INTERMEDIATE RESULTS FROM ON-GOING CIGRÉ ENQUIRY ON RELIABILITY OF HIGH VOLTAGE EQUIPMENT

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Abstract: ***CIGRÉ WG A3.06 is presently carrying out a worldwide enquiry of failures in service on high voltage equipment rated for voltages greater than or equal to 60 kV. The survey covers circuit breakers (only single pressure SF_6 technology), disconnector switches, earthing switches, instrument transformers and GIS. The collection of information from utilities started in 2004 and will continue to the end of 2007. The paper presents intermediate equipment populations covered by the survey, and gives samples of major failure modes and causes. Preliminary trends, in relation to previous CIGRÉ surveys, are discussed.***

Keywords: High voltage apparatus - Failure statistics - Reliability survey - Service experience

1. INTRODUCTION

Accurate information about service experience of high voltage equipment is of significant value for both electric utilities and manufacturers of such equipment. It helps the manufacturers improve their products, and provides important inputs for the utilities when choosing equipment and when organizing maintenance. Equipment reliability data is also required when assessing the overall reliability of an electric power system, including studies of the electric energy supply security. Furthermore, international standards applicable to high voltage equipment are being improved on the basis of service experience and reliability data.

Hence, CIGRÉ has considered collecting, analyzing and publishing reliability data as important tasks. A number of years have now passed since the last surveys on high voltage components. For example, in the previous study on circuit breaker service experience, the data collection ended in 1991. Deregulation and new technologies, among other things, have caused the service and maintenance practises to change significantly, and it is thus time for renewed studies.

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CIGRÉ is now carrying out a new worldwide enquiry on service experience on high voltage equipment. The enquiry covers the period 2004 - 2007, and is fairly comprehensive in that it includes circuit breakers, disconnector switches (d. s.) and earthing switches (e. s.), instrument transformers and gas insulated substations (GIS).

This paper starts by briefly summarizing essential features of the survey, including a description of the applied data collection procedures. Then, by considering one component type at the time, a selection of preliminary results, like information about the equipment populations being surveyed and the failures that have occurred in the period 2004 - 2005 is presented. The results are discussed and compared to corresponding results of previous CIGRÉ investigations.

2. PROCEDURES FOR COLLECTING AND ANALYZING DATA

The reliability survey is carried out as a co-operation between CIGRÉ Study Committees A3 and B3. A working group, "A3.06: Reliability of high voltage equipment", was established in 2002 to organize the work and analyze the results.

The enquiry comprises equipment rated for voltages greater than or equal to 60 kV. For circuit breakers only single pressure SF_6 technology is included, thus in practice excluding equipment installed before around 1970. For disconnector switches, earthing switches and instrument transformers there is no such limitation in age or technology.

Only failures occurring in a four year period starting January 2004 are collected. To be able to determine failure rates, numbers and details of the equipment service years that are covered by the survey also have to be recorded for the same time interval. Thus for each of the four equipment types included, the enquiry employs two types of forms or cards or questionnaires: one for equipment populations and one for failures. Population cards are to be completed annually (i.e., one for each year 2004 - 07), whereas a failure card should be filled in each time a failure occurs. The information is collected directly and solely from the utility sector, and all information is treated as confidential.

A main objective with the present reliability survey is to identify trends by comparing the findings from this investigation with those from the previous ones. Consequently, the majority of the definitions and questions in the present survey are completely or nearly identical to those applied earlier. For example, the division into minor and major failures follows the procedures used in the previous circuit breaker surveys.

More details about the procedures and tools for collecting the information can be found in a previous publication [1].

3. SOME INTERMEDIATE RESULTS

3.1 Circuit breakers

In the past, two circuit breaker reliability surveys have been carried out. The first was performed in 1974 - 77 and concerned nearly 79,000 circuit breaker years of service [2]. In the second survey [3] data were collected in the period 1988 - 91 and almost the same number of circuit breaker years were covered, but the survey was limited to single pressure SF_6 technology (as the present survey is). In the following sections a few intermediate results are presented and in some cases also compared with findings from the second circuit breaker survey.

The present survey has at its mid term, i.e., when including the years 2004 - 05, covered more than 75,500 circuit breaker years of service. So far utilities from 25 countries are participating, but the participation is very unevenly distributed. One country accounts for more than 36 % of the surveyed service years.

Fig. 1 shows the surveyed service experience grouped after operating voltage, kind of service and split into GIS and live tank apparatuses. GIS equipment constitutes a very large portion of the experience.

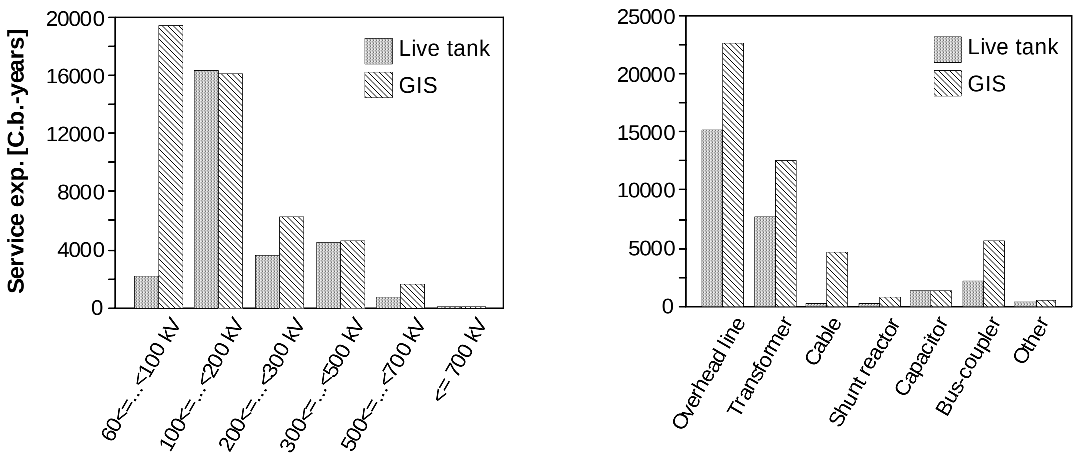

Fig. 1. Surveyed service experience of SF_6 circuit breakers segmented by voltage (left) and application (right). Dead tank breakers are included in the GIS population.

It appears that the majority of the circuit breakers are serving at voltage levels between 60 and 200 kV and only around 3 % from 500 kV and above. This is comparable with the previous survey. Moreover, around 50 % of the circuit breakers are used for switching of overhead lines.

Both the previous and the present survey collect information about what type of operating mechanism the circuit breakers are equipped with. Hydraulic drives were the most common type in the previous survey. Since then the part employing spring mechanisms has more than doubled and comprises nearly half the population of the present survey, see Fig. 2.

Table I shows the major failures grouped after which part of the circuit breaker that has failed for the two surveys. No major differences are observed. The operating mechanism remains the most unreliable part of the breaker. A more detailed analysis reveals that the “mechanical transmission” and “making and breaking unit” i.e., the arcing chamber, each account for around 17 % of the major failures.

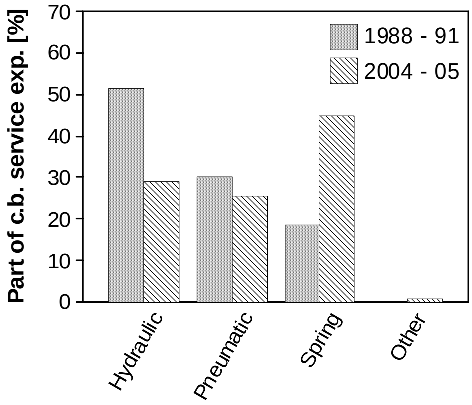

Fig. 2. Distribution of operating mechanism types in the previous and the present circuit breaker survey.

Also with regard to the failure mode/type there appears to be only modest differences between the two surveys. As can be seen from Table II, “Does not close/open on command” and “Locked in open or closed position” remain the most frequently occurring failure modes.

Table I. Major failures sorted by originating component.

	1988 - 91 [%]	2004 - 05 [%]
Component at service voltage	21	26
Electrical control and auxiliary circuits	29	22
Operating mechanism, including kinematic chain	50	52

Table II. Most frequently occurring major failures modes/types.

	1988 - 91 [%]	2004 - 05 [%]
Does not close on command	25*	29
Locked in open or closed position (alarm triggered)	28*	19
Dielectric breakdown	14	15
Does not open on command	8*	14
Loss of mechanical integrity (mechanical damages)	**	10
Opens without command	7	4
Other	18	9

* Some confusion in the previous survey about which failures belonged to which of these three modes
** Not listed as a separate failure mode in previous survey; included under "Other".

The causes for the failures are also asked for. Among the preliminary findings for the reported major failures are that:

- One out of four was introduced before the circuit breakers were put into service; most of these are categorized as "Design fault" or "Manufacturing fault".
- More than one out of three were attributed to "Wear/aging".
- One out of five cannot be blamed on circuit breaker itself as these were due to external factors, e.g. caused by failures in adjacent equipment; due to electrical, mechanical or environmental stresses exceeding the breaker rating; incorrect operation or monitoring, etc.
- One out of four are reported as "Unknown other causes".

In 7 % of the cases the failure was reported to "caused fire and / or explosion of the circuit breaker".

The overall circuit breaker major failure rate appears to be substantially lower than in the previous survey. Moreover, the previous survey indicated that failure rates increase with increasing voltage level and that metal enclosed circuit breakers are more reliable than non-metal enclosed breakers. So far the on-going survey shows the same tendency, although more comprehensive data quality checks and analyses are needed to confirm this.

3.2 Disconnectors and earthing switches

No reliability survey on a large international scale has previously been carried out on disconnectors and earthing switches, so the present survey is in a sense breaking new ground.

So far 24 countries are participating and nearly 350,000 switch-years of surveyed service experience are included. A large fraction of these components are rather old; about 25 % were put into service before 1974. Fig. 3 shows the service experience sorted by voltage level, component type and type of operating mechanism.

As can be seen, the population contains nearly three disconnectors for each earthing switch. More than half of both disconnectors and earthing switches are motor operated.

Fig. 4 shows the major failures grouped by failed component and failure cause. The general finding for AIS is that the failures split about equally between live parts, drives and auxiliary equipment. For GIS the majority of the failures are associated with the operating mechanism.

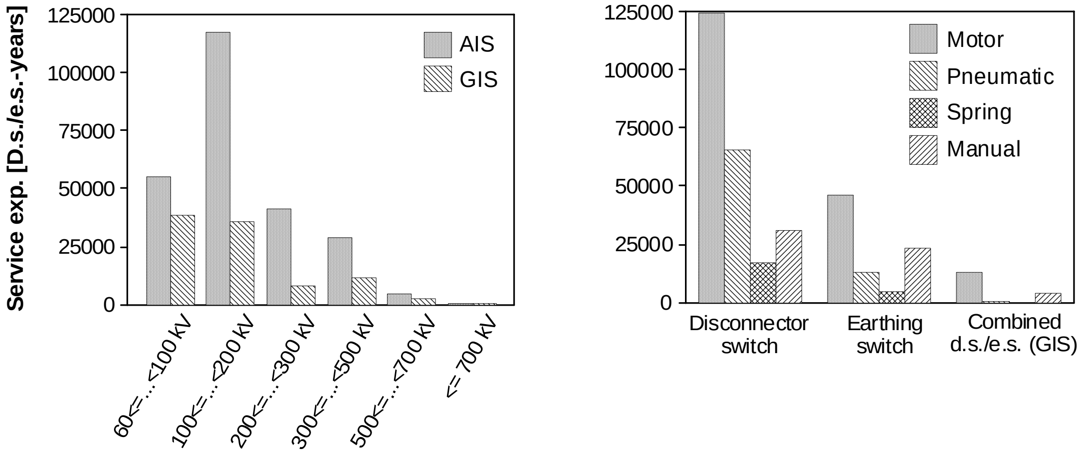

Fig. 3. Disconnector/earthing switch surveyed service experience segmented by voltage (left) and operating mechanism (right).

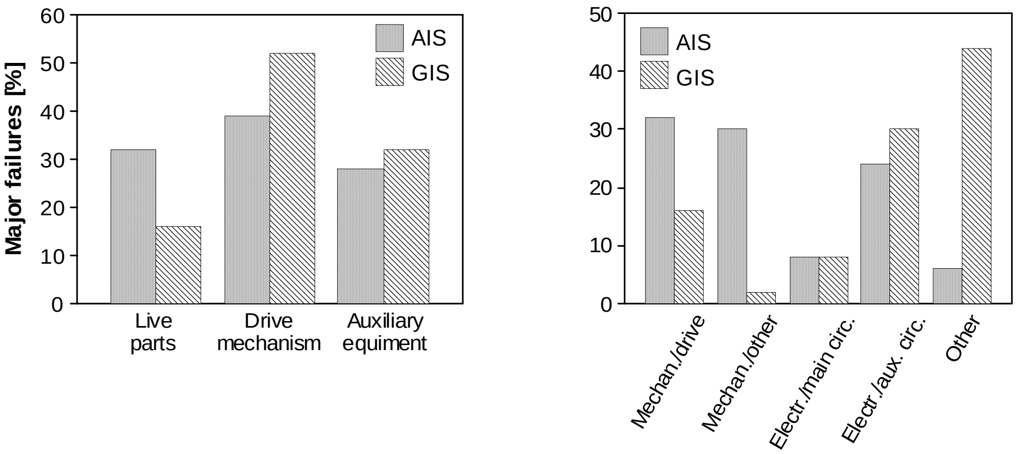

Fig. 4. Distribution of major failures between the different subcomponents of the disconnector / earthing switches (left) and grouped after failure cause (right).

Furthermore, mechanical failures account for the majority of the major failures in AIS. For GIS the majority of the failures are electrical and "Other" (presumably unknown) failure causes.

With regard to the overall major failure rate the intermediate results indicate that the failure rates for disconnectors and earthing switches are comparable to those found for circuit breakers. The failure rates do not seem to vary with the service voltage, but are substantially higher for AIS than for GIS equipment.

3.3 Instrument transformers

Two failure surveys on instrument transformers have been carried out in the past. Only the results from the first have been published [4]. These surveys are in several ways different from the present one. They are retrospective (i.e., they include failures that have occurred since the equipment was put into service), only AIS instrument transformer were covered, the questions differ substantially from the on-going survey, and in the first survey also manufacturers contributed. Consequently, making comparisons and identifying trends are in some respects difficult.

In the present survey utilities from 24 countries have so far provided data. Unlike the components discussed so far, instrument transformers are counted in single phase units; the reason being that they are not always applied as complete three phase sets. Up to now the instrument transformer surveyed service experience includes more than 500,000 units. Fig. 5 shows how it distributes with regard to type and service voltage.

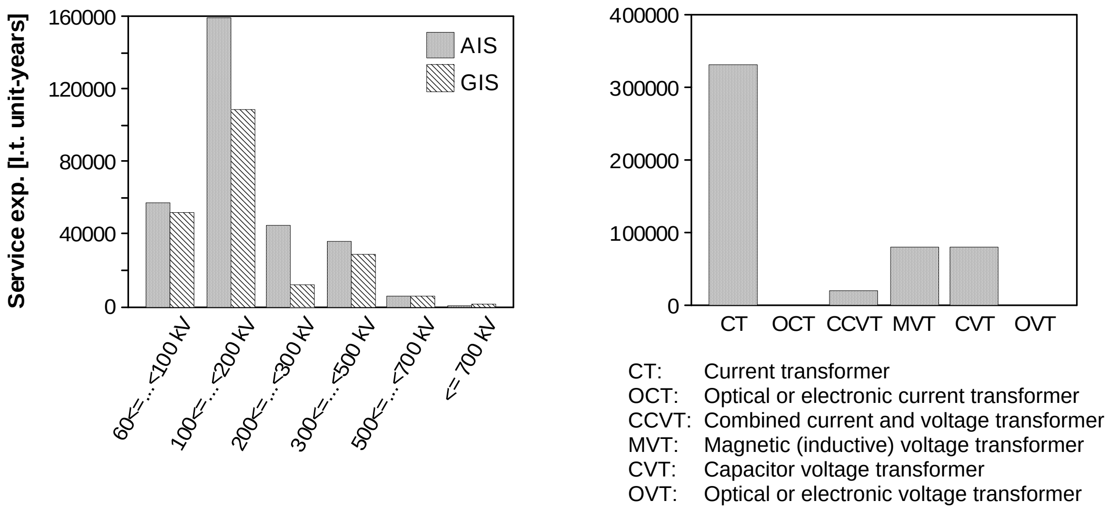

Fig. 5. The instrument transformer (i. t.) surveyed service experience segmented by voltage (left) and type (right).

GIS equipment constitutes as much as 40 % of the service experience. Around two thirds of the experience is from current transformers, whereas optical and electronic devices account for less than 0.1%.

Tables III and IV show the major failures grouped according to failed subcomponent and failure modes.

Table III. Most frequently reported failing subcomponent.

	Fraction of major failures [%]
Main internal insulation (oil, paper, SF6, resin, air,…)	39
Secondary winding	8
High voltage tank (primary terminals incl.)	8
Insulator (porcelain, composite or resin)	6
Sealing (e.g. gaskets and O-rings)	6
Capacitors in CVT	6

Table IV. Most frequently reported failure modes.

	Fraction of major failures [%]
Internal dielectric failure (flashover, breakdown, PD)	46
Leakage of insulation medium (loose part)	12
Loss of electrical connection integrity in secondary	6
Loss of mechanical integrity (mechanical damages)	6

It appears that dielectric failures in the main insulation are by far the most common major failure type for instrument transformers.

Concerning the overall reliability; preliminary analyses indicate that the major failure rates are substantially lower that of the first survey.

3.4 GIS

Two GIS reliability enquires have previously been carried out. The latter one covers service experience up to and including 1995 [5]. At that time utilities from 30 countries participated. In the present survey, GIS failure and population cards have been submitted so far by 27 countries. There is only a partial overlapping of participating countries as well as participating utilities between the two surveys. This is a complicating factor when making comparisons between results.

For the first year of the present study, a total of 8,996 GIS installations have been reported, which may be compared to a total of 2,115 GIS installations in the previous survey. In the same way as in the previous study, there is a strong dominance of one country: For 2004, this dominating country contributed no less than 82% of the GIS installations, while they have so far not provided data for the following years.

One GIS circuit breaker bay represents one circuit breaker and its associated disconnector and earthing switches, instrument transformers, busducts and a part of busbars if applicable. Fig. 6 shows the GIS service experience collected so far, grouped after service voltage.

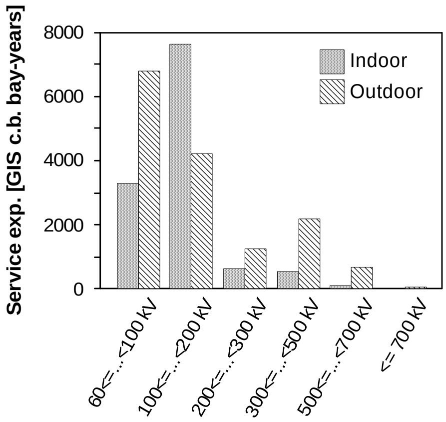

Fig. 6. GIS surveyed service experience segmented by voltage level and location (indoor/outdoor).

Since much more population and failure data are expected to be submitted, all conclusions regarding GIS major failure characteristics are very preliminary. The trends mentioned may change at the end of the survey. Table V shows a major failure analysis from the failed component distribution point of view. Switching equipment remains the least reliable component. It appears that instrument transformer reliability has decreased whereas the reliability of busbar has increased.

Table VI shows a major failure analysis from the major failure mode point of view. It seems that the prevailing major failure mode is total changed from “dielectric breakdown” in the previous study, to “failing to perform requested operation or function” in the present survey. However this trend is not so evident at all when subtracting the data from the dominating country.

Table V. Major failures sorted after failing component type.

	Previous survey [%]	Present survey; One dominating country incl./excl. [%]
Circuit breaker or switch	35	30 / 48
Disconnector or earthing switch	32	43 / 20
Instrument transformer	10	22 / 32
Other part of GIS	23	5 / 0

Table VI. Most frequently occurring major failure modes.

	Previous survey [%]	Present survey; One dominating country incl./excl. [%]
Failing to perform requested operation or function	10	57 / 30
Loss of electrical connections integrity in primary	} 3	1 / 3
Loss of electrical connections integrity in secondary		1 / 3
Dielectric breakdown in normal service (without switching operation)	} 64	19 / 47
Dielectric breakdown in connection with switching operation		4 / 12
Loss of mechanical integrity (mechanical damages, big SF_6 leakage incl.)	15	2 / 3
Other or unknown	8	16 / 2

Only 2% of the major failures led to an explosion of GIS enclosure, however this small value has not changed in comparison with the previous study.

Compared to the previous study, the overall major failure rates have decreased, except for the lowest voltage class, i.e., 60 - 100 kV. A significant reliability improvement is visible for the voltage classes 100 - 200 kV and 300 - 500 kV, i.e. for the classes containing only little equipment from the dominating country.

4. DISCUSSION AND CONCLUSION

The collection of data for the present survey is still ongoing, and therefore all evaluations and conclusions are preliminary. Participating countries and utilities have changed to a relatively great extent, compared to previous surveys, and parts of the questions have been modified. Therefore, it is not straightforward to compare results. Disconnector and earthing switches are included for the first time. A comparatively large part of all data is from one single country, and relates to GIS.

Based on the material available so far, the major failure rates for circuit breakers, instrument transformers and GIS are lower than in previous studies. For GIS, the improvement is especially clear for voltage classes 100-200 kV and 200-500 kV. The major failure rate for disconnector and earthing switches is similar to that of circuit breakers.

The survey is now in the last year of the data collection period, i.e., the interval 2004-2007. Thereafter final evaluation and analysis of data will be undertaken. It is essential for a good outcome of the survey that participating utilities continue to supply both population and failure data for the entire period.

5. REFERENCES

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