential effect of the latest version of the IEC 61378-3 [6] standard as well as a strong action that followed an upsurge of the HVDC Converter Transformers caused to a full or a partial extent by corrosive oil.

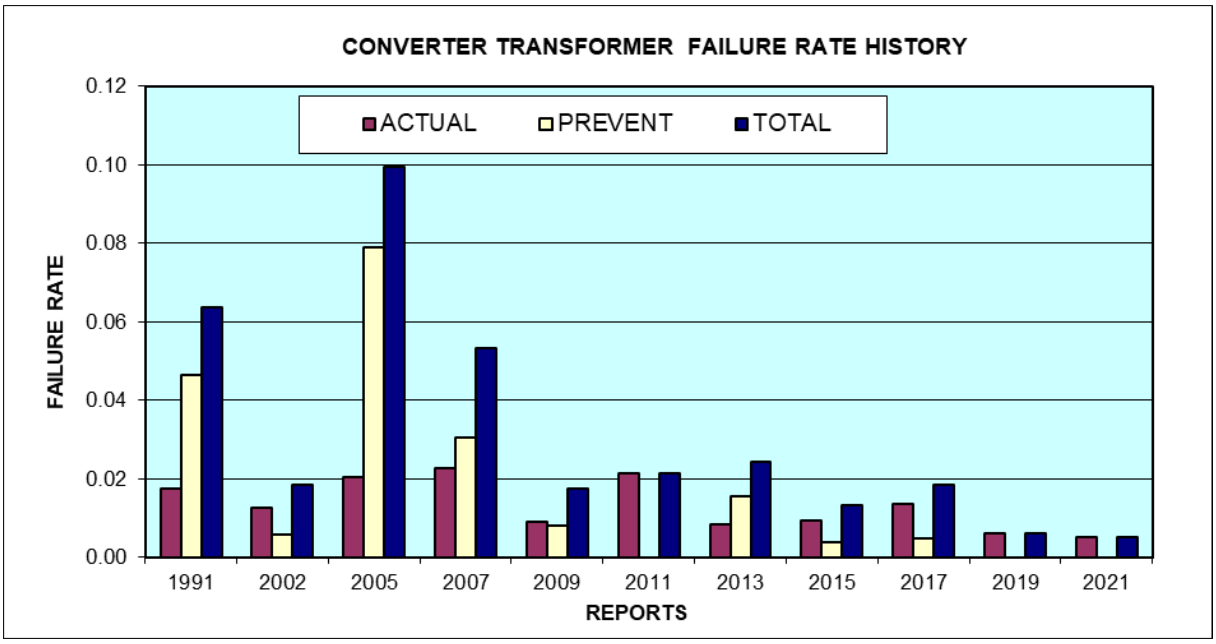

Figure 7-1- Failure Rate for the period 1972 to 2020

7.3 Failure rate by year of commissioning

When the failure rate is plotted against the year of commissioning it can be seen (Figure 7-2.) that for the systems installed before 1985 the failure rate was low but an increase could be observed for transformers placed in service in the period from 1985 to 1990. This was a period when transformers of ratings of over 300 MVA were first installed and a higher DC voltage (500 kV and 600 kV) was first introduced.

The failure rate of the systems commissioned between 1991 and 1995 continues to be low. This is the period when no large rating HVDC systems were installed but only a number of small projects were commissioned

Figure 7-2 also shows that the failure rate of the systems commissioned between 1996 and 2000 increased. Most of the systems installed during this period were of higher ratings requiring installation of large Converter Transformers.

For systems installed between 2001 and 2010, the preventive failure rate is slightly higher than the actual failure rate. This phenomenon could be attributed to the following;

a. Modern transformers are now more closely monitored (e.g. on-line gas monitoring).
b. Most of the systems are designed with spare transformers being readily available so that when a potential problem occurs the unit can be changed before the actual failure.

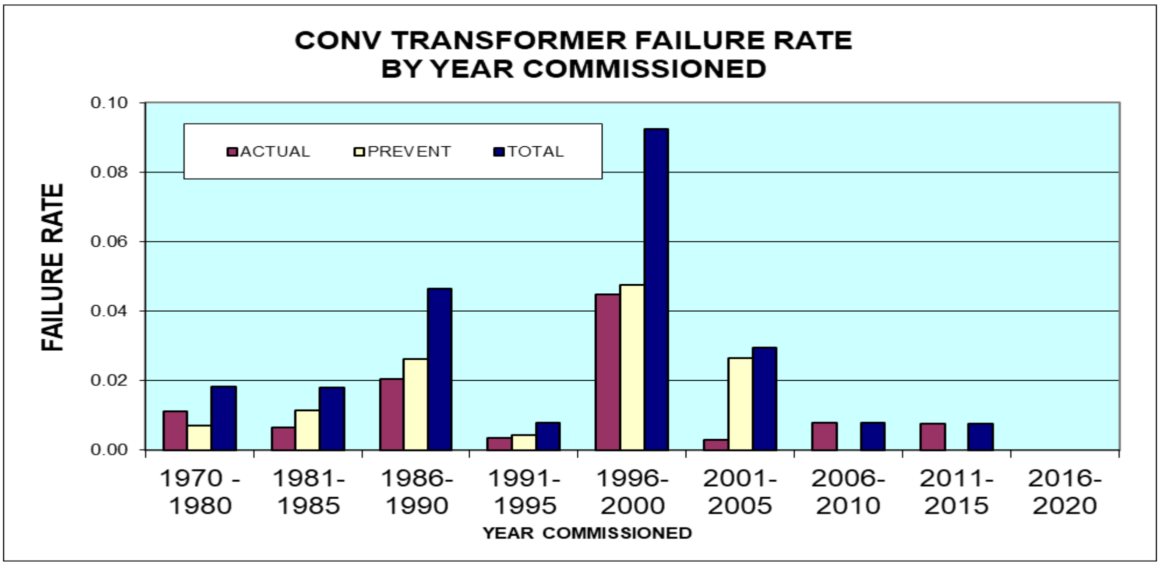

Figure 7-2 - Converter Transformer failure rate by year of commissioning

Table 7-1 shows the detailed information about the systems that were commissioned after 2005.

Table 7-1 – Transformer Failures on Systems Commissioned Between 2006 and 2020

Year Commissioned	Number of Systems	Transformer Years	Total Failures	Failure Rate
2006-2010	11	631	5	0.0079
2011-2015	6	396	3	0.0076
2016-2020	6	336	0	0
Combined 2006-2020	**23**	**1363**	**8**	**0.0059**

The failure rate of the systems installed after 2005 is very low. So far, the systems installed between 2016 and 2020 have not reported any failures. Five out of six systems installed between 2016 and 2020 are at 800 kV level.

Another possible contributing factor to the reduction of the actual failure rate in this period is the effect of the modified IEC Standard 61378-3 [6] issued in 2001.

7.4 Failure rate by configuration

In this section, the failures have been classified by the winding configuration of the converter transformer in a single tank. The winding configurations are defined as follows:

- 1-2 Single phase, two winding (line winding, star or delta valve windings)
- 1-3 Single phase, three winding (line winding, star valve winding & delta valve winding)

- 1-4 Single phase, four winding (line winding, star valve winding , delta valve winding & tertiary winding)
- 3-2 Three phase, two winding (3 phase line windings , 3 phase star or delta valve windings)
- 3-3 Three phase, three winding (3 phase line windings, 3 phase star & 3 phase delta valve windings)

Figure 7-3 shows the failure rate of the various configurations for all the survey reports combined. Figure 7-4 shows the failure rate of the various configurations by the year of commissioning.

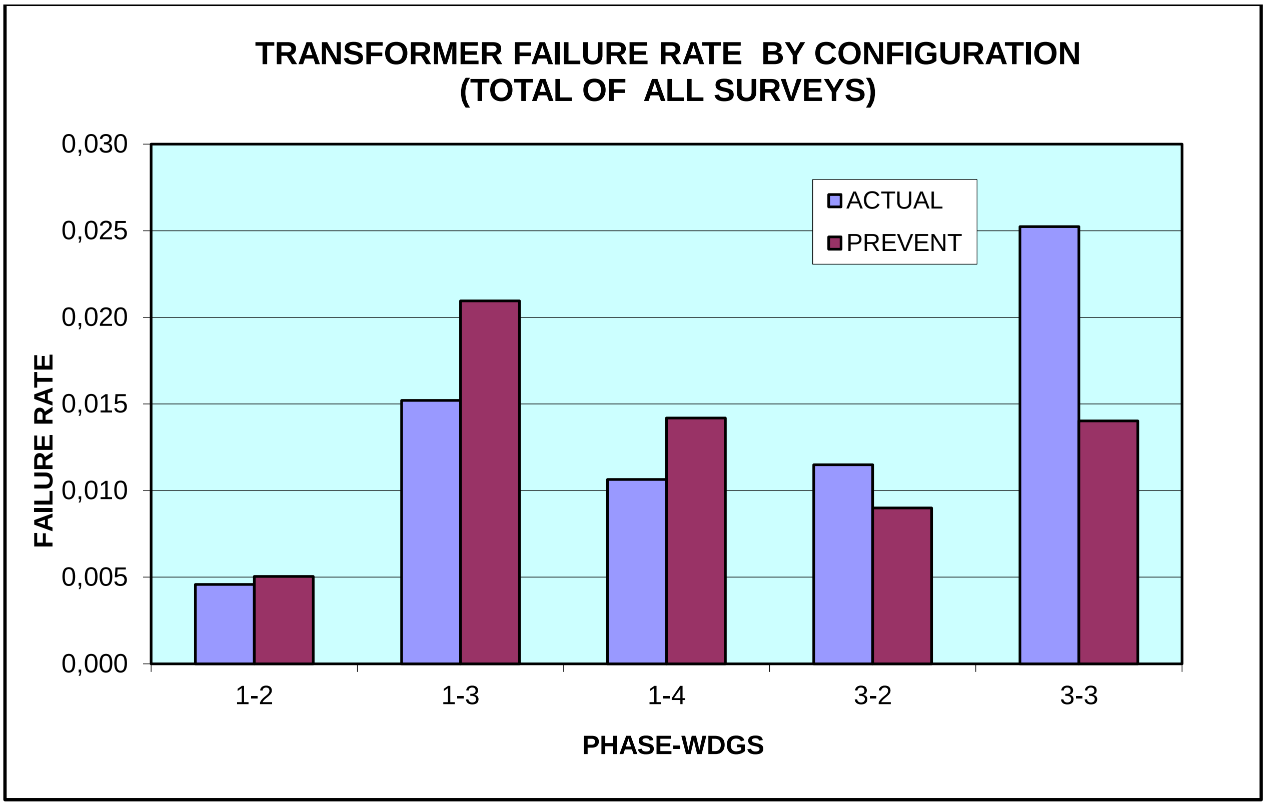

Figure 7-3 - Failure rate of transformers by configuration

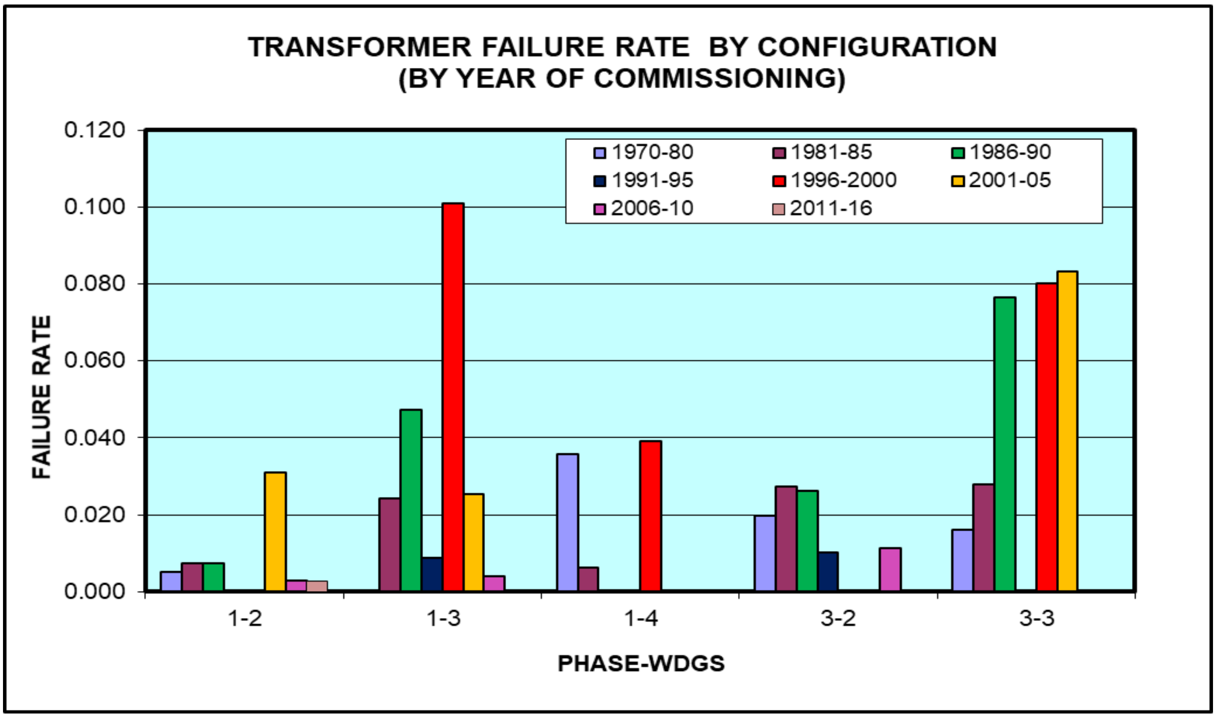

Figure 7-4 - Failure rate by configuration and by year of commissioning

Figures 7-3 and 7-4 show that **most failures occurred in single phase units containing line winding and star and delta valve windings**. These transformers were of the ratings 275 MVA and above and installed in the HVDC systems of 500 kV or above. This increased failure rate could be associated with the complex winding insulation and lead exit design.

7.5 Failures by component

Figures 7-5, 7-6 and 7-7 show the failures by component for various reporting periods.

These figures include all reported failures irrespective of the in service date.

Figure 7-5 show failures reported in JTF 12-14/10-01 report [1] up to year 1990. The three major causes of failure during this period were as following;

Core	44%
Connections	21%
DC winding	16%

JTF 12-14/10-01 made several recommendations for changes to test procedure and design review process. See ref [1] for more information.

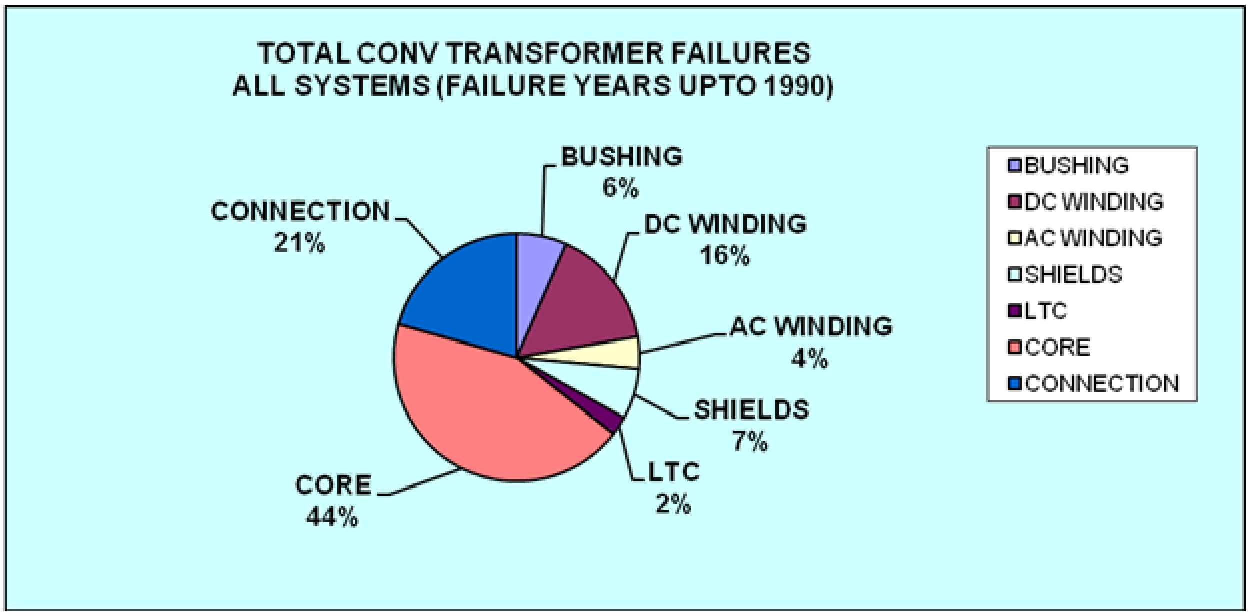

Figure 7-5- Failure by components up to 1990

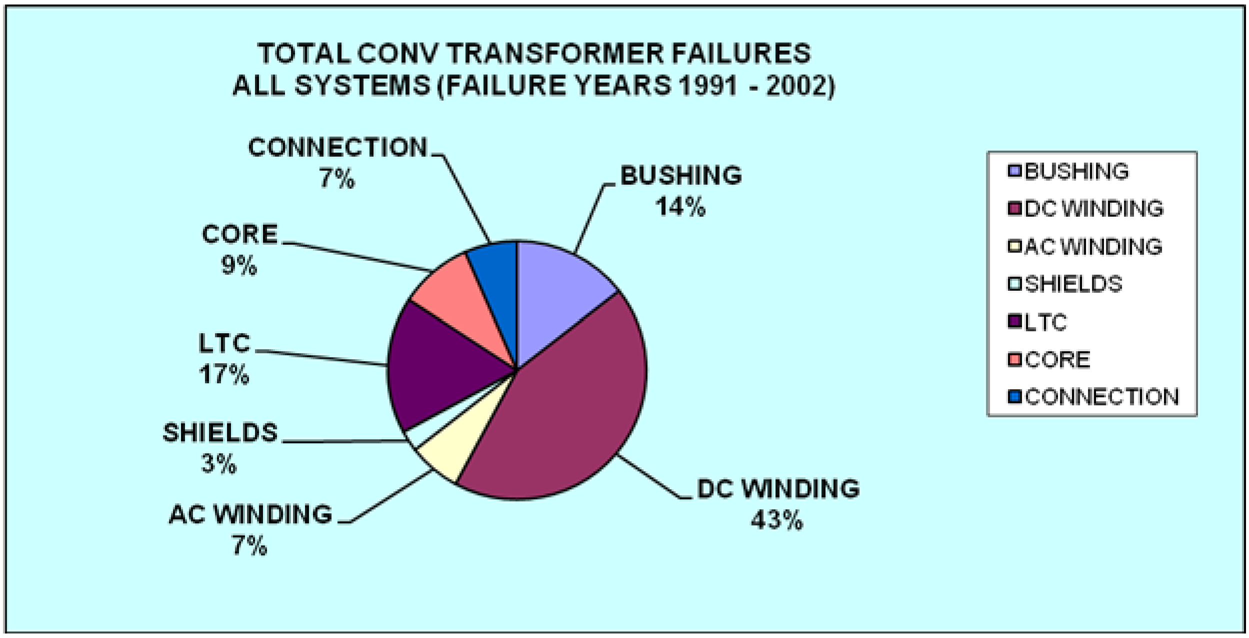

Figure 7-6 – Failure by component 1991 to 2002

Figure 7-6 show all failures reported in JTF B4.04/A2-1 report [2] from 1991 to 2002. The three major causes of failure during this period were as following;

DC winding	43%
Tap Changer	17%
Bushing	14%

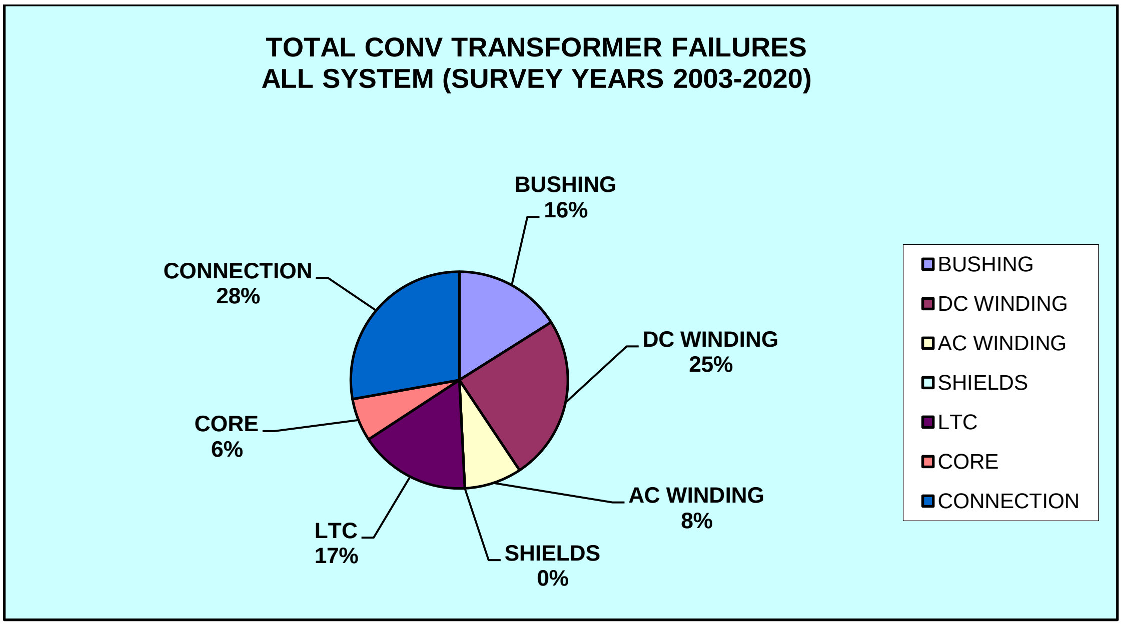

Figure 7-7 – Failure by component 2003 -2020 (All systems)

Figure 7-7 shows the total failures (actual and preventive) by components, for the period from 2003 to 2020 (combined). Figure 7-7 includes all the systems that reported irrespective of the year of installation.

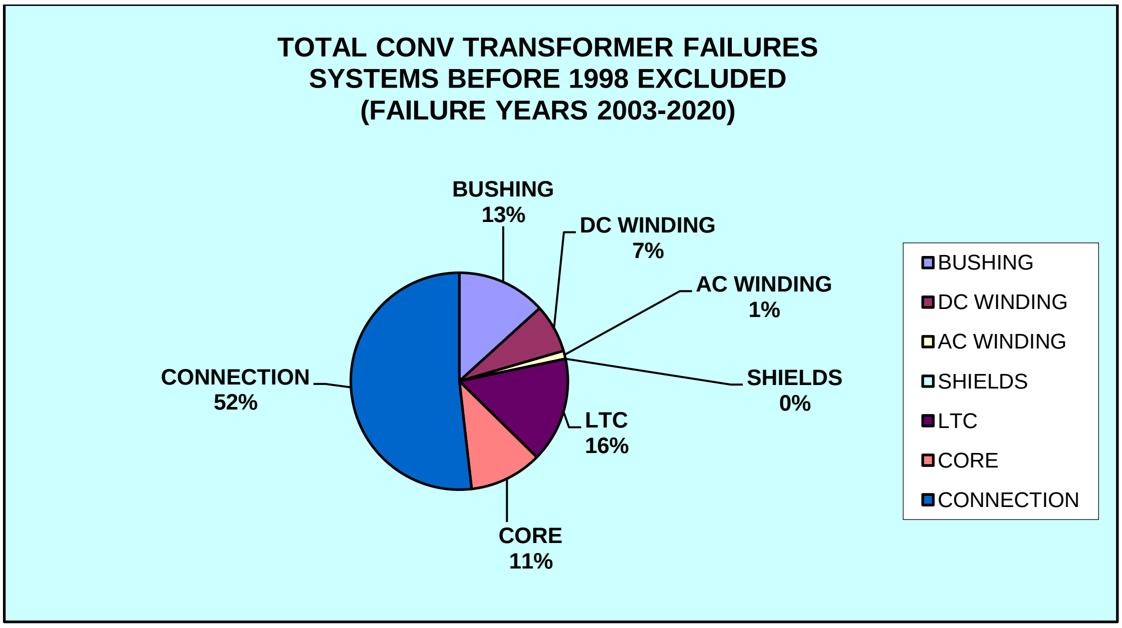

Figure 7-8 - Failures by component 2003-2020 excluding systems commissioned before 1998

Figure 7-8 shows the total failures (actual and preventive) by component for the systems installed in 1998 or later. The percentage failures by components are as following

Connections	52%
LTC	16%
Bushings	13%
Core	11%
DC Winding	7%
AC Winding	1%
Shields	0%

Figures 7-7 and figure 7-8 show that failures in the connections, valve winding and OLTCs were the most dominant contributors to the failure statistics when all years of commissioning are taken into account while the failure in the connections remained to be the most dominant factor for the systems installed since 1998.

While the multiple failures in the valve windings were significantly affected by the quality of oil i.e. the presence of the semiconducting Copper Sulfide resulting from the application of the corrosive oil and the failures in the OLTC could partly be attributed to the transient phenomena associated with the converter operation, the increasing failure rate in the connection could be attributed to the increased design complexity and increasing voltage levels.

7.6 Failures by cause

Failure of converter transformers by probable cause is shown in figure 7-9. The data is divided into four reporting periods as following:

- Upto 1990 As reported by JTF 12/14 10-1
- 1991-2002 As reported by JTF B4.04/A2-1
- 2003 -2012 All surveys by JWG A2/B4-28 and AG B4-04
- 2013- 2020 All surveys by AG B4-04

Figure 7-9 shows that following the recommendations of JTF 12/14 10-1, the failures due to induced current have been successfully mitigated. The mechanical failures are mostly related to bushings and LTCs. The dielectric and thermal failures continue to be the two dominant causes. For systems commissioned after 1998 the failures in the connections (figure 7-8) are mostly due to thermal overheating (figure 7-9).

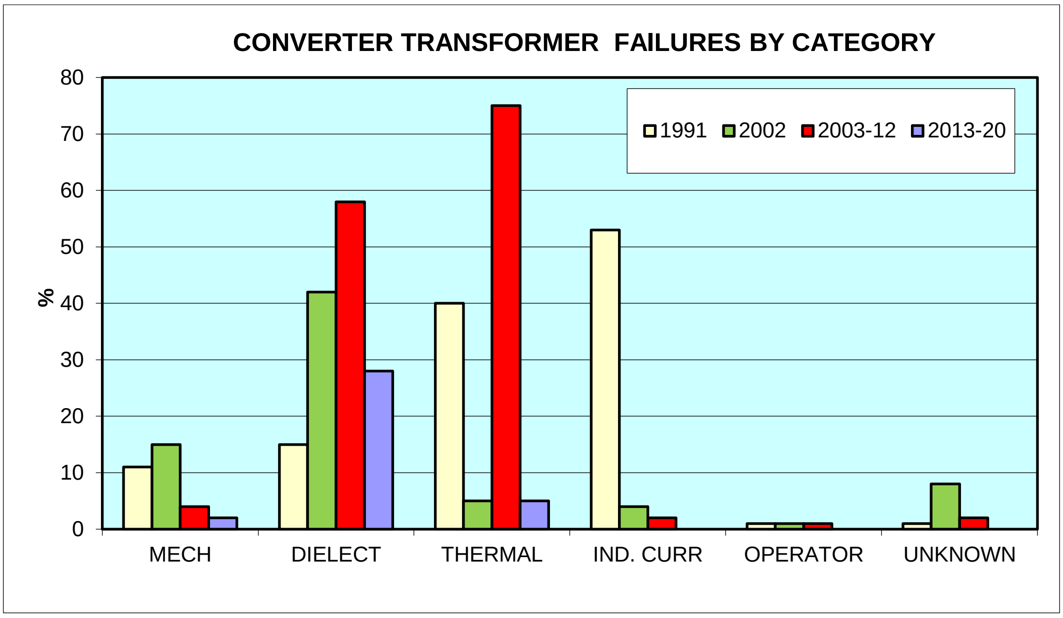

Figure 7-9 – Probable cause of failures

7.7 Failures by transformer MVA rating

Figure 7-10 shows the failure rate of converter transformers as a function of unit MVA rating. The failure rate increases as the unit rating increases. Higher rating presents a challenge of keeping the dimensions as small as possible for transportation reasons and at the same time meet all the electrical clearances and provide sufficient cooling of all the parts.

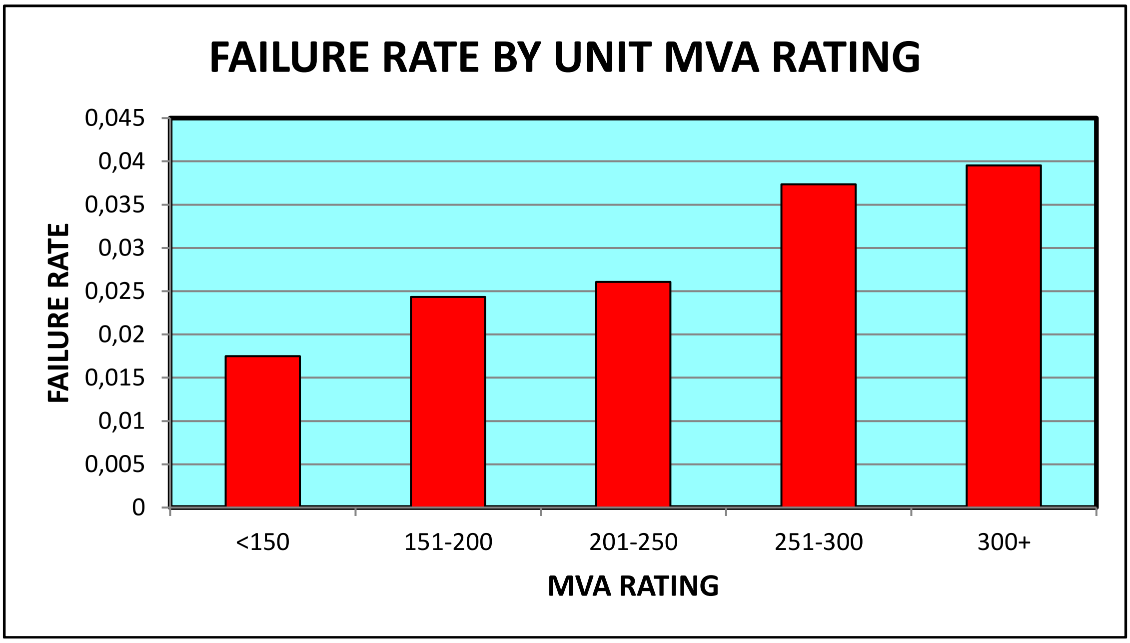

Figure 7-10 - Failure rate by unit MVA rating

8. Acknowledgement

AG B4-04 would like to thank all the systems that participated in the survey, the regular members of CIGRE B4 committee and other experts for their assistance in obtaining the information for this survey. Thanks also to the manufacturers for their assistance as well.

9. References

[1] CIGRE JTF 12/14.10-01; " In service performance of HVDC Converter Transformers and oil-filled Smoothing Reactors", Electra, No. 155, August, 1994, pages 6 – 30.

[2] CIGRE JTF B4.04/A2-1; "Analysis of HVDC Thyristor Converter Transformer performance", Brochure No. 240. 2004.

[3] CIGRE JWG A2/B4-28; "HVDC Converter Transformers- Design Review, Test Procedures, Aging Evaluation and Reliabliity in Service", Brochure No. 406, February 2010.

[4] CIGRE Technical Brochure 617, "HVDC LCC Converter Transformers – Converter Transformer Failure Survey Results from 2003 to 2012", AG B4-04, April 2015.

[5] "Report on 2015 Tranformer Failure Survey", N. Dhaliwal, CIGRE B4 Study Commitee Meeting, Agra, India, Sept. 2015.

[6] "Report on 2017 Tranformer Failure Srvey", N. Dhaliwal, CIGRE B4 Study Commitee Meeting, Winnipeg, Canada, Oct. 2017.

[7] "Report on 2019 Tranformer Failure Survey", L. Crowe and N. Dhaliwal, CIGRE B4 Study Commitee Meeting, Johannesburg, South Africa, Sep. 2019.

[8] "Report on 2021 Tranformer Failure Survey", L. Crowe and N. Dhaliwal, CIGRE Virtual Centenial Session, Paris, France, Aug 2021.

[9] IEC 61378-3, Ed. 1.0; Converter Transformers, Part 3- Application Guide, 14/487 CDV, April 2006.

APPENDIX A. - Questionnaire

CIGRE

International Conference of

Large High Voltage Electric Systems

Study Committees B4

DC Systems and Power Electronics

QUESTIONNAIRE ON PERFORMANCE OF CONVERTER TRANSFORMERS

For LCC AND VSC SYSTEMS

For

Advisory Group AG B4-04

HVDC System Performance

This questionnaire is addressed to Users of HVDC thyristor valve converters and VSC converters for obtaining information and data on converter transformers operating experience. Last survey was performed in 2019 by AG B4-04. The performance for the years 2017 and 2018 was reported.

Failure Definitions

Actual Failure – Actual failure is a failure where a unit actually failed and resulted in a forced outage.

Prevent Failure – Prevent failure is a failure where the monitoring system indicated a potential problem with the unit. There was no forced outage but the unit had to be repaired by taking a planned outage as soon as possible (For example: High gassing rate).

Please report all failures for the years 2019 and 2020 and any other failure for the previous years which may not have been reported.

If your system did not have any failures during this period, please fill out Part 1 only and return the survey with comments "No failures".

Your response will be of considerable value to CIGRE AG B4-04 in fulfilling its mandate. Your answers are essential to study committees A2 and B4 for trying to establish areas within converter transformers that still require additional attention. These areas could imply design, construction, testing, operation and/or maintenance aspects.

The survey addresses all HVDC converter transformers for systems rated power as low as 50 MW.

This questionnaire has two parts:

Part 1, -- This part relates to the characteristics of the transformers and the related HVDC system.

Part 2, -- This part report applies to Transformer Failures in years 2019 and 2020 and any other failures that may have been reported previously.

PLEASE RETURN THE SURVEY BY   Mar 15, 2021 by E-mail to AG B4-04

QUESTIONNAIRE ON PERFORMANCE OF HVDC VALVE

CONVERTER/ INTERFACE TRANSFORMERS

PART 1

HVDC Link Name: ____________________

1. Transformer Characteristics

	Station 1 ________________			Stn 2______________
1.	Voltage Rating			
	i. System side	kV		
	ii. Valve winding side	kV		
2.	Power Rating (single unit)	MVA		
3.	Number of windings (in tank)	#		
4.	Number of phases (in tank)	#		
5.	Number of Units in service	#		
6.	Year of In-service	year		
7.	Any windings other than those used for converter (in tank)	Yes/No		
8.	Function of winding in Q6			
	i. Synchronous condenser	Yes/No		
	ii. AC Filters	Yes/No		
	iii. other	Please specify		

2. HVDC System Characteristics

2.1 LCC Systems

1.	System DC voltage	kV – DC	
2.	Power Rating	MW	
3.	Long Distance	Yes/No	
4.	Back to Back	Yes/No	
5.	Number of poles	#	
6.	Number of converters per pole	#	
7.	Type of converters		
	i. 6-pulse	Yes/No	
	ii. 12-pulse	Yes/No	

2.2 VSC Systems

1.	System DC voltage		kV – DC	
2.	Power Rating		MW	
3.	Long Distance		Yes/No	
4.	Back to Back		Yes/No	
5.	Cable/Overhead			
6.	System Configuration			
	i.	Symmetrical Monopolar	Yes/No	
	ii.	Bipolar	Yes/No	
	iii.	Monopolar Ground return	Yes/No	
	iv.	Other		
7.	Type of converters			
	i. MMC		Yes/No	
	ii. Other		Yes/No	

Were there any Transformer Failures During this period (Actual or Prevent) ?

Yes______/ NO_____

If YES, please complete part 2.

3. QUESTIONNAIRE ON PERFORMANCE OF CONVERTER/INTERFACE TRANSFORMERS
PART 2 (Analysis Information)

Use this form to report all converter/interface transformer failures in 2019, 2020 and any other failures that may not have been reported previously.

Transformer Type of Failure

For the purpose of this questionnaire, a failure is defined as removal of the unit from service because of major damage to active (energized) parts, or potential failure of active parts following diagnostic such as gas in oil, or non active part requiring transformer to be repaired. If you have experienced converter transformer failure, please answer the followings:

1. Indicate which of the transformer component or accessory has failed

1.01	AC winding:	
1.02	Valve winding:	
1.03	On load tap changer winding:	
1.04	Core:	
1.05	Internal connection between winding and bushing:	
1.06	On load tap changer diverter/selector switch:	
1.07	Cooling pump:	
1.08	Cooling radiator/ or valve leak:	
1.09	Conservator/ or main tank oil leak:	
1.10	Oil dielectric failure:	
1.11	Other:	

2. Description of transformer failure/replacement

2.1	Date of failure or replacement	
2.2	Describe in as much details as possible problem experienced with failed transformer or its accessories:	

3. Operating conditions prior to failure: (Describe)

3.1	What were the operating conditions prior to failure: (Describe):	

4. Transformer replacement by spare unit

4.1	What has been total time (in hours) for replacement of failed unit by spare transformer from time of failure to time of resuming service to pre-fault power level	

5. Multiple transformer failures

If more than one unit failure was experienced in a converter station, or for the same generation of transformers in converters of a same system, please provide information requested below:

5.01	How many units failed?	
5.02	What period of time(months) between failures?	
5.03	Was problem considered as generic?	
5.04	Was it possible to have transformer repaired before another unit failed? If not, for how many months was converter off service?	
5.05	In the case of a generic failure, were all units in converter removed from service, sent for repair/modified in factory and put back in service?	
5.06	What was the average time (hours), from time of stopping converter to time of restart, for replacing existing transformer by newly modified unit?	
5.07	How many transformer units needed to be removed from service, modified and put back in service?	
5.08	What has been approximate total time (hours) of converter or converter group forced outage?	

6. Tests performed

6.01	Were factory type and routine tests performed to ensure against such failure?	

7. Used test standards

7.01	Please identify test standards used for factory type and routine tests	

8. Failed factory test (explain why):

8.01	Indicate whether unit failed factory test (explain why):	

9. Other pertinent information relative to the questionnaire:

9.01	Please indicate any other pertinent information relative to the questionnaire:	
9.02	By the moment, during the three years in service, we haven't had any failure.	
9.03	If you have any concern or suggestions for futures studies or investigations by the AG B4-04, please identify your concerns or suggestions:	

10. Any other comment:

Reported by	
Date:	

APPENDIX B – Year 2013 and 2014 failures

Converter Transformer Failure Data for Years 2013 and 2014

Note: Systems where no data is shown in the last three columns did not respond to the survey

AG B4-04

Analysis of HVDC System Performance Correlated to Converter Transformer Performance

2013-2014 TRANSFORMER FAILURES

Thyristor Valves SYSTEM	Year(1) Commissioned	kV	Type(3)	Continuous MW	Transformers(3) Tank	Wdgs	No.	Tfr.(6) Years	No. of Failures(3) Actual	Prevent
Eel River	1972	80	BB	350	1	4	12			
Skagerrak 1&2	1977	250	TL/SC	550	3	2	8	16.0	0	0
Skagerrak 3	1993	350	TL/SC	500	3	2	4	8.0	0	0
Cahora Bassa	1997	533	TL	1800	1	3	48			
Vancouver P2	1978	280	TL/SC	476	1	2	12			
Hamil	1977	50	BB	110	3	3	2			
Square Butte	1977	250	TL/SC	550	1	2	12	24.0	0	0
Shin-Shinano 1	1977	125	BB	300	3	3	4	8.0	0	0
Shin-Shinano 2	1992	125	BB	300	3	3	4	8.0	0	0
Nelson River				900						
BP1 Pole 1	1991/92	464	TL	927	1	3	18	36.0	0	0
BP1 Pole 2	2005	464	TL	927	1	3	18	36.0	0	0
BP2, Stage1	1978	500	TL	1000	3	2	8	16.0	0	0
BP2 Stages 2	1984-85	500	TL	1000	3	2	8	16.0	0	0
Hokkaido-Honshu								0.0	0	0
Stage1&2	1979/80	250	TL/SC	300	3	2	4	8.0	0	0
Stage3	1993	125	TL/SC	300	3	2	4	8.0	0	0
CU	1979	400	TL	1138	3	2	8	16.0	0	0
Vyborg										
V Stage1	1981	170	BB	355	1	4	6			
V Stage2	1980	170	BB	355	1	4	6			
V Stage3	1984	170	BB	355	1	4	6			
V Stage4	1999	170	BB	355	1	4	6			
Inga Shaba										
Gotland II	1983	150	TL/SC	320	3	2	4			
Gotland III	1987	150	TL/SC	320	3	2	4			
Eddy County	1983	82	BB	220	3	3	2			
Chateauguay	1984	140	BB	1000	1	3	1			
Oklaunion	1985	82	BB	220	3	3	2			
Blackwater	1985	56	BB	200	1	4	6			
Madawaska	1985	130	BB	435	1	3	4			
Itaipu BP1	1985	600	TL	3150	1	3	24	48.0	2	3
Itaipu BP2	1988	600	TL	3150	1	3	24	48.0	0	0
Miles City	1985	82	BB	200	3	3	2			

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Analysis of HVDC System Performance Correlated to Converter Transformer Performance

2013-2014 TRANSFORMER FAILURES

Thyristor Valves SYSTEM	Year(1) Commissioned	kV	Type(3)	Continuous MW	Transformers(3) Tank	Wdgs	No.	Tfr.(6) Years	No. of Failures(3) Actual	Prevent
Highgate	1985	56	BB	200	3	3	2	4.0	0	0
PIE Upgrade	1985	500	TL	#REF!	1	2	12			
PIE Expansion	1989	500	TL	1100	1	3	12			
Cross Channel 1										
France BP1	1986	270	SC	1000	1	3	6			
UK BP1	1986	270	SC	1000	3	3	4	8.0	4	0
Cross Channel 2										
France BP2	1986	270	SC	1000	1	3	6			
UK BP2	1986	270	SC	1000	3	3	4	8.0	0	0
IPP	1986	500	TL	1920	1	3	12	24.0	0	0
Quebec/USA(5)										
Radisson	1990	500	TL	2250	1	3	6			
Sandy Pond	1990	450	TL	1800	1	3	6			
Nicolet	1991	450	TL	2138	1	3	6			
SACOI 2										
Lucciana	1987	200	TL/SC	50	1	3	3	6.0	0	0
Codrongianos	1992	200	TL/SC	300	1	3	3	6.0	0	0
Suvereto	1992	200	TL/SC	300	1	3	3	6.0	0	0
Virginia Smith	1988	50	BB	200	1	3	6			
Konti Skan 2	1988	285	TL/SC	300	3	2	4			
McNeil	1989	42	BB	150	3	4	2			
Gezhouba-Nanqia	1989	500	TL	1200	1	3	12			
Vindhyachal	1989	70	BB	250	3	2	8	16.0	0	0
Fennoskan	1989	400	TL/SC	500	1	3	6	12.0	0	0
Rihand-Dadri	1990	500	TL	1500	1	3	12	24.0	1	0
New Zealand Pole	1992	350	TL/SC	700	1	3	6			
Sakuma	1993	125	BB	300	1	2	4	8.0	0	0
Baltic Cable	1994	450	SC	600	1	3	6	12.0	0	0
Welsh	1995	162	BB	600	1	3	6			
Haenam-Chezu	1996	180	SC	300	3	3	4			
Chandrapur	1998	205	BB	1000	1	3	12	24.0	0	0
Chandrapur-Padg	1999	500	TL	1500	1	3	12	24.0	0	0
Leyte-Luzon	1998	350	TL/SC	440	1	3	6			
Kontek	1998	400	SC	600	1	3	6	12.0	0	0
India Nat. Experim. Line										
Stage 1	1989	100	TL	100	1	2	6			
Stage 2	2000	200	TL	200	1	2	6			
Vizag -1	1999	200	BB	500	1	3	6	12.0	0	0
SwePol	2000	450	SC	600	1	3	6			

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Analysis of HVDC System Performance Correlated to Converter Transformer Performance

2013-2014 TRANSFORMER FAILURES

Thyristor Valves SYSTEM	Year(1) Commissioned	kV	Continuous Type(3)	MW	Transformers(3) Tank	Wdgs	No.	Tfr.(6) Years	No. of Failures(3) Actual	Prevent
Rivera	2001	22	BB	75	3	4	2			
Thailand-Malaysi	2002	300	TL	300	1	3	6			
Moyle Interconne	2002	250	TL/SC	1000	1	3	12	24.0	0	0
Sas RETIRED	2002	205	BB	500	1	3	6			
East-South (India	2002	500	TL	1800	1	3	12	24.0	0	0
Tian-Guang	2003	500	TL	1800	1	3	12			
3Gorges-Changzh	2003	500	TL	3000	1	2	24			
BPA-Upgrade 2	2004	400(8)	TL	1600	1	3	18			
Sylmar Upgrade	2004	500(9)	TL	3100	1	2	12			
Gui-Guang 1	2004	500	TL	3000	1	2	24			
3Gorges-Guang	2004	500	TL	3000	1	2	24			
Lingbao	2004	120	BB	360	3	3	6			
Vizag II	2005	176	BB	500	1	3	6	12.0	0	0
Lamar	2005	63.6	BB	210	3	3	2	4.0	0	0
Konti Skan 1	2006	282	TL/SC	380	3	2	4			
3G-Shanghai	2006	500	TL	3000	1	2	24			
Italy - Greece	2001	400	TL/SC	500	1	3	6	12.0	0	0
Basslink	2006	400	TL/SC	500	1	3	6	12.0	0	0
Neptune	2007	500	TL/SC	660	0	0	0			
Gui-Guang 2	2008	500	TL	3000	1	2	24			
NorNed	2008	450	TL/SC	700	1	3	6	12.0	0	0
Gaoling	2008	125	BB	750	1	3	12			
Ballia-Bhiwadi	2010	500	TL	2500	1	3	12	24.0	0	0
Xiangjiaba-Shang	2010	800	TL	6400	1	2	48			
Storbaelt	2010	400	TL/SC	600	1	3	6	12.0	0	0
Yunan-Guang	2010	800	TL	5000	1	2	48			
Hulunbeir-Liaonin	2010	500	TL	3000	1	2	24			
COMETA	2010	250	SC	400	1	3	12	24.0	0	0
SAPEI	2011	500	SC	1000	1	3	12	24.0	0	0
BritNed	2011	400	SC	1000	1	3	12	24.0	0	0
FennoSkan 2	2012	500	SC	800	1	3	6	12.0	0	0
Adani	2013	500	TL	2500	1	3	12	24.0	0	0
							Total	**746**	**7**	**3**

Appendix C – Year 2015 And 2016 Failures

Converter Transformer Failure Data for Years 2015 and 2016

Note: Systems where no data is shown in the last three columns did not respond to the survey

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Analysis of HVDC System Performance Correlated to Converter Transformer Performance

2015-2016 TRANSFORMER FAILURES

Thyristor Valves SYSTEM	Year(1) Commissioned	kV	Type(3)	Continuous MW	Transformers(3) Tank	Wdgs	No.	Tfr.(6) Years	No. of Failures(3) Actual	Prevent
Eel River	1972	80	BB	350	1	4	12			
Skagerrak 1&2	1977	250	TL/SC	550	3	2	8	16.0	0	0
Skagerrak 3	1993	350	TL/SC	500	3	2	4	8.0	0	0
Cahora Bassa	1997	533	TL	1800	1	3	48	48.0	3	0
Vancouver P2	1978	280	TL/SC	476	1	2	12			
Hamil	1977	50	BB	110	3	3	2			
Square Butte	1977	250	TL/SC	550	1	2	12	24.0	2	0
Shin-Shinano 1	1977	125	BB	300	3	3	4	8.0	0	0
Shin-Shinano 2	1992	125	BB	300	3	3	4	8.0	0	0
Nelson River				900						
BP1 Pole 1	1991/92	464	TL	927	1	3	18	36.0	0	1
BP1 Pole 2	2005	464	TL	927	1	3	18	36.0	0	0
BP2, Stage1	1978	500	TL	1000	3	2	8	16.0	0	0
BP2 Stages 2	1984-85	500	TL	1000	3	2	8	16.0	0	1
Hokkaido-Honshu								0.0	0	0
Stage1&2	1979/80	250	TL/SC	300	3	2	4	8.0	0	0
Stage3	1993	125	TL/SC	300	3	2	4	8.0	0	0
CU	1979	400	TL	1138	3	2	8	16.0	0	0
Vyborg										
V Stage1	1981	170	BB	355	1	4	6			
V Stage2	1980	170	BB	355	1	4	6			
V Stage3	1984	170	BB	355	1	4	6			
V Stage4	1999	170	BB	355	1	4	6			
Inga Shaba										
Gotland II	1983	150	TL/SC	320	3	2	4			
Gotland III	1987	150	TL/SC	320	3	2	4			
Eddy County	1983	82	BB	220	3	3	2			
Chateauguay	1984	140	BB	1000	1	3	1			
Oklaunion	1985	82	BB	220	3	3	2			
Blackwater	1985	56	BB	200	1	4	6			
Madawaska	1985	130	BB	435	1	3	4			
Itaipu BP1	1985	600	TL	3150	1	3	24	48.0		1
Itaipu BP2	1988	600	TL	3150	1	3	24	48.0	0	1
Miles City	1985	82	BB	200	3	3	2			
Highgate	1985	56	BB	200	3	3	2			
PIE Upgrade	1985	500	TL	#REF!	1	2	12			
PIE Expansion	1989	500	TL	1100	1	3	12			

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Analysis of HVDC System Performance Correlated to Converter Transformer Performance

2015-2016 TRANSFORMER FAILURES

Thyristor Valves SYSTEM	Year(1) Commissioned	kV	Type(3)	Continuous MW	Transformers(3) Tank	Wdgs	No.	Tfr.(6) Years	No. of Failures(3) Actual	Prevent
Cross Channel 1										
France BP1	1986	270	SC	1000	1	3	6	12.0	0	0
UK BP1	1986	270	SC	1000	3	3	4	8.0	2	0
Cross Channel 2										
France BP2	1986	270	SC	1000	1	3	6	12.0	0	0
UK BP2	1986	270	SC	1000	3	3	4	8.0	0	0
IPP	1986	500	TL	1920	1	3	12	24.0	0	0
Quebec/USA(5)										
Radisson	1990	500	TL	2250	1	3	6			
Sandy Pond	1990	450	TL	1800	1	3	6			
Nicolet	1991	450	TL	2138	1	3	6			
SACOI 2										
Lucciana	1987	200	TL/SC	50	1	3	3	6.0	0	0
Codrongianos	1992	200	TL/SC	300	1	3	3	6.0	0	0
Suvereto	1992	200	TL/SC	300	1	3	3	6.0	0	0
Virginia Smith	1988	50	BB	200	1	3	6			
Konti Skan 2	1988	285	TL/SC	300	3	2	4			
McNeil	1989	42	BB	150	3	4	2			
Gezhouba-Nanqiao	1989	500	TL	1200	1	3	12			
Vindhyachal	1989	70	BB	250	3	2	8	16.0	1	0
Fennoskan	1989	400	TL/SC	500	1	3	6	12.0	0	0
Rihand-Dadri	1990	500	TL	1500	1	3	12	24.0	1	0
New Zealand Pole 2	1992	350	TL/SC	700	1	3	6	12.0	0	0
Sakuma	1993	125	BB	300	1	2	4	8.0	0	0
Baltic Cable	1994	450	SC	600	1	3	6	12.0	0	0
Welsh	1995	162	BB	600	1	3	6			
Haenam-Chezu	1996	180	SC	300	3	3	4			
Chandrapur	1998	205	BB	1000	1	3	12	24.0	2	0
Chandrapur-Padghe	1999	500	TL	1500	1	3	12			
Leyte-Luzon	1998	350	TL/SC	440	1	3	6			
Kontek	1998	400	SC	600	1	3	6	12.0	0	0
India Nat. Experim. Line										
Stage 1	1989	100	TL	100	1	2	6			
Stage 2	2000	200	TL	200	1	2	6			
Vizag -1	1999	200	BB	500	1	3	6	12.0	0	0
SwePol	2000	450	SC	600	1	3	6			
Rivera	2001	22	BB	75	3	4	2			
Thailand-Malaysia	2002	300	TL	300	1	3	6			
Moyle Interconnecto	2002	250	TL/SC	1000	1	3	12	24.0	0	0
Sasra RETIRED	2002	205	BB	500	1	3	6			
East-South (India)	2002	500	TL	1800	1	3	12	24.0	0	0

B4-AG04

Analysis of HVDC System Performance Correlated to Converter Transformer Performance

2015-2016 TRANSFORMER FAILURES

Thyristor Valves SYSTEM	Year(1) Commissioned	kV	Type(3)	Continuous MW	Transformers(3) Tank	Wdgs	No.	Tfr.(6) Years	No. of Failures(3) Actual	Prevent
Tian-Guang	2003	500	TL	1800	1	3	12			
3Gorges-Changzhou	2003	500	TL	3000	1	2	24			
BPA-Upgrade 2	2004	400(8)	TL	1600	1	3	18			
Sylmar Upgrade	2004	500(9)	TL	3100	1	2	12			
Gui-Guang 1	2004	500	TL	3000	1	2	24			
3Gorges-Guang	2004	500	TL	3000	1	2	24			
Lingbao	2004	120	BB	360	3	3	6			
Vizag II	2005	176	BB	500	1	3	6	12.0	0	0
Lamar	2005	63.6	BB	210	3	3	2	4.0	0	0
Konti Skan 1	2006	282	TL/SC	380	3	2	4	8.0	0	0
3G-Shanghai	2006	500	TL	3000	1	2	24			
Italy - Greece	2001	400	TL/SC	500	1	3	6	12.0	0	0
Basslink	2006	400	TL/SC	500	1	3	6			
Neptune	2007	500	TL/SC	660	0	0	0			
Gui-Guang 2	2008	500	TL	3000	1	2	24			
NorNed	2008	450	TL/SC	700	1	3	6			
Gaoling	2008	125	BB	750	1	3	12			
Ballia-Bhiwadi	2010	500	TL	2500	1	3	12	24.0	0	0
Xiangjiaba-Shanghai	2010	800	TL	6400	1	2	48			
Storbaelt (Great Bel	2010	400	TL/SC	600	1	3	6	12.0	0	0
Yunan-Guang	2010	800	TL	5000	1	2	48			
Hulunbeir-Liaoning	2010	500	TL	3000	1	2	24			
COMETA	2010	250	SC	400	1	3	12	24.0	0	0
SAPEI	2011	500	SC	1000	1	3	12	24.0	0	0
BritNed	2011	400	SC	1000	1	3	12			
FennoSkan 2	2012	500	SC	800	1	3	6	12.0	0	0
Adani	2013	500	TL	2500	1	3	12	24.0	0	0
Rio Madeira- PV	2015	600	TL	3150	1	3	6	12.0	0.0	0.0
Rio Madeira - Ar	2015	600	TL	3150	1	2	12	24.0	0.0	0.0
Alberta - EATL	2016	500	TL	1000	1	3	6	12.0	0.0	0.0
						Total		**810**	**11**	**4**

APPENDIX D – Year 2017 and 2018 failures (LCC)

Converter Transformer Failure Data for Years 2017 and 2018 (LCC SYSTEMS)

Note: Systems where no data is shown in the last three columns did not respond to the survey

B4-AG04

Analysis of HVDC System Performance Correlated to Converter Transformer Performance

2017-2018 TRANSFORMER FAILURES

Thyristor Valves	Year(1)			Continuous	Transformers(3)			Tfr.(6)	No. of Failures(3)	
SYSTEM	Commissioned	kV	Type(3)	MW	Tank	Wdgs	No.	Years	Actual	Prevent
Eel River	1972	80	BB	350	1	4	12			
Skagerrak 1&2	1977	250	TL/SC	550	3	2	8	16.0	1	0
Skagerrak 3	1993	350	TL/SC	500	3	2	4	8.0	0	0
Cahora Bassa	1997	533	TL	1800	1	3	48			
Vancouver P2	1978	280	TL/SC	476	1	2	12			
Hamil	1977	50	BB	110	3	3	2			
Square Butte	1977	250	TL/SC	550	1	2	12			
Shin-Shinano 1	1977	125	BB	300	3	3	4	8.0	0	0
Shin-Shinano 2	1992	125	BB	300	3	3	4	8.0	0	0
Nelson River				900						
BP1 Pole 1	1991/92	464	TL	927	1	3	18	36.0	0	0
BP1 Pole 2	2005	464	TL	927	1	3	18	36.0	0	0
BP2, Stage1	1978	500	TL	1000	3	2	8	16.0	0	0
BP2 Stages 2 &	1984-85	500	TL	1000	3	2	8	16.0	0	0
Hokkaido-Honshu								0.0	0	0
Stage1&2	1979/80	250	TL/SC	300	3	2	4	8.0	0	0
Stage3	1993	125	TL/SC	300	3	2	4	8.0	0	0
CU	1979	400	TL	1138	3	2	8	16.0	0	0
Vyborg										
V Stage1	1981	170	BB	355	1	4	6	12.0	1	0
V Stage2	1980	170	BB	355	1	4	6	12.0	0	0
V Stage3	1984	170	BB	355	1	4	6	12.0	0	0
V Stage4	1999	170	BB	355	1	4	6	12.0	0	0
Inga Shaba										
Gotland II	1983	150	TL/SC	320	3	2	4			
Gotland III	1987	150	TL/SC	320	3	2	4			
Eddy County	1983	82	BB	220	3	3	2			
Chateauguay	1984	140	BB	1000	1	3	1			
Oklaunion	1985	82	BB	220	3	3	2			
Blackwater	1985	56	BB	200	1	4	6			
Madawaska	1985	130	BB	435	1	3	4			
Itaipu BP1	1985	600	TL	3150	1	3	24	48.0	1	0
Itaipu BP2	1988	600	TL	3150	1	3	24	48.0	0	0
Miles City	1985	82	BB	200	3	3	2			
Highgate	1985	56	BB	200	3	3	2	4.0	0	0
PIE Upgrade	1985	500	TL		1	2	12			
PIE Expansion	1989	500	TL	1100	1	3	12			

B4-AG04

Analysis of HVDC System Performance Correlated to Converter Transformer Performance

2017-2018 TRANSFORMER FAILURES

Thyristor Valves SYSTEM	Year(1) Commissioned	kV	Type(3)	Continuous MW	Transformers(3) Tank	Wdgs	No.	Tfr.(6) Years	No. of Failures(3) Actual	Prevent
Cross Channel 1										
France BP1	1986	270	SC	1000	1	3	6	12.0	0	0
UK BP1	1986	270	SC	1000	3	3	4			
Cross Channel 2										
France BP2	1986	270	SC	1000	1	3	6	12.0	0	0
UK BP2	1986	270	SC	1000	3	3	4			
IPP	1986	500	TL	1920	1	3	12	24.0	1	0
Quebec/USA(5)										
Radisson	1990	500	TL	2250	1	3	6			
Sandy Pond	1990	450	TL	1800	1	3	6			
Nicolet	1991	450	TL	2138	1	3	6			
SACOI 2										
Lucciana	1987	200	TL/SC	50	1	3	3	6.0	0	0
Codrongianos	1992	200	TL/SC	300	1	3	3	6.0	0	0
Suvereto	1992	200	TL/SC	300	1	3	3	6.0	0	0
Virginia Smith	1988	50	BB	200	1	3	6			
Konti Skan 2	1988	285	TL/SC	300	3	2	4	8.0	0	0
McNeil	1989	42	BB	150	3	4	2			
Gezhouba-Nanqiao	1989	500	TL	1200	1	3	12			
Vindhyachal	1989	70	BB	250	3	2	8	16.0	1	0
Fennoskan	1989	400	TL/SC	500	1	3	6	12.0	0	0
Rihand-Dadri	1990	500	TL	1500	1	3	12	24.0	1	0
New Zealand Pole 2	1992	350	TL/SC	700	1	3	6	12.0	0	0
Sakuma	1993	125	BB	300	1	2	4	8.0	0	0
Baltic Cable	1994	450	SC	600	1	3	6			
Welsh	1995	162	BB	600	1	3	6			
Haenam-Chezu	1996	180	SC	300	3	3	4			
Chandrapur/Badrawati	1998	205	BB	1000	1	3	12	8.0	0	0
Chandrapur-Padghe	1999	500	TL	1500	1	3	12			
Leyte-Luzon	1998	350	TL/SC	440	1	3	6			
Kontek	1998	400	SC	600	1	3	6	12.0	0	0
India Nat. Experim. Line										
Stage 1	1989	100	TL	100	1	2	6			
Stage 2	2000	200	TL	200	1	2	6			
Vizag -1	1999	200	BB	500	1	3	6	12.0	0	0
SwePol	2000	450	SC	600	1	3	6	12.0	0	0
Rivera	2001	22	BB	75	3	4	2			
Thailand-Malaysia	2002	300	TL	300	1	3	6			
Moyle Interconnector	2002	250	TL/SC	1000	1	3	12	24.0	0	0
Sasram	2002	205	BB	500	1	3	6	12.0	0	0
East-South (India)	2002	500	TL	1800	1	3	12	24.0	0	0

B4-AG04

Analysis of HVDC System Performance Correlated to Converter Transformer Performance

2017-2018 TRANSFORMER FAILURES

Thyristor Valves SYSTEM	Year(1) Commissioned	kV	Type(3)	Continuous MW	Transformers(3) Tank	Wdgs	No.	Tfr.(6) Years	No. of Failures(3) Actual	Prevent
Tian-Guang	2003	500	TL	1800	1	3	12			
3Gorges-Changzhou	2003	500	TL	3000	1	2	24			
BPA-Upgrade 2	2004	400(8)	TL	1600	1	3	18			
Sylmar Upgrade	2004	500(9)	TL	3100	1	2	12			
Gui-Guang 1	2004	500	TL	3000	1	2	24			
3Gorges-Guang	2004	500	TL	3000	1	2	24			
Lingbao	2004	120	BB	360	3	3	6			
Vizag II	2005	176	BB	500	1	3	6	12.0	0	0
Lamar	2005	63.6	BB	210	3	3	2	4.0	0	0
Konti Skan 1	2006	282	TL/SC	380	3	2	4	8.0	0	0
3G-Shanghai	2006	500	TL	3000	1	2	24			
Italy - Greece	2001	400	TL/SC	500	1	3	6	12.0	0	0
Basslink	2006	400	TL/SC	500	1	3	6	12.0	0	0
Neptune	2007	500	TL/SC	660	0	0	0			
Gui-Guang 2	2008	500	TL	3000	1	2	24			
NorNed	2008	450	TL/SC	700	1	3	6	12.0	0	0
Gaoling	2008	125	BB	750	1	3	12			
Ballia-Bhiwadi	2010	500	TL	2500	1	3	12	24.0	0	0
Xiangjiaba-Shanghai	2010	800	TL	6400	1	2	48			
Storbaelt (Great Belt)	2010	400	TL/SC	600	1	3	6	12.0	0	0
Yunan-Guang	2010	800	TL	5000	1	2	48			
Hulunbeir-Liaoning	2010	500	TL	3000	1	2	24			
COMETA	2010	250	SC	400	1	3	12	24.0	0	0
SAPEI	2011	500	SC	1000	1	3	12	24.0	0	0
BritNed	2011	400	SC	1000	1	3	12	24.0	0	0
FennoSkan 2	2012	500	SC	800	1	3	6	12.0	0	0
Adani	2013	500	TL	2500	1	3	12	24.0	0	0
Rio Madeira- PV	2015	600	TL	3150	1	3	6	12.0	0	0
Rio Madeira- Ara	2015	600	TL	3150	1	2	12	24.0	0	0
Alberta - EATL	2016	500	TL	1000	1	3	6			
AL Fadhili	2008	222	BB	1800	3	2	12	24.0	0	0
Belo Monte BP1	2017	800	TL	4000	1	2	24	24.0	0	0
EastLink2	2014	450	SC	600						
Agra - NE										
Agra P1 & P2	2016	800	TL	3000	1	2	12	24.0	0	0
Agra P3 & P4	2017	800	TL	3000	1	2	12	18.0	0	0
Biswanath P1 & P2	2016	800	TL	3000	1	2	12	24.0	0	0
Alipurdaur P3 & P4	2017	800	TL	3000	1	2	12	18.0	0	0
Champa -KKR BP1	2017	800	TL	3000	1	2	24	36.0	0	0
Champa - KKR BP2										
New Zealand Pole 3	2013	350	TL/SC	700	1	3	6	12.0	0	0
						Total		**994**	**6**	**0**

APPENDIX E – Year 2019 and 2020 failures (LCC)

Converter Transformer Failure Data for Years 2019 and 2020 (LCC SYSTEMS)

Note: Systems where no data is shown in the last three columns did not respond to the survey

LCC SYSTEMS

Analysis of HVDC System Performance Correlated to Converter Transformer Performance

2019-2020 TRANSFORMER FAILURES

Thyristor Valves	Year(1)		Continuous		Transformers(3)			Tfr.(6)	No. of Failures(3)	
SYSTEM	Commissioned	kV	Type(3)	MW	Tank	Wdgs	No.	Years	Actual	Prevent
Eel River	1972	80	BB	350	1	4	12			
Skagerrak 1&2	1977	250	TL/SC	550	3	2	8	16.0	0	0
Skagerrak 3	1993	350	TL/SC	500	3	2	4	8.0	0	0
Cahora Bassa	1997	533	TL	1800	1	3	48			
Vancouver P2	1978	280	TL/SC	476	1	2	12			
Hamil	1977	50	BB	110	3	3	2			
Square Butte	1977	250	TL/SC	550	1	2	12			
Shin-Shinano 1	1977	125	BB	300	3	3	4	8.0	0	0
Shin-Shinano 2	1992	125	BB	300	3	3	4	8.0	0	0
Nelson River				900						
BP1 Pole 1	1991/92	464	TL	927	1	3	18	36.0	0	0
BP1 Pole 2	2005	464	TL	927	1	3	18	36.0	0	0
BP2, Stage1	1978	500	TL	1000	3	2	8	16.0	0	0
BP2 Stages 2 & 3	1984-85	500	TL	1000	3	2	8	16.0	0	0
Hokkaido-Honshu								0.0	0	0
Stage1&2	1979/80	250	TL/SC	300	3	2	4	8.0	0	0
Stage3	1993	125	TL/SC	300	3	2	4	8.0	0	0
CU	1979	400	TL	1138	3	2	8	16.0	0	0
Vyborg										
V Stage1	1981	170	BB	355	1	4	6			
V Stage2	1980	170	BB	355	1	4	6			
V Stage3	1984	170	BB	355	1	4	6			
V Stage4	1999	170	BB	355	1	4	6			
Inga Shaba										
Gotland II	1983	150	TL/SC	320	3	2	4			
Gotland III	1987	150	TL/SC	320	3	2	4			
Eddy County	1983	82	BB	220	3	3	2			
Chateauguay	1984	140	BB	1000	1	3	1			
Oklaunion	1985	82	BB	220	3	3	2			
Blackwater	1985	56	BB	200	1	4	6			
Madawaska	1985	130	BB	435	1	3	4			
Itaipu BP1	1985	600	TL	3150	1	3	24	48.0	0	0
Itaipu BP2	1988	600	TL	3150	1	3	24	48.0	0	0
Miles City	1985	82	BB	200	3	3	2			

LCC SYSTEMS

Analysis of HVDC System Performance Correlated to Converter Transformer Performance

2019-2020 TRANSFORMER FAILURES

Thyristor Valves SYSTEM	Year(1) Commissioned	kV	Type(3)	Continuous MW	Transformers(3) Tank	Wdgs	No.	Tfr.(6) Years	No. of Failures(3) Actual	Prevent
Highgate	1985	56	BB	200	3	3	2	4.0	0	0
PIE Upgrade	1985	500	TL		1	2	12			
PIE Expansion	1989	500	TL	1100	1	3	12			
Cross Channel 1										
France BP1	1986	270	SC	1000	1	3	6			
UK BP1	1986	270	SC	1000	3	3	4			
Cross Channel 2										
France BP2	1986	270	SC	1000	1	3	6			
UK BP2	1986	270	SC	1000	3	3	4			
IPP	1986	500	TL	1920	1	3	12			
Quebec/USA(5)										
Radisson	1990	500	TL	2250	1	3	6			
Sandy Pond	1990	450	TL	1800	1	3	6			
Nicolet	1991	450	TL	2138	1	3	6			
SACOI 2										
Lucciana	1987	200	TL/SC	50	1	3	3			
Codrongianos	1992	200	TL/SC	300	1	3	3			
Suvereto	1992	200	TL/SC	300	1	3	3			
Virginia Smith	1988	50	BB	200	1	3	6			
Konti Skan 2	1988	285	TL/SC	300	3	2	4			
McNeil	1989	42	BB	150	3	4	2			
Gezhouba-Nanqiao	1989	500	TL	1200	1	3	12			
Vindhyachal	1989	70	BB	250	3	2	8	16.0	0	0
Fennoskan	1989	400	TL/SC	500	1	3	6	12.0	0	0
Rihand-Dadri	1990	500	TL	1500	1	3	12	24.0	1	0
New Zealand Pole 2	1992	350	TL/SC	700	1	3	6	12.0	0	0
Sakuma	1993	125	BB	300	1	2	4	8.0	0	0
Baltic Cable	1994	450	SC	600	1	3	6			
Welsh	1995	162	BB	600	1	3	6			
Haenam-Chezu	1996	180	SC	300	3	3	4	8.0	0	0
Chandrapur/Badrawati	1998	205	BB	1000	1	3	12	8.0	2	0
Chandrapur-Padghe	1999	500	TL	1500	1	3	12	8.0	0	0
Leyte-Luzon	1998	350	TL/SC	440	1	3	6			
Kontek	1998	400	SC	600	1	3	6			

LCC SYSTEMS

Analysis of HVDC System Performance Correlated to Converter Transformer Performance

2019-2020 TRANSFORMER FAILURES

Thyristor Valves	Year(1)			Continuous	Transformers(3)			Tfr.(6)	No. of Failures(3)	
SYSTEM	Commissioned	kV	Type(3)	MW	Tank	Wdgs	No.	Years	Actual	Prevent
India Nat. Experim. Line										
Stage 1	1989	100	TL	100	1	2	6			
Stage 2	2000	200	TL	200	1	2	6			
Vizag -1	1999	200	BB	500	1	3	6	12.0	0	0
SwePol	2000	450	SC	600	1	3	6			
Rivera	2001	22	BB	75	3	4	2			
Thailand-Malaysia	2002	300	TL	300	1	3	6			
Moyle Interconnector	2002	250	TL/SC	1000	1	3	12	24.0	0	0
Sasram	2002	205	BB	500	1	3	6	12.0	0	0
East-South (India)	2002	500	TL	1800	1	3	12	24.0	0	0
Tian-Guang	2003	500	TL	1800	1	3	12			
3Gorges-Changzhou	2003	500	TL	3000	1	2	24			
BPA-Upgrade 2	2004	400(8)	TL	1600	1	3	18			
Sylmar Upgrade	2004	500(9)	TL	3100	1	2	12			
Gui-Guang 1	2004	500	TL	3000	1	2	24			
3Gorges-Guang	2004	500	TL	3000	1	2	24			
Lingbao	2004	120	BB	360	3	3	6			
Vizag II	2005	176	BB	500	1	3	6	12.0	0	0
Lamar	2005	63.6	BB	210	3	3	2			
Konti Skan 1	2006	282	TL/SC	380	3	2	4			
3G-Shanghai	2006	500	TL	3000	1	2	24			
Italy - Greece	2001	400	TL/SC	500	1	3	6			
Basslink	2006	400	TL/SC	500	1	3	6	12.0	0	0
Neptune	2007	500	TL/SC	660	0	0	0			
Gui-Guang 2	2008	500	TL	3000	1	2	24			
NorNed	2008	450	TL/SC	700	1	3	6	12.0	0	0
Gaoling	2008	125	BB	750	1	3	12			
Ballia-Bhiwadi	2010	500	TL	2500	1	3	12	24.0	0	0
Xiangjiaba-Shanghai	2010	800	TL	6400	1	2	48			
Storbaelt (Great Belt)	2010	400	TL/SC	600	1	3	6			
Yunan-Guang	2010	800	TL	5000	1	2	48			
Hulunbeir-Liaoning	2010	500	TL	3000	1	2	24			
COMETA	2010	250	SC	400	1	3	12	24.0	0	0

LCC SYSTEMS

Analysis of HVDC System Performance Correlated to Converter Transformer Performance

2019-2020 TRANSFORMER FAILURES

Thyristor Valves	Year(1)			Continuous	Transformers(3)			Tfr.(6)	No. of Failures(3)	
SYSTEM	Commissioned	kV	Type(3)	MW	Tank	Wdgs	No.	Years	Actual	Prevent
SAPEI	2011	500	SC	1000	1	3	12			
BritNed	2011	400	SC	1000	1	3	12			
FennoSkan 2	2012	500	SC	800	1	3	6	12.0	0	0
Adani	2013	500	TL	2500	1	3	12			
Rio Madeira- PV	2015	600	TL	3150	1	3	6	12.0	0	0
Rio Madeira- Ara	2015	600	TL	3150	1	2	12	24.0	1	0
Alberta - EATL	2016	500	TL	1000	1	3	6			
AL Fadhili	2008	222	BB	1800	3	2	12	24.0	0	0
Belo Monte BP1	2017	800	TL	4000	1	2	24	24.0	0	0
EastLink2	2014	450	SC	600						
Agra - NE										
Agra P1 & P2	2016	800	TL	3000	1	2	12	24.0	0	0
Agra P3 & P4	2017	800	TL	3000	1	2	12	18.0	0	0
Biswanath P1 & P2	2016	800	TL	3000	1	2	12	24.0	0	0
Alipurdaur P3 & P4	2017	800	TL	3000	1	2	12	18.0	0	0
Champa -KKR BP1	2017	800	TL	3000	1	2	24	36.0	0	0
Champa - KKR BP2	2019	800	TL	3000	1	2	24	36.0	0	0
New Zealand Pole 3	2013	350	TL/SC	700	1	3	6	12.0	0	0
						Total	**644**	**792**	**1**	**0**

APPENDIX F - Year 2019 and 2020 failures (VSC symmetrical monopolar)

VSC SYMMETRICAL MONOPOLAR SYSTEMS

Transformer Survey Result (2019-2020 Failures)

SYMMETRICAL MONPOLAR VSC

Analysis of HVDC System Performance Correlated to Transformers for VSC Systems

TRANSFORMER FAILURES for years 2019 and 2020

SYSTEM	Year(1) Commissioned	kV	Continuous Type(3)	MW	Transformers(3) Phases	Wdgs	No.	Tfr.(6) Years	No. of Failures(3) Actual	Prevent
Direct Link	2000	80	LC	180	3	2	6	No Response		
Murray Link	2002	150	LC	200	1	3	6	No Response		
Troll 1 & 2	2004	60	SC	160	3	2	2	4.0	0.0	0.0
East Link	2006	150	SC	350	3	3	2	4.0	0.0	0.0
TransBay	2010	200	SC	400	1	3	6	No Response		
Valhall	2011	150	SC	78	3	3	2	No Response		
Borwin1 - Onshore	2012	150	SC	400	3	3	1	2.0	0.0	0.0
Borwin1 -Offshore					1	3	3	6.0	0.0	0.0
East-West(UK-Ire)	2012	200	SC	500	1	3	6	12.0	0.0	0.0
AL Link	2015	80	SC	100	3	3	2	4.0	0.0	0.0
Borwin2	2015	300	SC	800	3	3	4	8.0	0.0	0.0
Dolwin 1	2015	320	SC	800	3	3	4	8.0	0.0	0.0
Helwin 1	2015	250	SC	576	3	3	4	8.0	0.0	0.0
Helwin 2	2015	320	SC	690	3	3	4	8.0	0.0	0.0
Sylwin1	2015	320	SC	864	3	3	4	8.0	0.0	0.0
INELFE Spain-France 1	2015	320	LC	1000	1	3	6	12.0	0.0	0.0
INELFE Spain-France 2	2015	320	LC	1000	1	3	6	12.0	0.0	0.0
NorBalt (Swe-Lith)	2015	300	SC	700	1	3	6	12.0	0.0	0.0
Troll 3 & 4	2015	66	SC	100	3	2	2	4.0	0.0	0.0
Dolwin 2	2016	320	SC	900	3	3	4	8.0	0.0	0.0
Sydvastlanmen(Swe - GE)	2016	300	LC	720				No record yet		
Dolwin 3	2018	320	SC	900	3	3	4	8.0	0.0	0.0
NEMO Link	2019	400	SC	1000	1	3	6	No record yet		
Cobra Link	2019	320	SC	700	1	3	6			
Hokkaido - Honshu	2019	320	SC	900	1	3	6	12.0	0.0	0.0
						Total	102	140	0	0

APPENDIX G – Year 2019 and 2020 failures (VSC bipole & monopolar)

VSC BIPOLAR & MONOPOLAR GROUND RETURN SYSTEMS

Transformer Survey Result (2019-2020 Failures)

BIPOLAR OR MONPOLAR GROUND RETURN VSC SYSTEMS										
Analysis of HVDC System Performance Correlated to Transformers for VSC Systems										
TRANSFORMER FAILURES for years					2019	and	2020			
	Year(1)		Continuous		Transformers(3)			Tfr.(6)	No. of Failures(3)	
SYSTEM	Commissioned	kV	Type(3)	MW	Phases	Wdgs	No.	Years	Actual	Prevent
Zambezi	2010	350	TL	300	1	4	6	12.0	0.0	0.0
Skagerrak 4	2015	500	SC	700	1	2	6	12.0	0.0	0.0
						Total	12	24	0	0

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TECHNICAL BROCHURES

Reference 859 - December 2021