B3/A3 Colloquium 2023
PS 2 & 3

Paper No:105

CIGRE fourth reliability survey on switching equipment

Hiroki Ito, Frank Richter, Robert le Roux, Wayne Pepper
On behalf of CIGRE WG A3.48

Hiroki Ito@aj.MitsubishiElectric.co.jp

SUMMARY

Reliability of substation equipment in power systems is of major concern especially for transmission and distribution system operators and asset owners. A major failure of substation equipment may result in significant system outages with the associated power restoration efforts as well as possible safety implications. Poor reliability will contribute to higher system operating and maintenance costs to the operators and, ultimately, their customers.

CIGRE periodically conducts an international reliability survey on equipment in power systems that can provide good feedback on the validity of international standards. The first reliability survey collected the data of circuit breakers with all technologies serviced in 1974-1977 [1]. The second survey collected the data of single pressure SF_6 circuit breakers serviced in 1988-1991[2],[3]. The reliability data related to GIS were also collected in 1991 (first survey [4], [5]) and in 1996 (second survey [6], [7]).

The previous third survey collected the data for not only circuit breakers (CB) but also disconnecting switches (DS), earthing switches (ES), instrument transformers (IT) and gas insulated switchgear (GIS) serviced in 2004-2007. The results were presented in CIGRE Technical Brochures 509 to 514 [8]-[13].

The paper will present the results of the recent fourth survey focusing on switching equipment such as CB, DS, ES, VCB and GIS and compare them with the results in previous surveys.

KEYWORDS

Transmission & Distribution equipment, Reliability, Life management, End-of-life decision

1. Introduction

Reliability of substation equipment such as circuit breakers, disconnecting switches, earthing switches, instrumental transformers and gas insulated switchgears (GIS) applied in power systems is of major concern for transmission and distribution system operators and asset owners, since the cost of a system outage and its restoration, poor reliability will contribute to higher system operating and maintenance costs to the operators and, ultimately, their customers.

For these reasons, CIGRE periodically conducted an international reliability survey on equipment and updated the reliability data on different equipment and analyse the equipment populations and their failure frequencies classified with voltage ratings, switching applications, technologies, designs and maintenance strategies [1]-[13].

CIGRE recently executes a fourth reliability survey on equipment serviced in 2014-2017. The survey expands the equipment scope to cover generator circuit breakers, HV and MV vacuum circuit breakers, and surge arresters. This paper presents the updated results of different substation equipment collected in the fourth reliability survey and compares them with the results in the previous surveys.

2. General results of the fourth CIGRE reliability survey on equipment

The fourth CIGRE reliability survey collected the data of HV switching equipment such as circuit breakers (CB), disconnecting switches (DS), earthing switches (ES) and gas insulated switchgears (GIS) including CB unit with the voltage rating higher than or equal to 60 kV. The GIS employed a vacuum interrupter (VCB) as a circuit breaker are excluded from the scope of GIS survey.

The fourth survey expanded the scope to over vacuum circuit breakers (VCB) with the voltage ratings higher than 1 kV and generator circuit breakers (GCB) directly connected to a generator used as a base load. The voltage ratings of GCB are approximately ranged from 6 to 36 kV. The circuit breakers connected to a wind turbine are excluded from the scope of GCB survey.

Table 1 summarizes the population and the average major failure frequency for different equipment collected in the fourth survey, which are compared with the results in the previous third survey. It includes the data of instrumental transformers (IT) and those of surge arresters (SA). They generally show good service experience. The major failure frequency of CB shows slightly higher values than the results in the third survey. The number of ageing equipment serviced longer than 35 years are considerably increased in the fourth survey and some specific designs show extremely higher major failure frequency. The major failure frequency of GIS is significantly improved in the fourth survey.

Table 1: Results of equipment population and major failure frequency in the third and fourth surveys

Equipment	Third CIGRE survey in 2004-2007			Fourth CIGRE survey in 2014-2017		
	Populations	Major failures	Frequency	Populations	Major failures	Frequency
CB	278,480 CB-year	828	0.2973 %	597,990 CB-year	2,850	0.4766 %
DS	706,003 DS-year	1,624	0.2300 %	1,878,778 DS-year	735	0.0391 %
ES	218,356 ES-year	335	0.1534 %	246,492 ES-year	72	0.0292 %
IT	1,288,695 IT-year	686	0.0532 %	935,439 IT-year	1,325	0.1416 %
GIS	88,948 CB bay-year	326	0.3665 %	236,578 CB bay-year	191	0.0807 %
MOSA	---		---	564,469 SA-year	466	0.0826 %
VCB	---		---	2,538,436 CB-year	374	0.0147 %
GCB	---		---	2,306 CB-year	4	0.1734 %

3. Reliability survey on Circuit Breakers (CB)

Table 2 provides an overview of the participations and time periods collected by the past three reliability surveys and the recent fourth reliability survey on circuit breakers (CB). Even though only 24 utilities from 14 countries participate in the fourth survey, the number of circuit breaker populations exceeds those in the last third survey, due to first participation of the country with large installations of recent equipment. There is important difference in the service year between the previous third survey and the present fourth survey. The longest service year in the previous third survey was from 30 to 34 years. However, the present fourth survey collected the service experience of large number of ageing CB serviced longer than 35 years (including many CB serviced over 40 years).

Table 2: CIGRE reliability surveys on Circuit Breakers (CB)

CIGRE survey	First survey	Second survey	Third survey	Fourth survey
Period	1974-1977	1988-1991	2004-2007	2014-2017
Scope of CB survey	All design types, in service after 1964	Single pressure SF6, in service after 1978	Single pressure SF6, no limitation	Single pressure SF6, no limitation
Voltage ratings	63 kV and above	63 kV and above	60 kV and above	60 kV and above
Participation	120 utilities from 22 countries	132 utilities from 22 countries	83 utilities from 26 countries	24 utilities from 14 countries
CB population	77,892 CB-year	70,708 CB-year	281,090 CB-year	597,990 CB-year
Major failure rate	1.5804 %	0.6718 %	0.2973 %	0.4766 %

Figure 1 shows a plot of major failure frequency as a function of CB population for different countries The plot is classified into three design group such as Live-tank (LT), dead-tank (DT) and GIS type designs in the fourth survey. The CB reliability significantly differs among the participating countries. The maximum value of major failure frequency of LT CB is 17.28 % and the minimum value of major failure frequency of LT CB is 0.0086 %. On the other hand, the maximum value of major failure frequency of DT CB is 5.30 % and the minimum value of major failure frequency of DT CB is 0.0052 %. Three CB designs suggest that the utilities with larger population show lower major failure frequency.

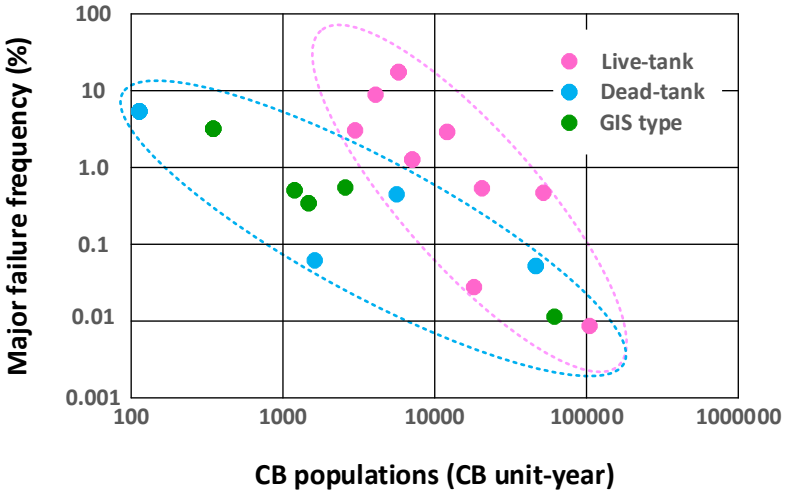

Figure 1: CB major failure frequency plotted by populations for different countries

Figure 2 shows the transition of the major failure frequencies on circuit breakers (CB) in all surveys as a function of voltage ratings. The red line shows the average major failure frequency of the CB with all voltage ratings. The reliability of the CB with the voltage ratings from 60 to 100 kV as well as from 500 to 700 kV is continuously improving through the four surveys.

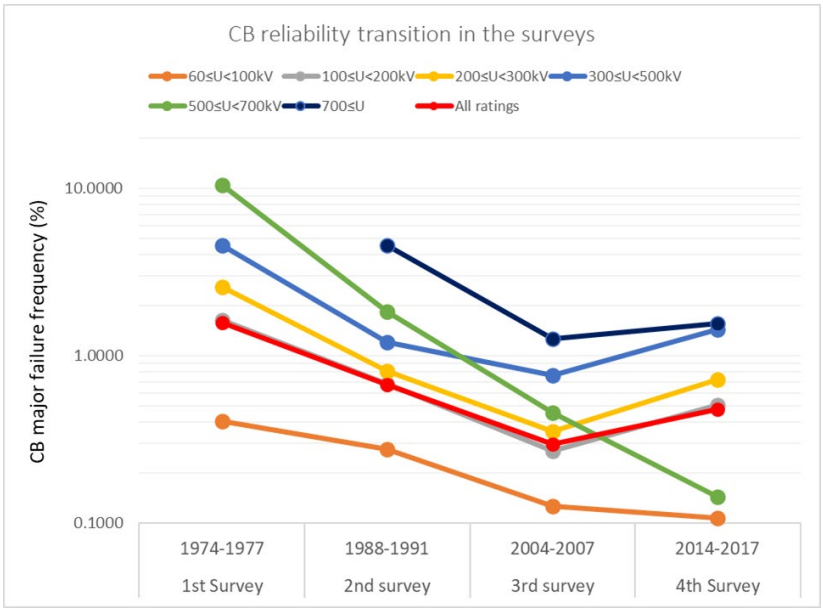

Figure 2: CB major failure frequency transition in the surveys classified into voltage ratings

Figure 3 shows the CB major failure frequency transition in the surveys classified into enclosure tapes. The red line shows the average major failure frequency of the CB with all enclosure types. While the reliability of CB with dead tank types and GIS types are improving, however, the reliability of CB with live tank designs is degraded in the present fourth survey.

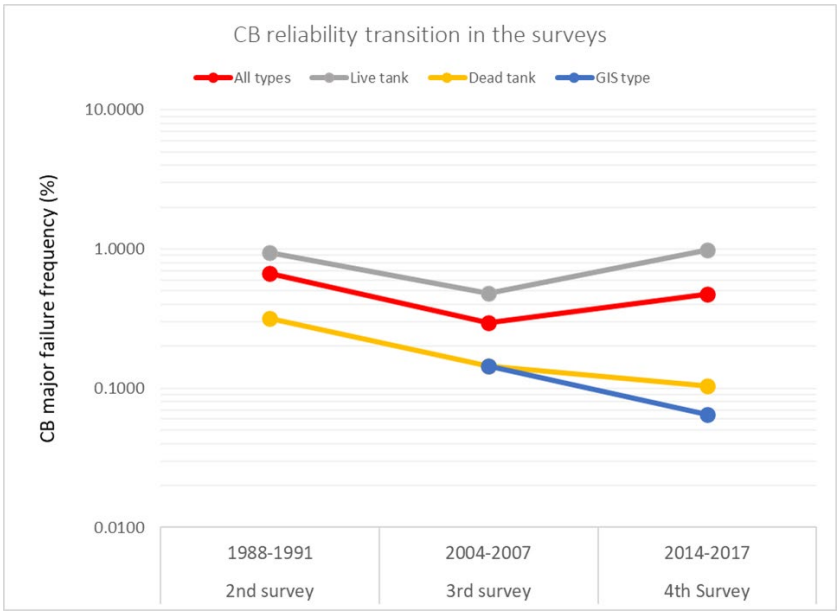

Figure 3: CB major failure frequency transition in the surveys classified into enclosure tapes

4. CIGRE reliability survey on Disconnecting Switches (DS)

Table 3 summarized an overview of the participations and time periods on the DS in the previous third and the present fourth surveys. The surveys cover all AIS and GIS types. Even though only 19 utilities participate in the fourth survey, the number of DS populations is about 2.7 times larger than that in the previous third survey. Even though the population of ageing DS serviced for more than 35 years is considerably increased in the fourth survey, the average of the major failure is significantly improved.

Table 3: CIGRE reliability surveys on Disconnecting Switches (DS)

CIGRE survey	Third survey	Fourth survey
Period	2004-2007	2014-2017
Scope of DS survey	All AIS & GIS types	All AIS & GIS types
Voltage ratings	60 kV and above	60 kV and above
Participations	69 utilities from 25 countries	19 utilities from 10 countries
DS population	706,003 DS-year	1,878,778 DS-year
Major failures frequency	0.2300 %	0.0391 %

Figure 4 shows a comparison of major failure frequencies on disconnecting switches (DS) classified into the voltage ratings between the previous third and the present fourth surveys. The reliability of DS with all voltage ratings is considerably improved in the fourth survey.

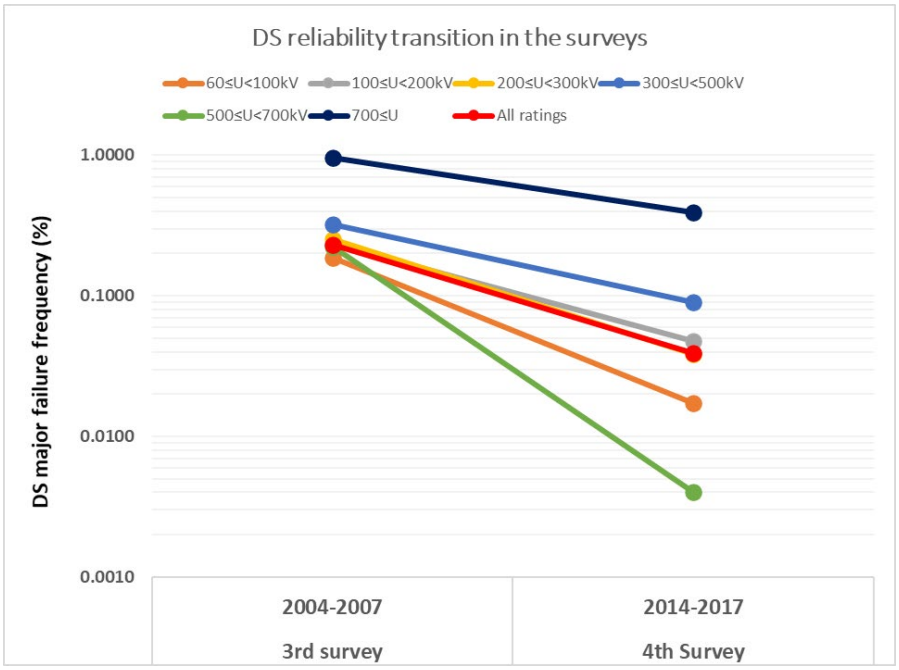

Figure 4: DS major failure frequency transition in the surveys classified into voltage ratings

Figure 5 shows the DS major failure frequency plotted for the population of the DS group depending on designs. The design group are classified into knee break, vertical break, semi-pantograph, central break, pantograph, double break, and GIS types.

DS reliability is generally excellent but shows certain difference in the designs; single arm design group (which includes semi-pantograph, knee, and vertical break) shows higher major failure frequency as compared with double arm design group (which includes centre, pantograph, and double break). The major failure frequency for the DS with single arm designs are ranged from 0.1815 to 0.2593 %, while that for the DS with double arm designs are ranged from 0.026 to 0.1190 %. The major failure frequency for the GIS type DS also shows excellent reliability (The frequency is 0.0163 %).

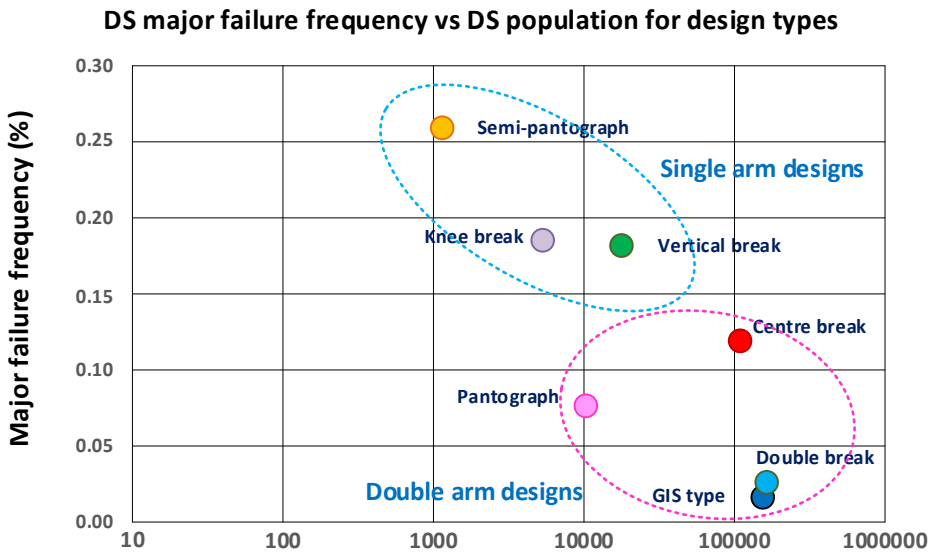

Figure 5: DS major failure frequency transition as a function of the population

5. CIGRE reliability survey on Gas Insulated Switchgears (GIS)

Table 4 shows a summary of the populations and the major failure frequencies of gas insulated switchgears (GIS) collected by the past three surveys and the present fourth survey. The GIS reliability has been improving though the four surveys, especially the fourth survey show that the GIS reliability is significantly improving, even though the participating countries is limited.

Table 4: CIGRE reliability survey on Gas Insulated Switchgears (GIS)

CIGRE survey	First survey	Second survey	Third survey	Fourth survey
Period	up to 1990	up to 1995	2004-2007	2014-2017
Voltage ratings	60 kV and above	60 kV and above	60 kV and above	60 kV and above
Participation	109 utilities from 34 countries	80 utilities from 30 countries	55 utilities from 24 countries	20 utilities from 11 countries
GIS population	70,491 CB-bay-year	116,068 CB-bay-year	88,948 CB-bay-year	236,578 CB-bay-year
Major failure frequency	1.0015 %	0.7504 %	0.3665 %	0.0807 %

Figure 6 shows a plot of GIS major failure frequency dependence on population for different countries in the previous third survey and the present fourth survey. The plots of the frequency in both third and fourth surveys are scattered widely among the participating countries. It is interesting that they show a single correlation for both third and fourth surveys even the participants considerably differ between the surveys. The maximum value of GIS major failure frequency is 6.5359 % and the minimum value

of major failure frequency is 0.0 % in the present fourth survey. It is also founded that the utility with larger GIS population generally tend to show lower major failure frequency.

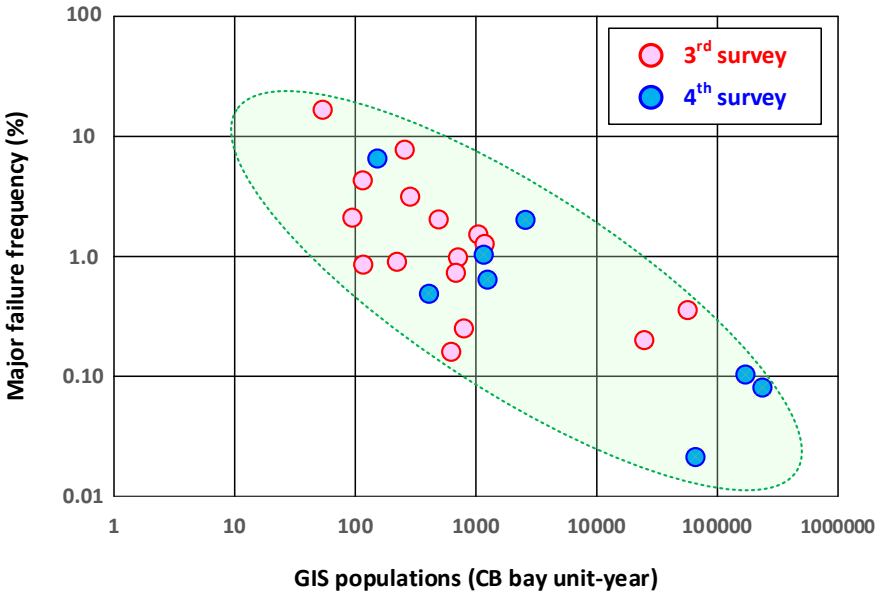

Figure 6: GIS major failure frequency dependence on population for different countries

Figure 7 shows the transition of major failure frequencies on gas insulated switchgears (GIS) in the surveys as a function of voltage ratings using polygonal line graph. The red line shows the average major failure frequency of the GIS with all voltage ratings. The reliability of the GIS for all voltage ratings is continuously improving through the surveys.

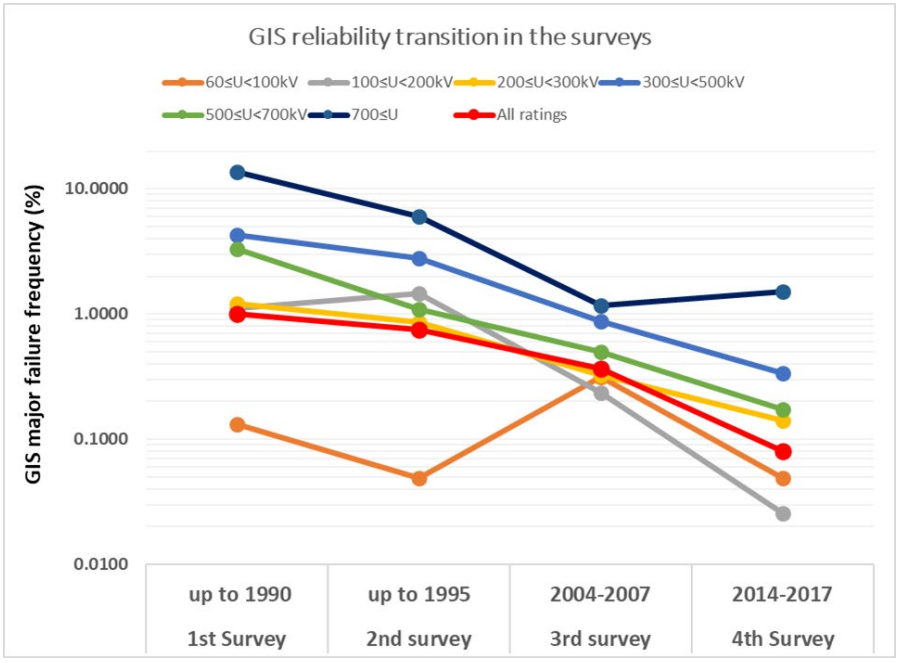

Figure 7: GIS major failure frequency transition in the surveys classified into voltage ratings

6. Conclusions

The paper provides an updated reliability data collected in the fourth CIGRE reliability survey on different substation equipment and compares the results with the past surveys. The world average major failure frequency for different equipment generally shows good service experience. The major failure frequency of CB shows slightly higher rates than those in the third survey, because the CB group with specific live tank designs show the extremely high major failures serviced with longer than 40 years. On the other hand, the major failure frequency of GIS serviced in 2014-2017 is considerably improved as compared with the results in the previous third survey.

The reliability on switching equipment seems to differ widely among the countries, it may provide useful information if CIGRE would investigate the background information of the reliability and its dependence on the designs, the specifications, the maintenance practices, and operating conditions.

The present fourth survey is also collecting the information on vacuum circuit breakers (VCB) and generator circuit breakers (GCB) for the first time. VCBs applied at both MV distribution and HV transmission levels generally show excellent service experience. GCB also show good service experience.

CIGRE established new WG A3.48 in July 2022 to update the reliability performance of various equipment collected in the fourth survey. The WG will explore useful information on life management and end-of-life assessment of equipment.

Bibliography

[1] G. Mazza and R. Michaca on behalf of CIGRE WG 13.06, “The first international enquiry on circuit-breaker failures and defects in service”, Electra 79, pp. 21-91, 1981

[2] CIGRE WG 13.06, “Final report of the second international enquiry on high voltage circuit-breaker failures and defects in service”, CIGRE Technical Brochure 083, 1994

[3] CIGRE WG A3.08, “Life Management of Circuit Breakers”, CIGRE Technical Brochure 165, 2000

[4] I. M. Welch, “GIS Experience Survey and Database”, ELECTRA No. 157, page 81-83, December 1994

[5] I. M. Welch, C. J. Jones, D. Kopejtkova, S. Kobayashi, T. Molony, P. O’Connell, “GIS in Service, Experience and Recommendations”, CIGRE Session Report SC 23-104, 1994

[6] T.M. Chan, F. Heil, D. Kopejtkova, P. O’Connell, J.-P. Taillebois, I. Welch, “Report on the Second International Survey on High Voltage gas Insulated Substation (GIS) Service Experience”, CIGRE Session Report SC23-102, 1998

[7] CIGRE WG 23.02, “Report on the Second International Survey on High Voltage Gas Insulated Substations (GIS) Service Experience”, CIGRE Technical Brochure 150, 2000

[8] CIGRE WG A3.06, “Final Report of the 2004-2007 International Enquiry on Reliability of High Voltage Equipment, Part 1: Summary and General Matters”, CIGRÉ Technical Brochure 509, 2012

[9] CIGRE WG A3.06, “Reliability of High Voltage Equipment - Part 2: SF6 Circuit Breakers”, CIGRE Technical brochure 510, 2012

[10] CIGRE WG A3.06, “Final Report of the 2004-2007 International Enquiry on Reliability of High Voltage Equipment, Part 3: Disconnectors and Earthing Switches”, CIGRE Technical Brochure 511, 2012

[11] CIGRE WG A3.06, “Final Report of the 2004-2007 International Enquiry on Reliability of High Voltage Equipment, Part 4: Instrument transformer”, CIGRE Technical Brochure 512, 2012

[12] CIGRE WG A3.06, “Final Report of the 2004-2007 International Enquiry on Reliability of High Voltage Equipment, Part 5: Gas Insulated Switchgears”, CIGRE Technical Brochure 513, 2012

[13] CIGRE WG A3.06, “Final Report of the 2004-2007 International Enquiry on Reliability of High Voltage Equipment, Part 6: Gas Insulated Switchgears (GIS) Practices”, CIGRE Technical Brochure 514, 2012