Annex G

Report of Transformer Reliability Survey—Industrial Plants and Commercial Buildings

By
James W. Aquilino

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Report of Transformer Reliability Survey—Industrial Plants and Commercial Buildings

JAMES W. AQUILINO, MEMBER, IEEE

***Abstract*—The Power Systems Reliability Subcommittee of the IEEE Industry Applications Society has been conducting surveys of the reliability of electrical equipment in industrial and commercial power systems. A previous survey published in 1973 and 1974 [1] included data on the reliability of transformers. Some of the questions raised by the previous results, together with a general need for updated data, prompted a new survey which was conducted in 1979. The results of that survey are presented in this paper.**

INTRODUCTION

ACCURATE reliability data on transformers, together with similar data on other types of electrical equipment, are necessary for evaluating power system reliability. Information of this type is often the only means of showing economic justification for spares, redundancy, or improved maintenance programs. The purpose of this 1979 transformer reliability survey of industrial plants and commercial buildings was to improve upon the results of the previous survey published in 1973-1974 [1] by answering some of the questions raised and eliminating some of the controversy created. The major reasons for conducting the new survey were outlined in a paper presented at the 1979 Industrial and Commercial Power Systems Technical Conference [2].

The most controversial items in the previous survey concerned the average outage duration time after a transformer failure in relation to the failure restoration method. Another item which raised questions was the comparatively high failure rate for rectifier transformers. The 1979 survey form was condensed considerably from the 1973-1974 version. Most of the items found to be of little significance in the past have been omitted. The remaining survey items are aimed at factors believed to have the most influence on the important transformer reliability and availability parameters.

Another major consideration in preparing the new survey form was simplicity. This was intended to enable the respondent to reply with minimal effort, thereby assuring maximum possible response. Obviously, the condensation could only be carried to a certain extent before the survey results would become so general that they would be of little practical value.

Results of the 1979 transformer survey are presented in this paper in tabular form. The discussion which follows under *Survey Results* attempts to expand upon some of the more significant survey data obtained. In any survey of this type there will undoubtedly be some new questions raised and also some old questions and controversies left unresolved. We feel, however, that this data will be of considerable value to system planners, designers, and users.

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The author was with Northrop Corporation, 100 Morse Street, Norwood, MA 02062. He is now with General Radio (GenRad), 170 Tracer Lane, Waltham, MA 02154.

SURVEY FORM

The form used for the 1979 survey is shown in the Appendix. As mentioned before, the Total Population form was condensed to include data relating specifically to transformer reliability. Important influencing factors were rating, voltage, age, and maintenance. However, reporting the response to maintenance quality is difficult. The 1973-1974 survey asked the respondent to give his or her opinion of the maintenance quality as excellent, fair, poor, or none. It is very difficult to be completely objective in responding to this type of question. The new survey, therefore, asked for a brief description of the extent of maintenance performed, the idea being to enable the reader to judge for himself the benefits derived from a particular maintenance procedure. The failed unit data requested is basically the same as that in the previous survey. The most important categories here are the causes of failure, the restoration method, restoration urgency, duration of failure, and age at time of failure.

SURVEY RESPONSE

The response to the survey is summarized in Tables I and II. Responses were received from 25 different companies, and in many cases several locations within the companies were reported. Various types of industrial and commercial facilities are represented including chemical and petro-chemical plants, steel mills, paper mills, manufacturing plants, and hospitals, to name a few. Similar data from the 1973-1974 survey are shown in Table III for comparative purposes. A summarized comparison between the two survey results appears in Table IV. Direct comparisons cannot be made in some instances because of changes made in the sub-classes. For example, the new survey broke the ratings down into two groups, units 300-10 000 kVA and those greater than 10 000 kVA. The ratings in the previous survey were 300-750 kVA, 751-2 499 kVA, and 2 500 kVA and up.

One of the reasons for conducting this new survey was the need for reliability data on arc-furnace transformers. Unfortunately, the response to this category was very poor. The sample size reported was too small to obtain reliable results, therefore, the arc-furnace data were omitted. Hopefully, the response will improve in subsequent surveys. The response to the latest survey did improve over the 1973-

TABLE I
POWER TRANSFORMERS 1979 SURVEY

Type	Number of Units	Unit-Years	Number of Failures	Failure Rate Failures/ Unit-Year	Average Repair Time (Hours)	Average Replacement Time (Hours)
All liquid filled	1814	17 996	111	0.0062	356.1 N: 60 F[2]	85.1 N: 39 F[2]
Liquid 300–10 000 kVA	1750	17 410	102	0.0059	297.4 N: 56 F[2]	79.3 N: 37 F[2]
Liquid >10 000 kVA	64	586	9	0.0153	1178.5[1] N: 4 F[2]	192[1] N: 2 F[2]
Dry 300–10 000	159	1700	1[1]	0.0006[1]	6[1] N: 1 F[2]	– N: 0 F[2]

[1] Small sample size–less than eight failures.
[2] F is failures.

TABLE II
RECTIFIER TRANSFORMERS 1979 SURVEY

Type	Number of Units	Unit-Years	Number of Failures	Failure Rate Failures/ Unit-Year	Average Repair Time (Hours)	Average Replacement Time (Hours)
All liquid filled	85	841	16	0.0190	2316 N: 8 F[2]	41.4 N: 8 F[2]
Liquid 300–10 000 kVA	61	644	10	0.0153	1664[1] N: 3 F[2]	38.7[1] N: 7 F[2]
Liquid >10 000 kVA	24	197	6[1]	0.0303[1]	2707.2[1] N: 5 F[2]	60[1] N: 1 F[2]

[1] Small sample size–less than eight failures.
[2] F is failures.

TABLE III
ALL TRANSFORMERS[1]

Number of Plants in Sample Size	Sample Size Unit-Years	Number of Failures Reported	Industry		Failure Rate-Failures per Unit-Year	Industry Average	Actual Hours Downtime/Failure Minimum Plant Average	Median Plant Average	Maximum Plant Average
33	15,210	63	All..........	Liquid Filled - All............	0.0041	529.0	2.0	219.	3744.
30	13,210	39	"	601-15,000 volts-All Sizes....	0.0030	174.	2.0	49.	840.
12	3,002	11	"	300-750 kVA...............	0.0037	61.0	4.5	10.7	336.
18	6,040	15	"	751-2,499 kVA...............	0.0025	217.	2.0	64.0	840.
11	4,036	13	"	2,500 kVA & up...............	0.0032	216.	24.0	60.0	403.
12	1,848	24	"	Above 15,000 volts...........	0.0130	1076.	12.8	1260.	3744.
16	4,937	18	"	Dry Type; 0-15,000 volts........	0.0036	153.	0.5	28.	720.
3	672	20	"	Rectifier; Above 600 volts......	0.0298	380.	24.0	80.	867.
14	8,598	43	Chemical.....	Liquid Filled - All............	0.0050	338.	8.0	168.	1800.
12	6,838	24	"	601-15,000 volts-All Sizes....	0.0035	52.3	8.0	48.5	336.
7	3,274	10	"	300-750 kVA...............	0.0031	19.3	3.0	8.0	120.
9	1,601	19	"	Above 15,000 volts...........	0.0119	670.	12.8	708.	3600.
2	662	16	"	Rectifier; Above 600 volts......	0.0242	425.	80.0	474.	867.
3	2,512	14	Petroleum....	Liquid Filled - All............	0.0056	843.	4.5	591.	1178.
3	2,334	10	"	601-15,000 volts-All Sizes....	0.0043	244.	4.5	204.	403.

[1] From IEEE Survey published in 1973–1974 [1].

TABLE IV
ALL TRANSFORMERS[1]

	Sample Size Unit-Years	Number of Failures	Type	Failure Rate Failures/ Unit-Year	Average Hours Downtime/ Failure
1979 Survey	17996	111	Power-Liquid Filled	0.0062	249.3
	1700	1[2]	Power-Dry	0.0006[2]	6
	841	16	Rectifier	0.0190	1178.7
1973/74 Survey	15210	63	Liquid Filled	0.0041	529
	4937	18	Dry	0.0036	153
	672	20	Rectifier	0.0298	380

[1] Comparison of 1979 and 1973-1974 surveys.
[2] Small sample size-less than eight failures.

TABLE V
FAILURE RATE VERSUS AGE

Power Transformers					
Type	Age[1] (Yrs)	Number of Units	Sample Size Unit-Years	Number of Failures[2]	Failure Rate Failures/ Unit-Year
Liquid					
300-10 000 kVA	1-10	638	2625.5	19	0.0072
300-10 000 kVA	11-25	715	8846.5	47	0.0053
300-10 000 kVA	>25	397	5938.0	36	0.0060
Liquid					
>10 000 kVA	1-10	27	144.0	0[3]	
>10 000 kVA	11-25	28	283.5	7[3]	0.0246[3]
>10 000 kVA	>25	9	158.0	2[3]	0.0126[3]

[1] Age is the age at end of reporting period.
[2] Relay or tap changer faults were not considered in calculations for failure rates or repair and replacement times.
[3] Small sample size-less than eight failures.

1974 survey as seen by comparing the total number of unit-years for both the power and rectifier transformers. Not too surprisingly, the largest sample size reported occurred among the power transformers 300-10 000 kVA which totaled 17410 unit-years.

SURVEY RESULTS

In Table IV it is clear that the results from the largest category, liquid filled power transformers, compared favorably between the 1973-1974 and 1979 surveys. This table also confirms the high failure rates for rectifier transformers. Before a further discussion on the results of the survey, in general, it would be worthwhile to note how the data compared with the controversial items in the previous survey.

The total number of hours (130 h) to replace a failed transformer with a spare appeared in Table 48 of the results of the 1973-1974 survey, under units 601-15 000 volts requiring a round-the-clock all out effort, and was felt by many to be too high. Units that were repaired showed an average outage time of 342 h. The new survey shows a considerable variation among power transformers depending upon size. The higher voltage units, reported in Table 49 of the results published in the 1973-1974 survey, showed an average repair time of 1842 h. This difference could be due to several factors, such as the transportation and handling problems associated with the larger units and the greater likelihood of having spares for the smaller units on hand at the site.

The results of the new survey confirmed the long replacement time after a transformer failure. The much longer times needed to repair a failed transformer than to replace it with a spare were also confirmed. The new survey also confirmed the fact that the failure rates for rectifier transformers are much higher than those for the other transformer categories. This may be due to severe duties or the environments to which they are subjected.

AGE

Table V contains data broken down into three age groups. The failure rates for power transformers 300-10 000 kVA were approximately equal in all three age groups. The slightly higher failure rates for the units aged 1-10 years, and greater than 25 years, can probably be attributed to the infant mortality rate and units approaching end of life, respectively.

RESTORATION METHOD

Tables I and II also include data on restoration times versus restoration method. The data clearly indicate that the restoration of a unit to service by repair rather than replacement results in a much longer outage duration in all cases. This compares favorably with the previous survey which showed

TABLE VI
FAILURE INITIATING CAUSE

All Power Transformers

	No. of Failures[1]	Percentage
Transient overvoltage disturbance (switching surges, arcing ground fault, etc...)	18	16.4
Overheating	3	2.7
Winding insulation breakdown	32	29.1
Insulating bushing breakdown	15	13.6
Other insulation breakdown	6	5.4
Mechanical breaking, cracking, loosening, abrading or deforming of static or structural parts	8	7.3
Mechanical burnout, friction or seizing of moving parts.	3	2.7
Mechanically caused damage from foreign source (digging, vehicular accident, etc.)	3	2.7
Shorting by tools or other metal objects	1	0.9
Shorting by birds, snakes, rodents, etc.	3	2.7
Malfunction of protective relay control device or auxiliary device	5	4.5
Improper operating procedure	4	3.6
Loose connection or termination	8	7.3
Others	1	0.9
Continuous overvoltage	0	0
Low voltage	0	0
Low frequency	0	0
	110	

[1] Failure initiating cause not specified for two failures.

TABLE VII
FAILURE CONTRIBUTING CAUSE

All Power Transformers

	No. of Failures[1]	Percentage
Persistent overloading	1	1.1
Abnormal temperature	5	5.5
Exposure to aggressive chemicals, solvents, dusts, moisture or other contaminants	13	14.4
Normal deterioration from age	12	13.3
Severe wind, rain, snow, sleet or other weather conditions	4	4.4
Lack of protective device	2	2.2
Malfunction of protective device	7	7.8
Loss, deficiency, contamination, or degradation of oil or other cooling medium	9	10.0
Improper operating procedure or testing error	3	3.3
Inadequate maintenance	7	7.8
Others	27	30.0
Exposure to non-electrical fire or burning	0	0
Obstruction of ventilation by foreign object or material	0	0
Improper setting of protective device	0	0
Inadequate protective device	0	0
	90	

[1] Failure contributing cause not specified for 22 failures.

TABLE VIII
SUSPECTED FAILURE RESPONSIBILITY

All Power Transformers

	Number of Failures[1]	Percentage
Manufacturer defective component or improper assembly	32	33.3
Transportation to site, improper handling	1	1
Application engineering, improper application	3	3.1
Inadequate installation and testing prior to start-up	6	6.3
Inadequate maintenance	25	26.0
Inadoquate operating procedures	4	4.2
Outside agency–personnel	3	3.1
Outside agency–others	6	6.3
Others	16	16.7
	96	

[1] Suspected failure responsibility not specified for 16 failures.

repair times considerably longer than replacement times. Despite this fact, in most cases, a larger number of units was restored to service by repair. Results such as these show the obvious benefits in having spares at the site or readily available. The data may also help system planners and users determine the economic feasibility of purchasing spares. In computing the average repair and replacement times, those instances in which the repair or replacement was deferred were excluded to avoid distorting the averages. The averages shown represent only those cases where restoration was begun immediately.

FAILURE CAUSE

Tables VI-XI summarize the causes which initiate and contribute to the failure and the suspected failure responsibility for both power and rectifier transformers. Tables VI and IX show large percentages of failures initiated by some type of insulation breakdown or transient overvoltages. Table IX, however, shows a surprisingly large percentage of rectifier transformer failures initiated by mechanical causes.

Tables VII and X, which show the failure contributing causes, compare well with the 1973-1974 survey results. Normal deterioration from age contributed to a large number of both power and rectifier transformer failures. As in the past, Table VIII shows that respondents believed that manufacturer defects and inadequate maintenance were responsible for the greatest numbers of failures of power transformers. Table XI shows inadequate operating procedure was also a significant cause of failures of rectifier transformers.

MAINTENANCE CYCLE AND EXTENT OF MAINTENANCE

The large percentage of failures which resulted from inadequate maintenance shows the importance of accurate data on the extent and frequency of the maintenance performed. The latest survey attempted to obtain this data in a simple form. The response did not lend itself to reporting in tabular form. Maintenance information continues to be the most difficult to obtain in useful form, not only for transformers, but for all other equipment that have been surveyed as well. Hopefully in the future, we will be able to devise a method of obtaining this data and reporting it in a manner that will enable system users to establish effective preventive maintenance programs.

TYPE OF FAILURE

The 1979 survey limited the choices of failure type to "winding" and "other" (Tables XII and XIII). About half of the failures occurred on transformer windings.

TABLE IX
FAILURE INITIATING CAUSE

All Rectifier Transformers	Number of Failures[1]	Percentage
Transient overvoltage disturbance (lightning, switching surges, arcing ground fault, etc.).	2	13.3
Overheating	1	6.6
Winding insulation breakdown	2	13.3
Insulation bushing breakdown	1	6.6
Other insulation breakdown	3	20
Mechanical breaking, cracking, loosening, abrading or deforming of static or structural parts	3	20
Mechanical burnout, friction or seizing of moving parts	2	13.3
Loose connection or termination	1	6.6
Continuous overvoltage	0	0
Mechanically caused damage from foreign source (digging, vehicular accident, etc.)	0	0
Shorting by tools or other metal objects	0	0
Shorting by birds, snakes, rodents, etc.	0	0
Malfunction of protective relay control device or auxiliary device	0	0
Low voltage	0	0
Low frequency	0	0
Improper operating procedure	0	0
Other	0	0
	15	

[1] Failure initiating cause not specified for 1 failure.

TABLE X
FAILURE CONTRIBUTING CAUSE

All Rectifier Transformers	No. of Failures[1]	Percentage
Abnormal temperature	1	7.1
Exposure to aggressive chemicals, solvents dusts, moisture or other contaminants	1	7.1
Normal deterioration from age	4	28.6
Inadequate protective device	1	7.1
Loss, deficiency, contamination or degradation of oil or other cooling medium	3	21.4
Inadequate maintenance	3	21.4
Others	1	7.1
Persistent overloading	0	0
Exposure to non-electrical fire or burning	0	0
Obstruction of ventilation by foreign object or material	0	0
Severe wind, rain, snow, sleet or other weather conditions	0	0
Improper setting of protective device	0	0
Lack of protective device	0	0
Malfunction of protective device	0	0
Improper operating procedure or testing error	0	0
	14	

[1] Failure contributing cause not specified for two failures.

FAILURE CHARACTERISTIC

As would be expected, Tables XIV and XV show that about 3/4 of transformer failures resulted in removal from service by automatic protective devices, however, the percentage requiring manual removal was significant. Increasing use of transformer oil or gas analysis could be a factor here. This would enable detection of incipient faults in their early stages, allowing manual removal before a large scale failure occurs.

TABLE XI
SUSPECTED FAILURE RESPONSIBILITY

All Rectifier Transformers	Number of Failures	Percentage
Manufacturer–defective component or improper assembly	5	31.2
Application engineering–improper application	2	12.5
Inadequate maintenance	2	12.5
Inadequate operating procedures	5	31.2
Others	2	12.5
Transportation to site–improper handling	0	0
Inadequate installation and testing prior to startup	0	0
Outside agency–personnel	0	0
Outside agency–others	0	0
	16	

TABLE XII
TYPE OF FAILURE

Type of Failure	Power Transformers Number of Failures	Percentage
Winding	59	53
Others	53	47

TABLE XIII
TYPE OF FAILURE

Type of Failure	Rectifier Transformers Number of Failures	Percentage
Winding	8	50
Others	8	50

TABLE XIV
FAILURE CHARACTERISTICS

Failure Characteristic	Power Transformers Number of Failures	Percentage
Automatic removal by protective device	83	75
Partial failure reducing capacity	5	5
Manual removal	23	20

TABLE XV
FAILURE CHARACTERISTIC

Failure Characteristic	Rectifier Transformers Number of Failures	Percentage
Automatic removal by protective device	11	69
Partial failure reducing capacity	0	0
Manual removal	5	31

VOLTAGE

Table XVI shows the failure rate for liquid filled power transformers broken down by voltage rating. From Table XVI it is evident that the failure rates for 600–15 000 volt transformers are less than those for the higher voltage units in both

TABLE XVI
FAILURE RATE VERSUS VOLTAGE

		Power Transformers			
Type	Voltage (kV)	Number of Units	Sample Size Unit-Years	Number of Failures	Failure Rate Failures/Unit-Year
Liquid 300–10 000 kVA	.6–15	1626	15775	82	0.0052
Liquid 300–10 000 kVA	>15	124	1637	18	0.0110
Liquid >10 000 kVA	>15	52	490	9	0.0184

TABLE XVII
FAILURE RATE VERSUS VOLTAGE

		Rectifier Transformers			
Type	Voltage (kV)	Number of Units	Sample Size Unit-Years	Number of Failures	Failure Rate Failures/Unit-Year
All Liquid	.6–15	65	745	15	0.0201

size categories. The small sample sizes in several categories in Table XVII make it impossible to draw any definite conclusions on the effect of voltage on the failure rates of rectifier transformers.

CONCLUSION

The purpose of this survey was to update the results of the 1973–1974 survey and to clarify some of the issues raised by those results. In general, the data obtained in the latest survey confirm the previous results.

Only that data from which meaningful results could be obtained were included in this report. Obviously more information was requested in the survey than discussed in the previous sections. The remaining data were eliminated either because the sample sizes were too small, because analysis showed it to have little or no influence on transformer reliability, or because it could not be reported in a meaningful way.

APPENDIX

December 15, 1978

Subject: *Reliability Survey for Power, Rectifier, and Arc-Furnace Transformers*

Dear Sir:

The Power System Reliability Subcommittee of the Industrial and Commercial Power Systems Committee requests your cooperation in a survey to determine the reliability of power, rectifier, and arc-furnace transformers in industrial plants. This survey is part of a program to update the information obtained in our 1971 general reliability survey of plant equipment and to provide additional information on rectifier and arc-furnace transformers.

The results of this survey will be published in an IEEE paper. The information obtained is expected to be of value to system planners, designers, and users in the reliability evaluation of various alternatives. Individual responses will be held in confidence and only summaries published.

SURVEY INSTRUCTIONS

Definitions, brief instructions, and sample survey forms (Figs. 1-2) are provided for guidance. We wish to emphasize that all requested data is important, but it is also realized that some of the information requested may be unknown. In such cases, simply provide the information that is known, and leave the other spaces blank. If additional survey forms are needed, please duplicate the forms provided.

Definitions

1) Failure: A failure is any trouble with a power system component that causes any of the following to occur:
- a) partial or complete shutdown, or below standard plant operation,
- b) unacceptable performance of user's equipment,
- c) operation of the electrical protective relaying or emergency operation of the plant electrical system,
- d) de-energization of any electric circuit or equipment.

2) Failure Duration: Duration of a failure or repair time of a failed component is the clock hours from the time of the occurrence of the failure to the time when the component is restored to service, either by repair of the component or by substitution with a spare component. It includes time for diagnosing the trouble, locating the failed component, waiting for parts, repairing or replacing, and restoring the component to service. *It is not the time required to restore service to a load by putting alternate circuits into operation.*

Company Name and Plant: ____________________

Location: ____________________

Industry Type: ____________________

Period Reported: From: Month __________ Year __________

To: Month __________ Year __________

TOTAL POPULATION: (List each transformer by number on a separate line.)

Transformer Number	Type 1/	Subclass Type 1/	Age at End of Period (Years)	Location 1/	Number of Phases	Primary Voltage Class (kV)	Rating 1/	Maintenance Cycle (Months)	Extent of Maintenance

1/ Use code from attached sheets.

Fig. 1. Reliability survey for power, rectifier, and arc-furnace transformers.

						Type of Failure 2/		Restoration Method 2/		Restoration Urgency 2/				
Transformer Number	Age at Time of Failure (Years)	Failure Initiating Cause 1/	Failure Contributing Cause 1/	Suspected Failure Responsibility 1/	Failure Characteristic 1/	Winding	Other	Repair Failed Component	Replace with Spare	Round the Clock Basis Emergency	Normal Work Hours	Scheduled Later	Duration of Outage (Hours)	Description of Failed Component

1/ Use code from attached sheets.
2/ Check applicable box.

Fig. 2. Failed Unit Data: Use transformer number from total population form.

General Data

1) It is vitally important that the period being reported be given.
2) Indicate the general type of industry involved at the plant being reported, such as auto, cement, chemical, metalworking, petroleum, pulp and paper, textile, etc.

Total Population Data

1) Using the Total Population data block, give the requested data for ***all power, rectifier, and arc-furnace transformers in service during the period reported whether or not failures have been experienced.*** Data should be reported on only those transformers used on a continuous basis. Transformers which are de-energized for substantial periods of time should not be included.
2) The age is the number of years from the time of installation to the end of the period reported under General Data.
3) Give a brief description of the extent of maintenance.

Failed Unit Data

1) List each failure separately.
2) Transformer Number for each failure is the Transformer Number used on the Total Population form.
3) Specify the age of the transformer at the time of failure.
4) Specify the failure initiating cause, contributing cause, and suspected failure responsibility using the code numbers on the attached sheets.
5) Check the restoration urgency.
6) Specify the time in hours from the onset of the failure until the transformer was restored to service.
7) Describe briefly the component that failed, including the component material.

Your participation in this survey will be greatly appreciated.

Sincerely,

J. W. Aquilino
Working Group Chairman

CODE NUMBERS TO BE USED WITH TOTAL POPULATION FORM

Transformer Type

1) Power
2) Rectifier
3) Arc-Furnace

Subclass Type

1) Liquid
2) Dry

Location

1) Indoor
2) Outdoor

Rating

1) 300–10 000 kVA
2) >10 000 kVA

CODE NUMBERS TO BE USED WITH FAILED UNIT DATA FORM

Failure Initiating Cause

1) Transient overvoltage disturbance (lightning, switching surges, arcing ground fault, etc.).
2) Continuous overvoltage.
3) Overheating.
4) Winding insulation breakdown.
5) Insulating bushing breakdown.
6) Other insulation breakdown.
7) Mechanical breaking, cracking, loosening, abrading, or deforming of static or structural parts.
8) Mechanical burnout, friction, or seizing of moving parts.
9) Mechanically caused damage from foreign source (digging, vehicular accident, etc.).
10) Shorting by tools or other metal objects.
11) Shorting by birds, snakes, rodents, etc.
12) Malfunction of protective relay control device or auxiliary device.
13) Low voltage.
14) Low frequency.
15) Improper operating procedure.
16) Loose connection or termination.
17) Others.

Failure Contributing Cause

1) Persistent overloading.
2) Abnormal temperature.
3) Exposure to aggressive chemicals, solvents, dusts, moisture, or other contaminants.
4) Exposure to nonelectrical fire or burning.
5) Obstruction of ventilation by foreign object or material.
6) Normal deterioration from age.
7) Severe wind, rain, snow, sleet, or other weather conditions.
8) Improper setting of protective device.
9) Lack of protective device.
10) Inadequate protective device.
11) Malfunction of protective device.
12) Loss, deficiency, contamination, or degradation of oil or other cooling medium.
13) Improper operating procedure or testing error.
14) Inadequate maintenance.
15) Others.

Suspected Failure Responsibility

1) Manufacturer-defective component or improper assembly.

2) Transportation to site-improper handling.
3) Application engineering-improper application.
4) Inadequate installation and testing prior to startup.
5) Inadequate maintenance.
6) Inadequate operating procedures.
7) Outside agency-personnel.
8) Outside agency-others.
9) Others.

Failure Characteristic

1) Automatic removal by protective device.
2) Partial failure reducing capacity.
3) Manual removal.

REFERENCES

[1] "Report on reliability survey of industrial plants," *IEEE Trans. Ind. Appl.*, Mar./Apr., July/Aug., and Sept./Oct., (Parts I–VI), 1974.

[2] "Reasons for conducting a new reliability survey on power, rectifier and arc-furnace transformers," in the *Ind. Comm. Power Syst. Tech. Conf.*, May 1979, pp. 70–75.

James W. Aquilino (M'76) was born in Arlington, MA, in 1949. He received the B.S.E.E. degree from Northeastern University, Boston, MA, in 1972.

After a brief period working in the field of special electronic instrumentation, he joined the Factory Mutual Engineering Association as a Loss Prevention Engineer specializing in electrical equipment and electric utility generating plants. He later joined the electrical section of the Factory Mutual Research Corporation, Boiler and Machinery Standards Department, where his duties included the preparation of standards for the protection and maintenance of electrical equipment. While employed at Factory Mutual, he represented the company as a member of the National Fire Protection Association on NFPA No. 75, Electronic Data Processing, on NEC Code Panels Nos. 11 and 23, and as an alternate on Panel No. 4. He then joined GenRad, Inc., in Concord, MA, as a Senior Facilities Engineer in the Corporate Plant Engineering Department where his responsibilities included plant electrical engineering, utilities monitoring, energy conservation, and preventive maintenance, among others. He was employed as a Plant Engineer at Northrop Corporation's Precision Products Division in Norwood, MA. He has since returned to GenRad.

Mr. Aquilino is a member of the IEEE Industry Applications Society Industrial Power Systems Department, Power Systems Support Committee, and the Power System Reliability Subcommittee. He served as the Chairman of the Working Group on Transformer Reliability. He is a Registered Professional Engineer in the State of Massachusetts.

