Annexes A–Q

(These annexes are not a part of IEEE Std 493-2007, IEEE Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems, and are included for information only.)

Annex A

Report on Reliability Survey of Industrial Plants

Part I
Reliability of Electrical Equipment

Part II
Cost of Power Outages, Plant Restart Time, Critical Service Loss Duration Time, and Type of Loads Lost Versus Time of Power Outages

Part III
Causes and Types of Failures of Electrical Equipment, the Methods of Repair, and the Urgency of Repair

By
Reliability Subcommittee
Industrial and Commercial Power Systems Committee
IEEE Industry Applications Society

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Report on Reliability Survey of Industrial Plants, Part I: Reliability of Electrical Equipment

IEEE COMMITTEE REPORT

Abstract—An IEEE sponsored survey of electrical equipment reliability in industrial plants was completed during 1972. The results are reported from this survey which included a total of 1982 equipment failures that were reported by 30 companies covering 68 plants in nine industries in the United States and Canada.

INTRODUCTION

A KNOWLEDGE of the reliability of electrical equipment is an important consideration in the design of power distribution systems for industrial plants. It is possible to make quantitative reliability comparisons between alternative designs of new systems and then use this information in cost-reliability tradeoff studies to determine which type of power distribution systems to use [1]-[10]. The cost of power outages at the various plant locations can be factored into the decision as to which type of power distribution system to use. These decisions can then be based upon total owning cost over the useful life of the equipment rather than first cost.

In 1969 a Reliability Working Group was formed under the Industrial Plants Power Systems Subcommittee, Industrial and Commercial Power Systems Committee. In 1972 the activity was changed to a Reliability Subcommittee under the same Committee. One of the major activities of the Reliability Working Group and the Reliability Subcommittee has been to conduct a survey of equipment reliability in industrial plants. This survey was conducted during the latter half of 1971 and the early part of 1972 and attempted to update a similar survey [11] which had been conducted eleven years ago. The results from the present survey contain data on failure rate and average downtime per failure for 74 equipment categories. The Reliability Subcommittee also felt that additional information was needed in the present survey beyond what was collected twelve years ago. Some of the additional information is the following:

1) cost of power outages of industrial plants;
2) plant restart time;
3) critical service loss duration time;
4) type of loads lost versus time of power outages;
5) repair or replacement time data;
6) repair urgency information;
7) causes and types of failures;
8) maintenance data and policies.

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Members of the Reliability Subcommittee of the IEEE Industrial and Commercial Power Systems Committee are W. H. Dickinson, *Chairman*, P. E. Gannon, M. D. Harris, C. R. Heising, D. W. McWilliams, R. W. Parisian, A. D. Patton, and W. J. Pearce.

It is not practical to publish all the results contained in the survey in a single paper. They will be presented in six separate parts. The first three parts are published at this time

Part 1: Reliability of Electrical Equipment;
Part 2: Cost of Power Outages, Plant Restart Time, Critical Service Loss Duration Time, and Type of Loads Lost Versus Time of Power Outages [11];
Part 3: Causes and Types of Failures, Methods of Repair, and Urgency of Repair [12].

A major part of the data in these three papers are presented in summary form. It is expected that the additional three papers will be presented at a later date and will contain further in-depth information where questions have been raised to point out the need for such data.

SURVEY FORM

The survey form is shown in Appendix A. Three types of cards were used for reporting the information.

Card type 1 asks for data on plant identification and other general plant information.

Card type 2 asks for data on a specific equipment class, including the total number of installed units, on their failure experience, on maintenance practices, and on estimated repair times of failed equipment.

Card type 3 asks for data on each individual failure reported on a card type 2.

It was necessary to provide definitions for "failure" and "repair time."

A *failure* is defined as any trouble with a power system component that causes any of the following to occur:

1) partial or complete plant shutdown, or below-standard plant operation;
2) unacceptable performance of user's equipment;
3) operation of the electrical protective relaying or emergency operation of the plant electrical system;
4) de-energization of any electric circuit or equipment.

A failure on a public utility supply system may cause the user to have either 1) a power interruption or loss of service, or 2) a deviation from normal voltage or frequency of sufficient magnitude or duration to disrupt plant production. A failure on an in-plant component causes a forced outage of the component, and the component thereby is unable to perform its intended function until it is repaired or replaced.

Repair time of a failed component or duration of a failure 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 is not the time required to restore service to a load by putting alternate circuits into operation. It includes time for diagnosing the trouble, locating the failed component, waiting for parts, repairing or replacing, testing, and restoring the component to service.

Response to Survey

A total of 30 companies responded to the survey questionnaire, reporting data on 68 plants from nine industries in the United States and Canada as shown in Table I. There was a total of 1982 equipment failures reported in the survey; this included more than 620 000 unit-years of experience. Many of the plants reported data covering more than one year of experience.

Most of the data were reported to the IEEE Reliability Subcommittee during late 1971 and early 1972. Unfortunately, a downturn in the business cycle during this period of time caused many companies to reduce their work force and because of this fewer were able to participate in the survey than had been originally hoped.

Survey Data Preparation

All of the returned survey questionnaire forms were reviewed. An attempt was made to clarify any discrepancies that were detected. Usable data were punched onto IBM cards for use in data processing.

Statistical Analysis of Equipment Failures

Two equipment parameters are of prime importance in making system reliability studies. These parameters are 1) failure rate and 2) average outage duration or repair time. The best estimate for the failure rate of a particular type of equipment is the number of failures actually observed, divided by the total exposure time in unit-years, that is,

$$\hat{\lambda} = \frac{f}{T} \tag{1}$$

where

$\hat{\lambda}$ best estimate of failure rate in failures per unit-year
λ true failure rate
f number of failures observed
T total exposure time in unit-years.

Statements regarding the accuracy of failure rate estimates can be made through the use of confidence limits [10], [14]-[17]. Failure rate confidence limits are upper and lower values of failure rate such that the following equations hold:

$$\Pr\left[\lambda_L \geqq \lambda\right] = \frac{1-\gamma}{2} \tag{2}$$

$$\Pr\left[\lambda \geqq \lambda_U\right] = \frac{1-\gamma}{2} \tag{3}$$

where

λ_L lower confidence limit of failure rate
λ_U upper confidence limit of failure rate
γ confidence interval (or confidence level).

A typical value often chosen for the confidence interval is 0.90. Once values for λ_L and λ_U are found, one can say that λ, whose best estimate is $\hat{\lambda}$, lies between λ_L and λ_U with 100γ percent confidence. Clearly the narrower the interval between λ_L and λ_U, the greater one's confidence that $\hat{\lambda}$ is a good estimate of λ, the true failure rate. Expressions for λ_L and λ_U are given as follows [17]:

$$\lambda_L = \frac{\chi^2(1-\gamma)/2, 2f}{2T} \tag{4}$$

$$\lambda_U = \frac{\chi^2(1+\gamma)/2, 2f+2}{2T} \tag{5}$$

where $\chi^2 p, n$ is the p percentage point of a chi-squared distribution with n degrees of freedom. $\chi^2 p, n$ is tabled in statistical handbooks.

By substituting the value of T from (1) into (4) and (5) we get

$$\lambda_L = \frac{\chi^2(1-\gamma)/2, 2f}{2f}(\hat{\lambda}) \tag{6}$$

$$\lambda_U = \frac{\chi^2(1+\gamma)/2, 2f+2}{2f}(\hat{\lambda}). \tag{7}$$

The deviation of the lower confidence level from $\hat{\lambda}$ in percent of $\hat{\lambda}$ is

$$\%\text{dev}_L = 100\left(1 - \frac{\lambda_L}{\hat{\lambda}}\right). \tag{8}$$

Similarly, the deviation of the upper confidence level from $\hat{\lambda}$ in percent of $\hat{\lambda}$ is

$$\%\text{dev}_U = 100\left(\frac{\lambda_U}{\hat{\lambda}} - 1\right). \tag{9}$$

Equations (6)-(9) were used to develop Fig. 1. These curves avoid the need of looking up $\chi^2 p, n$. Here λ_L and λ_U are plotted in terms of percent deviation from λ as a function of the observed number of failures.

The best estimate for the average outage duration or repair time for a particular type of equipment is simply the average of the observed outage durations. Confidence limit expressions for average outage durations are also available if the distributional nature of outage durations is known [17]. However, such expressions are not given here primarily because the average outage durations given in this paper are intended as a rough guide only. Equipment outage durations are believed to be more a function of the nature of a power system's operator than an inherent function of the equipment itself. Hence, average outage durations for equipment used in reliability studies should be values believed most reasonable for the particular system being studied.

The data from the survey contained information on the failure and repair characteristics of 217 categories of equipment. However, the number of observed failures for many equipment categories was too small to allow adequately accurate estimates of failure rates to be made. The Reliability Subcommittee felt that a minimum of eight to ten observed failures was required for "good" accuracy when estimating equipment failure rates (see Fig. 1). Therefore, whenever possible and reasonable from an engineering point of view, equipment categories having less than ten observed failures were combined with other categories so as to bring the number of observed failures in the combined category up to a minimum of ten. In some cases an equipment category with a large number of

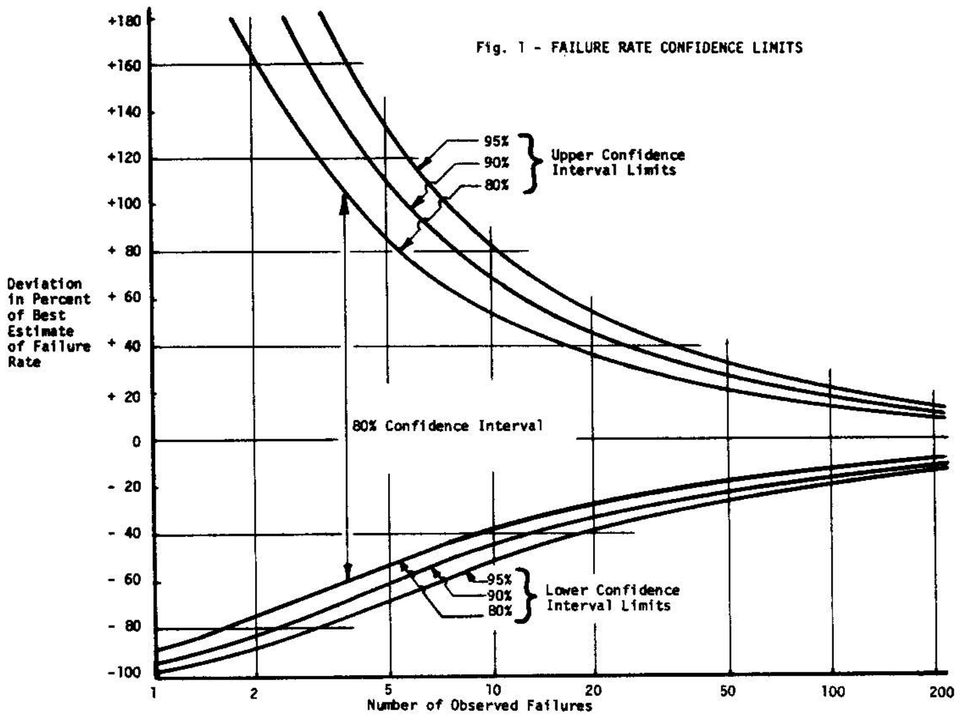

TABLE 1 - RESPONSE TO SURVEY QUESTIONNAIRE

Type of Industry	Number of Companies	Number of Plants
All Industry - USA & Canada	30*	68
Auto	0	0
Cement	0	0
Chemical	8	21
Metal	3	3
Mining	0	0
Petroleum	5	8
Pulp and Paper	1	1
Rubber & Plastics	3	3
Textile	1	3
Other Light Manufacturing	4	17
Other Heavy Manufacturing	1	2
Other	9	10
Foreign	1	1

*Some companies include more than one industry observed failures was further subdivided. In most cases the equipment size attribute was eliminated by combining categories that were identical except for equipment size. These steps reduced the original 217 equipment categories to the 74 categories published in this paper. A total of 66 equipment categories have eight or more observed failures each; the other eight categories have between four and seven observed failures each.

Survey Results of Equipment Failures

Table 2 gives a summary of the "All Industry" equipment failure rate and equipment outage duration data for the 66 equipment categories that contain eight or more failures. The "actual hours downtime per failure" is based upon the actual outage data of the failed equipment; the "industry average" uses all equipment failures, and the "median plant average" uses all plants that reported actual outage time data on equipment failures.

The 1962 survey [11] contained equipment outage duration data on failures that have been challenged for two reasons.

1) Repairing a failed component may take much longer than replacing with a spare (for example, a large power transformer).

2) The urgency for repair is a significant factor in the outage time (low priority repairs may take days or weeks).

In order to help correct these deficiencies, two additional columns on "repair" and "replace with spare" were included in the survey and contain average estimated clock hours to fix failure during a 24-hour work day. These estimates are averaged over all the plants participating in the survey, even where there were no actual failures. These results are reported in Table 2 and are not included in the more detailed Tables 3-19.

Tables 3-19 give more detailed data on equipment failure rate and actual hours of equipment downtime per failure for 74 equipment categories; this includes the 66 equipment categories in Table 2 plus the eight equipment categories containing from four to seven failures. The additional detail includes

1) sample size in unit years;
2) number of failures;
3) number of plants reporting data;
4) additional data on actual hours of downtime per failure;
5) data for various industry groups where there were ten or more failures in that industry.

The data on average estimated clock hours to fix failure during 24-hour work day have been omitted from Tables 3-19.

The reliability data in Tables 14, 16, and 18 on cables, joints, and terminations represent a different look at the same data that are contained in Tables 13, 15, and 17. One set of tables looks at the type of insulation and the other set of tables looks at the application of the cable.

General Comments and Discussion

A survey that collects data from many plants often contains errors. Some of the errors are due to a misinterpretation of the question by the respondent, and in other cases they can be caused by omission.

Many of the respondents apparently misinterpreted the question on "number of installed units" for double- or triple-circuit electric utility power supplies. In addition, there was some confusion on the outage time after a failure of a single circuit of a double- or triple-circuit utility power supply. See the separate discussion elsewhere in this paper on these points. These are the only known major problems of misinterpretation of survey questions.

It is suspected that the failure rate estimates may be biased on the high side due to the tendency of companies to report only on equipment that has actually experienced failures. In other words, some companies may have omitted submitting unit-years of experience data on equipment that had no failures. This factor may be partially balanced out by the belief that the companies that participated in the survey may be the ones that have the best maintenance programs and keep the best records and thus may have lower failure rates than the average.

It is expected that a future paper will contain a comparison of the equipment reliability from this survey with the results from the previous survey [11] that was published in 1962. A preliminary comparison has been made and shows the following overall conclusion for 1973 versus 1962.

1) The 1973 equipment failure rates are about 0.6 times the 1962 failure rates.

2) The 1973 average downtime per failure is about 1.6 times the 1962 average downtime per failure.

3) The product of failure rate times average downtime per failure is almost the same in 1973 as 1962.

Both of these parameters are within a factor of two; and this is often the best accuracy that can be expected from reliability data.

How accurate are the failure rates shown in Tables 2-19? Fig. 1 shows the upper and lower confidence limits of the failure rate versus the number of failures observed. It can be seen that ten failures has upper and lower confidence limits of +70 percent and -46 percent for a 90 percent confidence interval. It is possible to determine the upper and lower confidence limits for the failure rate data shown in Tables 3-19.

Example of Confidence Limit Calculation

The use of Fig. 1 to determine confidence limits will be illustrated with an example. Suppose that it is desired to compute confidence limits on the failure rate of liquid-filled transformers with voltage above 15 kV in the chemical industry. The desired confidence interval is 90 percent. From Table 4, $\hat{\lambda} = 0.0119$ failures per unit-year, and the number of observed failures is 19. Entering Fig. 1 with 19 observed failures and using the 90 percent confidence interval curves yields

$$\lambda_L = \hat{\lambda} - 0.34\hat{\lambda}$$
$$= 0.0119 - 0.0041 = 0.0078 \text{ failures per unit-year}$$
$$\lambda_U = \hat{\lambda} + 0.46\hat{\lambda}$$
$$= 0.0119 + 0.0055 = 0.0174 \text{ failures per unit-year.}$$

There is a 90 percent chance that the true failure rate lies between 0.0078 and 0.0174 failures per unit-year.

TABLE 2 - SUMMARY OF "ALL INDUSTRY" EQUIPMENT FAILURE RATE AND EQUIPMENT OUTAGE DURATION DATA
FOR 66 EQUIPMENT CATEGORIES CONTAINING 8 OR MORE FAILURES

Equipment	Equipment Sub Class	Failure Rate-Failures per Unit-Year	Actual Hours Downtime per Failure: Industry Average	Actual Hours Downtime per Failure: Median Plant Average	Average Estimated Clock Hours to Fix Failure During 24 Hour Work Day: Repair Failed Component	Average Estimated Clock Hours to Fix Failure During 24 Hour Work Day: Replace with Spare
Electric Utility Power Supplies..	All..................................	0.643	1.33	1.04	-	-
" " " "	Single Circuit......................	0.537	5.66	5.10	-	-
" " " "	Double or Triple Circuit-All........	0.622	0.85	1.17	-	-
" " " "	Automatically Switched Over.......	0.735	0.59	0.93	-	-
" " " "	Manual Switchover.................	0.458	1.87	2.00	-	-
" " " " ...	Loss of All Circuits at One Time..	0.119	2.00	1.58	-	-
Transformers....................	Liquid Filled-All.....................	0.0041	529.	219.	378.	73.4
"	601 - 15,000 Volts - All Sizes......	0.0030	174.	49.	382.	74.3
"	300-750 kVA........................	0.0037	61.0	10.7	49.0	3.7
"	751-2,499 kVA.....................	0.0025	217.	64.	297.	39.7
"	2,500 kVA & up....................	0.0032	216.	60.0	618.	150.
"	Above 15,000 Volts..................	0.0130	1076.	1260.	367.	71.5
"	Dry Type; 0 - 15,000 Volts...........	0.0036	153.	28.	67.	39.9
"	Rectifier; Above 600 Volts...........	0.0298	380.	80.	300.	20.0
Circuit Breakers................	Fixed Type ('ncl. molded case) - All..	0.0052	5.8	4.0	31.7	4.5
" "	0 - 600 Volts - All Sizes...........	0.0044	4.7	4.0	6.0	2.0
" "	0 - 600 amps......................	0.0035	2.2	1.0	4.0	2.0
" "	Above 600 amps....................	0.0096	9.6	8.0	8.0	2.0
" "	Above 600 Volts.....................	0.0176	10.6	3.8	44.5	12.0
" "	Metalclad Drawout - All..............	0.0030	129.	7.6	54.2	3.9
" "	0 - 600 Volts - All sizes...........	0.0027	147.	4.0	47.2	2.9
" "	0 - 600 amps......................	0.0023	3.2	1.0	75.6	1.2
" "	Above 600 amps....................	0.0030	232.	5.0	29.4	4.0
" "	Above 600 Volts.....................	0.0036	109.	168.	62.4	5.2
Motor Starters..................	Contact Type; 0 - 600 Volts...........	0.0139	65.1	24.5	8.0	4.6
" "	Contact Type; 601 - 15,000 Volts......	0.0153	284.	16.0	23.6	13.8

TABLE 2 (Continued)

Equipment	Equipment Sub Class	Failure Rate - Failures per Unit-Year	Actual Hours Downtime per Failure: Industry Average	Actual Hours Downtime per Failure: Median Plant Average	Average Estimated Clock Hours to Fix Failure During 24 Hour Work Day: Repair Failed Component	Average Estimated Clock Hours to Fix Failure During 24 Hour Work Day: Replace with Spare
Motors..........................	Induction; 0 - 600 Volts..............	0.0109	114.	18.3	50.2	13.0
"	Induction; 601 - 15,000 Volts.........	0.0404	76.0	91.5	71.4	19.7
"	Synchronous; 0 - 600 Volts............	0.0007	35.3	35.3	32.0	10.0
"	Synchronous; 601 - 15,000 Volts.......	0.0318	175.	153.	146.	18.7
"	Direct Current - All..................	0.0556	37.5	16.2	69.0	5.3
Generators......................	Steam Turbine Driven..................	0.032	165.	66.5	234.	201.
"	Gas Turbine driven....................	0.638	23.1	92.0	190.	400.
Disconnect Switches............	Enclosed..............................	0.0061	3.6	2.8	50.1	13.7
Switchgear Bus - Indoor & Outdoor	Insulated; 601 - 15,000 Volts.........	0.00170	261.	26.8	41.0	66.0
(Unit = Number of Connected	Bare; 0 - 600 Volts...................	0.00034	550.	24.0	41.5	24.5
Circuit breakers or Instrument	Bare; Above 600 Volts.................	0.00063	17.3	13.0	20.6	7.3
Transformer Compartments)						
Bus duct - Indoor & Outdoor...... (Unit = One Circuit Foot)	All Voltages..........................	0.000125	128.	9.5	12.9	6.0
Open Wire......................	0 - 15,000 Volts......................	0.0189	42.5	4.0	4.6	8.0
(Unit = 1,000 Circuit Feet)...	Above 15,000 Volts....................	0.0075	17.5	12.0	8.0	-
Cable - All Types of Insulation.	Above Ground & Aerial					
(Unit = 1,000 Circuit Feet)...	0 - 600 Volts......................	0.00141	457.	10.5	20.8	39.7
" "	601 - 15,000 volts - All............	0.01410	40.4	6.9	26.8	60.4
" "	In Trays Above Ground...........	0.00923	8.9	8.0	49.4	119.
" "	In Conduit Above Ground.........	0.04918	140.	47.5	-	19.8
" "	Aerial Cable....................	0.01437	31.6	5.3	10.6	28.0
" "	Below Ground & Direct Burial					
" "	0 - 600 Volts......................	0.00388	15.0	24.0	-	26.8
" "	601 - 15,000 Volts - All............	0.00617	95.5	35.0	20.4	26.8
" "	In Duct or Conduit Below Ground...	0.00613	96.8	35.0	20.9	26.8
"	Above 15,000 Volts..................	0.00336	16.0	16.0	16.0	-

TABLE 2 (Continued)

Equipment	Equipment Sub Class	Failure Rate - Failures per Unit-Year	Actual Hours Downtime per Failure Industry Average	Actual Hours Downtime per Failure Median Plant Average	Average Estimated Clock Hours to Fix Failure During 24 Hour Work Day Repair Failed Component	Average Estimated Clock Hours to Fix Failure During 24 Hour Work Day Replace with Spare
Cable..........................	601 - 15,000 Volts					
(Unit = 1,000 Circuit Feet)...	Thermoplastic....................	0.00387	44.5	10.0	22.5	29.3
"	Thermosetting....................	0.00889	168.	26.0	27.2	55.2
"	Paper Insulated Lead Covered.....	0.00912	48.9	26.8	17.3	18.3
"	Other............................	0.01832	16.1	28.5	23.2	44.8
Cable Joints -All Types of Insul.	601 - 15,000 Volts					
" "	In Duct or Conduit Below Ground..	0.000864	36.1	31.2	14.7	5.5
Cable Joints....................	601 - 15,000 Volts					
" "	Thermoplastic....................	0.000754	15.8	8.0	12.6	22.0
" "	Paper Insulated Lead Covered.....	0.001037	31.4	28.0	30.0	-
Cable Terminations - All Types of Insulation.......	Above Ground & Aerial					
" " " "	0 - 600 Volts....................	0.000127	3.8	4.0	8.0	8.0
" " " "	601 - 15,000 Volts - All.........	0.000879	198.	11.1	34.6	40.6
" " " "	Aerial Cable.....	0.001848	48.5	11.3	15.3	18.0
" " " "	in Trays Above Ground.........	0.000333	8.0	9.0	48.8	58.3
" " " "	In Duct or Conduit Below Ground					
" "	601 - 15,000 Volts..............	0.000303	25.0	23.4	28.8	30.0
Cable Terminations.............	601 - 15,000 Volts					
	Thermoplastic..................	0.004192	10.6	11.5	12.0	12.0
" "	Thermosetting..................	0.000307	451.	11.3	30.2	42.8
" "	Paper Insulated Lead Covered...	0.000781	68.8	29.2	39.0	30.0
Miscellaneous..................	Inverters........................	1.254	107.	185.	5.0	8.0
"	Rectifiers.......................	0.038	39.0	52.2	41.5	12.0

TABLE 3 - ELECTRIC UTILITY POWER SUPPLIES

Number of Plants in Sample Size	Sample Size Unit - Years	Number of Failures Reported	Industry	Equipment Sub Class	Failure Rate - Failures per Unit-Year	Actual Hours Downtime/Failure Industry Average	Minimum Plant Average	Median Plant Average	Maximum Plant Average
30	314.4	202	All............	All................................	0.643	1.33	*	1.04	24.0
7	70.8	38	"	Single Circuit....................	0.537	5.66	0.25	5.10	10.3
23	210.7	131	"	Double or Triple Circuit - All....	0.622	0.85	*	1.17	24.0
17	140.2	103	"	Automativally Switched Over.....	0.735	0.59	*	0.93	6.00
6	54.6	25	"	Manual Switchover..............	0.458	1.87	1.82	2.00	24.0
23	210.7	25	"	Loss of All Circuits At One Time	0.119	2.00	*	1.58	6.00
7	64.8	20	Chemical.........	All................................	0.309	1.42	*	1.58	6.00
7	64.8	20	"	Double or Triple Circuit - All....	0.309	1.42	*	1.58	6.00
6	60.1	20	"	Automatically Switched Over.....	0.333	1.42	*	1.58	6.00
3	46.5	10	Petroleum........	All................................	0.215	6.80	0.33	4.95	9.57
2	18.5	49	Textile..........	All................................	2.649	0.28	0.014	2.17	4.33
2	18.5	49	"	Double or Triple Circuit - All....	2.649	0.28	0.014	2.17	4.33
1	3.4	46	"	Automatically Switched Over.....	13.46	0.014	0.014	0.014	0.014
5	67.3	27	Other Light Manuf.	All................................	0.402	1.34	**	0.58	24.0
4	51.3	22	" " "	Double or Triple Circuit - All....	0.429	1.51	**	0.79	24.0
3	27.3	15	" " "	Automatically Switched Over.....	0.549	0.51	**	0.04	1.46

* 19 cycles
** 2 seconds

TABLE 4 - TRANSFORMERS

Number of Plants in Sample Size	Sample Size Unit-Years	Number of Failures Reported	Industry		Failure Rate - Failures per Unit-Year	Actual Hours Downtime/Failure Industry Average	Minimum Plant Average	Median Plant Average	Maximum Plant Average
33	15,210	63	All.............	Liquid Filled - All...	0.0041	529.	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.

TABLE 5 - CIRCUIT BREAKERS

Number of Plants in Sample Size	Sample Size Unit-Years	Number of Failures Reported	Industry		Failure Rate - Failures per Unit-Year	Actual Hours Downtime/Failure Industry Average	Minimum Plant Average	Median Plant Average	Maximum Plant Average
16	9,501	49	All............	Fixed Type(includes molded case) - all	0.0052	5.8	0.5	4.0	72.0
12	8,990	40	"	0 - 600 volts - All Sizes...........	0.0044	4.7	0.5	4.0	11.0
9	7,643	27	"	0-600 amps........................	0.0035	2.2	0.5	1.0	9.0
4	1,347	13	"	Above 600 amps....................	0.0096	9.6	5.0	8.0	11.0
5	510	9	"	Above 600 volts....................	0.0176	10.6	1.5	3.8	72.0
28	40,770	124	"	Metalclad, Drawout - All..............	0.0030	129.	0.3	7.6	890.
18	24,490	66	"	0-600 volts - All Sizes.............	0.0027	147.	0.2	4.0	894.
11	11,270	26	"	0-600 amps........................	0.0023	3.2	0.2	1.0	4.0
13	13,220	40	"	Above 600 amps....................	0.0030	232.	0.2	5.0	894.
22	16,280	58	"	Above 600 volts....................	0.0036	109.	1.1	168.	883.
5	1,961	20	Chemical.......	Fixed Type(includes molded case) - All	0.0102	8.1	4.3	9.0	11.0
3	1,520	15	"	0-600 volts - All Sizes.............	0.0099	9.5	5.0	9.0	11.0
2	937	13	"	Above 600 amps....................	0.0139	9.6	5.0	8.0	11.0
7	10,850	33	"	Metalclad, Drawout - All..............	0.0030	83.7	5.8	97.7	576.
7	4,808	31	"	Above 600 volts....................	0.0064	89.3	6.3	97.7	576.
3	1,885	18	Petroleum.......	Fixed Type(includes molded case) - All	0.0095	5.8	1.0	4.0	72.0
2	1,817	17	"	0-600 volts - All Sizes.............	0.0094	1.9	1.0	2.5	4.0
2	1,817	17	"	0-600 amps........................	0.0094	1.9	1.0	2.5	4.0
3	10,430	28	Textile.........	Metalclad, Drawout - All..............	0.0027	289.	0.3	4.0	890.
3	9,655	25	"	0-600 volts - All Sizes.............	0.0026	218.	0.3	4.0	894.
2	4,943	19	"	0-600 amps........................	0.0038	3.8	0.3	2.2	4.0

TABLE 6 - MOTOR STARTERS

Number of Plants in Sample Size	Sample Size Unit-Years	Number of Failures Reported	Industry	Equipment Sub Class	Failure Rate - Failures per Unit-Year	Actual Hours Downtime/Failure Industry Average	Minimum Plant Average	Median Plant Average	maximum Plant Average
			All...........	Contact Type					
9	4,522	63	"	0-600 volts.........................	0.0139	65.1	1.0	24.5	75.5
15	6,518	100	"	601-15,000 volts....................	0.0153	284.	3.0	16.0	1440.
3	854	5	"	Circuit Breaker.......................	0.0059	2.8	2.8	2.8	2.8
7	5,340	14	Chemical......	Contact Type; 601-15,000 volts........	0.0026	298.	4.5	16.0	1323.
1	207	51	Metal.........	Contact Type; 0-600 volts.............	0.2470	75.5	75.5	75.5	75.5
2	626	81	Petroleum.....	Contact Type; 601-15,000 volts........	0.1294	1440.	1440.	1440.	1440.

TABLE 7 - MOTORS

Number of Plants in Sample Size	Sample Size Unit-YEars	Number of Failures Reported	Industry	Equipment Sub Class	Failure Rate - Failures per Unit-Year	Actual Hours Downtime/Failure Industry Average	Minimum Plant Average	Median Plant Average	Maximum Plant Average
			All...............	Induction					
17	19,610	213	"	0-600 volts......................	0.0109	114.	0.5	18.3	312.
17	4,229	171	"	601-15,000 volts................	0.0404	76.0	3.3	91.5	191.
			"	Synchronous					
2	13,790	10	"................	0-600 volts.....................	0.0007	35.3	35.3	35.3	35.3
11	4,276	136	"	601-15,000 volts................	0.0318	175.	8.0	153.	360.
6	558	31	"	Direct Current.....................	0.0556	37.5	4.0	16.2	139.
			Chemical..........	Induction					
6	9,638	50	"	0-600 volts.............	0.0052	22.5	6.	10.3	45.7
8	2,819	122	"	601-15,000 volts........	0.0433	56.3	3.3	38.	191.
			"	Synchronous					
1	13,750	10	"	0-600 volts.............	0.0007	35.3	35.3	35.3	35.3
4	1,201	52	"	601-15,000 volts........	0.0433	129.	25.8	113.	218.
			Petroleum.........	Induction					
3	6,467	146	"	0-600 volts.............	0.0226	158.	120.	139.	159.
2	1,015	34	"	601-15,000 volts........	0.0335	139.	90.	119.	147.
			"	Synchronous					
2	2,826	78	"	601-15,000 volts........	0.0276	207.	167.	210.	254.
			Rubber & Plastics.	Induction					
3	161	12	" "	601-15,000 volts........	0.0748	144.	132	150.	168.
1	161	17	Textile...........	Direct Current............	0.1056	9.4	9.4	9.4	9.4

TABLE 8 - GENERATORS

Number of Plants in Sample Size	Sample Size Unit-Years	Number of Failures Reported	Industry	Equipment Sub Class	Failure Rate - Failures per Unit-Year	Actual Hours Downtime/Failure Industry Average	Minimum Plant Average	Median Plant Average	Maximum Plant Average
8	761.8	24	All............	Steam Turbine Driven......	0.032	165.	1.5	66.5	1080.
4	89.4	57	".............	Gas Turbine Driven........	0.638	23.1	5.0	92.0	720.
4	59.4	4	".............	Driven by Motor, Diesel, or Gas Engine.............	0.067	127.	121.	133.	144.
1	5.5	54	Petroleum.......	Gas Turbine Driven............	9.818	5.0	5.0	5.0	5.0

TABLE 9 - DISCONNECT SWITCHES

Number of Plants in Sample Size	Sample Size Unit-Years	Number of Failures Reported	Industry	Equipment Sub Class	Failure Rate - Failures per Unit-Year	Actual Hours Downtime/Failure Industry Average	Minimum Plant Average	Median Plant Average	Maximum Plant Average
8	2,065	6	All..............	Open.....................	0.0029	183.	3.0	6.0	1080.
16	15,490	94	"...............	Enclosed.................	0.0061	3.6	0.2	2.8	9.3
4	2,205	22	Chemical..........	Enclosed.................	0.0100	6.0	2.0	5.1	6.5
1	4,293	61	Metal.............	Enclosed.................	0.0142	2.8	2.8	2.8	2.8

TABLE 10 - SWITCHGEAR BUS: INDOOR & OUTDOOR
(Unit = Number of Connected Circuit Breakers or Instrument Transformer Compartments)

Number of Plants in Sample Size	Sample Size Unit-Years	Number of Failures Reported	Industry	Equipment Sub Class	Failure Rate - Failures per Unit-Year	Actual Hours Downtime/Failure Industry Average	Minimum Plant Average	Median Plant Average	Maximum Plant Average
12	11,740	20	All.............	Insulated; 601-15,000 volts....	0.00170	261.	5.0	26.8	1613.
			".............	Bare					
12	32,280	11	".............	0-600 volts...............	0.00034	550.	2.0	24.0	2520.
5	20,560	13	".............	Above 600 volts...........	0.00063	17.3	6.9	13.0	48.
5	4,003	15	Chemical........	Insulated; 601-15,000 volts.	0.00375	340.	18.0	26.8	1613.
			"	Bare					
3	17,270	10	"	Above 600 volts...........	0.00058	19.3	6.9	42.0	48.

TABLE 11 - BUS DUCT: INDOOR & OUTDOOR
(Unit = 1 Circuit Foot)

Number of Plants in Sample Size	Sample Size Unit-Years	Number of Failures Reported	Industry	Equipment Sub Class	Failure Rate - Failures per Unit-Year	Actual Hours Downtime/Failure Industry Average	Minimum Plant Average	Median Plant Average	Maximum Plant Average
12	160,400	20	All...........	All Voltages...............	0.000125	128.	0.5	9.5	2160.

TABLE 12 - OPEN WIRE
(Unit = 1,000 Circuit Feet)

Number of Plants in Sample Size	Sample Size Unit-Years	Number of Failures Reported	Industry	Equipment Sub Class	Failure Rate- Failures per Unit-Year	Actual Hours Downtime/Failure Industry Average	Minimum Plant Average	Median Plant Average	Maximum Plant Average
10	5,185	98	All..................	0-15,000 volts..........	0.0189	42.5	1.0	4.0	3600.
7	1,460	11	"	Above 15,000 volts........	0.0075	17.5	0.4	12.0	48.
3	292.6	10	Chemical.............	0-15,000 volts............	0.0342	606.	4.0	7.5	3600.
1	2,121	76	Petroleum............	0-15,000 volts............	0.0358	4.1	4.1	4.1	4.1

TABLE 13 - CABLE (ALL TYPES OF INSULATION)
(Unit = 1,000 Circuit Feet)

Number of Plants in Sample Size	Sample Size Unit-Years	Number of Failures Reported	Industry	Equipment SUb Class	Failure Rate-Failures per Unit-Year	Actual Hours Downtime/Failure Industry Average	Minimum Plant Average	Median Plant Average	Maximum Plant average
			All.................	Above Ground & Aerial					
10	5,692	8	"	0-600 volts......................	0.00141	457.	2.0	10.5	1802.
18	5,248	74	"	601-15,000 volts - All...........	0.01410	40.4	0.2	6.9	360.
7	1,517	14	"	In Trays Above Ground..........	0.00923	8.9	6.0	8.0	12.7
6	183	9	"	In Conduit Above Ground........	0.04918	140.	4.0	47.5	360.
11	3,548	51	"	Aerial Cable..................	0.01437	31.6	0.2	5.3	178.
			"	Below Ground & Direct Burial					
3	2,060	8	"	0-600 volts......................	0.00388	15.0	8.0	24.0	48.0
26	19,120	118	"	601-15,000 volts - All...........	0.00617	95.5	0.3	35.0	4320.
26	18,940	116	"	In Duct or Conduit Below Ground	0.00613	96.8	0.3	35.0	4320.
1	2,975	10	"	Above 15,000 volts...............	0.00336	16.0	16.0	16.0	16.0
			Chemical............	Above Ground & Aerial					
7	1,961	44	"	601-15,000 volts - All...........	0.02244	35.5	2.0	4.7	154.
3	1,137	11	"	In Trays Above Ground..........	0.00968	7.8	6.0	7.0	8.0
5	737	28	"	Aerial Cable..................	0.03800	47.1	2.0	4.7	178.
			"	Below Ground & Direct Burial					
10	11,420	70	"	601-15,000 volts - All...........	0.00613	53.0	2.6	25.0	514.
10	11,420	70	"	In Duct or Conduit Below Ground	0.00613	53.0	2.6	25.0	514.
			Petroleum..........	Above Ground & Aerial					
2	2,838	15	"	601-15,000 volts - All...........	0.00529	21.0	7.7	27.7	47.6
2	2,669	12	"	Aerial Cable..................	0.00450	23.1	7.7	53.8	100.
			"	Below Ground & Direct Burial					
2	981	23	"	601-15,000 volts - All...........	0.02345	94.0	26.8	69.7	113.
2	981	23	"	In Duct or Conduit Below Ground	0.02345	94.0	26.8	69.7	113.
1	2,975	10	"	Above 15,000 volts...............	0.00336	16.0	16.0	16.0	16.0

TABLE 14 - CABLE (ALL APPLICATIONS)
(Unit = 1,000 Circuit Feet)

Number of Plants in Sample Size	Sample Size Unit-Years	Number of Failures Reported	Industry	Equipment Sub Class	Failure Rate-Failures per Unit-Year	Actual Hours Downtime/Failure Industry Average	Minimum Plant Average	Median Plant Average	Maximum Plant Average
			All..................	601-15,000 volts					
9	9,819	38	"	Thermoplastic.................	0.00387	44.5	2.0	10.0	178.
15	5,960	53	"	Thermosetting.................	0.00889	168.	0.2	26.0	4320.
10	7,126	65	"	Paper Insulated Lead Covered..	0.00912	48.9	0.3	26.8	120.
8	1,419	26	"	Other.........................	0.01832	16.1	0.7	28.5	168.
			Chemical.............	601-15,000 volts.					
7	9,158	36	"	Thermoplastic.................	0.00393	45.4	2.0	9.8	178.
3	2,578	26	"	thermosetting.................	0.01009	117.	17.3	202.	387.
4	937	26	"	Paper Insulated Lead Covered..	0.02774	10.7	2.6	25.0	120.
3	697	16	"	Other.........................	0.02297	18.3	8.0	9.0	168.
			Petroleum............	601-15,000 volts					
2	2,520	15	"	Thermosetting.................	0.00595	21.0	7.7	27.7	47.6
2	1,299	23	"	Paper Insulated Lead Covered..	0.01770	94.0	26.8	69.7	113.

TABLE 15 - CABLE JOINTS (ALL TYPES OF INSULATION)

Number of Plants in Sample Size	Sample Size Unit-Years	Number of Failures Reported	Industry	Equipment Sub Class	Failure Rate-Failures per Unit-Year	Actual Hours Downtime/Failura Industry Average	minimum Plant Average	Median Plant Average	Maximum Plant Average
			All................	601-15,000 volts					
5	7,401	6	"	Above ground & Aerial..........	0.000811	20.3	8.0	16.5	48.0
12	40,500	35	"	In Duct or Conduit Below Ground	0.000864	36.1	1.0	31.2	160.
			Chemical...........	601-15,000 volts					
5	24,120	21	"	In Duct or Conduit Below Ground	0.000871	17.0	1.0	8.0	34.4

TABLE 16 - CABLE JOINTS (ALL APPLICATIONS)

Number of Plants in Sample Size	Sample Size Unit-Years	Number of Failures Reported	Industry	Equipment Sub Class	Failure Rate-Failures per Unit-Year	Actual Hours Downtime/Failure Industry Average	Minimum Plant Average	Median Plant Average	Maximum Plant Average
			All................	601-15,000 volts					
5	27,860	21	"	Thermoplastic..................	0.000754	15.8	3.4	8.0	36.0
4	4,857	6	"	Thermosetting..................	0.001235	102.	14.0	60.0	160.
5	13,500	14	"	Paper Insulated Lead Covered...	0.001037	31.4	1.0	28.0	75.5
			Chemical............	601-15,000 volts					
4	22,900	20	"	Thermoplastic..................	0.000873	14.8	3.4	8.0	34.4

TABLE 17 - CABLE TERMINATIONS (ALL TYPES OF INSULATION)

Number of Plants in Sample Size	Sample Size Unit-Years	Number of Failures Reported	Industry	Equipment Sub Class	Failure Rate-Failures per Unit-Year	Actual Hours Downtime/Failure Industry Average	Minimum Plant Average	Median Plant Average	Maximum Plant Average
			All................	Above Ground & Aerial					
4	63,120	8	"	0-600 volts..................	0.000127	3.8	0.5	4.0	5.9
13	39,840	35	"	601-15,000 volts - All.......	0.000879	198.	1.0	11.1	728.
4	24,010	8	"	In Trays Above Ground......	0.000333	8.0	7.0	9.0	11.0
3	3,920	5	"	In Conduit Above Ground....	0.001276	1157.	24.0	732.	1440.
7	11,910	22	"	Aerial Cable...............	0.001848	48.5	1.0	11.3	84.4
			"	In Duct or Conduit Below Ground					
6	26,390	8	"	601-15,000 volts.............	0.000303	25.0	16.0	23.4	34.5
			chemical...........	Above Ground & Aerial					
7	25,790	21	"	601-15,000 volts - All.......	0.000814	284.	7.0	11.2	728.
4	1,677	9	"	Aerial Cable...............	0.005367	14.6	9.0	13.7	24.0
			Petroleum..........	Above Ground & Aerial					
2	10,150	12	"	601-15,000 volts - All.......	0.001182	79.3	24.0	54.2	84.4
1	10,120	11	"	Aerial cable...............	0.001087	84.4	84.4	84.4	84.4

TABLE 18 - CABLE TERMINATIONS (ALL APPLICATIONS)

Number of Plants in Sample Size	Sample Size Unit-Years	Number of Failures Reported	Industry	Equipment Sub Class	Failure Rate-Failures per Unit-Year	Actual Hours Downtime/Failure Industry Average	Minimum Plant Average	Median Plant Average	Maximum Plant Average
			All.............	601-15,000 volts					
2	2,385	10	"	Thermoplastic................	0.004192	10.6	7.0	11.5	16.0
9	42,310	13	"	Thermosetting................	0.000307	451.	9.3	11.3	1440.
5	20,490	16	"	Paper Insulated Lead Covered.	0.000781	68.8	16.0	29.2	82.6

TABLE 19 - MISCELLANEOUS

Number of Plants in Sample Size	Sample Size Unit-Years	Number of Failures Reported	Industry	Equipment Sub Class	Failure Rate-Failures per Unit-Year	Actual Hours Downtime/Failure Industry Average	Minimum Plant Average	Median Plant Average	Maximum Plant Average
5	3,164.	6	All............	Fuses........................	0.0019	5.5	1.0	2.0	24.0
3	30,600.	6	"	Protective Relays............	0.0002	5.0	0.5	3.8	7.2
3	11.2	14	"	Inverters....................	1.25	107.	2.1	185.	369.
3	314.	12	"	Rectifiers...................	0.0382	39.0	32.4	52.2	72.0
2	5.6	14	Chemical.......	Inverters....................	2.51	107.	2.1	185.	369.
1	16.8	10	Petroleum......	Rectifiers...................	0.5970	32.4	32.4	32.4	32.4

APPENDIX A (P. 1 of

USER INSTRUCTIONS FOR IEEE SURVEY FORM ON
RELIABILITY OF ELECTRIC EQUIPMENT IN INDUSTRIAL PLANTS

(SPONSORED BY THE RELIABILITY WORKING GROUP,
INDUSTRIAL PLANTS POWER SYSTEMS SUBCOMMITTEE,
INDUSTRIAL AND COMMERCIAL POWER SYSTEMS COMMITTEE)

PURPOSE This survey is intended to collect data on failures that occur in in-plant electric equipment and in public utility electric power supplies that affect operations in industrial plants. We hope that these data will determine not only accurate failure rates and repair times on major classes of equipment, but will also give an insight into the causes of these failures in such a way that remedial recommendations may be formulated to reduce failures and to improve plant performance.

MAILING INSTRUCTIONS Mail all filled-out forms to the following address.

IEEE-IGA Reliability Working Group
Care of Assistant Professor A D Patton, Dept of Electrical Engineering
Texas A&M University
College Station, Texas 77843

DATA PROCESSING These forms will be given a confidential company code, and will then be key punched on cards for processing by a digital computer along with data collected from others. The computer will prepare a suitable report on failure rates, durations, and causes of failure.

ADDITIONAL INFORMATION The reverse side of the Survey Form asks for additional information. The following information should be filled in on the reverse side of the first page of data for each plant: company name, plant name, type and location, the name, address, and phone number of the individual submitting the data and/or the individual to whom questions about the data may be directed.

In addition, space is provided for remarks or clarifying comments on the data being reported. These comments should be filled in on all data sheets, if needed to clarify data.

DEFINITIONS

A component is a piece of equipment, a line or circuit, or a section of a line or circuit, or a group of items which is viewed as an entity.

A system is a group of components connected or associated in a fixed configuration to perform a specified function of generating, transmitting, or distributing power.

A failure is defined as any trouble with a power system component that causes any of the following to occur.

(1) Partial or complete plant shutdown, or below-standard plant operation
(2) Unacceptable performance of user's equipment
(3) Operation of the electrical protective relaying or emergency operation of the plant electrical system
(4) Deenergization of any electric circuit or equipment

A failure on a public utility supply system may cause the user to have either (1) a power interruption or loss of service, or (2) a deviation from normal voltage or frequency of sufficient magnitude or duration to disrupt plant production.

A failure on an in-plant component causes a forced outage of the component, and the component thereby is unable to perform its intended function until it is repaired or replaced.

Repair time of a failed component or duration of a failure 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 is not the time required to restore service to a load by putting alternate circuits into operation.

It includes time for diagnosing the trouble, locating the failed component, waiting for parts, repairing or replacing, testing, and restoring the component to service.

Revision 3-4-71

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USER INSTRUCTIONS FOR IEEE SURVEY FORM ON
RELIABILITY OF ELECTRIC EQUIPMENT IN INDUSTRIAL PLANTS
(SPONSORED BY THE RELIABILITY WORKING GROUP,
INDUSTRIAL PLANTS POWER SYSTEMS SUBCOMMITTEE,
INDUSTRIAL AND COMMERCIAL POWER SYSTEMS COMMITTEE)

GENERAL INSTRUCTIONS

THE SURVEY FORM The IEEE Survey Form 1- -1-70 is an input data form for a computer program. The data on these forms will be key punched onto computer cards and analyzed by the computer program.

CODED DATA The Survey Form asks for coded and uncoded data. It is necessary to refer to the instructions in filling in either. The following shows the columns on each card type that requires filling in a code.

CARD TYPE	COLUMNS REQUIRING CODES
1	1-10, 36
2	11-18, 33-36
3	25, 29, 30-53, 57, 58

It may happen that none of the codes shown fit the particular case being reported. For such cases, the "other" code should be used, by filling a "9" or a "99" in the space provided. "Other" means not otherwise classified. If this is done, explain on reverse side of page, referring to card type and column number.

EQUIPMENT CLASS A group of codes is used to specify an equipment class. An equipment class consists of a main code, two sub-class codes, a voltage code and a size code. These are explained in the instructions. For the example shown on the filled-out form, this code is as follows.

CLASS	CODE	DESCRIPTION
Main	20	= transformer
Sub 1	4	= power
Sub 2	34	= liquid filled
Voltage	2	= 601-15,000 volts primary
Size	3	= 300-750 kVA

The above coded equipment class covers all liquid-filled power transformers, with a primary voltage of 601-15,000 volts and rated 300-750 kVA. Any transformer in the plant that does not fit this example is a different classification and requires a different coding. Thus, a 5000 kVA power transformer, liquid filled, 13.8 kV primary voltage would be coded 20-4-34-2-5.

CARD-TYPES The Survey Form asks for three types of information under the headings CARD-TYPE 1, CARD-TYPE 2, and CARD-TYPE 3.

In general, CARD-TYPE 1 asks for data on plant identification and other general plant information.

CARD-TYPE 2 asks for data on a specific equipment class, including the total number of installed units, on their failure experience, on maintenance practices, and on estimated repair times of failed equipment. The total installed units and their failure experience is the most essential data asked for.

CARDS-TYPE 3 asks for data on each individual failure reported on a CARD-TYPE 2.

A typical plant might have as many as, say 30 different equipment classes. These 30 equipment classes might have, for example 10 different failures. To report this information requires 30 pages of the Survey Form, one for each different equipment class. CARD-TYPE 1 is filled in completely on the first page and partly thereafter. CARD-TYPE 2 is filled in on each page. CARDS-TYPE 3 are filled in 10 times, once for each failure, if any.

CARD-TYPE 1 CARD-TYPE 1 is used to identify the reporting company and plant of that company and to give general information about that plant. The first 10 columns on this card are to be repeated by the key puncher onto CARD-TYPE 2 and CARDS-TYPE 3 for identification purposes.

Only one CARD-TYPE 1 is used by the computer program. However, we ask that on each page of the IEEE Survey Form that the first 7 columns be filled-in in case the filled-out survey forms become separated.

Fill in Items 1-8 on reverse side of first page of data for each plant.

ALL CARD TYPES Fill in CARD-TYPE, column number, and remarks or comments on reverse side, if any, on all data cards.

APPENDIX A (P. 2 of

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USER INSTRUCTIONS FOR IEEE SURVEY FORM ON
RELIABILITY OF ELECTRIC EQUIPMENT IN INDUSTRIAL PLANTS
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INDUSTRIAL PLANTS POWER SYSTEMS SUBCOMMITTEE,
INDUSTRIAL AND COMMERCIAL POWER SYSTEMS COMMITTEE

CARD-TYPE 2 The second or CARD-TYPE 2 is used to report on each different equipment class in the plant. A typical plant might have a one type of utility supply, and several different classes each of transformers, circuit breakers, cables, etc. These different classes are shown in Columns 11-18. These Columns 11-18 are to be repeated by the key puncher on all CARDS-TYPE 3. There will be as many CARDS-TYPE 2 as there are different equipment classes.

Each CARD-TYPE 2 is used to report (1) the total number installed of one equipment class and the total number of failures experienced (if any) of that equipment class.

In addition, each CARD-TYPE 2 is used to report on maintenance practices and estimated repair times. These are your best estimate of repair times. These estimated times will be used if actual repair times are not known, or if actual repair times are much different from the average for some special reason which is unlikely to recur. We prefer to use actual data if available.

These data are to be left blank for failures on the utility power supply, since this information is not normally available.

CARD-TYPE 3 The third or CARD-TYPE 3 is used to report on actual data for each failure reported on a corresponding CARD-TYPE 2. Thus, associated with each CARD-TYPE 2 is a set of CARDS-TYPE 3. The number of CARDS-TYPE 3 will be the same as the number of failures (column 31) reported on CARDS-TYPE 2, for example, if a CARD-TYPE 2 has a 3 in Column 31, then 3 CARDS-TYPE 3 should be filled in.

Each CARD-TYPE 3 reports specific information on one failure, such as failure duration, urgency of repair, cause of failure, loads affected by the failure, and effect of failure on plant operations.

RIGHT-ADJUSTMENT OF DATA In filling in data, numbers should be right-adjusted, that is, they must end in the right-hand column of the assigned field. This means that if, for example, the survey form provides 3 columns to insert data but a two-digit number is to be inserted in the space available, then the number should be filled into the two right-hand columns.

SAMPLE FILLED-OUT FORM Refer to the attached sample filled-out form. This gives an example of a report on one class of transformers with two failures.

7) DATE 3 - 4 - 71 SAMPLE IEEE SURVEY FORM 11-1-70 PAGES 15 PAGE 4

RELIABILITY OF ELECTRIC EQUIPMENT IN INDUSTRIAL PLANTS

CARD – TYPE 1 (REFER TO SURVEY FORM INSTRUCTIONS) (NOTE – * REFERS TO CODED DATA)

COMPANY CODE	PLANT* NO.	PLANT* TYPE	PLANT* LOCATION	PLANT* CLIMATE	PLANT* ATMOSPHERE	PLANT OPERATING SCHEDULE HR. PER DAY	PLANT OPERATING SCHEDULE DAYS PER WK.	ESTIMATED PLANT OUTAGE COST, $ PER FAILURE	ESTIMATED PLANT OUTAGE COST, $ PER HR. DOWNTIME	PLANT MAX. DEMAND AT PLANT DESIGN CAPACITY, KW	PLANT RESTART TIME, HOURS	CRITICAL SERVICE LOSS DURATION NO. OF UNITS	CRITICAL SERVICE LOSS DURATION UNITS*		CARD TYPE	CARD NO.
1	4	6	8	9	10	11	13	15	20	25	31	33	36		79	80
GEL	1	10	1	5	1	8	5	4000	2000	54000	2	10	4		1	1

CARD – TYPE 2

EQUIPMENT CLASS* MAIN	SUB 1	SUB 2	VOLTAGE	SIZE	PERIOD COVERED BY THIS REPORT FROM MO.	FROM YR.	TO MO.	TO YR.	NO. OF INSTALLED UNITS	NUMBER OF FAILURES	AVERAGE AGE*	MAINTENANCE NORMAL CYCLE, NO.	MAINTENANCE QUALITY	ESTIMATED CLOCK HOURS TO REPAIR A FAILURE: REPAIR FAILED COMPONENT 24-HR. PER DAY	REPAIR FAILED COMPONENT 8-HR. PER DAY	REPLACE WITH SPARE 24-HR. PER DAY	REPLACE WITH SPARE 8-HR. PER DAY	CARD TYPE	CARD NO.
11	13	15	17	18	19	21	23	25	27	31	33	34	36	37	41	45	48	79	80
20	4	34	2	3	1	66	10	70	120	2	3	3	2	100	300	14	48	2	1

CARDS – TYPE 3

FAILURE: NUMBER	DATE MO.	DATE YR.	FOREWARNING*	DURATION NO. OF UNITS	DURATION UNITS*	REPAIR METHOD*	REPAIR URGENCY*	NO. SINCE LAST MAINTAINED*	DAMAGED PART*	TYPE*	RESPONSIBILITY*	INITIATING CAUSE*	CONTRIBUTING CAUSE*	CHARACTERISTICS*	LOADS LOST* COMPUTER	MOTOR	LIGHTING	SOLENOID	OTHER	% PRODUCTION LOST*	PLANT OUTAGE DURATION NO. OF UNITS	PLANT OUTAGE DURATION UNITS*	SERVICE RESTORED*	CARD TYPE	CARD NO.
19	21	23	25	26	29	30	32	34	36	38	40	42	44	46	48	49	50	51	52	53	54	57	58	79	80
1	9	69		60	2	2	1	2	9	1	1	4	99	15	1	1	1	1	1	2	4	4	4	3	1
2	8	70		180	2	1	1	3	2	1	5	99	10	6	1	1	0	9	1	2	4	4	4	3	2
3																								3	3
4																								3	4
5																								3	5
6																								3	6
7																								3	7
8																								3	8
9																								3	9
10																								3	0

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USER INSTRUCTIONS FOR CARD-TYPE 1

CARD - TYPE 1

(REFER TO SURVEY FORM INSTRUCTIONS)
(NOTE - * REFERS TO CODED DATA)

COMPANY CODE	PLANT*					PLANT OPERATING SCHEDULE		ESTIMATED PLANT OUTAGE COST, $		PLANT MAX. DEMAND AT PLANT DESIGN CAPACITY, KW	PLANT RESTART TIME, HOURS	CRITICAL SERVICE LOSS DURATION			CARD TYPE	CARD NO.
	NO.	TYPE	LOCATION	CLIMATE	ATMOSPHERE	HR. PER DAY	DAYS PER WK.	PER FAILURE	PER HR. DOWNTIME			NO. OF UNITS	UNITS*			
1	4	6	8	9	10	11	13	15	20	25	31	33	36		79	80
															1	1

COLUMN	NAME	CODE	DESCRIPTION
1	Company Code		Fill in on all pages a three-letter abbreviation of company name for identification of data.
4	Plant No		Fill in on all pages a sequence number starting with "1" for Plant 1, "2" for Plant 2, etc. for identification of data. A plant may consist of one or more units at the same site.
6	Plant Type		Fill in on all pages the plant type
		1	Auto Industry
		2	Cement Industry
		3	Chemical Industry
		4	Metal Industry
		5	Mining Industry
		6	Petroleum Industry
		7	Pulp and Paper Industry
		8	Rubber and Plastics Industry
		9	Textile Industry
		10	Other Light Manufacturing
		11	Other Heavy Manufacturing
		99	Other
8	Plant Location	1	USA and Canada
		2	Foreign
9	Plant Climate (For entire plant site)		Average of daily maximums for hottest month: <u>Temperature</u> — <u>Relative Humidity (RH)</u> (measured at noon to 2 PM ST)
		1	Hot (>90F) — High (>55 RH)
		2	Hot (>90F) — Moderate (50-55 RH)
		3	Hot (>90F) — Low (<50 RH)
		4	Moderate (80-90F) — High (>55 RH)
		5	Moderate (80-90F) — Moderate (50-55 RH)
		6	MOderate (80-90F) — Low (<50 RH)
		7	Low (<80F) — High (>55 RH)
		8	Low (<80F) — Moderate (50-55 RH)
		9	Low (<80F) — Low (<50 RH)
10	Plant Atmosphere (For entire plant site)	1	Clean to slightly polluted air
		2	With salt spray and corrosive chemicals
		3	With salt spray and dust or sand
		4	With salt spray only
		5	With corrosive chemicals and dust or sand
		6	With corrosive chemicals only
		7	With dust or sand only
		8	With conductive dust
		9	Other
	Plant Operating Schedule		
11	Hours per day		Give hours per normal working day that plant operates
13	Days per week		Give days per normal working week that plant operates
	Estimated Plant Outage Cost, Dollars		
15	Per Failure		Extra expense incurred because of a failure only (not including plant downtime), such as for damaged equipment, spoiled product, extra maintenance, or extra repair costs

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USER INSTRUCTIONS FOR CARD-TYPE 1

CARD – TYPE 1

(REFER TO SURVEY FORM INSTRUCTIONS)
(NOTE – * REFERS TO CODED DATA)

COMPANY CODE	PLANT*					PLANT OPERATING SCHEDULE		ESTIMATED PLANT OUTAGE COST, $		PLANT MAX. DEMAND AT PLANT DESIGN CAPACITY, KW	PLANT RESTART TIME, HOURS	CRITICAL SERVICE LOSS DURATION			CARD TYPE	CARD NO.
	NO.	TYPE	LOCATION	CLIMATE	ATMOSPHERE	HR. PER DAY	DAYS PER WK.	PER FAILURE	PER HR. DOWNTIME			NO. OF UNITS	UNITS*			
1	4	6	8	9	10	11	13	15	20	25	31	33	36		79	80
															1	1

COLUMN	NAME	CODE	DESCRIPTION
20	Per hour downtime		Value of lost production in dollars per hour of plant downtime only. This is the estimated revenues (sales price) of product not made, less expenses saved in labor, material, utilities, etc. If this varies with the duration of the plant downtime, use an average value per hour.
25	Plant maximum demand at design capacity, kW		Give the maximum electric power demand when the plant is operating at its rated or design capacity in kilowatts.
31	Plant restart time, hours		Give the time required to get the plant back into operation after service is restored following a failure that has caused a complete plant shutdown, hours.
	Critical service loss duration		
33	No of units		Give the maximum time in units defined in Col 36 of loss of service to the plant which will not cause a complete plant shutdown. Any power interruption of longer duration will cause a plant shutdown. In other words, give maximum length of power failure that will not stop plant production. This time is typically in the range of cycles to minutes.
36	Units		Select code for appropriate time unit that will give accurate results.
		1	Days
		2	Hours
		3	Minutes
		4	Seconds
		5	Cycles

IEEE

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USER INSTRUCTIONS FOR CARD-TYPE 2

CARD - TYPE 2

EQUIPMENT CLASS*					PERIOD COVERED BY THIS REPORT				NO. OF INSTALLED UNITS	NUMBER OF FAILURES	AVERAGE AGE*	MAIN-TENANCE		ESTIMATED CLOCK HOURS TO REPAIR A FAILURE				CARD TYPE	CARD NO.
					FROM		TO							REPAIR FAILED COMPONENT		REPLACE WITH SPARE			
MAIN	SUB 1	SUB 2	VOLTAGE	SIZE	MO.	YR.	MO.	YR.				NORMAL CYCLE, MO.	QUALITY	24-HR. PER DAY	8-HR. PER DAY	24-HR. PER DAY	8-HR. PER DAY		
11	13	15	17	18	19	21	23	25	27	31	33	34	36	37	41	45	49	79	80
																		2	1

COL UMN	NAME	CODE	DESCRIPTION
			Select appropriate code for Column 11-18
11	Main Class	10	Utility power supplies to plant
		20	Transformers
		30	Circuit Breakers
		40	Cable (Excluding joints and terminations)
		41	Cable Joints
		42	Cable Terminations
		43	Cable Duct or Busway
		44	Open Wire
		45	Busduct
		46	Switchgear Bus -insulated
		47	Switchgear Bus -bare
		50	Motors
		60	Generators
		70	Motor Starters
		80	Disconnect Switches
		90	Miscellaneous
		99	Other
13	Sub Class 1		<u>For 10-Utility Power Supplies</u> (A redundant supply will carry the plant load, if the normal circuit is out of service)
		1	Single Circuit (No redundant supply)
		2	Double Circuit (One redundant supply)
		3	Three or more circuits (two or more redundant supplies)
			<u>For 20 - Transformers</u>
		4	Power
		5	Other
			<u>For 30-Circuit Breakers</u>
		6	Metal Clad, drawout
		7	Fixed Type (includes molded case type)
			<u>For 40-47 Cable or Bus</u>
		9	Cable in Trays - aboveground
		10	Cable in Conduit -aboveground
		11	Aerial Cable
		12	Direct Buried Cable
		13	Cable in Duct or Conduit -belowground
		14	Bus or Busduct -indoor
		15	Bus or Busduct -outdoor
			<u>For 50 - Motors</u>
		16	Induction, ac
		17	Synchronous, ac
		18	Direct-current
			<u>For 60 - Generators</u>
		19	Steam Turbine Driven
		20	Gas Turbine Driven
		21	Diesel or Gas Engine Driven
		22	Motor-driven
			<u>For 70 - Motor Starters</u>
		23	Contactor Type
		24	Circuit Breaker

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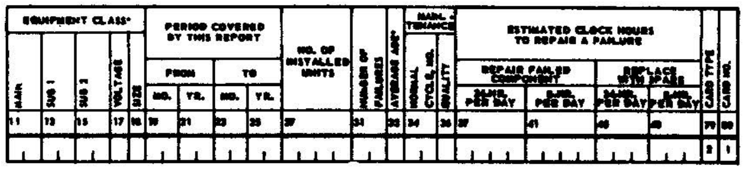
USER INSTRUCTIONS FOR CARD-TYPE 2

CARD - TYPE 2



COL UMN	NAME	CODE	DESCRIPTION
13	Sub Class 1 (Cont)		<u>For 80 - Disconnect Switches</u>
		25	Open
		26	Enclosed
			<u>For 90 - Miscellaneous</u>
		27	Fuses
		28	Protective relays
		29	Batteries
		30	Inverters
		31	Rectifiers
		99	Other
15	Sub Class 2		<u>For 10-Utility Supplies</u> When service is lost because of a loss of one circuit of a redundant supply service is restored
		1	Automatically
		2	By remote control
		3	Manually
			<u>For 20 - Transformers</u>
		34	Liquid Filled
		35	Dry Type
		38	Rectifier
			<u>For 40-51 Cable</u> Type of Insulation
		40	Thermoplastic (PVC)
		41	Thermoplastic (Polyethylene)
		42	Thermosetting (SBR (Buna S) Rubber)
		43	Thermosetting (Butyl Rubber)
		44	Thermosetting (Oil Based Rubber)
		45	Thermosetting (Cross-Linked Polyethylene)
		46	Thermosetting (Silicone Rubber)
		47	Thermosetting (Ethylene Propylene)
		48	Thermosetting (Chlorosulphated Propylene)
		49	Paper-Insulated Lead Covered
		50	Varnished Cambric Insulated-Lead Covered
		51	Mineral-Insulated
		99	Other (Applies to Col 13-15, all classes, if not otherwise classified)
17	Volt Class	1	0-600 volt (Note: For transformers this is primary voltage)
		2	601-15,000 volt
		3	Above 15,000 volt

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USER INSTRUCTION FOR CARD-TYPE 2

CARD – TYPE 2

EQUIPMENT CLASS*					PERIOD COVERED BY THIS REPORT				NO. OF INSTALLED UNITS	NUMBER OF FAILURES	AVERAGE AGE*	MAIN-TENANCE		ESTIMATED CLOCK HOURS TO REPAIR A FAILURE				CARD TYPE	CARD NO.
					FROM		TO							REPAIR FAILED COMPONENT		REPLACE WITH SPARE			
MAIN	SUB 1	SUB 2	VOLTAGE	SIZE	MO.	YR.	MO.	YR.				NORMAL CYCLE, MO.	QUALITY	24-HR. PER DAY	8-HR. PER DAY	24-HR. PER DAY	8-HR. PER DAY		
11	13	15	17	18	19	21	23	25	27	31	33	34	36	37	41	45	49	79	80
																		2	1

COLUMN	NAME	CODE	DESCRIPTION
18	Size Class		For Main Class 10 - Utility Supplies For Main Class 30 - Circuit Breakers For Main Class 80 - Disc Switches For Main Class 90 - Miscellaneous, Fuses
		1	100-600 Amperes
		2	Above 600 amperes
			For Main Class 20 - Transformers
		3	300-750 kVA
		4	751-2499 kVA
		5	2500-up kVA
			For Main Class 40-45 - Cable, etc
		6	Above No 1 AWG
			For Main Class 50 - Motors For Main Class 70 - Motor Starters
		7	50-1500 horsepower
		8	Above 1500 horsepower
			For Main Class 60 - Generators
		9	500-up kW
	Period covered by this report		Give month and year (numerals) for period for which failure data is available
19	From: Mo		Starting Month (Try to include data from date of installation)
21	From: Yr		Starting Year
23	To: Mo		Ending Month (Try to include data to date of this report)
25	To: Yr		Ending Year
27	No of installed units		Give total number of units installed. For cable or open wire, give length of circuit or run in M ft. For cable duct or busduct, give circuit length in feet. For switchgear bus, give the number of connected circuit breakers or instrument transformer compartments. For utility power supplies, give the number of separate supplies.
31	No of Failures		Give total number of failures that occurred during period of report. If more than 10 use additional page.
			Select codes for Column 30-53
33	Average Age	1	Less than 1 year old
		2	1-10 years old
		3	More than 10 years old
	Maintenance		Give normal cycle for preventive maintenance - (even if a failure has not occurred)
34	Normal Cycle, Mo	1	Less than 12 months
		2	12-24 months
		3	More than 24 months
		4	No preventive maintenance
36	Maintenance Quality		Your estimate of quality of preventive maintenance is -
		1	Excellent (by own forces)
		2	Fair (by own forces)
		3	Poor, inadequate (by own forces)
		4	None
		5	Excellent (by contracted forces)
		6	Fair (by contracted forces)
		7	Poor inadequate (by contracted forces)

WHD

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USER INSTRUCTIONS FOR CARD-TYPE 2

CARD – TYPE 2

EQUIPMENT CLASS*					PERIOD COVERED BY THIS REPORT				NO. OF INSTALLED UNITS	NUMBER OF FAILURES	AVERAGE AGE*	MAINTENANCE		ESTIMATED CLOCK HOURS TO REPAIR A FAILURE				CARD TYPE	CARD NO.
MAIN	SUB 1	SUB 2	VOLTAGE	SIZE	FROM		TO					NORMAL CYCLE NO.	QUALITY	REPAIR FAILED COMPONENT		REPLACE WITH SPARE			
					MO.	YR.	MO.	YR.						24-HR. PER DAY	8-HR. PER DAY	24-HR. PER DAY	8-HR. PER DAY		
11	13	15	17	18	19	21	23	25	27	31	33	34	36	37	41	45	48	79	80
																		2	1

COLUMN	NAME	CODE	DESCRIPTION
	Estimated clock hours		Repair time (see definitions) Fill in the clock time for diagnosing the trouble, locating the failed component, waiting for parts repairing or replacing, testing and restoring the component to service. This is your estimate of the average repair time. Please note that actual repair times are requested in CARD-TYPE 3, Col 26. Explain on reverse side how work is done if by other than own forces.
	Repair failed component		With repair of failed equipment
37	24-hr per day		On round-the-clock emergency basis
41	8-hr per day		On basis of repair during normal work day
			With replacement of failed equipment with a spare by removal of failed equipment and substitution of spare equipment
	Repair with spare		
45	24-hr per day		On round-the-clock emergency basis
48	8-hr per day		On basis of repair during normal work day

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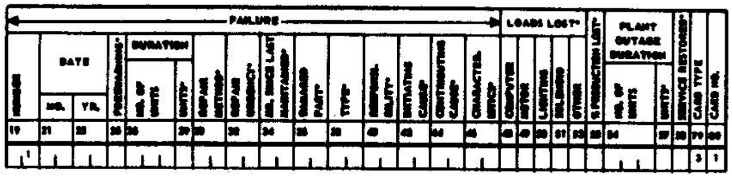
USER INSTRUCTIONS FOR CARD-TYPE 3

CARDS - TYPE 3



COL UMN	NAME	CODE	DESCRIPTION
19	Failure No		Fill in one card (line) for each failure. The last failure number in Col 19 should correspond with the total failures reported in Col 31 of CARD-TYPE 2. If that number was "0" then no TYPE 3 cards should be filled in.
	Failure Date		
21	Mo		Fill in month failure occured (numeral)
23	Yr		Fill in year failure occurred (numeral)
25	Failure Forewarning		For public utility power interruption only
		1	If no forewarning was given
		2	If forewarning was given
			For other types of failure, leave blank
	Failure Duration		Fill in duration of failure from its initiation until (1) service is restored to normal, if a power interruption, or (2) the affected component or its replacement once again becomes available to perform its intended function.
26	No of Units		Fill in the number of time units selected in Col 29.
29	Units		Select code for appropriate time unit that will give accurate results. For most cases select hours as unit.
		1	Days
		2	Hours
		3	Minutes
		4	Seconds
		5	Cycles
			Select code for Col 30-44 (Leave blank for utility failures)
30	Failure Repair Method	1	Repair of failed component in place or sent out for repair
		2	Repair by replacement of failed component with spare
32	Failure Repair Urgency	1	Requiring round-the-clock all out efforts
		2	Requiring repair work only during regular workday, perhaps with some overtime.
		3	Requiring repair work on a non-priority basis.
34	Failure, months since maintained		Failed component last had preventive maintenance -
		1	Less than 12 months ago
		2	12-24 months ago
		3	Over 24 months ago
		4	No preventive maintenance
36	Failure, Damaged Part	1	Insulation - winding
		2	Insulation - bushing
		3	Insulation - other
		4	Mechanical - bearings
		5	Mechanical - other moving parts
		6	Mechanical - other
		7	Other electrical - auxiliary device
		8	Other electrical - protective device
		9	Tap changer - no load type
		10	Tap changer - load type
		99	Other

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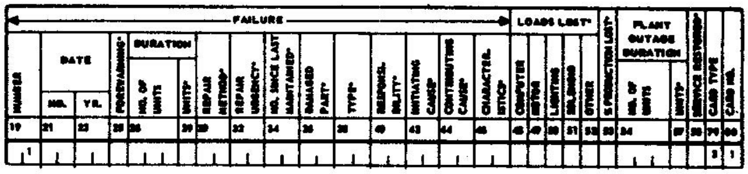
USER INSTRUCTIONS FOR CARD-TYPE 3

CARDS - TYPE 3



COLUMN	NAME	CODE	DESCRIPTION
38	Failure Type	1	Flashover or arcing involving ground
		2	All other flashover or arcing
		3	Other electrical defect
		4	Mechanical defect
		99	Other
			Your best estimate of suspected responsibility
40	Failure Responsibility	1	Manufacturer-defective Component
		2	Transportation to Site - defective 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 -other
		99	Other
42	Failure Initiating Cause		Insulation breakdown caused by
		1	Transient overvoltage disturbance (lightning, switching surges, arcing ground fault in ungrounded system)
		2	Overvoltage
		3	Overheating
		4	Other insulation breakdown
		21	Mechanical breaking, cracking, loosening, abrading, or deforming of static or structural parts
		22	Mechanical burnout, friction, or seizing of moving parts
		23	Mechanically caused damage from foreign source (digging, vehicular accident, etc)
		41	Shorting by tools or metal objects
		42	Shorting by birds, snakes, rodents, etc
		51	Loss of control power
		52	Malfunction of protective relay control device, or auxiliary device
		61	Low voltage
		62	Low frequency
		99	Other
44	Failure Contributing Cause	1	Persistent overloading
		2	Above-normal temperatures
		3	Below-normal temperature
		4	Exposure to agressive chemicals or solvents
		5	Exposure to abnormal moisture or water
		6	Exposure to non-electrical fire or burning
		8	Obstruction of ventilation by foreign object or material
		9	Normal deterioration from age
		10	Severe wind, rain, snow, sleet, or other weather conditions
		11	Protective relay improperly set
		12	Loss or deficiency of lubricant
		13	Loss or deficiency of oil or cooling medium
		14	Misoperation or testing error
		15	Exposure to dust or other contaminents
		99	Other

WHD

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USER INSTRUCTIONS FOR CARD-TYPE 3

CARDS – TYPE 3

FAILURE															LOADS LOST*					% PRODUCTION LOST*	PLANT OUTAGE DURATION		SERVICE RESTORED*	CARD TYPE	CARD NO.
NUMBER	DATE		FOREWARNING*	DURATION		REPAIR METHOD*	REPAIR URGENCY*	NO. SINCE LAST MAINTAINED*	DAMAGED PART*	TYPE*	RESPONSIBILITY*	INITIATING CAUSE*	CONTRIBUTING CAUSE*	CHARACTERISTIC*	COMPUTER	MOTOR	LIGHTING	SOLENOID	OTHER		NO. OF UNITS	UNITS*			
	MO.	YR.		NO. OF UNITS	UNITS*																				
19	21	23	25	26	29	30	32	34	36	38	40	42	44	46	48	49	50	51	52	53	54	57	58	79	80
1																								3	1

COLUMN	NAME	CODE	DESCRIPTION
46	Failure Characteristic		<u>Utility Power Supplies</u> (Select code)
		1	Failure of single circuit (No redundant supply)
		2	Failure of one circuit of a double-circuit redundant supply
		3	Failure of both circuits of a double-circuit redundant supply
		4	Failure of all circuits of a three or more circuit redundant supply
		5	Partial failure of a three or more circuit redundant supply
			<u>Transformers</u> (Select code)
		6	Automatic removal by protective equipment
		7	Partial failure reducing capacity
		8	Manual removal
			<u>Circuit Breakers</u> (Select code)
		9	Failed to close when it should
		10	Failed while opening
		11	Opened when it shouldn't
		12	Damaged while successfully opening
		13	Damaged while closing
		14	Failed while operating (not while opening or closing)
			<u>General</u> (Select code for any other class)
		15	Failed (this applies to all classes)
		16	Failed during testing or maintenance
		17	Damage discovered during testing or maintenance
		20	Partial failure
		99	Other
	Loads Lost		What loads were lost because of failure (1=yes, 0=no, 9= not known) even though power is restored promptly
48	Computer		One or more computers or solid-state control devices operated incorrectly
49	Motor		One or more motors (contactor dropout)
50	Lighting		Lighting load
51	Solenoid		One or more solenoid -operated devices dropped out, such as a solenoid-operated fuel valve
52	Other		Lost other loads, describe in remarks
53	Percent Production Lost	0	None
		1	0-30 percent
		2	Above 30 percent

WHD

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USER INSTRUCTIONS FOR CARD-TYPE 3

CARDS – TYPE 3

FAILURE															LOADS LOST*						PLANT OUTAGE DURATION				
NUMBER	DATE		FOREWARNING*	DURATION		REPAIR METHOD*	REPAIR URGENCY*	NO. SINCE LAST MAINTAINED*	DAMAGED PART*	TYPE*	RESPONSIBILITY*	INITIATING CAUSE*	CONTRIBUTING CAUSE*	CHARACTERISTICS*	COMPUTER	MOTOR	LIGHTING	SOLENOID	OTHER	% PRODUCTION LOST*			SERVICE RESTORED*	CARD TYPE	CARD NO.
	MO.	YR.		NO. OF UNITS	UNITS*																NO. OF UNITS	UNITS*			
19	21	23	25	26	29	30	32	34	36	38	40	42	44	46	48	49	50	51	52	53	54	57	58	79	80
1																								3	1

COLUMN	NAME	CODE	DESCRIPTION
54	No of Units		Fill in number of time units selected in Col 57
57	Units		Select code for appropriate time unit that will give accurate results. For most cases select hours as unit.
		1	Days
		2	Hours
		3	Minutes
		4	Seconds
		5	Cycles
58	Service restored		Give method of restoring service to plant
		1	Primary selection -manual
		2	Primary selection -automatic
		3	Secondary selection -manual
		4	Secondary selection -automatic
		5	Network protector operation -automatic
		6	Repair of failed componenet
		7	Replacement of failed component with spare
		8	Utility restored service
		9	Other -explain in remarks

Discussion

Motors

The data in Tables 7 and 2 show that synchronous motors, 0–600 V, have a failure rate approximately 15 times lower than induction motors, 0–600 V. It is believed that the failure 0.0007 per year for synchronous motors, 0–600 V, is much too low and is in error. It is believed that synchronous and induction motors, 0–600 V, should have failure rates that are nearly the same.

Generators

The data in Tables 8 and 2 show that steam turbine driven generators have a failure rate almost 20 times lower than gas turbine driven generators. It is believed that the failure rate of 0.032 per year for steam turbine driven generators is too low; the failure rate should probably be several times higher than this value. The gas turbine data in Table 8 show that one plant in the petroleum industry had 54 failures in 5.5 unit-years; this compares with 3 failures in 83.9 unit-years for the other three plants that submitted data in the survey. It is believed that the overall failure rate of 0.638 per year for gas turbines is too high.

Open Wire

A clear definition was not given for "open wire" on the survey form (see Appendix A). It is believed that all of the respondents interpreted "open wire" to mean "bare or weatherproof conductors supported on insulators."

Cable

The data in Tables 13 and 2 show that cable above ground and aerial has a failure rate for 0–600 V that is ten times lower than 601–15 000 V. It is believed that the failure rate of 0.00141 per unit-year for 0–600 V above ground and aerial is too low.

There is a wide variation in the failure rate for cable, 601–15 000 V, based upon the application (in trays above ground, in conduit above ground, aerial cable, in duct or conduit below ground). This variation covers a range of 8 to 1. It is believed that the failure rate of 0.04918 per year is too high for cable, 601–15 000 V, in conduit above ground.

There is a wide variation in the cable failure rate shown in Table 14 (and Table 2) for the different types of insulation (601–15 000 V, all applications). These failure rates vary over a range of 5 to 1. The very low failure rate data for thermoplastic insulation and the high failure rate data for other insulation came primarily from the chemical industry.

Switchgear Bus

The failure rate in Table 10 (and Table 2) shows that insulated bus, 601–15 000 V, has a failure rate about three times higher than bare bus, above 600 V. It is believed that this is the opposite of what it should be. The data submitted by the chemical industry has caused this distortion; they had a very high failure rate for insulated bus (601–15 000 V) and a low failure rate for bare bus (above 600 V).

Electric Utility Power Supplies

The data for electric utility power supplies are shown in Tables 3 and 2. The failure rate is about the same for a single circuit and a double or triple circuit. This is evidently due to the predominance of the throwover mode of operation of multiple-circuit supplies. However, the actual downtime per failure is about three to nine times higher for a single circuit than for a double or triple circuit; the downtime depends on whether manual switchover or automatic switchover is used on a multiple-circuit system.

It appears that many respondents misinterpreted the "number of installed units" for double- or triple-circuit electric utility power supplies. What was desired was the number of separate and independent points of supply, but this was often interpreted to be the number of circuits in the utility supply system. Thus the tendency was to report two installed units for double-circuit supplies. It is believed that this error was made in almost every case. Therefore, *the Reliability Subcommittee changed the number of installed units for multiple-circuit utility supplies to 1 except in those cases where other evidence indicated the presence of more than one point of supply.* The sample size shown in Tables 3 and 2 reflects this change for double- or triple-circuit electric utility power supplies. Thus a double- or triple-circuit supply for one year is counted as one unit-year.

It also appears that a few respondents incorrectly interpreted failure duration on card type 3 for multiple-circuit electric utility supplies. What was desired was the period of time during which service was interrupted. However, in a few cases it appears that what was given was the time to repair one circuit of a multiple-circuit supply even though the supply interruption time is limited to the time required to throw over to the alternate supply circuit. The *Reliability Subcommittee changed the failure duration to the value given for plant outage duration in those cases in which such an error was believed to exist.* However, it is suspected that not all of these errors were corrected. The effect of this change was to reduce the actual hours of downtime per failure for multiple-circuit supplies. The majority of the multiple-circuit supply failures are due to loss of the normal feed, and the duration of the failure is limited to the time to switch to the alternate feed. The average outage duration in Tables 3 and 2 is shorter for automatic switching than for manual switching, as one would expect.

There were 25 recorded cases of simultaneous failure of all circuits in a double- or triple-circuit supply. This gives a failure rate of 0.119 failure per year for loss of all circuits at one time. Further details on this are given in Part 3 [13]. Thus a multiple-circuit electric utility power supply has a failure rate (loss of all circuits at one time) that is only about five times lower than the failure rate (0.537 failures per year) for a single-circuit supply and about six times lower than the all-inclusive failure rate of 0.643 failure per year. The ratio between all-inclusive failure rate and the failure rate for loss of all circuits at one time is not as large as one might suspect. Some of the reasons for this are the following.

1) Some portion of utility supply failures are due to failure of the bulk power system which feeds all the supply circuits.

2) At least some cases of loss of all circuits at one time occur when a forced outage of one circuit overlaps a scheduled or maintenance outage of the other circuit (typical utility industry data indicate that this type of overlapping outage is often more probable than overlapping forced outages).

3) The all-inclusive failure rate is, in effect, an average outage rate reflecting the performance of some throwover schemes and some normally closed breaker schemes. Thus, since throw-

over schemes are expected to have higher outage rates than normally closed breaker schemes, it follows that the computed all-inclusive outage rate is probably somewhat lower than the outage rate which would be computed for throwover schemes only. (Unfortunately we cannot compute the throwover scheme outage rate since we do not know which of the reported utility supplies are throwover schemes.)

Only point 3) reflects on the accuracy of the data; the other two points just reflect the facts of life.

A comparison of the all-inclusive failure rate (0.643 failures per year) with the failure rate for loss of all circuits at one time (0.119 failures per year) gives a rough idea of the degree of supply failure rate improvement possible by going from a throwover scheme to a scheme using normally closed circuit breakers.

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Report on Reliability Survey of Industrial Plants, Part II: Cost of Power Outages, Plant Restart Time, Critical Service Loss Duration Time, and Type of Loads Lost Versus Time of Power Outages

IEEE COMMITTEE REPORT

Abstract—An IEEE sponsored reliability survey of industrial plants was completed during 1972. This survey included the cost of power outages, plant restart time, critical service loss duration time, and type of loads lost versus power outage duration time. Survey results reflect data from 30 companies covering 68 plants in nine industries in the United States and Canada. This information is useful in the design of industrial power distribution systems.

INTRODUCTION

KNOWLEDGE of the cost of power outages and of plant restart time is important information for use in the design of industrial power distribution systems. In addition it is also desirable to know the critical service loss duration time and the type of loads lost versus the time of power outage.

During 1972 the Reliability Subcommittee of the IEEE Industrial and Commercial Power Systems Committee completed a reliability survey of industrial plants. This is the second part, which reports results from the survey. Included in this paper are the following results:

1) cost of power outages to industrial plants in the United States and Canada (dollars per kilowatt interrupted plus dollars per kilowatthour of undelivered energy);
2) plant restart time after a failure that has caused complete plant shutdown;
3) critical service loss duration time, that is, the maximum length of power failure that will not stop plant production;
4) type of loads lost versus the time of power outage (this includes computer, motor, lighting, and solenoid loads, and gives plant outage duration times resulting from these failures).

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Members of the Reliability Subcommittee of the IEEE Industrial and Commercial Power Systems Committee are W. H. Dickinson, *Chairman*, P. E. Gannon, M. D. Harris, C. R. Heising, D. W. McWilliams, R. W. Parision, A. D. Patton, and W. J. Pearce.

SURVEY FORM

The survey form used is shown in Appendix A of Part 1 [1]. The information on the cost of power outages came from card type 1, columns 13, 20, and 25. Card type 1 also contained plant restart time (column 31) and critical service loss duration (columns 33 and 36).

The data on type of loads lost came from card type 3, columns 48, 49, 50, 51, and 52. The data on time of power outage came from columns 26 and 29 of card type 3; these data are actually the outage duration time after a failure of the electric utility power supply or a failure of electrical equipment in the power distribution system.

RESPONSE TO SURVEY

A total of 30 companies responded to the survey questionnaire reporting data on 68 plants from nine industries in the United States and Canada. Every response did not supply all the information requested on every question. Tables 22-29 give data on how many plants provided answers to the various questions.

STATISTICAL ANALYSIS

The results were compiled for the United States and Canada. Data from one foreign plant are also included separately.

SURVEY RESULTS

Cost of Power Outages

Each plant was asked to report data on the cost of power outages as follows:

1) Dollars per failure, i.e., extra expense incurred because of a failure only (not including plant downtime) such as for damaged equipment, spoiled product, extra maintenance, or extra repair costs.

2) Dollars per hour of downtime, i.e., value of lost production in dollars per hour of plant downtime only. This is the estimated revenues (sales price) of product not made, less expenses saved in labor, material, utilities, etc. If this varies with the duration of the plant downtime, an average value per hour was to be given.

3) Maximum electric power demand when the plant is operating at its rated or design capacity in kilowatts.

This made it possible to calculate an estimate of the cost of power outages in terms of the dollars per kilowatts interrupted plus the dollars per kilowatthours of undelivered energy. The average cost of power outages from the survey is given in Table 20.

Of the 41 plants that reported outage cost data in the survey, 31 had a maximum demand greater than 1000 kW and 10 had a maximum demand less than 1000 kW. Cost data for plants with maximum demands less than 1000 kW are not considered particularly reliable due to the small number of such plants represented in the data.

There is a wide spread in the cost of power outages. Consequently few plants with high outage costs can have a significant effect on the overall average cost. In such cases the median cost of power outages may be more representative than the average cost. The median cost is such that half of the plants have a cost greater than this value and half have less. Table 21 shows the median power outage costs. Additional details on the cost of power outages are given in Tables 22-27. These additional details include: 1) number of plants reporting the outage cost per failure and the outage cost per hour of downtime, 2) minimum plant cost, 3) maximum plant cost, 4) costs for various industries.

Tables 22, 24, and 26 give the cost of outage per failure per kilowatt maximum demand. Tables 23, 25, and 27 give the cost of a sustained outage per hour down per kilowatt maximum demand.

Plant Restart Time

Each plant was asked to report data on the time required to get the plant back into operation after service is restored following a failure that has caused a complete plant shutdown. A total of 43 plants reported these data. The average plant

TABLE 20 - AVERAGE COST OF POWER OUTAGES FOR INDUSTRIAL PLANTS IN THE UNITED STATES OF AMERICA AND CANADA

All Plants	\$1.89 per kW + \$2.68 per kWh
Plants > 1000 kW Max. Demand	\$1.05 per kW + \$0.94 per kWh
Plants < 1000 kW Max. Demand	\$4.59 per kW + \$8.11 per kWh

TABLE 21 - MEDIAN COST OF POWER OUTAGES FOR INDUSTRIAL PLANTS IN THE UNITED STATES OF AMERICA AND CANADA

All plants	\$0.69 per kW + \$0.83 per kWh
Plants > 1000 kW Max. Demand	\$0.32 per kW + \$0.36 per kWh
Plants < 1000 kW Max. Demand	\$3.68 per kW + \$4.42 per kWh

restart time was 17 h. The median was 4 h. Additional details are given in Table 28.

Critical Service Loss Duration Time

One of the most commonly asked questions is, What is a power failure? In particular, How long can power be lost without causing a complete plant shutdown? Each plant was asked to report data giving the maximum length of power failure that will not stop plant production. This time is typically in the range of cycles to minutes and is called "critical service loss duration time."

A total of 55 plants reported data on critical service loss duration time. The median value was 10 s, that is, half of the plants were greater than this value and half were less. Additional details are given in Table 29.

Loads Lost Versus Time of Power Outage

Each plant was asked, What loads were lost because of failure even though power was restored promptly? Five types of loads were included in the survey:

1) *computer:* one or more computers or solid-state control devices operated incorrectly;
2) *motor:* one or more motors (contactor dropout);
3) *lighting:* lighting load;
4) *solenoid:* one or more solenoid-operated devices dropped out, such as a solenoid-operated fuel valve;
5) *other:* lost other loads, to be described in remarks.

A very short outage duration time after an equipment failure (including electric utility power supply) might not result in a loss of load. Table 30 shows how short power outage duration times after an equipment failure affected the loads lost. The average plant outage duration resulting from these failures is also given in Table 30.

Discussion of Results

Cost of Power Outages (Tables 20–27)

1) There is a wide spread in the cost of power outages (per kilowatt and per kilowatthour) of industrial plants. Even within a given industry, such as chemical, there is a wide spread in the cost of power outages (per kilowatt and per kilowatthour) for different plants.

2) Plants with a maximum demand of less than 1000 kW have a much higher cost of power outages (per kilowatt and per kilowatthour) than plants with a maximum demand of greater than 1000 kW. This indicates that small industrial plants have a higher cost of power outages (per kilowatt and per kilowatthour) than large industrial plants. It is suspected that this may be because the small industrial plants have more employees per kilowatt (and per kilowatthour). It is also possible that high-consumption industries tend to have a lot of electrochemical or heating processes, and these tend to have low outage costs; for example, heat not supplied now can be supplied later, providing the outage is not too long.

3) It is suggested that the "all-industry" data for the 41 and 42 plants should be compiled to show 25 percent and 75 percent in addition to the minimum median and maximum values already tabulated (Tables 22 and 23).

4) It is suggested that future surveys also include the cost of power outages (per kilowatt and per kilowatthour) of commercial buildings.

TABLE 22 - PLANT OUTAGE COST PER FAILURE PER kW OF MAXIMUM DEMAND - ALL PLANTS ($ per kW)

Industry	Number of Plants Reporting	Minimum	Median	Maximum	Average
All Industry - USA & Canada	42	.002	.69	10.00	1.89
Auto	0	-	-	-	-
Cement	0	-	-	-	-
Chemical	11	.02	.22	3.33	.75
Metal	2	.18	2.42	4.67	2.42
Mining	0	-	-	-	-
Petroleum	5	.002	.07	.31	.12
Pulp and Paper	1	.33	.33	.33	.33
Rubber and Plastics	2	.28	.50	.71	.50
Textile	2	.07	1.00	1.92	1.00
Other Light Manufacturing	6	.09	1.10	2.80	1.22
Other Heavy Manufacturing	8	1.67	3.85	10.00	5.11
Other	5	.25	.94	7.50	2.86
Foreign	1	.33	.33	.33	.33

TABLE 23 - PLANT OUTAGE COST PER HR. DOWNTIME PER kW OF MAXIMUM DEMAND - ALL PLANTS ($ per kWh)

Industry	Number of Plants Reporting	Minimum	Median	Maximum	Average
All Industry - USA & Canada	41	.0009	.83	27.00	2.68
Auto	0	-	-	-	-
Cement	0	-	-	-	-
Chemical	12	.0009	.14	2.11	.33
Metal	2	.55	.94	1.33	.94
Mining	0	-	-	-	-
Petroleum	2	.04	1.24	2.43	1.24
Pulp and Paper	1	.07	.07	.07	.07
Rubber and Plastics	3	.28	.36	1.33	.66
Textile	1	.24	.24	.24	.24
Other Light Manufacturing	6	.33	.79	2.00	.91
Other Heavy Manufacturing	8	.93	6.35	27.00	9.73
Other	6	.75	2.50	5.77	2.69
Foreign	1	.07	.07	.07	.07

TABLE 24 - PLANT OUTAGE COST PER FAILURE PER kW OF MAXIMUM DEMAND - PLANTS MORE THAN 1,000 kW MAX. DEMAND ($ per kW)

Industry	Number of Plants Reporting	Minimum	Median	Maximum	Average
All Industry - USA & Canada	32	.002	.32	7.50	1.05
Auto	0	-	-	-	-
Cement	0	-	-	-	-
Chemical	11	.02	.22	3.33	.75
Metal	1	.18	.18	.18	.18
Mining	0	-	-	-	-
Petroleum	5	.002	.07	.31	.12
Pulp and Paper	1	.33	.33	.33	.33
Rubber and Plastics	2	.28	.50	.71	.50
Textile	2	.07	1.00	1.92	1.00
Other Light Manufacturing	4	.09	1.10	2.80	1.27
Other Heavy Manufacturing	1	1.87	1.87	1.87	1.87
Other	5	.25	.94	7.50	2.86
Foreign	1	.33	.33	.33	.33

TABLE 25 - PLANT OUTAGE COST PER HR. DOWNTIME PER kW OF MAXIMUM DEMAND - PLANTS MORE THAN 1,000 kW MAX. DEMAND ($ per kWh)

Industry	Number of Plants Reporting	Minimum	Median	Maximum	Average
All Industry - USA & Canada	31	.0009	.36	5.77	.94
Auto	0	-	-	-	-
Cement	0	-	-	-	-
Chemical	12	.0009	.14	2.11	.33
Metal	1	.55	.55	.55	.55
Mining	0	-	-	-	-
Petroleum	2	.04	1.24	2.43	1.24
Pulp and Paper	1	.07	.07	.07	.07
Rubber and Plastics	3	.28	.36	1.33	.66
Textile	1	.24	.24	.24	.24
Other Light Manufacturing	4	.33	.54	1.20	.65
Other Heavy Manufacturing	1	.93	.93	.93	.93
Other	6	.75	2.50	5.77	2.69
Foreign	1	.07	.07	.07	.07

TABLE 26 - PLANT OUTAGE COST PER FAILURE PER kW OF MAXIMUM DEMAND - PLANTS LESS THAN 1,000 kW MAX. DEMAND ($ per kW)

Industry	Number of Plants Reporting	Minimum	Median	Maximum	Average
All Industry - USA & Canada	10	.50	3.68	10.00	4.59
Auto......................	0	-	-	-	-
Cement.....................	0	-	-	-	-
Chemical...................	0	-	-	-	-
Metal......................	1	4.67	4.67	4.67	4.67
Mining.....................	0	-	-	-	-
Petroleum..................	0	-	-	-	-
Pulp and Paper.............	0	-	-	-	-
Rubber and Plastics.........	0	-	-	-	-
Textile....................	0	-	-	-	-
Other Light Manufacturing...	2	.50	1.11	1.72	1.11
Other Heavy Manufacturing...	7	1.67	5.00	10.00	5.57
Other......................	0	-	-	-	-
Foreign....................	0	-	-	-	-

TABLE 27 - PLANT OUTAGE COST PER HR. DOWNTIME PER kW OF MAXIMUM DEMAND - PLANTS LESS THAN 1,000 kW MAX. DEMAND ($ per kWh)

Industry	Number of Plants Reporting	Minimum	Median	Maximum	Average
All Industry - USA & Canada	10	.86	4.42	27.00	8.11
Auto......................	0	-	-	-	-
Cement.....................	0	-	-	-	-
Chemical...................	0	-	-	-	-
Metal......................	1	1.33	1.33	1.33	1.33
Mining.....................	0	-	-	-	-
Petroleum..................	0	-	-	-	-
Pulp and Paper............	0	-	-	-	-
Rubber and Plastics........	0	-	-	-	-
Textile...................	0	-	-	-	-
Other Light Manufacturing..	2	.86	1.43	2.00	1.43
Other Heavy Manufacturing..	7	3.33	7.69	27.00	11.00
Other.....................	0	-	-	-	-
Foreign...................	0	-	-	-	-

TABLE 28 - PLANT RESTART TIME (After Service is Restored Following a Failure that has Caused Complete Plant Shutdown)

Industry	Number of Plants Reporting	Average (Hours)	Median (Hours)
All Industry - USA & Canada..	43	17.4	4.0
Auto........................	0	-	-
Cement......................	0	-	-
Chemical....................	19	20.7	20
Metal.......................	1	4	4
Mining......................	0	-	-
Petroleum...................	3	37.3	24
Pulp and Paper..............	1	10	10
Rubber & Plastics...........	3	2.33	2
Textile.....................	3	58.3	72
Other Light Manufacturing....	7	2.14	2
Other Heavy Manufacturing....	1	2	2
Other.......................	5	2.6	1
Foreign.....................	1	48	48

TABLE 29 - CRITICAL SERVICE LOSS DURATION (Maximum Length of Power Failure that Will Not Stop Plant Production)

Industry	Number of Plants Reporting	Average	Median
All Industry - USA & Canada....	55	12.6 min.	10.0 sec.
Auto..........................	0	-	-
Cement........................	0	-	-
Chemical......................	20	4.56 min.	1.25 sec.
Metal.........................	2	15.0 min.	15.0 min.
Mining........................	0	-	-
Petroleum.....................	1	1.0 sec.	1.0 sec.
Pulp and Paper................	1	10.0 cycles	10.0 cycles
Rubber & Plastics.............	3	30.0 sec.	20.0 sec.
Textile.......................	3	3.34 min.	30.0 cycles
Other Light Manufacturing......	7	10.3 min.	10.0 sec.
Other Heavy Manufacturing......	10	47 min.	45 min.
Other.........................	8	1.9 min.	20.0 cycles
Foreign.......................	1	15.0 cycles	15.0 cycles

TABLE 30 - LOADS LOST VERSUS TIME OF POWER OUTAGE
(Tabulation of the Percentage of Equipment Failures for Which the Designated Load was Lost and Average Plant Outage Duration Resulting from these Failures)

	For Equipment Failures 1 Cycle or less in Duration			For Equipment Failures Between 1 and 10 Cycles in Duration			For Equipment Failures 10 Cycles or More in Duration		
Type of Load	Yes	No	Not Known	Yes	No	Not Known	Yes	No	Not Known
Computer	0%	0%	0%	4%	96%	0%	9%	91%	0%
Motor	0%	0%	0%	33%	67%	0%	67%	33%	0%
Lighting	0%	0%	0%	22%	78%	0%	38%	61%	2%
Solenoid	0%	0%	0%	22%	74%	4%	25%	66%	9%
Other	0%	0%	0%	7%	15%	78%	25%	62%	13%
Average Plant Outage Duration	0.0 Hours			1.39 Hours			22.6 Hours		

Only non-zero data was used in computing the average plant outage duration

5) Additional information on the cost of power outages in Sweden, Norway, and the United States is contained in [2].

Plant Restart Time (Table 28)

The textile, petroleum, and chemical industries have a much longer plant restart time than the other industries included in the survey.

Critical Service Loss Duration (Table 29)

1) There is a wide spread in critical service loss duration time for the 55 plants in the survey.

2) It is suggested that the data from the 55 plants should be compiled to show several percentiles (10, 25, 75, and 90 percent) in addition to the median value already tabulated.

Loads Lost Versus Time of Power Outage (Table 30)

1) An outage between 1 to 10 cycles resulted in 33 percent of the plants losing motor loads and 22 percent losing a solenoid and only 4 percent losing a computer load. An outage greater than 10 cycles resulted in 67 percent of the plants losing motor loads and 25 percent losing a solenoid and only 9 percent losing a computer load; many plants must not have had computer loads to give such a low value. In fact, many plants must not have had motor loads or solenoid loads either. The important parameter to look at is the change in these percentages from 0 to the maximum value as the length of power outage time is increased.

2) It is suggested that loss of load data be compiled for the following additional categories of outage duration time:

a) 10 to 15 cycles,
b) 15+ to 30 cycles,
c) 0.5 + to 2.0 s,
d) 2.0+ to 4.0 s,
e) greater than 4.0 s.

The average plant outage duration should also be determined for these categories.

References

[1] IEEE Committee Report, "Report on reliability survey of industrial plants; Part I: Reliability of electrical equipment," this issue, pp. 213–235.

[2] R. B. Shipley, A. D. Patton, and J. S. Denison "Power reliability cost vs worth," *IEEE Trans. Power App. Syst.*, vol. PAS-91, pp. 2204–2212, Sept./Oct. 1972.

Report on Reliability Survey of Industrial Plants, Part III: Causes and Types of Failures of Electrical Equipment, the Methods of Repair, and the Urgency of Repair

IEEE COMMITTEE REPORT

***Abstract*—An IEEE sponsored reliability survey of industrial plants was completed during 1972. This included the causes and types of failures of electrical equipment, the methods of repair, and the urgency of repair. The results are reported from the survey of 30 companies covering 68 plants in nine industries in the United States and Canada. This information is useful in the design of industrial power distribution systems.**

Introduction

A KNOWLEDGE of the causes and types of failures of electrical equipment is useful in the design of industrial power distribution systems. In addition it is also useful to know the failure repair method, whether or not the repair was urgent, and how long it had been since the previous maintenance had been performed. During 1972 the Reliability Subcommittee of the IEEE Industrial and Commercial Power Systems Committee completed a reliability survey of industrial plants. This is the third paper reporting results from the survey. Included in this paper are the results for 14 main classes of electrical equipment on

1) failure repair method;
2) failure repair urgency;
3) failure, months since maintained;
4) failure, damaged part;
5) failure type;
6) suspected failure responsibility;
7) failure initiating cause;
8) failure contributing cause;
9) failure characteristic.

The failure repair method includes either the repair of the failed component or the replacement of the failed component with a spare. This can have a significant effect on the average downtime per failure, and thus is an important factor in reliability and availability calculations.

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Members of the Reliability Subcommittee of the IEEE Industrial and Commercial Power Systems Committee are W. H. Dickinson, *Chairman*, P. E. Gannon, M. D. Harris, C. R. Heising, D. W. McWilliams, R. W. Parisian, A. D. Patton, and W. J. Pearce.

The failure repair urgency also has a significant effect on the average downtime per failure and thus is an important factor in reliability and availability calculations.

A preventive maintenance program can have an effect on the failure rate of electrical equipment. Thus a knowledge of whether or not maintenance has been performed recently prior to the failure is a significant factor in helping to determine whether or not the maintenance program is adequate.

The damaged part from a failure is of interest. In addition, a knowledge is also desirable of the type of failure, initiating cause, contributing cause, and suspected responsibility. This information is useful for correcting deficiencies in electrical equipment and electrical systems.

The failure characteristic can be defined as the effect that the failure has on the electrical system. Thus this information is very important.

Survey Form

The survey form used is shown in Appendix A of Part 1 [1]. All of the information reported on in this paper came from card type 3, columns 30-46. The definitions of *failure* and *repair time* are given in Part 1 [1].

Response to Survey

A total of 30 companies responded to the survey questionnaire, reporting data on 68 plants from nine industries in the United States and Canada. Every failure report on card type 3 did not have filled in all the information called for in columns 30-46. Tables 31 and 32 give the data for each main equipment class on how many failures had the information called for in columns 30-46. Each main equipment class contains 18 or more failures; this is believed to be an adequate statistical sample size.

Statistical Analysis

The results were compiled for 14 main equipment classes. The number of failures were tabulated for each category of each column (30-46, card type 3). This was then divided by the total failures in each column so as to give the percentage for each category for each column (for each main equipment class).

SURVEY RESULTS

The results are tabulated for the 14 main equipment classes in Tables 33–41. Each table represents one column (of 30–46, card type 3).

SUMMARY OF CONCLUSIONS

Transformers

In the cases reported, there were approximately an equal number of incidences of repairing the failed transformer and replacing it with a spare. The repair urgency slightly favored a round-the-clock repair over the regular work-day schedule. Inadequate preventive maintenance did not seem to have much influence on the reported failures since no preventive maintenance was reported on only 5 percent of the failures; 11 percent of the failures were blamed on inadequate maintenance. Damaged insulation both in the windings and bushings accounted for the majority of the transformer damage, with the majority of failures being flashovers involving ground. 24 percent of the reported cases considered normal deterioration from age as the contributing cause of the failure, yet 39 percent reported that they felt the manufacturer was primarily responsible. Transient overvoltages, from lightning or switching surges, and other insulation breakdown account for 41 percent of the reported failures. In 90 percent of the reported cases the transformers were removed from the system by automatic protective devices; only 7 percent had manual removal.

Circuit Breakers

About the same number of circuit breakers were repaired in place as were replaced by spares. The relative importance of circuit breakers was indicated by 73 percent of the survey respondents making repairs on a round-the-clock basis. The bulk of the reported failures involved flashovers to ground with damage primarily to the protective device components and the device insulation. Transient overvoltages, insulation breakdowns, and protective device malfunctions were considered a major initiating cause with normal deterioration from age and misoperation or testing errors considered as contributing causes. However, 33 percent of the respondents could not classify the initiating cause into any of the survey classes, and 55 percent could not classify the contributing cause into any of the survey classes. In addition, 36 percent of the suspected causes of failure were blamed on "other." 42 percent of the reported failures involved circuit breakers opening when they should not; it is possible that several of these failures were external to the circuit breaker and of unknown cause and were blamed on the circuit breaker. 32 percent of the reported failures involved circuit breakers that failed during a load-carrying condition.

23 percent of the failures were blamed on the manufacturer and another 23 percent on inadequate maintenance, but 36 percent were blamed on "other." Inadequate preventive maintenance (PM) could be a factor of some significance since no PM was reported on 16 percent of the failures.

Motor Starters

Of the reported motor starter failures, about two thirds were repaired by replacing the starter with a spare and two thirds were repaired on a round-the-clock basis. About half of the cases reported indicate that the damage was other than the classes listed in the survey, primarily resulting from flashovers or electrical defects. 64 percent felt that a malfunction of a protective relay control device initiated the failure with 40 percent of the respondents reporting that normal deterioration from age was a contributing cause. Over half of the respondents felt that improper application was primarily responsible for the failure. In the cases reported 36 percent had been discovered during testing or maintenance, and 20 percent were only partial failures. Lack of preventive maintenance was not a big problem. Those starters that had been maintained less than 12 months prior to the failure accounted for 67 percent of the cases reported.

Motors

Of the reported motor failures, about three quarters were repaired versus about one fourth being replaced by a spare. About three quarters were repaired on a regular work-day basis. The types of failures varied from flashovers to electrical defects, to mechanical defects, with winding insulation and bearings sustaining the majority of the damage. Insulation breakdown, overheating, and mechanical seizing were blamed as the primary initiating causes with normal deterioration from age, loss or deficiency of lubricant, exposure to abnormal moisture, and exposure to aggressive chemicals ranking high on the list of contributing causes. 30 percent of the failures were discovered during testing or maintenance, which probably resulted in less actual damage in those cases. Inadequate maintenance, improper application, and defective equipment were listed as having primary responsibility. However, over half of the respondents could not assign responsibility into one of the survey classes. The motors that had been maintained between 12 and 24 months prior to the failure accounted for 57 percent of the reported cases with less than 12 months and more than 24 months accounting for 22 percent and 19 percent, respectively. No preventive maintenance accounted for only 2 percent, yet this does not correlate well with inadequate maintenance being listed as having primary responsibility in 17 percent of the reported cases.

Generators

Of the reported generator failures 84 percent were repaired in place. About the same number were repaired on a round-the-clock basis as were repaired on a regular work-day basis. 69 percent of the respondents reported damage other than the survey classes with electrical auxiliaries, winding insulation, and moving parts sustaining some damage. Mechanical breaking, transient overvoltages, and about half unclassified items were considered the primary initiating causes with normal deterioration from age and persistent overloading considered contributing causes. Responsibility was spread between inadequate maintenance and defective components with about half of the respondents unable to place primary responsibility into any of the survey classes. Infrequent or no preventive maintenance were not involved in any of the reported cases, a point that does not correlate with the fact that some of the respondents felt inadequate maintenance was the primary responsibility.

Disconnect Switches

Of the reported disconnect switch failures, 70 percent were repaired by replacement with a spare, with work in 80 percent of the cases being performed on a regular work-day schedule. Electrical defects, mechanical defects, and flashovers to ground resulted in damage to mechanical components and insulation. Some form of mechanical breaking or contact from foreign

TABLE 31 - NUMBER OF FAILURES FOR ELECTRIC UTILITY POWER SUPPLIES THAT CONTAINED THE INFORMATION CALLED FOR IN COLUMNS 30-46, CARD - TYPE 3

Card Type 3 Column	Title	Number of Failures
30	Failure Repair Method............	28
32	Failure Repair Urgency............	35
34	Failure, Months Since Maintained..	25
36	Failure, Damaged Part.............	39
38	Failure Type......................	49
40	Suspected Failure Responsibility..	43
42	Failure Initiating Cause..........	53
44	Failure Contributing Cause........	53
46	Failure Characteristic............	145

TABLE 32 - NUMBER OF FAILURES FOR EACH MAIN EQUIPMENT CLASS THAT CONTAINED THE INFORMATION CALLED FOR IN COLUMNS 30-46, CARD-TYPE 3

Main Equipment Class	Maximum	Minimum	Avg.
Transformers	101	97	100
Circuit Breakers	176	161	171
Motor Starters	88	88	88
Motors	561(col.36)	493(col.40)	517
Generators	83(col.36)	31(all other)	37
Disconnect Switches	101	100	101
Swgr. Bus-Insulated	20	20	20
Swgr. Bus-Bare	24	20	23
Bus Duct	20	18	20
Open Wire	109	104	108
Cable	223	211	218
Cable Joints	45	44	45
Cable Terminations	51	47	50

sources accounted for about half of the initiating causes, with exposure to dust and contaminants and a large number of unclassified items considered contributing causes. Inadequate operating procedures, inadequate maintenance, and defective components were considered primarily responsible, which seems to correlate with over 66 percent of the reported cases not having any preventive maintenance and 21 percent not having any preventive maintenance 24 months prior to the failure.

Switchgear Bus, Bare

Of the reported uninsulated switchgear bus failures, about two thirds were repaired in place, with a little more than half of them being repaired on a round-the-clock basis. 79 percent of the respondents report some form of insulation damage all resulting from flashovers either to ground (79 percent) or between phases (21 percent). Mechanical failure, shorting by metal objects, and insulation breakdown were the predominant initiating causes with exposure to abnormal moisture, exposure to dust, exposure to aggressive chemicals, and normal deterioration due to age listed as contributing causes. Interestingly, 15 percent of the respondents listed misoperation or testing errors as a contributing cause. 39 percent felt that an outside agency was responsible for the failure, while 22 percent blamed inadequate maintenance.

Switchgear Bus, Insulated

Of the reported insulated switchgear bus failures, essentially all were repaired in place with over two thirds of the repairs being completed on a round-the-clock basis. 90 percent of the respondents reported insulation damage resulting primarily from flashovers to ground and between phases. Insulation breakdown was considered to have initiated the failure in about half of the cases, with exposure to contaminants, moisture, severe weather, and normal deterioration from age being considered as contributing factors. Improper application (45 percent) and inadequate maintenance (35 percent) were held responsible for the failures.

Bus Duct

Of the reported bus duct failures, 65 percent were repaired in place with the majority of them being repaired on a round-the-clock basis. 90 percent of the respondents reported some form of damaged insulation resulting from a flashover to ground. Mechanical failure, insulation breakdown, and overheating were blamed as initiating factors, with normal deterioration due to age being listed as a contributing factor in half of the cases. Responsibility for the reported failures varied from defective components (26 percent), improper application (16 percent), to inadequate maintenance (16 percent).

Open Wire

Of the reported open-wire failures, 70 percent were repaired in place with a little over half involving a round the clock effort. About half of the failures involved flashovers either to ground or between phases and about 25 percent involved other electrical defects. In the reported failures, transient overvoltages, overheating, or shorting by metal objects were considered the most significant initiating causes, with severe weather and exposure to aggressive chemicals being the predominant contributing causes. 81 percent of the respondents indicated that no preventive maintenance had been performed in over two years, which supports the fact that over a third of them blamed inadequate maintenance as being responsible.

Cables

The relative importance of primary cable was again indicated by about two thirds of the reported cases making repairs on a round-the-clock basis. There were a few more reported cases where repairs to cables were made by complete replacement rather than by in-place repairs. About three quarters of the failures involved flashovers to ground, resulting in insulation damage.

TABLE 33 - FAILURE REPAIR METHOD
TABLE 34 - FAILURE REPAIR URGENCY

ELECTRIC UTILITY POWER SUPPLIES	TRANSFORMERS	CIRCUIT BREAKERS	MOTOR STARTERS	MOTORS	GENERATORS	DISCONNECT SWITCHES	SWITCHGEAR BUS - INSULATED	SWITCHGEAR BUS - BARE	BUS DUCT	OPEN WIRE	CABLE	CABLE JOINTS	CABLE TERMINATIONS	Table, Title, Category
%	%	%	%	%	%	%	%	%	%	%	%	%	%	TABLE 33 - FAILURE REPAIR METHOD (Col. 30)
50	47	51	33	78	84	30	95	71	65	70	47	87	60	1. Repair of failed component in place or sent out for repair
46	53	49	67	22	16	70	5	29	35	9	53	13	34	2. Repair by replacement of failed component with spare
4	0	0	0	0	0	0	0	0	0	21	0	0	6	99. Other
														TABLE 34 - FAILURE REPAIR URGENCY (Col. 32)
91	51	73	66	23	48	20	70	58	80	55	66	56	53	1. Requiring round-the-clock all out efforts
9	45	22	34	74	52	80	25	33	15	26	28	22	31	2. Requiring repair work only during regular workday, perhaps with some overtime
0	4	5	0	2	0	0	5	8	5	0	6	22	16	3. Requiring repair work on a non-priority basis
0	0	0	0	0	0	0	0	0	0	19	0	0	0	99. Other

TABLE 35 - FAILURE, MONTHS SINCE MAINTAINED
TABLE 36 - FAILURE, DAMAGED PART

ELECTRIC UTILITY POWER SUPPLIES	TRANSFORMERS	CIRCUIT BREAKERS	MOTOR STARTERS	MOTORS	GENERATORS	DISCONNECT SWITCHES	SWITCHGEAR BUS - INSULATED	SWITCHGEAR BUS - BARE	BUS DUCT	OPEN WIRE	CABLE	CABLE JOINTS	CABLE TERMINATIONS	Table, Title, Category
														TABLE 35 - FAILURE, MONTHS SINCE MAINTAINED (Col. 34)
56	34	18	67	22	58	8	10	35	25	1	11	18	12	1. Less than 12 months ago
40	38	60	17	57	42	5	35	30	45	8	13	20	12	2. 12-24 months ago
4	22	5	16	19	0	21	55	13	10	81	10	2	36	3. Over 24 months ago
0	5	16	0	2	0	66	0	22	20	9	66	60	40	4. No preventive maintenance
0	0	0	0	0	0	0	0	0	0	0	0	0	0	99. Other
														TABLE 36 - FAILURE, DAMAGED PART (Col. 36)
0	68	0	5	50	7	0	0	0	15	0	5	0	0	1. Insulation - winding
8	13	2	0	0	0	1	5	8	10	1	0	0	12	2. Insulation - bushing
10	3	19	10	3	0	14	90	71	65	6	84	91	75	3. Insulation - other
0	0	1	0	29	2	0	0	0	0	0	3	0	0	4. Mechanical - bearings
3	0	11	16	3	7	9	0	0	0	0	0	0	0	5. Mechanical - other moving parts
15	1	6	2	1	4	30	0	0	0	4	1	0	4	6. Mechanical - other
10	3	6	13	3	10	8	5	0	0	3	1	0	0	7. Other electrical - auxiliary device
10	1	28	2	0	1	1	0	0	0	3	1	0	0	8. Other electrical - protective device
0	7	1	0	0	0	0	0	0	0	0	0	0	0	9. Tap changer - no load type
0	1	0	0	0	0	0	0	0	0	0	0	0	0	10. Tap changer - load type
44	3	26	52	11	69	38	0	21	10	84	6	9	10	99. Other

TABLE 37 - FAILURE TYPE

ELECTRIC UTILITY POWER SUPPLIES	TRANSFORMERS	CIRCUIT BREAKERS	MOTOR STARTERS	MOTORS	GENERATORS	DISCONNECT SWITCHES	SWITCHGEAR BUS - INSULATED	SWITCHGEAR BUS - BARE	BUS DUCT	OPEN WIRE	CABLE	CABLE JOINTS	CABLE TERMINATIONS	Table, Title, Category
														TABLE 37 - FAILURE TYPE (col. 38)
43	58	33	14	28	19	15	65	79	70	34	73	70	55	1. Flashover or arcing involving ground
4	13	10	20	4	3	4	35	21	30	23	1	9	4	2. All other flashover or arcing
14	12	19	55	32	29	47	0	0	0	25	7	20	37	3. Other electrical defect
8	10	11	11	31	32	14	0	0	0	6	5	0	4	4. Mechanical defect
31	7	27	0	6	16	21	0	0	0	12	14	0	0	99. Other

TABLE 38 - SUSPECTED FAILURE RESPONSIBILITY

ELECTRIC UTILITY POWER SUPPLIES	TRANSFORMERS	CIRCUIT BREAKERS	MOTOR STARTERS	MOTORS	GENERATORS	DISCONNECT SWITCHES	SWITCHGEAR BUS - INSULATED	SWITCHGEAR BUS - BARE	BUS DUCT	OPEN WIRE	CABLE	CABLE JOINTS	CABLE TERMINATIONS	Table, Title, Category
%	%	%	%	%	%	%	%	%	%	%	%	%	%	TABLE 38 - SUSPECTED FAILURE RESPONSIBILITY
8	39	23	18	15	19	29	5	9	26	0	16	0	0	1. Manufacturer-defective Component
0	0	0	0	0	0	0	0	0	0	0	0	0	0	2. Transportation to Site - defective handling
0	2	4	51	9	0	6	45	4	16	2	8	0	18	3. Application Engineering - improper application
0	3	3	0	1	3	4	10	17	5	9	14	50	39	4. Inadequate installation and testing prior to start-up
0	11	23	8	17	19	13	35	22	16	30	10	18	22	5. Inadequate maintenance
6	9	6	3	4	3	40	0	0	0	2	3	0	0	6 Inadequate operating procedures
17	2	5	0	0	0	1	0	22	5	5	4	5	0	7. Outside agency - personnel
32	4	1	0	1	6	0	0	17	0	21	6	2	8	8. Outside agency - other
38	30	36	19	53	48	8	5	9	32	31	38	25	14	99. Other

TABLE 39 - FAILURE INITIATING CAUSE

ELECTRIC UTILITY POWER SUPPLIES	TRANSFORMERS	CIRCUIT BREAKERS	MOTOR STARTERS	MOTORS	GENERATORS	DISCONNECT SWITCHES	SWITCHGEAR BUS – INSULATED	SWITCHGEAR BUS – BARE	BUS DUCT	OPEN WIRE	CABLE	CABLE JOINTS	CABLE TERMINATIONS	Table, Title, Category
														TABLE 39 - FAILURE INITIATING CAUSE(Col. 42)
33	23	13	1	6	10	4	5	5	0	26	26	11	12	1. Transient overvoltage disturbance (lightning, switching surges, arcing ground fault in ungrounded system)
0	0	0	0	0	0	0	0	0	0	0	0	0	0	2. Overvoltage
0	11	3	1	26	3	4	0	5	30	21	1	0	2	3. Overheating
5	18	18	8	30	3	5	50	18	20	8	29	40	51	4. Other insulation breakdown
7	17	13	8	4	29	17	10	23	45	7	24	31	24	21. Mechanical breaking, cracking, loosening, abrading or deforming of static or structural parts
2	0	5	6	20	3	2	0	0	0	0	0	0	0	22. Mechanical burnout, friction, or seizing of moving parts.
14	1	1	0	3	3	20	0	0	0	10	7	0	4	23. Mechanically caused damage from foreign source (digging, vehicular, accident,etc.)
12	1	2	5	0	0	0	0	23	5	14	2	0	2	41. Shorting by tools or metal objects
2	2	1	1	0	0	0	0	9	0	3	0	0	2	42. Shorting by birds, snakes, rodents, etc.
0	0	1	0	0	3	0	0	0	0	0	0	0	0	51. Loss of control power
2	1	11	64	5	0	0	0	0	0	0	0	0	0	52. Malfunction of protective relay control device, or auxiliary device.
0	0	0	0	0	0	3	0	0	0	0	0	0	0	61. Low voltage
2	0	0	0	0	0	0	0	0	0	0	0	0	0	62. Low frequency
21	25	33	7	5	45	45	35	18	0	11	10	18	4	99. Other

TABLE 40 - FAILURE CONTRIBUTING CAUSE

ELECTRIC UTILITY POWER SUPPLIES	TRANSFORMERS	CIRCUIT BREAKERS	MOTOR STARTERS	MOTORS	GENERATORS	DISCONNECT SWITCHES	SWITCHGEAR BUS – INSULATED	SWITCHGEAR BUS – BARE	BUS DUCT	OPEN WIRE	CABLE	CABLE JOINTS	CABLE TERMINATIONS	Table, Title, Category
|	|	|	|	|	|	|	|	|	|	|	|	|	|	TABLE 40 - FAILURE CONTRIBUTING CAUSE (Col. 44)
2	13	4	0	5	10	8	0	0	6	0	2	0	0	1. Persistent overloading
4	0	1	0	1	6	3	5	0	0	0	0	2	0	2. Above-normal temperatures
0	0	0	0	0	0	1	0	0	0	0	0	0	0	3. Below-normal temperature
0	0	2	0	7	0	0	0	10	0	28	14	13	10	4. Exposure to aggressive chemicals or solvents
2	6	3	0	10	6	4	15	20	17	1	8	22	12	5. Exposure to abnormal moisture or water
0	0	0	0	0	3	0	0	5	0	3	2	0	0	6. Exposure to non-electrical fire or burning
0	0	0	0	2	0	0	0	0	0	0	1	0	0	8. Obstruction of ventilation by foreign objects or material
4	24	17	40	34	32	5	20	10	50	3	30	29	24	9. Normal deterioration from age
38	6	1	0	2	3	0	20	5	11	30	15	2	16	10. Severe wind, rain, snow, sleet, or other weather conditions
2	0	2	0	0	6	0	0	0	0	1	0	0	0	11. Protective relay improperly set
0	0	1	2	15	0	0	0	0	0	0	0	0	0	12. Loss or deficiency of lubricant
0	0	0	0	1	0	0	0	0	0	0	0	0	0	13. Loss or deficiency of oil or cooling medium
0	3	10	3	0	0	0	0	15	6	2	3	0	8	14. Misoperation or testing error
4	3	3	1	5	0	26	40	20	0	2	1	0	0	15. Exposure to dust or other contaminants
45	44	55	53	18	32	53	0	15	11	31	24	31	29	99. Other

TABLE 41 - FAILURE CHARACTERISTIC

ELECTRIC UTILITY POWER SUPPLIES	TRANSFORMERS	CIRCUIT BREAKERS	MOTOR STARTERS	MOTORS	GENERATORS	DISCONNECT SWITCHES	SWITCHGEAR BUS - INSULATED	SWITCHGEAR BUS - BARE	BUS DUCT	OPEN WIRE	CABLE	CABLE JOINTS	CABLE TERMINATIONS	Table, Title, Category
%	%	%	%	%	%	%	%	%	%	%	%	%	%	TABLE 41 - FAILURE CHARACTERISTIC (Col. 46)
														Utility Power Supplies (Select code)
10	1	0	0	0	0	0	30	8	10	0	17	0	12	1. Failure of single circuit (no redundant supply)
71	0	1	0	0	0	0	5	0	0	0	7	0	2	2. Failure of one circuit of a double-circuit redundant supply
15	0	0	0	0	0	0	0	0	0	0	0	0	0	3. Failure of both circuits of a double-circuit redundant supply
2	0	1	0	0	0	0	0	8	0	0	0	0	0	4. Failure of all circuits of a three or more circuit redundant supply
0	0	0	0	0	3	0	0	0	0	0	0	0	0	5. Partial failure of a three or more circuit redundant supply
														Transformers (Select Code)
0	90	0	0	0	0	4	0	0	0	0	4	0	2	6. AUtomatic removal by protective equipment
0	1	0	0	0	0	0	0	0	0	0	0	0	0	7. Partial failure reducing capacity
0	7	0	0	0	0	0	0	0	0	0	0	0	0	8. Manual removal

TABLE 41 - FAILURE CHARACTERISTIC

ELECTRIC UTILITY POWER SUPPLIES	TRANSFORMERS	CIRCUIT BREAKERS	MOTOR STARTERS	MOTORS	GENERATORS	DISCONNECT SWITCHES	SWITCHGEAR BUS - INSULATED	SWITCHGEAR BUS - BARE	BUS DUCT	OPEN WIRE	CABLE	CABLE JOINTS	CABLE TERMINATIONS	Table, Title, Category
														Circuit Breakers (Select Code)
0	0	5	1	0	0	0	0	0	0	0	0	0	0	9. Failed to close when it should
1	0	9	1	0	0	0	0	0	15	0	0	0	0	10. Failed while opening
0	0	42	1	0	6	0	0	0	0	0	0	0	0	11. Opened when it shouldn't
0	0	7	0	0	0	0	0	0	0	0	0	0	0	12. Damaged while successfully opening
0	0	2	0	0	0	0	0	0	0	0	0	0	0	13. Damaged while closing
0	0	32	0	0	0	0	0	0	0	0	0	0	0	14. Failed while operating (not while opening or closing)
														General (Select Code for any other class)
0	1	0	34	68	65	68	65	71	65	69	65	96	65	15. Failed (this applies to all classes
0	0	1	5	1	0	3	0	13	5	2	2	4	2	16. Failed during testing or maintenance
0	0	1	36	30	0	18	0	0	0	1	2	0	12	17. Damage discovered during testing or maintenance
0	0	0	20	0	16	6	0	0	5	6	3	0	6	20. Partial failure
0	0	0	1	0	10	1	0	0	0	23	1	0	0	99. Other

An interesting point is that in over two thirds of the failures there had been no preventive maintenance, yet inadequate maintenance was only listed in 10 percent of the cases as being responsible for the failure. 16 percent placed the responsibility with the manufacturer, 14 percent with inadequate installation and testing prior to start-up, with 38 percent of the cases reporting reasons for the failure in classes other than those listed in the survey.

The initiating causes varied from transient overvoltage disturbances to insulation breakdown, to mechanical failures, with 30 percent reporting normal deterioration from age as a contributing cause.

Cable Joints

Of the failures reported, 87 percent were repaired in place, with just over half being repaired on a round-the-clock basis. Almost all of the failures resulted in damaged insulation, primarily from flashovers to ground, which were initiated by insulation breakdowns, transient overvoltages, or mechanical failure.

29 percent of the respondents felt that normal deterioration from old age contributed to the failure, while 35 percent blamed abnormal moisture or exposure to aggressive chemicals. Inadequate installation and testing were considered responsible for 50 percent of the failures. 60 percent of the respondents reported that no preventive maintenance had been performed, but only 18 percent blamed the failure on inadequate maintenance.

Cable Terminations

Of the reported cable termination failures, 60 percent were repaired in place with just over half of the repairs being made on a round-the-clock basis. The primary damage was insulation involving either a flashover to ground or other electrical defect. About half of the respondents felt that the failure was initiated by an insulation breakdown, with normal deterioration due to age, severe weather, and exposure to abnormal moisture or aggressive chemicals contributing significantly to the problem. 39 percent felt that inadequate installation and testing prior to start-up was primarily responsible, while 22 percent felt that inadequate maintenance should be blamed. This also seems to correspond to the reporting that in 40 percent of the cases no preventive maintenance had been performed in over two years.

General Conclusions

Electrical Equipment

The general picture from Tables 38 and 35 spotlights inadequate maintenance as a significant factor in the suspected responsibility for failures. Yet the owner appears willing to work round the clock to fix failures after they have occurred. Lack of cleaning and lubrication is apparent on disconnect switches, buses, open wire, cable, cable joints, cable terminations, and motors.

Electric Utility Power Supplies

Many of the results shown in Tables 33–38 are not really applicable for electric utility power supplies because the questions asked are not well suited. The importance of the utility supply was indicated by 91 percent of respondents making repairs on a round-the-clock basis. The failures were predominantly flashovers involving ground, caused by lightning during severe weather or by dig-ins or vehicular accident. Outside agencies, probably the local utility, were predominantly responsible for the failure with preventive maintenance having no apparent effect on the cases reported.

The data reported under "failure characteristic" in Table 41 are of special significance in the case of double- or triple-circuit electric utility power supplies. In particular, the failure rate can

TABLE 42 - SIMULTANEOUS FAILURE OF ALL CIRCUITS IN ELECTRIC UTILITY POWER SUPPLIES

% of 145 Failures from Table 41	Number of Failures	Utility Power Supplies - Failure Characteristic from Table 41
15%	22	3. Failure of both circuits of a double-circuit redundant supply
2%	3	4. Failure of all circuits of a three or more circuit redundant supply
17%	25	Total number of simultaneous failures of all circuits in a double or more circuit redundant supply

be calculated for the simultaneous failure of all circuits in a double- or triple-circuit electric utility power supply.

From Table 3 of Part 1 [1] the sample size is 210.7 unit-years for a double- or triple-circuit electric utility power supply. A double- or triple-circuit supply operating for one year is counted as one unit-year. It is possible to calculate a failure rate from these data as follows:

$$\frac{25}{210.7} = 0.119 \text{ failures per year for simultaneous failure of all circuits in a double- or triple-circuit electric utility power supply.}$$

Some discrepancies were found in the data on the number of installed units for double- and triple-circuit electric utility power supplies. See the discussion in Part 1 [1] on this point.

Discrepancies

A survey such as this one often obtains some data that appear to contain errors. Sometimes the results look ridiculous. However, some of the ridiculous looking results may actually be correct. Some of the errors are believed due to a misinterpretation of the question by the respondent.

The data in Tables 31-41 have been published without attempting to correct discrepancies or errors. A brief list of some possible discrepancies is given.

Table 36: The damaged part of one percent of failed circuit breakers is a tap changer. The damaged part of three percent of failed cables is a bearing. Winding insulation is shown as the damaged part in failures of cables, bus ducts, and motor starters.

Table 39: Three percent of the failures in disconnect switches were initiated by low voltage.

References

[1] IEEE Committee Report, "Report on reliability survey of industrial plants, Part I: Reliability of electrical equipment," this issue, pp. 213-235.

Discussion

J. Krasnodebski, N. M. Thompson, D. H. Cooke, A. W. W. Cameron, S. Basu, and T. J. Ravishanker (Ontario Hydro, Toronto, Ont., Canada):

1) *Quality of Input Data:* The confidence level of data in a survey of this kind cannot be assessed by mathematics only. One key problem is the adequacy of records and completeness of data. Some of the apparent discrepancies noted in the paper seem to indicate quite substantial omissions in records. Unless the industries involved keep much better failure records than we have done to date, this is not surprising. The first requirement of a useful reliability program is an adequately complete and accurate system for recording failures and consequences (in outage terms).

TABLE A
Generators

Forced Outages

EEI Report		
Sample Size (unit-years)	Number of Occurrences per Unit-Year	Outage Hours per Occurrence
204	0.142	91.8
404	0.839	126.5
705	0.521	54.4
483	0.393	125.6

	IEEE Reliability Survey		
Type of Drive	Sample Size (unit-years)	Number of Occurrences per Unit-Year	Outage Hours per Occurrence
Steam turbines*	761.8	0.032	165.0
Jet engines			
Gas turbines	89.4	0.638	23.1
Diesel engines	59.4	0.067	127.0

*EEI results are for generators 60-89 MW.

The requirements for better records, along with the detail involved in the report forms, indicate that acquiring useful data of this kind is time consuming.

It is suggested that, if a choice is necessary, it might be preferable to have a limited (but statistically adequate) number of plants establish a reliably complete recording and reporting system rather than increase the size of the sample under current record systems.

2) *Survey Results on Equipment Failures:* The failure rate is given in failures per unit-year. Is year in this context a calendar year or 8760 hours of plant or equipment operating time? If the failure rate is given per calendar year, were adjustments made for plants operating for 40 hours per week against those operating for up to 168 hours per week?

3) *Discussion of Equipment:*

Motors: It is suspected that the discrepancy in failure rates results from the different application of the two types of motors. Synchronous motors are usually applied only in engineered situations and are carefully designed for the application. Large synchronous motors are usually slow speed. Induction motors are mass produced, purchased off the shelf at the lowest cost, and usually operated to take advantage of any service factor. The survey figures are probably correct but cannot be used for comparison of reliability, leading to a conclusion that synchronous motors are more reliable. It is a comparison of apples and oranges.

Switchgear Bus: The paper states that the reported data are the opposite to what they should be. The reported figures may be correct. Manufacturers regularly reduce the spacing between buses and the spaces between phases and ground when they use insulated bus. As the conductor insulation is usually also reduced by design and occasionally by inferior material standards compared to that on insulated cables, and workmanship is frequently less than perfect, failures on this type of gear are probably at least as common as those on air-insulated equipment.

Circuit Breakers: The failure rate for circuit breakers appears much too low. It must of course be a function of the frequency of operation as well as lapsed time. We did not find a definition of circuit breaker failure, which we believe should differ from cable, transformer, or other static device failures. Circuit breaker failures should be based on failure to operate satisfactorily either to remain closed or to open or to close when called upon. It should be clear whether these figures include failures caused by auxiliaries such as instrument transformers, relays, and control switches. Since any calculation of the reliability of a power system would be made unreasonably complex by attempts to treat all these devices individually, a figure for circuit breaker failures which includes them is usually required by the designer.

Generators: For the generators in the electrical power industry a good source of data exists in the EEI "Report on Equipment Availability for Twelve-Year Period 1960–1971." The comparison between the failure rates and average repair time contained in that report and the survey discussed are shown in Table 43. EEI data quoted for steam turbine driven generators are for the size class 60–89 MW, which is probably larger than the average size of a corresponding generator included in the industrial survey.

It can be seen that the EEI failure rate for steam turbine driven generators based on forced outages is higher by a factor of 5 than in the industrial survey. For gas turbines, failure rates contained in both reports are of the same order, while the outage duration quoted in the EEI report is higher. 54 failures in 5.5 unit years in the petroleum industry can probably be explained by the start-up troubles.

In summary, experience in the utility industry seems to explain results obtained in the industrial survey to a large degree.

4) *Causes of Failure:*

a) How important is the age of equipment? It is mentioned only as a "contributing cause," second in frequency only to "other." Are there economic replacement times, or does obsolescence usually come first?

b) Should the inference be drawn that reliability of industrial equipment, which is reasonably well suited to its job, depends mainly on 1) stringent acceptance testing, especially overvoltage testing, 2) adequate cleaning, and 3) proper lubrication of bearings?

5) *Additional Suggestions for Analysis:* Consideration should be given to add the manufacturer of the main class of equipment to provide information on reliability of different manufacturers.

Carl Becker (Cleveland Electric Illuminating Company, Cleveland, Ohio 44101): The Reliability Subcommittee did an outstanding job in assembling and correlating the mountainous volume of data in a simple, easy to understand tabulation. I would like to add some discussion that I feel would help the value of these tables and add to the accuracy of future studies. My two main points are 1) the downtime per failure on a single-circuit utility supply is extremely high (possibly by a factor of five), and 2) the equation for the dollars lost per interruption may be improved by using other than the kilowatt demand and kilowatthour usage as bases.

My company gathers, codes, and analyzes by computer all interruptions to our three quarter million customers. The average downtime per customer on our distribution system (which is a single-circuit radial supply) has been between 51 and 61 min for five of the past six years. Our service area experienced a catastrophic storm during 1969 which caused the average downtime per customer to jump to 124 min. In addition, my company is of the opinion that no plant should be down for more than 4 h (barring major catastrophies). A report is therefore written for each interruption exceeding 4 h in duration, and these reports are extremely few in number. Furthermore, 13 utilities have polled their reliability statistics for customers fed from the distribution system and found the average downtime per interruption for 1971 to be approximately 1½ h long. The average downtimes ranged from 0.75 to 3.2 h.

This information shows that the downtime per failure for industrial plants is probably outside the predicted tolerance on the IEEE data. This variance may be due to either a major long disturbance affecting a majority of those industrial plants participating or to misinterpretation of the information required.

For over five years I have worked with our customers in regard to reliability problems. My experience has shown that the plant investment, labor cost, and value of product is a better gauge of the cost per minute down than would be either maximum kilowatthour demand or usage. For example, I worked with a manufacturer of magnesium parts for military aircraft (I will call this plant *A*) and another manufacturer of parts for conveyor systems (plant *B*). The dollar loss for *A* per minute down was 100 times greater than that for *B*. However, plant *B*'s demand is 2500 kW and *A*'s demand is 500 kW, which is an indication that the kilowatthour consumptions in these particular cases are not related at all to the economical loss due to a power interruption. In general I find that the cost of downtime is tied heavily to one of the following: 1) the number of employees, 2) the cost of the product in production (piecework), or 3) the dollar output per hour (high production). A combination of these three items would indicate that loss is tied to the dollars out of the plant per unit of time. Therefore I feel that future studies should relate downtime to dollars per minute of plant production, gross plant, etc.

J. W. Beard (Union Carbide Corporation, South Charleston, W. Va. 25303): The report format and the manner in which the information is presented is generally quite adequate. Appendix A (Part 1) is somewhat difficult to read because of the reduced print, but I am not suggesting it be upgraded for this report. Because of the many and various pieces of data used for the report, it is understandable that the reader must spend a great deal of time in studying and analyzing the information in order to properly apply it. The "readily" understandable factor should perhaps be given more consideration in defining the criteria for future surveys.

It is my opinion that the most useful types of information presented are:

1) failure rate and failure rate confidence limits;
2) failure, damaged part;
3) failure type;
4) failure initiating cause;
5) failure contributing cause;
6) failure characteristics.

I believe it is a good assumption that the raw data submitted for many of the other types of information represented were of much lesser accuracy than for these. For example, most plants reporting data for information types such as plant outage cost, critical service loss duration, and loads lost versus time of power outage probably had to draw on someone's memory of each failure and then apply the "best estimate" principle. This factor alone raises the question as to whether these types of information can ever be constructed to have useful meaning. Except for near catastrophic failures, which result in heavy financial losses, it is doubtful that most plants will spend the money to document this type of data. Furthermore, in a practical sense, when configuring systems and applying electrical equipment, the reliability requirement must be carefully considered for each producing unit served inasmuch as there are many variables that enter into the calculation of downtime losses.

The following suggestions are offered for consideration in any future surveys.

1) Basically concentrate on failure rates and failure causes.

2) Simplify and reduce scope of the survey questionnaire forms (present forms tend to scare users from contributing).

3) Omit asking for types of information such as cost of outage, repair time, plant start-up time, etc.

4) Instruct users *not to* report failures of equipment where reasonable preventative maintenance is not performed.

5) Instruct users *not to* report failures of misapplied equipment.

6) Instruct users *not to* include equipment installed prior to January 1, 1968.

7) Instruct users to give "in-service" date (energized) of all equipment units, not just on the reported failures.

8) Define "failure" as "damage to equipment sufficiently severe to force an outage by either manual or automatic removal of voltage." (Keep in mind that failures caused by the conditions in 4) and 5) are not to be reported.)

Part I: There seemed to be a great deal of confusion by the respondents on the information desired for electric power supplies. Thus the published failure rates may be questionable. It is my opinion that the questionnaire form for this was too nondescript. Perhaps one way to clearly describe the power supplies on which information is desired would be to include on the form simple single-line diagrams of the more common types of utility services.

It is my opinion that the lack of response by many companies was due primarily to poor and/or nonexistent records. A major contributing cause may have been the massive amount of information asked for.

The Reliability Subcommittee's judgement that a minimum of 8 to 10 observed failures was required for "good" accuracy when estimating equipment failure rates seems reasonable.

The value chosen for the confidence interval (0.90) was a good choice. The inclusion of confidence limits curves (Fig. 1) adds measurably to the report.

I generally concur with the Subcommittee's discussion comments. Their discussion of some of the results presented in the tables reinforces my feeling that the survey was too broad in scope, and the information submitted by the plants too ambiguous for meaningful interpretation.

While the sample sizes would be made smaller, as a general rule I feel that equipment should be grouped by voltage class. For example, in Table 2 one grouping of cable terminations is for 601–15 000 V. In this instance it would be especially helpful to know the failure rate on 15-kV cable terminations alone.

Part II: As stated in my general comments, I feel that it is not practical to generate reasonably accurate information of these types.

The bases for the units used in cost calculations, dollars per kilowatt plus dollars per killowatthour, are somewhat confusing. Clarification of this would be helpful.

In the Subcommittee's discussion of the cost of power outages, item 2), I must disagree with their thought that electrochemical or heating processes tend to have low outage costs because heat not supplied now can be supplied later.

In the discussion of loads lost versus time of power outage the "time" factor is questionable. Most plants are not equipped to measure short-duration power outages (cycles or even seconds).

Part III: Many of the information types in this part are very important. Some, I feel, are not. I suggest that the questions on failure repair method; failure repair urgency; failure, months since maintenance; and suspected failure responsibility be omitted from future surveys. The remaining types of information may be refined using knowledge gained from this survey.

In the Subcommittee's Summary of Conclusions they report that transient overvoltages were a major cause of failure in equipment such as, for example, transformers and circuit breakers; but I got the impression that much of this was speculation on the part of those responding. The possibility of transient overvoltage should be considered in the investigation of most equipment failures, and IEEE could perform an important service to industry by developing a socalled "evaluation of possibility of transient overvoltage contribution to equipment failures" guide.

Stanley Wells (Union Carbide Corporation, Port Lavaca, Tex. 77979): The Reliability Subcommittee should be congratulated for performing such a comprehensive reliability survey of industrial plants and for providing a very thorough report.

I would like to limit my discussion to Part 3 and, in particular, the preventive maintenance effect on the failure rate. A preventive maintenance program can very definitely have a direct effect on the failure rate of electrical equipment. In the modern automated plant of today, production demands and losses associated with downtime influence maintenance schedules. Equipment is often allowed to remain in operation for periods that exceed desired preventive maintenance time schedules. It is interesting to note that the survey indicates that preventive maintenance can be performed, yet equipment failures occur within a time period which is less than 12 months since preventive maintenance was performed. Our first attempt at a preventive maintenance program met with the same results. The program was reviewed in depth and it was found that it was inadequate and that the preventive maintenance procedures and time schedules should be reviewed and correlated with our failure experience. As experience was gained, the equipment preventive maintenance program developed into a very useful tool to practically eliminate electrical equipment failure. We soon recognized that where preventive maintenance periods were over 24 months or where no preventive maintenance at all was performed, chances of failure were extremely high. This fact is born out in the results of this survey. Table 35, "Failure–Months Since Maintained," has been rearranged to show that a large reduction in failures may be possible if preventive maintenance periods are on a 12- to 18-month basis (Table B).

Let's define preventive maintenance. Preventive maintenance is a system of routine inspections designed to minimize or forestall future equipment operating problems or failures, and which may, depending upon equipment type, require equipment exercising or proof testing. From this definition, the four following items listed under Table 38, "Suspected Failure Responsibility," can be considered a definite part of a maintenance program:

1) manufacture, defective components (locate by inspection or test);
2) application engineering, improper application;
3) inadequate installation and testing prior to start-up (proof test);
4) inadequate maintenance.

It is interesting to note that the survey indicates that these four items are responsible for a very large percentage of failures. The total for each category is listed below.

	Percent
Transformers	55
Circuit breakers	53
Motor starters	77
Motors	42
Generators	41
Disconnect switches	52
Switchgear bus insulated	95
Switchgear bus uninsulated	52
Bus duct	63
Open wire	41
Cable	48
Cable joints	68
Cable terminations	79

To increase the electrical system reliability, each failure should be very carefully analyzed to determine the failure cause, and corrective action to prevent additional failures should be applied to all applicable equipment.

TABLE B
FAILURES

	Less than 12 Months Ago Preventive Maintenance	12 Months or More or No Preventive Maintenance
Transformers	34	65
Circuit breakers	18	81
Motor starters	67	33
Motors	22	78
Generators	58	42
Disconnect switch	8	92
Switchgear bus insulated	10	90
Switchgear bus uninsulated	35	65
Bus duct	25	75
Open wire	1	98
Cable	11	89
Cable joint	18	82
Cable terminations	12	88

R. E. Kuehn (IEEE Reliability Group): The reliability, maintainability, and downtime logistics in the power area is very important and should lend itself to cost analysis, which is the ultimate judge of the value of reliability and maintainability programs. A great deal of data have been analyzed with all the obvious advantages and disadvantages that are entailed in such a data base. Parts 1 and 2 present me with a severe problem as a reliability professional and manager. In both papers a large effort was spent indicating that the survey results do not agree with what the engineering judgment says the results should be; for example, the discussion of Part 1 on motors, generators, cable, and switchgear bus. My quandary is that if I accept your judgment in all logic, I must question the validity of all the data collected, not just for motors, generators, cable, and switchgear bus. A possible procedure would have been to test the hypothesis that a part of the data was significantly different enough from the total grouped data to justify its rejection as part of the group data.

I would like to recommend analysis of variance or multiple regression in analyzing the data. It would appear that a number of possible variables exist and their effects are suitable for quantization. These procedures are covered in [1]-[4].

REFERENCES

[1] R. G. Stokes and F. N. Sehle, "Some life-cycle cost estimates for electronic equipments," in *Proc. 1968 Annu. Symp. on Reliability*, pp. 169-183.

[2] B. L. Retterer, "State of art assessment of reliability and maintainability as applied to ship systems," in *Proc. 1969 Annu. Symp. on Reliability*, pp. 133-145.

[3] H. Dagen, "Multiple regression," in *Proc. 1972 Annu. Symp. on Reliability*," pp. 51-58.

[4] "Cost effectiveness evaluation procedures for shipboard electronic equipment," ARINC Research Publ. 509-01-2-564 and 541-01-1-766.

Tai C. Wong (American Electric Power Service Corporation, New York, N.Y. 10004): The members of the Reliability Subcommittee are to be commended for conducting and analyzing the results of a survey that covers so many elements in industrial power systems.

Perhaps the authors want to clarify why the chi-squared distribution was used in fitting the data and what kind of statistical testing technique was employed to ensure the adequacy of the distribution chosen. The authors did compare the results of the recent survey against those obtained in 1962. The readers should be warned that this is only an observation based on empirical data and that any inference of a trend in the equipment reliability may not be valid. The paper indicates that many of the reported data cover more than one year of operating experience. Because the first survey was conducted twelve years ago, it is felt that the number of years that the different equipments were in service should be published (or the data collected during the next survey if they are not yet available) so that the reader can have a better understanding of the data background when he has to draw further conclusions, beyond the tables presented.

The authors indicated that the purpose of this survey is to make possible the quantitative reliability comparisons between alternative designs of new systems and then use this information in cost-reliability tradeoff studies to determine which type of power distribution system to use. It appears that the authors focus on making the economic tradeoff comparisons based on the available system components at a given time. However, the authors pointed out that the product of failure rate times the average downtime per failure is almost the same in 1973 as in 1962. Perhaps the equipment manufacturers and the industries can establish more dialogues, leading to an answer to the following two questions.

1) Should the equipments have a lower failure rate, but when failing, take longer to repair? or

2) Should the equipments have a higher failure rate, but when failing, need shorter repair time?

In a few instances during the survey, the respondents misinterpreted either the question(s) and/or the definition of the terms, thus leading to unreliable or biased results. This is especially true in the area of preventive maintenance. I might suggest that during the next survey 1) the definition of all terms that are likely to cause confusion in the questionnaire be included, 2) a pilot survey be instituted and any necessary modifications be made to the questionnaire before a full-scale survey is launched, or 3) the survey form be sent out without requesting data, but instead requesting the respondent's interpretations of the questions and the terms used. Then the survey form may be redesigned and data requested.

L. O. Sunderman (Lincoln Electric System, Lincoln, Nebr.): The authors have presented an interesting cross section of costs involved with industrial electric equipment downtime as accumulated by the computer. The data are to be utilized by interested parties in the choice of a reliability design for industrial power distribution systems. The wide range of costs as split into the two parts over 1000 kW and under 1000 kW suggests consideration of other kW brackets at 500, 2500, 5000, 7500, 10 000 kW, etc. The sufficiency of data will dictate breaking points, as the author already questions the cost data below 1000 kW.

In Part 3 the authors have reviewed and presented in excellent tables the results of electric equipment outage reports and repair. It must have been disturbing to note the numerous "other than categories classified." Perhaps further reporting on the "other" category comments, if available, would bring additional results to light.

IEEE Reliability Subcommittee: The authors wish to thank those who presented discussions on these three papers. Some of the suggestions given can be considered for incorporation into future surveys and they can also be used in the analysis of the results.

Several discussers have raised the question about the effect of "in service date" or age on the reliability of electrical equipment. Population data were collected on the average age of equipment in service; these will be published in Part 4. However, the Reliability Subcommittee did not request these data in the survey questionnaire on equipment failures. This subject was considered by the Subcommittee when making up the questionnaire; it was not included because this would have added additional complications to a questionnaire that was already considered too long. This meant that the assumption was made that the failure rate was constant with age. Thus a chi-squared distribution is appropriate for use in calculating the confidence limits of the failure rate. The assumption of a constant failure rate with age can be justified for most electrical equipment based upon reliability surveys made by others.

Mr. Becker and Mr. Beard have raised questions about the accuracy of the cost of power outage data and the attempt to relate it to kilowatts and kilowatthours. Information was collected but not published on the estimated plant outage costs 1) per failure and 2) per hour of downtime. The authors consider that the cost of power outages is an important factor that should be considered in the design of power distribution systems for industrial plants. Since power distribution systems are designed on the basis of kilowatt capacity and kilowatthour of delivered energy, it was felt that it is necessary to attempt to relate the cost of power outages to these two parameters. The approach used by the Reliability Subcommittee is the same as that which has been used by electric power companies in several European countries. The survey result of the median cost of 83¢ per kilowatthour of undelivered energy is in the same range as values obtained from surveys that have been made in Sweden, Norway, France, Italy, and West Germany. The authors agree that the published data of the cost of power outages are more meaningful if related to specific types of plants.

The authors acknowledge Mr. Beard's suggestion that a one-line diagram should be used in the survey of the electric utility supply. A new survey of the electric utility supply is being started, and Mr. Beard's suggestion will be included. This new survey should clear up the problem of the questionable accuracy mentioned by Mr. Beard. The authors acknowledge Mr. Beard's comment questioning the accuracy of the "time" factor in loads lost versus time of power outage in Table 30.

In answer to several questions raised by Mr. Krasnodebski, the authors make the following comments.

1) The failure rates are based upon a calendar year of 8760 h, not upon an operating time, which could be less and would thus result in a higher failure rate than reported in the survey.

2) The failures of circuit breakers are meant to include the auxiliaries.

3) The failure modes of circuit breakers are included in Table 41; this includes "fail to close," "fail to open," etc. However, data were not collected on the number of circuit breaker operations.

4) The Reliability Subcommittee does not consider that it would be appropriate for a technical society such as IEEE to collect and publish reliability data by name of manufacturer.

5) The authors agree that better record keeping of failures would improve survey results. It is expected that future surveys will cover only a few categories of electrical equipment that are considered trouble areas.

6) The authors acknowledge the logic in the very interesting comments made on synchronous motors and switchgear bus and generators.

7) The steam turbine generators in industrial plants probably have constant operation and thus could be expected to have a much lower failure rate than 60–89 MW units in utility applications where the operation was cyclical.

The authors wish to thank Mr. Kuehn for his suggestions in analyzing the data. These suggestions included 1) test hypothesis that part of data can be rejected, and 2) analysis of variance or multiple regression. Mr. Becker has raised a point where this approach for analyzing the data could possibly be tried. Mr. Becker feels that the survey results are too high on the downtime per failure of a single-circuit electric utility supply. This may be true for his system, but perhaps other utilities are not as good as his company's system.

Mr. Wong has raised a warning about drawing the conclusion that equipment reliability has improved since the previous survey conducted 11 to 12 years earlier. A separate paper has been prepared on this subject and will be published in the near future. This paper contains the conclusion that the failure rate of electrical equipment has shown a definite trend of improvement during the 12-year interval.

The authors wish to thank Mr. Wells for his discussion on preventive maintenance. A lot more data on preventive maintenance are being processed and will be included in Part 4. Mr. Wells' Table B shows more failures in the "12 months or more" category than for the "less than 12 months ago" category. The authors would like to point out that the electrical equipment has more unit-years of exposure in the "12 months or more" category and thus could be expected to have more failures. Thus it is not possible to conclude that more frequent preventive maintenance will reduce the failure rate. The Reliability Subcommittee is investigating this subject in further detail and will publish the results in Part 4.