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FAILURE OF LARGE OIL COOLED TRANSFORMERS

Working group report to the 29th conference of the International Machinery Insurers' Association, September 1996

Executive summary

Major losses due to failures of large oil cooled transformers appeared to be occurring with increasing frequency in the years leading up to 1995. An IMIA Working Group was established to examine and report on the topic at the IMIA Conference in 1996.

A request was sent to all national delegations seeking information on losses involving transformers rated at 100 MVA and above from 1989 onwards. In all, information was obtained in 75 cases of failures of large oil cooled transformers, and these formed the basis for further study.

The losses were examined by marshalling the information for successive years into the following categories:

Numbers and amounts of losses.
Ages of transformers.
Causes of failures.
Types of industry using the transformers.
Ratio of Business Interruption loss amounts to Physical Damage loss amounts.

The study revealed a fairly even pattern of losses over the years reviewed and demonstrated that failures of large oil cooled transformers are predominantly associated with the generation, transmission and distribution of power, are more likely to arise from internal failure than external failure, particularly during the early years in service, and a major failure could cost Insurers between $1 million and $3 million for Physical Damage and for Business Interruption in the same order of magnitude, although an exceptional Business Interruption loss may escalate to tens of millions of US dollars.

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Introduction

Major losses due to failures of large oil cooled transformers appeared to be occurring with increasing frequency in the years leading up to 1995. An IMIA Working Group was established to examine and report on the topic at the IMIA Conference in 1996. The Working Group have sought to provide information which would be of some practical benefit to the underwriting of large oil cooled transformers. The nature of the information gathered was not conducive to a rigorous statistical analysis, but some trends and pointers have emerged which may assist in the underwriting of large oil cooled transformers.

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Scope of study

A preliminary review of information immediately available indicated that the major losses which were a source of concern had occurred on transformers rated at 100 MVA and above. A request was sent to all national delegations seeking information on losses involving transformers rated at 100 MVA and above, ideally from 1989, or if loss details were no longer available as far back as 1989, as far back as records would allow.

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Information obtained

A preliminary review was made by extracting information from the "Details of Interesting Large Claims" appearing in the IMIA documents in the years 1990 and 1995. These losses for the years 1989 to 1994 produced 41 cases of failures. Further information was provided by the members of the Working Group and by other delegations in response to a request for information. In all, information was obtained on 75 cases of failures of large oil cooled transformers, and these formed the basis for further study. Losses occurring in the years 1989 and 1990 were drawn from a reduced base of information, resulting in a low number of cases considered compared with later years. This has to be taken into account when interpreting the figures with regard to the year by year progression of trends.

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Methodology

It was intended to examine the losses by marshalling the information for successive years into the following categories: Numbers and amounts of losses. Manufacturers. Ages of transformers. Causes of failures. Types of industry using the transformers. However, some of the major contributors of information were not in a position to identify the manufacturers of the transformers involved. As these outnumbered the remaining cases, where the transformer manufacturer had been identified, an analysis by manufacturer was not undertaken. An estimate of the total insured population of large oil cooled would have been most useful but it was recognised that it was impracticable to obtain this information in view of the blanket nature of many of the policies under which cover was provided for the transformers. All amounts of losses were converted to US dollars for computational purposes, using dollar exchange rates of French Francs 5.216, German Marks 1.5405, Great Britain Pounds 0.6791, Italian Lira 1567, Japanese Yen 106.78, Netherlands Guilders 1.7148, Spanish Pesetas 127.33, Swiss Francs 1.2635.

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Numbers and amounts of losses

Year	Number		Total MVA	Amount (US $) millions	Average per case $ millions	Average per case MVA
	(a)	(b)				
1989	5	3	1626	12.360	2.472	542
1990	8	6	2205	12.797	1.600	368
1991	14	10	2828	26.359	1.883	283
1994	13	11	4482	37.706	2.900	407
TOTALS	75	59	22048	152.650	2.035	374

NOTE: (a) total number of cases for which loss amounts are known.

(b) total number of cases for which MVA capacity is known, in addition to loss amount.

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Losses by ages of transformers (in five-year age bands)

Year	0-5	6-10	11-15	16-20	21-25	25+	Not known
1989	1	0	0	0	0	0	4
1990	1	1	0	1	1	0	4
1991	4	0	1	0	4	1	4
1992	7	1	1	6	1	2	0
1993	5	0	2	2	2	1	5
1994	3	1	1	0	2	2	4
TOTALS	21	3	5	9	10	6	21

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Losses by causes of failures

The quality of the information available was not amenable to close definition as to causes of failure and two broad categories were therefore adopted. The first category included those failures which occurred during normal operation, and may therefore be regarded as "internal" failure. Examples included excessive water content in the oil, ageing of insulation, short circuits between windings, short circuits between windings and their tanks, and failures of bushing connections. The other category contained those events which may be regarded as "external", such as lightning strikes, switching errors and short circuits on transmission lines.

Year	Internal causes	External causes	Not known
1989	4	0	1
1990	5	2	1
1991	5	4	5

1992	13	1	4
1993	10	3	4
1994	6	3	4
TOTALS	43	13	19

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Losses by types of industry

With a large preponderence of cases involving transformers used in generation, transmission and distribution, the remaining cases were insufficient in number to merit further segregation and the transformer losses were grouped under these two headings.

Year	Generation, transmission & distribution	Other industries	Not known
1989	3	1	1
1990	5	2	1
1991	8	2	4
1992	14	3	1
1993	15	0	2
1994	12	0	1
TOTALS	57	8	10

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Business interruption losses

In the vast majority of cases examined, the losses were attributed to physical damage categories, mainly machinery breakdown, but with some losses attributed to business interruption only. In other cases, a single loss amount was given for the combined physical damage and business interruption losses. To involve these cases in examining business interruption losses could have been misleading, and an alternative approach was adopted therefore.

Among the 75 cases reported to the Working Group, there were ten events for which physical damage and business interruption losses were both reported individually.

These ten cases have been tabulated as follows to examine the relationship between the two classes of loss. In view of the exceptional nature of one loss at $21.339 million, the next largest loss among the 75 cases being $5.497 million, the totals have also been re-calculated after excluding the physical damage and business interruption figures for this exceptionally large loss event. A description of the largest loss is given in the Appendix.

It is common for transformers of 100 MVA and over to be in service without provision for a spare transformer at the location or elsewhere and manufacturers rarely keep them in stock as ready replacements. With rewinds typically taking six to nine months, if in fact the copper is available,

and with special handling and shipping requirements (occasionally further complicated if PCB contamination is discovered) a large transformer failure can easily lead to a high BI loss.

	Loss amounts US$ millions		ratio BI : PD
	PD	BI	%
1989	3.629	0.000	0
1990	1.446	0.671	46
1991	2.250 2.400 3.300	0.975 0.750 0.450	43 31 14
1992	1.000 1.725 1.500	5.497 2.250 2.700	550 130 180
1994	0.993 2.090	21.339 0.640	2150 22
TOTALS	20.333	35.272	173

Excluding the entries for the penultimate case:

TOTALS	19.340	13.933	72

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Conclusions

Taking account of the reduced information base for the years 1989 and 1990 which produced a low number of cases for these years, and allowing for the exceptional single $22 million loss which occurred in 1994, Table 5 showed a fairly even pattern of losses over the years reviewed.

It was demonstrated in Table 6 that transformers have a vulnerability to failure in the first five years of their life, with a subsequent period of reliable service followed by a slightly increased susceptibility to failure approaching 20 years of service and beyond.

Over the years reviewed, Table 7 showed a fairly consistent preponderence of failures due to internal causes over those failures due to external causes. This indicated that losses were more likely to arise from actions or omissions during the design, manufacture, installation, maintenance and repair rather than from external causes such as lightning strike, transmission line short circuit or operator error.

With the scope of study directed at transformers of 100 MVA and above, it was not surprising to find that Table 8 reflected a heavy majority of failures among the transformers in the generation, transmission and distribution industry, where these large transformers are in such common use. However, a meaningful comparison of figures in Table 8 could have been made only if the respective populations of transformers were known.

The listing of Business Interruption losses against Physical Damage losses stemming from the same events showed no consistent relationship between these two classes of losses. However, the listing demonstrated the potential for comparatively huge Business Interruption losses.

In summary failures of large oil cooled transformers are predominantly associated with the generation, transmission and distribution of power, are more likely to arise from internal failure than external failure, particularly during the early years in service, and a major failure could cost Insurers between $1 million and $3 million for Physical Damage and for Business Interruption in the same order of magnitude, although an exceptional Business Interruption loss may escalate to tens of millions of US dollars.

This study has been limited by the quality and quantity of the information obtained, thus inhibiting thorough analysis and trend observation. If engineering insurers see a need for a more determined analytical approach to assist in future underwriting, then it will be necessary to seek and record systematically the relevant facts and information when dealing with loss events concerning large oil cooled transformers.

Working group

British Machinery Insurers' Association
Clive Fraser-Andrews (Chairman of Working Group)
Allan Schofield
Wilf Rawling/Tony Daley

Germany
Alexander von Streitberg

Japan
Mitsuhiro Miura

USA
William R Vandall

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Appendix

Description of Largest Loss Reviewed

By far the largest loss reviewed in this study involved a combined cycle gas turbine power plant, having one 166 MW gas turbine and one 63 MV steam turbine, each with their own alternators and generator transformers. The gas turbine generator transformer stepped up the voltage from 15.75 kV to 132 kV and was rated at 180 MVA. The cooling arrangements consisted of oil circulating pumps and air cooling fans under thermostatic control. On start up, the pumps and fans were stationary until the thermostat detected a temperature rise in the oil at which the pumps and fans began to operate.

However, the oil temperature detector was not sited at the hottest location during start up, with the result that the upper halves of the windings started to overheat until the oil pumps and air fans began to operate.

After 26 months of commercial service in this fashion, one of the transformer's phases suffered a short circuit in its low voltage windings, and the transformer tripped out of service. The damage to the windings due to overheating became evident on examination. It was decided to enhance the cooling system by doubling the capacity of the air fans and oil circulating pumps which were to commence operation from the first instant of start-up under an amended control sequence. A new transformer, up-rated to 220 MVA, was ordered accordingly with a scheduled delivery in eight months' time. Meanwhile emergency temporary repairs were carried out on the failed transformer as a matter of urgency, since the power station's entire generation was lost whilst the transformer was out of service. Six weeks later the transformer was returned to service at a reduced load pending the arrival of the new up-rated transformer.

After a further three months' service the transformer failed again, with extensive damage to all windings and ancillaries necessitating a complete rebuild. Following investigation, it was suspected that an internal contact had not been adequately secured during the temporary repair three months previously, leading to gradual overheating and eventual short circuit fault.

The transformer on order was urgently expedited and the delivery period was reduced from eight months to six months. Even so, the power station again lost all generation for a further two months.

Whilst the US $0.993 million physical damage loss was not remarkable for this size of transformer, the power station had lost all generation for an aggregate period of 31/2 months, with a partial loss of generation for 3 months. The BI loss amounted to US $21.339 million.

In the light of this experience, the power station now has two additional transformers on site as spares for the gas turbine and steam turbine generator transformers.

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