# The Locomotive

## An Analysis of International Transformer Failures, Part 1

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*[Editor's Note: In past articles, the author has discussed challenges and solutions involving transformer operations in the United States . In this two-part article, he addresses international developments. Part 1 includes an examination of the five-year loss trends as reported by international equipment breakdown insurers. In an upcoming issue, Part 2 will examine transformer aging and offer a global perspective of the industry as seen by those who manufacture transformer equipment.]*

### Introduction

Major losses involving large oil-cooled transformers continue to occur on a frequent basis. A working group of the International Association of Engineering Insurers (IMIA) (www.imia.com) was established in 1995 to examine this topic and presented a report at the 1996 Conference. The magnitude of the losses has increased significantly since the last study. Increased equipment utilization, deferred capital expenditures and reduced maintenance expenses are all part of today's strategies for transformer owners. To make matters worse, world power consumption is increasing, and the load on each aging transformer continues to grow.

### Scope of the Study

A request was sent to all IMIA national delegations seeking information on losses of transformers rated at 25 MegaVoltAmperes (MVA) and above for the period 1997 through 2001. Information was requested concerning year of loss, size in MVA, age at failure, application (such as utilities, industrials), cause of failure, property damage portion, and business interruption portion. Data was obtained on 94 cases. An estimate of the total population of power transformers would have been useful, but it is impractical to obtain this information. Some of the contributors were not able to identify the age of the transformers, and in some cases, the size of the transformer. The analysis is annotated wherever data is missing. All amounts of losses were converted to U.S. dollars, using the following exchange rates: 0.9278 euros; 8.542 Swedish kronas; and 6.0858 French francs.

### Five-Year Trend

During this period, the number of transformer claims reached a peak (25) in 1998. But, the dollars paid out, reached a maximum in 2000 due to several claims in the multi-million dollar range, plus one large business interruption loss. The largest transformer loss also occurred in 2000, at a power plant, with a business interruption portion the equivalent of more than U.S. $86 million. Three of the top four property damage claims were in industrial plants.

Table 1 displays the annual transformer claims. Not all of the data contributed had size information. Therefore, we could only analyze 78 claims for cost per size. The average cost (for property damage only) was approximately $9,000 per MVA (or $9 per kVA). Table 1A displays the annual transformer claims and cost per MVA.

Table 1 – Number and Amounts of Losses by Year

| Year | Total Losses | Total Loss | Property Damage (PD) | Business Interruption |
|---|---|---|---|---|
| 1997 | 19 | $ 40,779,507 | $ 25,036,673 | $15,742834 |
| 1998 | 25 | $ 24,932,235 | $ 24,897,114 | $35,121 |
| 1999 | 15 | $ 37,391,591 | $ 36,994,202 | $397,389 |
| 2000 | 20 | $ 150,181,779 | $ 56,858,084 | $93,323,695 |
| 2001 | 15 | $ 33,343,700 | $ 19,453,016 | $13,890,684 |
| Total | 94 | $ 286,628,811 | $ 163,239,089 | $123,389,722 |

** Total losses in 2000 includes one claim with a business interruption portion of more than $86 million*

Table 1A – Number and Amounts of Losses by MVA and Year

| Year | Total Losses | Losses w/data | Total MVA Reported | Total PD with Size Data | Cost/MVA |
|---|---|---|---|---|---|
| 1997 | 19 | 9 | 2,567 | $20,456,741 | $7,969 |
| 1998 | 25 | 25 | 5,685 | $24,897,114 | $4,379 |
| 1999 | 15 | 13 | 2,433 | $36,415,806 | $14,967 |
| 2000 | 20 | 19 | 4,386 | $56,354,689 | $12,849 |
| 2001 | 15 | 12 | 2,128 | $16,487,058 | $7,748 |
| Total | 94 | 78 | 17,199 | $154,611,408 | |

*During this five-year period, the average cost is $8,990 per MVA, or about $9 per WA.*

### Type of Application

During this period, the largest number of transformer claims (38) occurred in the Utility Substation sector, but the highest paid category was Generator Step Up transformers, with a total of more than $200millon. If the extraordinary business interruption loss is ignored, the Generator Step Up transformer category is still significantly higher than any other category. This is to be expected due to the very large size of these transformers. Table 2 displays the annual claims by application.

Table 2 – Losses by Application

| Year | Generator Step Up | | Industrial | | Utility Substations | | Unknown | | Annual Totals | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1997 | $29,201,329 | 3 | $2,239,393 | 4 | $5,243,075 | 11 | $4,095,710 | 1 | $40,779,507 | 19 |
| 1998 | $15,800,148 | 8 | $3,995,229 | 6 | $5,136,858 | 11 | | | $24,932,235 | 25 |
| 1999 | $3,031,433 | 4 | $24,922,958 | 4 | $6,116,535 | 6 | $3,320,665 | 1 | $37,391,591 | 15 |
| 2000 | $123,417,788 | 10 | $24,724,182 | 4 | $2,039,810 | 6 | | | $150,181,779 | 20 |
| 2001 | $32,082,501 | 11 | | | $1,261,199 | 4 | | | $33,343,700 | 15 |
| Totals | $203,533,199 | 36 | $55,881,762 | 18 | $19,797,476 | 38 | $7,416,375 | 2 | $286,628,811 | 94 |

### Cause of Failure

For the transformer failures reported, the leading cause was "insulation failure." This category includes inadequate or defective installation, insulation deterioration, and short circuits, but not exterior surges such as lightning and line faults. Table 3 lists the number of failures and percentage of total costs paid for each cause of failure. A description of each cause category is found below.

Table 3 – Cause of Failures

| Cause of Failure | Number | Total Paid |
|---|---|---|
| Insulation Failure | 24 | $149,967,277 |
| Design /Material/Workmanship | 22 | $64,696,051 |
| Unknown | 15 | $29,776,245 |
| Oil Contamination | 4 | $11,836,367 |
| Overloading | 5 | $8,568,768 |
| Fire /Explosion | 3 | $8,045,771 |
| Line Surge | 4 | $4,959,691 |
| Improper Maintenance/Operation | 5 | $3,518,783 |
| Flood | 2 | $2,240,198 |
| Loose Connection | 6 | $2,186,725 |
| Lightning | 3 | $657,935 |
| Moisture | 1 | $175,000 |
| Total | 94 | $286,628,811 |

The risk of a transformer failure is actually two-dimensional: the frequency of failure and the severity of failure (see "Transformer Asset Management," The Locomotive, Spring 2003, Vol. 77, No. 2).

### Causes of Transformer Failures

**Insulation Failures** – Insulation failures were the leading cause of failure in this study. This category excludes those failures where there was evidence of a lightning or a line surge. There are actually four factors that are responsible for insulation deterioration: pyrolosis (heat), oxidation, acidity and moisture. But moisture is reported separately. The average age of the transformers that failed due to insulation was 18 years.

**Design /Manufacturing Errors** – This category includes conditions such as: loose or unsupported leads; loose blocking; poor brazing; inadequate core insulation; inferior short circuit strength; and foreign objects left in the tank. In this study, this is the second leading cause of transformer failures.

**Oil Contamination** – This category pertains to those cases where oil contamination can be established as the cause of the failure. This includes sludging and carbon tracking.

**Overloading** – This category pertains to those cases where actual overloading could be established as the cause of the failure. It includes only those transformers that experienced a sustained load that exceeded the nameplate capacity.

**Fire /Explosion** – This category pertains to those cases where a fire or explosion outside the transformer can be established as the cause of the failure. This does not include internal failures that resulted in a fire or explosion.

**Line Surge** – This category includes switching surges, voltage spikes, line faults/flashovers, and other T&D abnormalities. This significant portion of transformer failures suggests that more attention should be given to surge protection, or the adequacy of coil clamping and short circuit strength.

**Maintenance /Operation** – Inadequate or improper maintenance and operation was a major cause of transformer failures, when you include overloading, loose connections and moisture. This category includes disconnected or improperly set controls, loss of coolant, accumulation of dirt and oil, and corrosion. Inadequate maintenance is to blame for transformer owners not discovering incipient troubles when there was ample time to correct them.

**Flood** – The flood category includes failures caused by inundation of the transformer due to man-made or naturally caused floods. It also includes mudslides.

**Loose Connections** – This category includes workmanship and maintenance in making electrical connections. One problem is the improper mating of dissimilar metals, although this has decreased somewhat in recent years. Another problem is improper torquing of bolted connections. Loose connections could be included in the maintenance category, but we customarily report it separately.

**Lightning** – Lightning surges are considerably fewer than in previous studies we have conducted. Unless there is confirmation of a lightning strike, a surge type failure is categorized as a Line Surge.

**Moisture** – The moisture category includes failures caused by leaky pipes, leaking roofs, water entering the tanks through leaking bushings or fittings, and confirmed presence of moisture in the insulating oil. Moisture could be included in the inadequate maintenance or the insulation failure category above, but we customarily report it separately.

***About the Author***

William Bartley, P.E., is a Principal Electrical Engineer in the Engineering Department of The Hartford Steam Boiler Inspection and Insurance Company. Bartley earned a B.S. degree in Electrical Engineering from University of Missouri at Rolla, and has been employed by Hartford Steam Boiler since 1971. He is responsible for developing standards, OEM relations, fleet problems, large failure investigations, repair procedure development, and new monitoring and testing technologies. He is a registered Professional Engineer in Connecticut, and a Senior Member of IEEE, serving on both the Transformer Committee and Rotating Machinery Committee. He has authored numerous papers on transformer failures