Annex B

Report on Reliability Survey of Industrial Plants

Part IV
Additional Detailed Tabulation of Some Data Previously Reported in the First Three Parts

Part V
Plant Climate, Atmosphere, and Operating Schedule, the Average Age of Electrical Equipment, Percent Production Lost, and the Method of Restoring Electrical Service after a Failure

Part VI
Maintenance Quality of Electrical Equipment

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

A. D. Patton, *Chair*

C. E. Becker
W. H. Dickinson
P. E. Gannon
C. R. Heising
D. W. McWilliams
R. W. Parisian
S. J. Wells

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Report on Reliability Survey of Industrial Plants, Part IV: Additional Detailed Tabulation of Some Data Previously Reported in the First Three Parts

IEEE COMMITTEE REPORT

Abstract—An IEEE sponsored reliability survey of industrial plants was completed during 1972. This survey included 30 companies covering a total of 68 industrial plants in the United States and Canada. Additional detailed results are reported on some data that were previously reported in the first three parts. This includes failure modes of circuit breakers, cost of power outages, critical service loss duration time, loss of motor load versus time of power outage, and the effect of failure repair method and repair urgency on the average downtime per failure of electrical equipment. This information is useful in the design of industrial power distribution systems.

INTRODUCTION AND RESULTS

DURING 1972 the Reliability Subcommittee of the Industrial and Commercial Power Systems Committee completed a reliability survey of industrial plants. This paper presents Part IV of the results from the survey. The first three parts [1]–[3] were published previously. Some of the data in the first three parts caused questions to be raised about the possibility of obtaining additional details. These additional details are being reported in this paper and include the following results.

Table 43 gives failure modes of circuit breakers, including

1) metalclad drawout
   a) 0–600 V
   b) 601–15 000 V
   c) all voltages
2) fixed type (includes molded case)
   a) 0–600 V
   b) all voltages.

Tables 44, 45 give cost of power outages, adding 25 and 75 percentile data to what was previously published.

Table 46 gives critical service loss duration time (maximum length of power failure that will not stop plant production), adding 10, 25, 75, and 90 percentile data to what was previously published.

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

Table 47 lists loss of motor load versus time of power outage, adding the following length of power outage categories:

1) 10 to 15 cycles
2) 15+ to 30 cycles
3) 0.5+ to 2.0 s
4) 2+ to 4.0 s
5) >4.0 s.

Tables 48 through 56 report the effect of failure repair method and failure repair urgency on the average downtime per failure for the following equipment categories:

1) transformers—liquid filled
   a) 601–15 000 V
   b) above 15 000 V
2) circuit breakers—metalclad drawout
   a) 0–600 V
   b) above 600 V
3) motors
   a) induction, 0–600 V
   b) induction, 601–15 000 V
   c) synchronous, 601–15 000 V
4) cable
   a) above ground and aerial, 601–15 000 V
   b) below ground and direct burial, 601–15 000 V

In each of the Tables 43 through 56 reference is made to the tables in Parts I, II, and III where previous results had been reported.

DISCUSSION—FAILURE MODES OF CIRCUIT BREAKERS

The data on failure modes of circuit breakers given in Table 43 show some very interesting results.

Circuit Breakers, 0–600 V

71 percent of the failures of metalclad drawout circuit breakers were "opened when it shouldn't" versus 5 percent of the failures for fixed-type circuit breakers (includes molded case). 77 percent of the failures of fixed-type circuit breakers (includes molded case) were "failed while operating (not while opening or closing)," and only 10 percent of the metalclad drawout failures included this failure mode.

None of the failures reported for either type of circuit breaker were "failed while opening." Only 9 percent and

TABLE 43 - FAILURE MODES OF CIRCUIT BREAKERS - Percent of Total Failures in Each Failure Mode
(Data Previously Reported in Tables 5 and 41)

All Circuit Breakers	Metalclad Drawout-All	Metalclad Drawout-601-15,000 Volts	Metalclad Drawout-0-600 Volts All Sizes	*Fixed Type 0-600 Volts All Sizes	*Fixed Type-All	Card-Type 3, Col. 46
%	%	%	%	%	%	FAILURE CHARACTERISTIC
5	5	2	7	8	6	Failed to close when it should
9	12	21	0	0	2	Failed while opening
42	58	49	71	5	4	Opened when it shouldn't
7	6	4	9	5	4	Damaged while successfully opening
2	1	0	0	0	4	Damaged while closing
32	16	24	10	77	73	Failed while operating (not while opening or closing)
1	0	0	0	0	2	Failed during testing or maintenance
1	2	0	3	0	0	Damage discovered during testing or maintenance
1	0	0	0	5	5	Other
100%	100%	100%	100%	100%	100%	Total Percent
-	117	53	59	39	48	Number of Failures in Total Percent
-	7	0	7	1	1	Number Not Reported in Col. 46, Card-Type 3
-	124	-	66	40	49	Total Failures in Table 5

*Includes molded case

5 percent, respectively, of the failures were "damaged while successfully opening." Only 7 to 8 percent of the failures were "failed to close when it should."

It appears that the dominate failure mode for metalclad drawout circuit breakers, 0–600 V, is "opened when it shouldn't." It is possible that some of these failures were external to the breaker and of unknown cause and were blamed on the breaker. Some of these may have been due to improper setting of the trip current.

The dominate failure mode for fixed-type circuit breakers (includes molded case), 0–600 V, is "failed while operating (not while opening or closing)."

Metalclad Drawout Circuit Breakers, 601–15 000 V

Metal drawout circuit breakers, 601–15 000 V, had 21 percent of the failures classified as "failed while opening" and 4 percent classified as "damaged while successfully opening." Another 24 percent of the failures were classified as "failed while operating (not while opening or closing)." 49 percent of the failures were classified as "opened when it shouldn't;" it is suspected that some of these may have been due to improper setting of the trip current.

It appears that metalclad drawout circuit breakers, 601–15 000 V, have about half of their failures as "opened when it shouldn't" and the other half as "failed while operating or while opening."

DISCUSSION—LOSS OF MOTOR LOAD VERSUS TIME OF POWER OUTAGE

The data on loss of motor load shown in Table 47 indicate that for power outages greater than 10 cycles duration most of the plants lose the motor load. However, for power outages between 1 to 10 cycles duration, only about half as many lose the motor load. Thus, power outages of less than 10 cycles duration may often not result in losing the motor load.

There were many power outages of more than 4.0 s duration, and 35 percent did not lose motor load. It is suspected that many of these did not have a motor load. Some may have had a duplicate feed and thus did not lose the motor load.

DISCUSSION—EFFECT OF FAILURE REPAIR METHOD AND FAILURE REPAIR URGENCY ON AVERAGE HOURS DOWNTIME PER FAILURE

Data were given in Part I on the average hours downtime per failure for 74 categories of electrical equipment. It is known that the downtime after a failure can be affected to a large extent by the failure repair method and the failure repair urgency. The failure repair method includes either repair of the failed component or else replacement with a spare. Some data were given in Tables 33 and 34 of Part III on the failure repair method and the failure repair urgency for whole classes of electrical equipment.

A more detailed study is reported in Tables 48–56 of this paper on the effect of the failure repair method and the failure repair urgency on the average hours downtime per failure. This is only reported for 9 electrical equipment categories, rather than the 74 categories given in Part I. These 9 electrical equipment categories were selected because an adequate sample size existed of the number of failures and because the average downtime per failure was effected significantly by the failure repair method and/or the failure repair urgency.

TABLE 44 - PLANT OUTAGE COST PER FAILURE PER kW OF MAXIMUM DEMAND ($ per kW)
All Industry - USA & Canada
(Data Previously Reported in Tables 22, 24 and 26)

Plant Size	Number of Plants Reporting	Minimum	25% Percentile	Median	75% Percentile	Maximum	Average
All Plants	42	.002	.17	.69	2.55	10.00	1.89
Plants > 1000 kW Max. Demand	32	.002	.09	.32	1.31	7.50	1.05
Plants < 1000 kW Max. Demand	10	.50	1.71	3.68	8.27	10.00	4.59

TABLE 45 - PLANT OUTAGE COST PER HR. DOWNTIME PER kW OF MAXIMUM DEMAND ($ per kWh)
All Industry - USA & Canada
(Data Previously Reported in Tables 23, 25 and 27)

Plant Size	Number of Plants Reporting	Minimum	25% Percentile	Median	75% Percentile	Maximum	Average
All Plants	41	.0009	.18	.83	2.71	27.00	2.68
Plants > 1000 kW Max. Demand	31	.0009	.12	.36	1.20	5.77	.94
Plants < 1000 kW Max. Demand	10	.86	1.83	4.42	12.50	27.00	8.11

TABLE 46 - CRITICAL SERVICE LOSS DURATION (Maximum Length of Power Failure that Will Not Stop Plant Production)
(Data Previously Reported in Table 29)

Industry	Number of Plants Reporting	Average	10% Percentile	25% Percentile	Median	75% Percentile	90% Percentile
All Industry - USA & Canada	55	12.6 min.	5.0 cycles	10.0 cycles	10.0 sec.	15.0 min.	60.0 min.
Chemical	20	4.56 min.	3.2 cycles	8.5 cycles	1.25 sec.	5.0 min.	28.5 min.

TABLE 47 - LOSS OF MOTOR LOAD VERSUS TIME OF POWER OUTAGE
Tabulation of the Percentage of Equipment Failures for Which the Motor Load was Lost
(Data Previously Reported in Table 30)

Length of Equipment Failure	Number of Failures Reported	TYPE OF LOAD LOST Motor Yes	No	Not Known
1 cycle or less	0	0%	0%	0%
1+ to 10- cycles	-	33%	67%	0%
10 to 15 cycles	7	86%	14%	0%
15+ to 30 cycles	28	96%	4%	0%
0.5+ to 2.0 sec.	30	77%	13%	10%
2.0+ to 4.0 sec.	10	100%	0%	0%
>4.0 second	998	64%	35%	0%

TABLE 48 TRANSFORMERS-LIQUID FILLED, 601-15,000 VOLTS
EFFECT OF FAILURE REPAIR METHOD AND FAILURE REPAIR URGENCY
ON THE AVERAGE HOURS DOWNTIME PER FAILURE
(Previous Data Given in Tables 4, 33 and 34)

FAILURE REPAIR METHOD			FAILURE REPAIR METHOD		
Repair	Replace with Spare	Total	Repair	Replace with Spare	
Number of Failures			Average Hours Downtime per Failure		FAILURE REPAIR URGENCY
4	22	26	*	130	1. Requiring round-the-clock all out efforts
10	3	13	342	*	2. Requiring repair work only during regular workday, perhaps with some overtime
0	0	0	-	-	3. Requiring repair work on a non-priority basis
14	25	39	Average 174. Hours		Total

*Small Sample Size

TABLE 49 - TRANSFORMERS-LIQUID FILLED, ABOVE 15,000 VOLTS
EFFECT OF FAILURE REPAIR METHOD AND FAILURE REPAIR URGENCY
ON THE AVERAGE HOURS DOWNTIME PER FAILURE
(Previous Data Given in Tables 4, 33 and 34)

FAILURE REPAIR METHOD			FAILURE REPAIR METHOD		
Repair	Replace with Spare	Total	Repair	Replace with Spare	
Number of Failures			Average Hours Downtime per Failure		FAILURE REPAIR URGENCY
2	5	7	*	*	1. Requiring round-the-clock all out efforts
12	4	16	1842	*	2. Requiring repair work only during regular workday, perhaps with some overtime
0	1	1	-	*	3. Requiring repair work on a non-priority basis
14	10	24	Average 1076. Hours		Total

*Small Sample Size

TABLE 50 - CIRCUIT BREAKERS - METALCLAD DRAWOUT, 0-600 VOLTS
EFFECT OF FAILURE REPAIR METHOD AND FAILURE REPAIR URGENCY
ON THE AVERAGE HOURS DOWNTIME PER FAILURE
(Previous Data Given in Tables 5, 33 and 34)

FAILURE REPAIR METHOD			FAILURE REPAIR METHOD		
Repair	Replace with Spare	Total	Repair	Replace with Spare	
Number of Failures			Average Hours Downtime per Failure		FAILURE REPAIR URGENCY
31	19	50	3.3	3.8	1. Requiring round-the-clock all out efforts
6	1	7	*	*	2. Requiring repair work only during regular workday, perhaps with some overtime
8	1	9	*	*	3. Requiring repair work on a non-priority basis
45	21	66	Average 147. Hours		Total

*Small Sample Size

TABLE 51 - CIRCUIT BREAKERS - METALCLAD DRAWOUT, ABOVE 600 VOLTS
EFFECT OF FAILURE REPAIR METHOD AND FAILURE REPAIR URGENCY
ON THE AVERAGE HOURS DOWNTIME PER FAILURE
(Previous Data Given in Tables 5, 33 and 34)

FAILURE REPAIR METHOD			FAILURE REPAIR METHOD		
Repair	Replace with Spare	Total	Repair	Replace with Spare	
Number of Failures			Average Hours Downtime per Failure		FAILURE REPAIR URGENCY
34	12	46	83.1	2.1	1. Requiring round-the-clock all out efforts
3	9	12	*	*	2. Requiring repair work only during regular workday, perhaps with some overtime
0	0	0	-	-	3. Requiring repair work on a non-priority basis
37	21	58	Average 109. Hours		Total

*Small Sample Size

TABLE 52 - MOTORS - INDUCTION, 0-600 VOLTS
EFFECT OF FAILURE REPAIR METHOD AND FAILURE REPAIR URGENCY
ON THE AVERAGE HOURS DOWNTIME PER FAILURE
(Previous Data Given in Tables 7, 33 and 34)

FAILURE REPAIR METHOD			FAILURE REPAIR METHOD		
Repair	Replace with Spare	Total	Repair	Replace with Spare	
Number of Failures			Average Hours Downtime per Failure		FAILURE REPAIR URGENCY
12	19	31	44.7	6.6	1. Requiring round-the-clock all out efforts
175	2	177	123	*	2. Requiring repair work only during regular workday, perhaps with some overtime
0	5	5	-	*	3. Requiring repair work on a non-priority basis
187	26	213	Average 114. Hours		Total

*Small Sample Size

TABLE 53 - MOTORS - INDUCTION, 601-15,000 VOLTS
EFFECT OF FAILURE REPAIR METHOD AND FAILURE REPAIR URGENCY
ON THE AVERAGE HOURS DOWNTIME PER FAILURE
(Previous Data Given in Tables 7, 33 and 34)

FAILURE REPAIR METHOD			FAILURE REPAIR METHOD		
Repair	Replace with Spare	Total	Repair	Replace with Spare	
Number of Failures			Average Hours Downtime per Failure		FAILURE REPAIR URGENCY
14	10	24	88.1	*	1. Requiring round-the-clock all out efforts
93	48	141	83.6	34.7	2. Requiring repair work only during regular workday, perhaps with some overtime
6	0	6	*	-	3. Requiring repair work on a non-priority basis
113	58	171	Average 76. Hours		Total

*Small Sample Size

TABLE 54 - MOTORS - SYNCHRONOUS, 601 - 15,000 VOLTS
EFFECT OF FAILURE REPAIR METHOD AND FAILURE REPAIR URGENCY
ON THE AVERAGE HOURS DOWNTIME PER FAILURE
(Previous Data Given in Tables 7, 33 and 34)

FAILURE REPAIR METHOD			FAILURE REPAIR METHOD		
Repair	Replace with Spare	Total	Repair	Replace with Spare	
Number of Failures			Average Hours Downtime per Failure		FAILURE REPAIR URGENCY
28	2	30	198	*	1. Requiring round-the-clock all out efforts
55	8	63	201	*	2. Requiring repair work only during regular workday, perhaps with some overtime
1	0	1	*	-	3. Requiring repair work on a non-priority basis
84	10	94	Average 175. Hours		Total

*Small Sample Size

TABLE 55 - CABLE - ABOVE GROUND & AERIAL, 601-15,000 VOLTS
EFFECT OF FAILURE REPAIR METHOD AND FAILURE REPAIR URGENCY
ON THE AVERAGE HOURS DOWNTIME PER FAILURE
(Previous Data Given in Tables 13, 33 and 34)

FAILURE REPAIR METHOD			FAILURE REPAIR METHOD		
Repair	Replace with Spare	Total	Repair	Replace with Spare	
Number of Failures			Average Hours Downtime per Failure		FAILURE REPAIR URGENCY
46	4	50	9.0	*	1. Requiring round-the-clock all out efforts
11	8	19	*	*	2. Requiring repair work only during regular workday, perhaps with some overtime
2	2	4	*	*	3. Requiring repair work on a non-priority basis
59	14	73	Average 40.4 Hours		Total

*Small Sample Size

TABLE 56 - CABLE - BELOW GROUND & DIRECT BURIAL, 601-15,000 VOLTS
EFFECT OF FAILURE REPAIR METHOD AND FAILURE REPAIR URGENCY
ON THE AVERAGE HOURS DOWNTIME PER FAILURE
(Previous Data Given in Tables 13, 33 and 34)

FAILURE REPAIR METHOD			FAILURE REPAIR METHOD		
Repair	Replace with Spare	Total	Repair	Replace with Spare	FAILURE REPAIR URGENCY
Number of Failures			Average Hours Downtime per Failure		
17	57	74	26.5	19.0	1. Requiring round-the-clock all out efforts
2	33	35	*	77.8	2. Requiring repair work only during regular workday, perhaps with some overtime
3	3	6	*	*	3. Requiring repair work on a non-priority basis
22	93	115	Average 95.5 Hours		Total

*Small Sample Size

In several cases there is a disparity in the downtime between the "average" and the cases where work is done "round the clock." When making availability calculations, this should be considered when deciding what value to use for the downtime after a failure.

Transformers, Liquid Filled

Transformers, above 15 000 V, had an average downtime per failure of 1842 h when sent out for repair without round-the-clock urgency. This compares with an overall average of 1076 h for all outage times, which included several cases of replacement with a spare. Thus it can be concluded that repair gives a much longer outage time than replacement with a spare for transformers, above 15 000 V.

Transformers, 601–15 000 V, had an average downtime per failure of 342 h when sent out for repair without round-the-clock urgency. This compares with 130 h for replacement with a spare while working round the clock. Thus it can be concluded that repair gives a much longer outage time for transformers, 601–15 000 V, than replacement with a spare while working round the clock.

Circuit Breakers, Metalclad Drawout

Metalclad drawout circuit breakers, 0–600 V, had an average downtime per failure of 3.3 h to 3.8 h when fixing the failure with round-the-clock efforts. This compares with an overall average of 147 h for all outage times. Thus it can be concluded that 24 percent of the outages of metalclad drawout circuit breakers, 0–600 V, had low urgency for fixing the failure, and that these 24 percent of the failures resulted in increasing the average downtime per failure from 3.8 h to 147 h.

Metalclad drawout circuit breakers above 600 V, had an average downtime per failure of 109 h for all outages. However, when round-the-clock effort was applied it only took 83 h for repair and only took 2.1 h for replacement with a spare. This shows that it is possible to reduce the downtime by having a spare and working round the clock when fixing metalclad drawout circuit breakers, above 600 V.

Motors

Most users of synchronous motors, 601–15 000 V, did not have a spare. Thus the average downtime per failure was 175 h for all failures.

Induction motors, 601–15 000 V, had an average downtime per failure of 35 h for replacement with a spare, compared to 84 to 88 h for repair. Induction motors, 0–600 V, had an average downtime per failure of 6.6 h for replacement with a spare while working round the clock. This compares with 123 h for repair and not working round the clock.

Cables

Cables, above ground and aerial, 601–15 000 V, had an average downtime per failure of 9 h for repair when working round the clock. This compares with 40 h for all failures. This shows that it is possible to reduce the downtime by working round the clock when fixing cables, above ground and aerial, 601–15 000 V.

Cables, below ground and direct burial, 601–15 000 V, had an average downtime per failure of 96 h for all failures. However, this was only 19 to 27 h when working round the clock. This shows that it is possible to reduce the downtime by working round the clock when fixing cables, below ground and direct burial, 601–15 000 V.

DISCUSSION—COST OF POWER OUTAGES

Data are given in Tables 44 and 45 on the cost of power outages to industrial plants. This has added 25th and 75th percentile data to what had previously been reported in Part II. These were added because of the wide spread in the cost of power outages to industrial plants.

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[3] W. H. Dickinson *et al.*, "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 Trans. Ind. Appl.*, vol. 14-10, pp. 242–252, Mar./Apr. 1974.

Report on Reliability Survey of Industrial Plants, Part V: Plant Climate, Atmosphere, and Operating Schedule, the Average Age of Electrical Equipment, Percent Production Lost, and the Method of Restoring Electrical Service after a Failure

IEEE COMMITTEE REPORT

***Abstract*—An IEEE sponsored reliability survey of industrial plants was completed during 1972. This survey included the plant climate, atmosphere, and operating schedule, the average age of electrical equipment, percent production lost, and the method of restoring electrical service after a failure. 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 AND RESULTS

During 1972 the Reliability Subcommittee of the Industrial and Commercial Power Systems Committee completed a reliability survey of industrial plants. This paper presents Part V of the results from the survey. The first three parts [1]–[3] were published previously; some of the data of lesser importance were not published at that time but are presented in this paper. Included in Part V are

Table 57—Failure Forewarning for Public Utility Power Interruption Only,
Table 58—Percent Production Lost,
Table 59—Method of Service Restoration,
Table 60—Average Age of Electrical Equipment,
Table 61—Plant Climate,
Table 62—Plant Atmosphere,
Table 63—Plant Operating Schedule.

These data are useful when using the results published in Parts I, II, III, IV [4], and VI [5]. This information is also useful in the design of industrial power distribution systems. The data on average age of electrical equipment and plant operating schedule provide answers to some points raised in the written discussion to Part I.

Paper TOD-74-33, approved by the Industrial and Commercial Power Systems Committee of the IEEE Industry Applications Society for presentation at the 1974 Industrial and Commercial Power Systems Technical Conference, Denver, Colo., June 2-6. Manuscript released for publication April 15, 1974.

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

TABLE 57 - FAILURE FOREWARNING for PUBLIC UTILITY POWER INTERRUPTION ONLY

Percent	Col. 25 Card-Type 3
97%	1. If no forewarning was given
3%	2. If forewarning was given
—	For other types of failure, leave blank
100%	Total Percent
172	Total Interruptions Reported

SURVEY FORM

The survey form is shown in Appendix A of Part I [1]. The information reported in this paper came from 1) card type 3, columns 25, 53, and 58; 2) card type 2, column 33; and 3) card type 1, columns 9–11 and 13. The definition of *failure* is given in Part I.

RESPONSE TO SURVEY

A total of 30 companies responded to the survey questionnaire, reporting data covering 68 plants in nine industries in the United States and Canada. For the purpose of reporting results in this paper, Part V, the number of industries were reduced from nine down to five plus an "all other" category. The five industries selected were the ones for which equipment failure rate data were reported in Tables 3 through 19, Part I. All of the remaining industries were combined into an "all other" category in Tables 61–63 on plant climate, plant atmosphere, and plant operating schedule.

DISCUSSION—FOREWARNING FOR PUBLIC UTILITY POWER INTERRUPTION

Only 3 percent of the time was a failure forewarning given for a public utility power interruption to the industrial plant. Data from Table 3, Part I, and Table 57, Part V, indicate that a large percentage of these interruptions were on double- or triple-circuit supplies. Forewarning can be important to plants with a single circuit. It can also be important to plants containing a double circuit with manual switchover.

TABLE 58 - PERCENT PRODUCTION LOST

Col. 53 Card Type 3 Percent Production Lost	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
	%	%	%	%	%	%	%	%	%	%	%	%	%	%
0 None	41	22	19	85	24	80	20	20	17	30	62	28	33	47
1 0-30 Percent	32	63	73	13	73	5	75	60	33	55	25	60	58	35
2 Above 30 Percent	27	15	8	2	3	15	5	20	50	15	13	13	9	18
Total Percent	100	100	100	100	100	100	100	100	100	100	100	101	100	100
Total Failures Reported	202	101	177	168	561	85	101	20	24	20	108	223	45	51

TABLE 59 - METHOD OF SERVICE RESTORATION

TOTAL	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	Col. 58 Card Type 3
%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	Give method of restoring service to plant
7	1	3	6	0	5	20	0	58	25	20	13	14	28	19	1 Primary selection - manual
2	8	0	1	0	0	0	0	0	5	0	4	5	8	0	2 Primary selection - automatic
11	1	25	6	0	14	33	0	17	10	10	2	20	32	23	3 Secondary selection - manual
2	1	3	8	0	0	0	0	0	0	0	1	0	8	4	4 Secondary selection - automatic
0+	0	0	0	0	0	0	0	0	5	0	0	0	0	0	5 Network protector operation - automatic
22	5	25	11	12	30	20	3	17	20	35	31	42	24	27	6 Repair of failed component
22	2	39	38	10	29	14	77	0	10	35	6	2	0	12	7 Replacement of failed component with spare
12	81	0	1	0	0	13	0	0	0	0	1	1	0	0	8 Utility restored service
22	1	5	29	78	22	0	20	8	25	0	42	16	0	15	9 Other - explain in remarks
100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	Total Percent
1204	171	75	160	68	318	15	69	12	20	20	103	122	25	26	TOTAL NUMBER REPORTED

TABLE 60 - AVERAGE AGE OF ELECTRICAL EQUIPMENT

TRANSFORMERS	CIRCUIT BREAKERS	MOTOR STARTERS	MOTORS	GENERATORS	DISCONNECT SWITCHES	SWITCHGEAR BUS-INSULATED	SWITCHGEAR BUS-BARE	BUS DUCT	OPEN WIRE	CABLE	CABLE JOINTS	CABLE TERMINATIONS	
NUMBER OF INSTALLED UNITS													Age
6	989	101	104	0	0	0	0	0	30	15	0	12	1 Less than 1 year old
694	3691	3162	1884	9	909	646	1998	1206	12	1019	1385	3314	2 1-10 years od
835	1944	608	3643	77	552	691	555	13640	472	1831	2338	5712	3 More than 10 years old

TABLE 61 - PLANT CLIMATE (for entire plant site)
TABLE 62 - PLANT ATMOSPHERE (for entire plant site)

ALL INDUSTRY	CHEMICAL	METAL	PETROLEUM	RUBBER AND PLASTICS	TEXTILE	ALL OTHER	Table, Title, Card-Type 1 Column No.	
NUMBER OF PLANTS							TABLE 61 - PLANT CLIMATE (Col. 9)	
							Average of Daily Maximums for Hottest Month	
							Temperature	Relative Humidity (RH) (measured at noon to 2 PM ST)
14	8	1	3	0	1	1	1 Hot (> 90F)	High (> 55 RH)
3	3	0	0	0	0	0	2 Hot (> 90F)	Moderate (50-55 RH)
12	0	0	0	0	0	12	3 Hot (> 90F)	Low (< 50 RH)
14	4	1	2	0	0	7	4 Moderate (80-90F)	High (> 55 RH)
16	5	1	0	1	1	8	5 Moderate (80-90F)	Moderate (50-55RH)
6	1	0	1	2	1	1	6 Moderate (80-90F)	Low (< 50 RH)
1	0	0	0	0	0	1	7 Low (<80F)	High (>55 RH)
2	0	0	2	0	0	0	8 Low (< 80F)	Moderate (50-55 RH)
0	0	0	0	0	0	0	9 Low (< 80F)	Low (< 50 RH)
							TABLE 62 - PLANT ATMOSPHERE (Col. 10)	
34	2	1	7	0	2	22	1 Clean to slightly polluted air	
5	4	0	1	0	0	0	2 With salt spray and corrosive chemicals	
0	0	0	0	0	0	0	3 With salt spray and dust or sand	
0	0	0	0	0	0	0	4 With salt spray only	
13	8	0	0	1	1	3	5 With corrosive chemicals and dust or sand	
4	4	0	0	0	0	0	6 With corrosive chemicals only	
2	0	0	0	0	0	2	7 With dust or sand only	
5	0	2	0	2	0	1	8 With conductive dust	
1	0	0	0	0	0	1	9 Other	

TABLE 63 - PLANT OPERATING SCHEDULE

ALL INDUSTRY	CHEMICAL	METAL	PETROLEUM	RUBBER AND PLASTICS	TEXTILE	ALL OTHER	Title, Card-Type 1 Column No.
NUMBER OF PLANTS							HOURS PER DAY (Col. 11)
0	0	0	0	0	0	0	Less than 8
9	2	0	1	0	0	6	8
0	0	0	0	0	0	0	9 to 15
19	0	2	0	0	0	17	16
0	0	0	0	0	0	0	17 to 23
40	19	1	7	3	3	7	24
							DAYS PER WEEK (Col. 13)
0	0	0	0	0	0	0	Less than 5
30	1	2	1	2	0	24	5
3	1	0	0	0	0	2	6
35	19	1	7	1	3	4	7

DISCUSSION—PERCENT PRODUCTION LOST

The most severe category of failure in an industrial plant is where above 30 percent of the production is lost. Data from Table 58 show that the following percent of equipment class failures resulted in losing above 30 percent of the production.

Switchgear bus—bare	50 percent
Electric utility power supplies	27 percent
Switchgear bus—insulated	20 percent
Cable terminations	18 percent
Bus duct	15 percent
Transformers	15 percent
Generators	15 percent
Open wire	13 percent
Cable	13 percent
Cable joints	9 percent
Circuit breakers	8 percent
Motors	3 percent
Motor starters	2 percent

It can be seen that failures of switchgear bus and electric utility power supplies often result in losing above 30 percent of the production.

DISCUSSION—METHOD OF SERVICE RESTORATION

The data on method of electrical service restoration to plant is shown in Table 59. A percentage breakdown of the total shows the following results.

Replacement of failed component with spare	22 percent
Repair of failed components	22 percent
Other	22 percent
Utility service restored	12 percent
Secondary selection—manual	11 percent
Primary selection—manual	7 percent
Primary selection—automatic	2 percent
Secondary selection—automatic	2 percent
Network protector operation—automatic	0+ percent

The most common methods of service restoration are replacement of failed component with a spare or repair of failed component. Only 22 percent of the time is primary selection or secondary selection used; this would indicate that most power distribution systems are radial.

DISCUSSION—AVERAGE AGE OF ELECTRICAL EQUIPMENT

Many respondents to the reliability survey of industrial plants submitted data covering a ten-year period. Thus it is not surprising to see that Table 60 shows a large population that is more than ten years old. The following percent of installed units are classified as more than ten years old.

Bus duct	92 percent
Open wire	92 percent
Generators	90 percent
Motors	65 percent
Cable	64 percent
Cable joints	63 percent
Cable terminations	63 percent
Transformers	54 percent
Switchgear bus—insulated	52 percent

Motor starters, disconnect switches, switchgear bus—bare, and circuit breakers had over 50 percent of the installed units one to ten years old.

15 percent of the circuit breakers were less than one year old. All other equipment classes had less than 6 percent of the installed units less than a year old.

DISCUSSION—PLANT CLIMATE AND ATMOSPHERE

Data on plant climate and plant atmosphere are given in Tables 61 and 62. 43 percent of the plants were in a hot climate, 53 percent in a moderate climate, and only 4 percent in a low climate (cold climate). 43 percent of the plants had high relative humidity, 31 percent had moderate relative humidity, and 26 percent had low relative humidity. 53 percent of the plants had a plant atmosphere classified as "clean to slightly polluted air." The other 47 percent had an atmosphere with some contamination.

DISCUSSION—PLANT OPERATING SCHEDULE

The data on plant operating schedule are given in Table 63. 52 percent of the plants operated 7 days per week, 4 percent for 6 days, and 44 percent for 5 days. 59 percent of the plants operated 24 h per day, 28 percent for 16 h, and 13 percent for 8 h.

REFERENCES

[1] W. H. Dickinson *et al.*, "Report on reliability survey of industrial plants, part I: Reliability of electrical equipment," *IEEE Trans. Ind. Appl.*, vol. IA-10, pp. 213–235, Mar./Apr. 1974.

[2] W. H. Dickinson *et al.*, "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 Trans. Ind. Appl.*, vol. IA-10, pp. 236–241, Mar./Apr. 1974.

[3] W. H. Dickinson *et al.*, "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 Trans. Ind. Appl.*, vol. IA-10, pp. 242–249, Mar./Apr. 1974.

[4] A. D. Patton *et al.*, "Report on reliability survey of industrial plants, part IV: Additional detailed tabulation of some data previously reported in the first three parts," this issue, pp. 456–462.

[5] A. D. Patton *et al.*, "Report on reliability survey of industrial plants, part VI: Maintenance quality of electrical equipment," this issue, pp. 467–476.

Report on Reliability Survey of Industrial Plants, Part VI: Maintenance Quality of Electrical Equipment

IEEE COMMITTEE REPORT

***Abstract*—An IEEE sponsored reliability survey of industrial plants was completed during 1972. This included maintenance quality, the frequency of schedule maintenance, and the failures caused by inadequate maintenance. 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 maintenance quality of electrical equipment in industrial plants is useful information when planning the maintenance program of industrial power distribution systems. In addition it is useful to know how this correlates with the normal maintenance cycle and the failures blamed on inadequate maintenance. During 1972 the Reliability Subcommittee of the Industrial and Commercial Power Systems Committee completed a reliability survey of industrial plants. This paper presents Part VI of the results from the survey. The first three parts [1]–[3] were published previously. Table 38 from Part III reported that inadequate maintenance was blamed for between 8 to 30 percent of the failures of electrical equipment. This information has caused the Reliability Subcommittee to make a further study of the failure data; the results from this study are being reported in this paper. Included in Part VI are the results for 12 main classes of electrical equipment on

1) equipment population versus a) maintenance quality and b) normal maintenance cycle;
2) failures due to all causes versus a) failure, months since maintained, and b) maintenance quality;
3) failures due to inadequate maintenance versus a) failure, months since maintained, and b) maintenance quality.

The "maintenance quality" is an opinion that was reported by each participant in the survey. The four classifications used were "excellent," "fair," "poor," and "none." The "normal maintenance" cycle is the frequency of performing preventive maintenance.

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

SURVEY FORM

The survey form is shown in Appendix A of Part I [1]. The information reported in this paper came from 1) card type 2, col. 34 (maintenance, normal cycle); 2) card type 2, col. 36 (maintenance quality); 3) card type 3, col. 34 (failure, months since maintained); 4) card type 3, col. 40 (suspected failure responsibility). The definition of *failure* is given in Part I.

RESPONSE TO SURVEY

A total of 30 companies responded to the survey questionnaire, reporting data from nine industries in the United States and Canada. Every plant did not report all the information called for in card type 2, columns 34 and 36. Every failure report did not have filled out all of the information called for in card type 3, columns 34 and 40; a total of 1469 failures had this information filled in and are reported here in Part VI, and 240 of these failures were blamed on inadequate maintenance. Differences in the number of failures and unit-years reported here in Part VI and those previously reported in Part I and Part III can be explained from the preceding.

STATISTICAL ANALYSIS

The subject of statistical analysis of equipment failures is discussed in Part I [1]. Confidence limits for the failure rate are shown in Fig. 1 of Part I. The Reliability Subcommittee concluded that eight failures is an adequate sample size for reporting failure rates in the summary in Table 2, Part I. In a few cases, failure rate data were reported in Tables 3 through 19, Part I, where there were less than eight failures.

In this paper several cases are reported in Tables 67 through 78, where the failure rate contains less than eight failures; these cases have been marked "small sample size."

SURVEY RESULTS

Results are tabulated for 12 main equipment classes in Table 64 where the equipment population is given versus 1) maintenance quality and 2) normal maintenance cycle.

Table 65 summarizes the percent of each electrical equipment class population versus the maintenance quality. Table 66 summarizes the percent of each electrical equipment class population versus the normal maintenance cycle.

Results are tabulated for each of the 12 main equipment classes in Tables 67 through 78, where the number of failures is given for 1) failures due to all causes and 2)

TABLE 64 - POPULATION OF ELECTRICAL EQUIPMENT
VERSUS MAINTENANCE QUALITY & NORMAL MAINTENANCE CYCLE

MAINTENANCE QUALITY Card-Type 2 Col. 36	MAINTENANCE, NORMAL CYCLE Card-Type 2 Col. 34				
	Less Than 12 Months	12 - 24 Months	More Than 24 Months	No Preventive Maintenance	Total
	Population: Unit-Years				
TRANSFORMERS					
Excellent	19	8,904	2,314	0	11,237
Fair	292	3,081	5,961	0	9,334
Poor	0	130	210	0	340
None	0	0	0	39	39
Total	311	12,115	8,485	39	20,950
CIRCUIT BREAKERS					
Excellent	297	11,640	5,014	0	16,951
Fair	1	12,620	11,860	0	24,481
Poor	0	0	1,810	0	1,810
None	0	0	0	7,608	7,608
Total	298	24,260	18,684	7,608	50,850
MOTOR STARTERS					
Excellent	126	2,724	0	0	2,850
Fair	68	4,348	3,435	0	7,851
Poor	0	680	427	70	1,177
None	0	0	0	0	0
Total	194	7,752	3,862	70	11,878
MOTORS					
Excellent	14,650	1,372	1,259	17	17,298
Fair	121	21,930	2,958	0	25,009
Poor	0	0	74	70	144
None	0	0	0	13	13
Total	14,771	23,302	4,291	100	42,464
GENERATORS					
Excellent	104.4	380.7	0	0	485.1
Fair	74.4	279.8	0	0	354.2
Poor	0	0	0	0	0
None	0	0	0	0	0
Total	178.8	660.5	0	0	839.3
DISCONNECT SWITCHES					
Excellent	0	6,287	1,435	0	7,722
Fair	58	426	2,642	0	3,126
Poor	0	402	0	0	402
None	0	0	0	7,365	7,365
Total	58	7,115	4,077	7,365	18,615

(see pp. 681 for the second part of Table 64)

Correction to "Report on Reliability Survey of Industrial Plants, Part VI: Maintenance Quality of Electrical Equipment"

IEEE COMMITTEE REPORT

TABLE 64 - POPULATION OF ELECTRICAL EQUIPMENT
VERSUS MAINTENANCE QUALITY & NORMAL MAINTENANCE CYCLE

MAINTENANCE QUALITY Card-Type 2 Col. 36	MAINTENANCE, NORMAL CYCLE Card-Type 2 Col. 34				
	Less Than 12 Months	12-24 Months	More Than 24 Months	No Preventive Maintenance	Total
	Population: Unit-Years				
SWITCHGEAR BUS - INSULATED**					
Excellent	0	364	12,160	0	12,524
Fair	0	1,706	0	0	1,706
Poor	0	0	0	0	0
None	0	0	0	1,541	1,541
Total	0	2,070	12,160	1,541	15,771
SWITCHGEAR BUS - BARE**					
Excellent	0	1,854	27,580	0	29,434
Fair	0	19,440	2,826	0	22,266
Poor	0	769	0	0	769
None	0	0	0	369	369
Total	0	22,063	30,406	369	52,838
OPEN WIRE (Unit = 1,000 Circuit Feet)					
Excellent	0	2,217	1,014	0	3,231
Fair	0	103	2,630	0	2,733
Poor	0	0	0	0	0
None	0	0	0	680	680
Total	0	2,320	3,644	680	6,644
CABLE (Unit = 1000 Circuit Feet)					
Excellent	600	329	400	0	1,329
Fair	7	7,900	8,519	135	16,561
Poor	0	23	563	35	621
None	0	0	203	9,920	10,123
Total	607	8,252	9,685	10,090	28,634
CABLE JOINTS					
Excellent	0	9,374	311	0	9,685
Fair	12	2,800	23,530	0	26,342
Poor	0	0	1,483	0	1,483
None	0	0	0	12,110	12,110
Total	12	12,174	25,324	12,110	49,620
CABLE TERMINATIONS					
Excellent	2,500	14,290	15,650	0	32,440
Fair	0	1,452	35,200	1,170	37,822
Poor	0	0	845	0	845
None	0	0	0	54,280	54,280
Total	2,500	15,742	51,695	55,450	125,387

**Unit - Number of Connected Circuit Breakers or Instrument Transformer Compartments failures due to inadequate maintenance, versus 1) failure, months since maintained, and 2) maintenance quality. Failure rate calculations are also given in Tables 67 through 78; these calculations used the population data from Table 64.

Table 79 summarizes the number of failures for all equipment classes combined versus the maintenance quality. Table 80 summarizes the number of failures for all equipment classes combined versus the months since maintained.

GENERAL CONCLUSIONS—MAINTENANCE QUALITY

The maintenance quality is an opinion that was reported by each participant in the survey. The major portion of the electrical equipment population in the survey had a maintenance quality that was classified as excellent or fair. Less than 5 percent of the population in each equipment class (except for motor starters) were classified as poor. Four equipment categories had between 24 percent to 43 percent of the population classified as "none" under maintenance quality; this included cable termination (43 percent), disconnect switches (40 percent), cable (35 percent), and cable joints (24 percent).

Maintenance quality had a significant effect on the percent of all failures that were blamed on inadequate maintenance. In the "poor" category 33 percent of all failures were blamed on inadequate maintenance. This compares with 18 percent for fair maintenance and 12 percent for excellent maintenance. The "none" category for maintenance quality also had 12 percent of all failures blamed on inadequate maintenance; but 82 percent of these failures were for equipment classes that do not require much maintenance (cable, cable terminations, cable joints,

TABLE 65 - PERCENT OF ELECTRICAL EQUIPMENT POPULATION VERSUS MAINTENANCE QUALITY
(All Data Taken from Table 64)

MAINTENANCE QUALITY Card-Type 2 Col. 36	TRANSFORMERS	CIRCUIT BREAKERS	MOTOR STARTERS	MOTORS	GENERATORS	DISCONNECT SWITCHES	SWITCHGEAR BUS-INSULATED	SWITCHGEAR BUS-BARE	OPEN WIRE	CABLE	CABLE JOINTS	CABLE TERMINATIONS
	%	%	%	%	%	%	%	%	%	%	%	%
Excellent	54	33	24	41	58	41	79	56	49	5	20	26
Fair	44	48	66	59	42	17	11	42	41	58	53	30
Poor	2	4	10	0+	0	2	0	1	0	2	3	1
None	0+	15	0	0+	0	40	10	1	10	35	24	43
Total	100	100	100	100	100	100	100	100	100	100	100	100

TABLE 66 - PERCENT OF ELECTRICAL EQUIPMENT POPULATION VERSUS NORMAL MAINTENANCE CYCLE
(All Data Taken from Table 64)

MAINTENANCE, NORMAL CYCLE Card-Type 2 Col. 34	TRANSFORMERS	CIRCUIT BREAKERS	MOTOR STARTERS	MOTORS	GENERATORS	DISCONNECT SWITCHES	SWITCHGEAR BUS-INSULATED	SWITCHGEAR BUS-BARE	OPEN WIRE	CABLE	CABLE JOINTS	CABLE TERMINATIONS
	%	%	%	%	%	%	%	%	%	%	%	%
Less than 12 Months	1	1	2	35	21	0+	0	0	0	2	0+	2
12-24 Months	58	47	65	55	79	38	13	42	35	29	25	13
More than 24 Months	41	37	32	10	0	22	77	57	55	34	51	41
No Preventive Maintenance	0+	15	1	0+	0	40	10	1	10	35	24	44
Total	100	100	100	100	100	100	100	100	100	100	100	100

TABLE 67 - NUMBER OF TRANSFORMER
FAILURES VERSUS MONTHS SINCE MAINTAINED AND MAINTENANCE QUALITY

MAINTENANCE QUALITY Card-Type 2 Col. 36	FAILURE, MONTHS SINCE MAINTAINED Card-Type 3, Col. 34 Less Than 12 Months Ago	12 - 24 Months Ago	More Than 24 Months Ago	No Preventive Maintenance	Total	Failures per Unit-Year
	Number of Failures Due to ALL CAUSES					ALL CAUSES
Excellent	22	11	5	0	38	
Fair	10	26	16	1	53	
Poor	2	1	1	1	5	
None	0	0	0	3	3	
Total	34	38	22	5	99	.00473
	Number of Failures Due to INADEQUATE MAINTENANCE (Card-Type 3 Col. 40)					INADEQUATE MAINTENANCE
Excellent	0	1	2	0	3	.00027*
Fair	1	0	6	0	7	.00075*
Poor	0	0	0	1	1	.00294*
None	0	0	0	0	0	.00000*
Total	1	1	8	1	11	.00053

* Small Sample Size

TABLE 68 - NUMBER OF CIRCUIT BREAKER
FAILURES VERSUS MONTHS SINCE MAINTAINED AND MAINTENANCE QUALITY

MAINTENANCE QUALITY Card-Type 2 Col. 36	FAILURE, MONTHS SINCE MAINTAINED Card-Type 3, Col. 34 Less Than 12 Months Ago	12 -24 Months Ago	More Than 24 Months Ago	No Preventive Maintenance	Total	Failures per Unit-Year
	Number of Failures Due to ALL CAUSES					ALL CAUSES
Excellent	13	60	3	1	77	
Fair	18	42	4	1	65	
Poor	0	2	2	0	4	
None	1	0	0	26	27	
Total	32	104	9	28	173	.00340
	Number of Failures Due to INADEQUATE MAINTENANCE (Card-Type 3 Col. 40)					INADEQUATE MAINTENANCE
Excellent	2	1	3	1	7	.00041*
Fair	2	18	2	0	22	.00090
Poor	0	1	2	0	3	.00166*
None	0	0	0	4	4	.00053*
Total	4	20	7	5	36	.00071

* Small Sample Size

TABLE 69 - NUMBER OF MOTOR STARTER
FAILURES VERSUS MONTHS SINCE MAINTAINED AND MAINTENANCE QUALITY

MAINTENANCE QUALITY Card-Type 2 Col. 36	FAILURE, MONTHS SINCE MAINTAINED Card-Type 3 Col. 34 Less Than 12 Months Ago	12 - 24 Months Ago	More Than 24 Months Ago	No Preventive Maintenance	Total	Failures per Unit-Year
	Number of Failures Due to ALL CAUSES					ALL CAUSES
Excellent	13	1	4	0	18	
Fair	45	13	8	0	66	
Poor	1	1	2	0	4	
None	0	0	0	0	0	
Total	59	15	14	0	88	.00741
	Number of Failures Due to INADEQUATE MAINTENANCE (Card-Type 3 Col. 40)					INADEQUATE MAINTENANCE
Excellent	1	0	0	0	1	.00035*
Fair	0	1	3	0	4	.00051*
Poor	1	0	1	0	2	.00170*
None	0	0	0	0	0	—
Total	2	1	4	0	7	.00059*

* Small Sample Size

TABLE 70 - NUMBER OF MOTOR
FAILURES VERSUS MONTHS SINCE MAINTAINED AND MAINTENANCE QUALITY

MAINTENANCE QUALITY Card-Type 2 Col. 36	FAILURE, MONTHS SINCE MAINTAINED Card-Type 3 Col. 34 Less Than 12 Months Ago	12 - 24 Months Ago	More Than 24 Months Ago	No Preventive Maintenance	Total	Failures per Unit-Year
	Number of Failures Due to ALL CAUSES					ALL CAUSES
Excellent	56	14	7	0	77	
Fair	58	280	90	11	439	
Poor	0	0	2	0	2	
None	0	0	0	0	0	
Total	114	294	99	11	518	.01221
	Number of Failures Due to INADEQUATE MAINTENANCE (Card-Type 3 Col. 40)					INADEQUATE MAINTENANCE
Excellent	8	1	1	0	10	.00058
Fair	2	25	41	2	70	.00280
Poor	0	0	2	0	2	.01390*
None	0	0	0	0	0	.00000*
Total	10	26	44	2	82	.00194

* Small Sample Size

TABLE 71 - NUMBER OF GENERATOR
FAILURES VERSUS MONTHS SINCE MAINTAINED AND MAINTENANCE QUALITY

MAINTENANCE QUALITY Card-Type 2 Col. 36	FAILURE, MONTHS SINCE MAINTAINED Card-Type 3 Col. 34 Less Than 12 Months Ago	12 - 24 Months Ago	More Than 24 Months Ago	No Preventive Maintenance	Total	Failures per Unit-Year
	Number of Failures Due to ALL CAUSES					ALL CAUSES
Excellent	14	9	0	0	23	
Fair	1	4	0	0	5	
Poor	0	0	0	0	0	
None	0	0	0	0	0	
Total	15	13	0	0	28	.03360
	Number of Failures Due to INADEQUATE MAINTENANCE (Card-Type 3 Col. 40)					INADEQUATE MAINTENANCE
Excellent	3	0	0	0	3	.00618*
Fair	0	2	0	0	2	.00565*
Poor	0	0	0	0	0	
None	0	0	0	0	0	
Total	3	2	0	0	5	.00596*

* Small Sample Size

TABLE 72 - NUMBER OF DISCONNECT SWITCH
FAILURES VERSUS MONTHS SINCE MAINTAINED AND MAINTENANCE QUALITY

MAINTENANCE QUALITY Card-Type 2 Col. 36	FAILURE, MONTHS SINCE MAINTAINED Card-Type 3 Col. 34 Less Than 12 Months Ago	12 - 24 Months Ago	More Than 24 Months Ago	No Preventive Maintenance	Total	Failures per Unit-Year
	Number of Failures Due to ALL CAUSES					ALL CAUSES
Excellent	4	0	1	0	5	
Fair	4	5	4	0	13	
Poor	0	0	16	0	16	
None	0	0	0	67	67	
Total	8	5	21	67	101	.00542
	Number of Failures Due to INADEQUATE MAINTENANCE (Card-Type 3 Col. 40)					INADEQUATE MAINTENANCE
Excellent	0	0	1	0	1	.00013*
Fair	0	4	1	0	5	.00160*
Poor	0	0	0	0	0	.00000*
None	0	0	0	7	7	.00095*
Total	0	4	2	7	13	.00070

* Small Sample Size

TABLE 73 - NUMBER OF SWITCHGEAR BUS-INSULATED
FAILURES VERSUS MONTHS SINCE MAINTAINED AND MAINTENANCE QUALITY

MAINTENANCE QUALITY Card-Type 2 Col. 36	FAILURE, MONTHS SINCE MAINTAINED Card-Type 3 Col. 34: Less Than 12 Months Ago	12 - 24 Months Ago	More Than 24 Months Ago	No Preventive Maintenance	Total	Failures per **Unit-Year
	Number of Failures Due to ALL CAUSES					ALL CAUSES
Excellent	2	3	10	0	15	
Fair	0	4	1	0	5	
Poor	0	0	0	0	0	
None	0	0	0	0	0	
Total	2	7	11	0	20	.00127
	Number of Failures Due to INADEQUATE MAINTENANCE (Card-Type 3 Col. 40)					INADEQUATE MAINTENANCE
Excellent	0	0	6	0	6	.00048*
Fair	0	0	1	0	1	.00059*
Poor	0	0	0	0	0	
None	0	0	0	0	0	.00000*
Total	0	0	7	0	7	.00044*

* Small Sample Size
**Unit = Number of Connected Circuit Breakers or Instrument Transformer Compartments

TABLE 74 - NUMBER OF SWITCHGEAR BUS-BARE
FAILURES VERSUS MONTHS SINCE MAINTAINED AND MAINTENANCE QUALITY

MAINTENANCE QUALITY Card-Type 2 Col. 36	FAILURE, MONTHS SINCE MAINTAINED Card-Type 3 Col. 34: Less Than 12 Months Ago	12 - 24 Months Ago	More Than 24 Months Ago	No Preventive Maintenance	Total	Failures per **Unit-Year
	Number of Failures Due to ALL CAUSES					ALL CAUSES
Excellent	2	1	1	0	4	
Fair	4	6	2	2	14	
Poor	2	0	0	0	2	
None	0	0	0	3	3	
Total	8	7	3	5	23	.00044
	Number of Failures Due to INADEQUATE MAINTENANCE (Card-Type 3 Col. 40)					INADEQUATE MAINTENANCE
Excellent	0	0	0	0	0	.00000*
Fair	1	1	2	0	4	.00018*
Poor	0	0	0	0	0	.00000*
None	0	0	0	1	1	.00271*
Total	1	1	2	1	5	.00009*

* Small Sample Size
**Unit = Number of Connected Circuit Breakers or Instrument Transformer Compartments

TABLE 75 - NUMBER OF OPEN WIRE
FAILURES VERSUS MONTHS SINCE MAINTAINED AND MAINTENANCE QUALITY

MAINTENANCE QUALITY Card-Type 2 Col. 36	FAILURE, MONTHS SINCE MAINTAINED Card-Type 3 Col. 34: Less Than 12 Months Ago	12 - 24 Months Ago	More Than 24 Months Ago	No Preventive Maintenance	Total	Failures per **Unit-Year
	Number of Failures Due to ALL CAUSES					ALL CAUSES
Excellent	0	1	3	0	4	
Fair	1	8	85	0	94	
Poor	0	0	0	0	0	
None	0	0	0	10	10	
Total	1	9	88	10	108	.01628
	Number of Failures Due to INADEQUATE MAINTENANCE (Card-Type 3 Col. 40)					INADEQUATE MAINTENANCE
Excellent	0	1	1	0	2	.00062*
Fair	0	1	30	0	31	.01132
Poor	0	0	0	0	0	—— *
None	0	0	0	0	0	.00000*
Total	0	2	31	0	33	.00497

* Small Sample Size
** Unit = 1,000 Circuit Feet

TABLE 76 - NUMBER OF CABLE
FAILURES VERSUS MONTHS SINCE MAINTAINED AND MAINTENANCE QUALITY

MAINTENANCE QUALITY Card-Type 2 Col. 36	FAILURE, MONTHS SINCE MAINTAINED Card-Type 3 Col. 34 — Less Than 12 Months Ago	12 - 24 Months Ago	More Than 24 Months Ago	No Preventive Maintenance	Total	Failures per **Unit-Year
	Number of Failures Due to ALL CAUSES					ALL CAUSES
Excellent	5	6	2	21	34	
Fair	18	19	16	6	59	
Poor	0	3	2	21	26	
None	0	0	2	95	97	
Total	23	28	22	143	216	.00755
	Number of Failures Due to INADEQUATE MAINTENANCE (Card-Type 3 Col. 40)					INADEQUATE MAINTENANCE
Excellent	0	0	0	0	0	.00000*
Fair	0	2	0	0	2	.00012*
Poor	0	0	2	6	8	.01290
None	0	0	0	12	12	.00119
Total	0	2	2	18	22	.00077

* Small Sample Size
** Unit = 1,000 Circuit Feet

TABLE 77 - NUMBER OF CABLE JOINT
FAILURES VERSUS MONTHS SINCE MAINTAINED AND MAINTENANCE QUALITY

MAINTENANCE QUALITY Card-Type 2 Col. 36	FAILURE, MONTHS SINCE MAINTAINED Card-Type 3 Col. 34 — Less Than 12 Months Ago	12 - 24 Months Ago	More Than 24 Months Ago	No Preventive Maintenance	Total	Failures per Unit-Year
	Number of Failures Due to ALL CAUSES					ALL CAUSES
Excellent	2	4	0	0	6	
Fair	6	5	1	5	17	
Poor	0	0	0	7	7	
None	0	0	0	15	15	
Total	8	9	1	27	45	.00091
	Number of Failures Due to INADEQUATE MAINTENANCE (Card-Type 3 Col. 40)					INADEQUATE MAINTENANCE
Excellent	0	0	0	0	0	.00000*
Fair	1	0	0	0	1	.00004*
Poor	0	0	0	6	6	.00405*
None	0	0	0	1	1	.00008*
Total	1	0	0	7	8	.00016

* Small Sample Size

TABLE 78 - NUMBER OF CABLE TERMINATION
FAILURES VERSUS MONTHS SINCE MAINTAINED AND MAINTENANCE QUALITY

MAINTENANCE QUALITY Card-Type 2 Col. 36	FAILURE, MONTHS SINCE MAINTAINED Card-Type 3 Col. 34 — Less Than 12 Months Ago	12 - 24 Months Ago	More Than 24 Months Ago	No Preventive Maintenance	Total	Failures per Unit-Year
	Number of Failures Due to ALL CAUSES					ALL CAUSES
Excellent	3	3	4	0	10	
Fair	3	3	14	3	23	
Poor	0	0	0	1	1	
None	0	0	0	16	16	
Total	6	6	18	20	50	.00040
	Number of Failures Due to INADEQUATE MAINTENANCE (Card-Type 3 Col. 40)					INADEQUATE MAINTENANCE
Excellent	1	1	1	0	3	.00009*
Fair	0	0	5	0	5	.00013*
Poor	0	0	0	0	0	.00000*
None	0	0	0	3	3	.00006*
Total	1	1	6	3	11	.00008

* Small Sample Size

TABLE 79 - NUMBER OF FAILURES VERSUS MAINTENANCE QUALITY FOR ALL EQUIPMENT CLASSES COMBINED

MAINTENANCE QUALITY Card-Type 2 Col. 36	Number of Failures in Tables 67 thru 78 ALL CAUSES	INADEQUATE MAINTENANCE	PERCENT of Failures Due to Inadequate Maintenance
Excellent	311	36	11.6%
Fair	853	154	18.1%
Poor	67	22	32.8%
None	238	28	11.8%
Total	1,469	240	16.4%

TABLE 80 - NUMBER OF FAILURES VERSUS MONTHS SINCE MAINTAINED FOR ALL EQUIPMENT CLASSES COMBINED

FAILURE, MONTHS SINCE MAINTAINED Card-Type 3, Col. 34	Number of Failures in Tables 67 thru 78 ALL CAUSES	INADEQUATE MAINTENANCE	PERCENT of Failures Due to Inadequate Maintenance
Less than 12 Months Ago	310	23	7.4%
12-24 Months Ago	535	60	11.2%
More Than 24 Months Ago	308	113	36.7%
No Preventive Maintenance	316	44	13.9%
Total	1,469	240	16.4%

and disconnect switches). Thus this 12 percent for "none" is explainable and is not inconsistent with what could be expected.

As maintenance quality decreases from "excellent" to "fair" to "poor," the following equipment classes showed an increasing failure rate from failures blamed on inadequate maintenance: transformers, circuit breakers, motor starters, motors, disconnect switches, switchgear bus—bare, open wire, cable, and cable joints. In some of these cases the sample size is smaller than desirable (less than eight failures) in order to conclusively prove this general statement.

OTHER CONCLUSIONS

Circuit Breakers

Approximately 15 percent of the circuit breaker population had a maintenance quality classified as "none." This compares with less than 1 percent of the population for transformers, motors, and generators.

It is of interest to note that data from Table 60, Part V also show that 15 percent of the circuit breaker population was less than one year old; this compares with less than 3 percent of the population for transformers, motors, and generators. This may possibly account for some of the listings of "none" under maintenance quality reported for failures of circuit breakers.

Motors

Motors with a maintenance quality of "fair" had a failure rate due to inadequate maintenance that was five times higher than motors with excellent maintenance quality.

Open Wire

Open wire with a maintenance quality of "fair" had a failure rate due to inadequate maintenance that was more than ten times higher than open wire with excellent maintenance quality.

DISCUSSION—MAINTENANCE QUALITY

From Table 79 it is possible to calculate for all equipment classes combined the ratio of the number of failures from inadequate maintenance to the number of failures from all other causes. This ratio versus maintenance quality is as follows: poor—0.49, fair—0.22, excellent—

0.13. This is a measure of how much improvement can be obtained by upgrading the maintenance quality from poor to fair to excellent. An excellent maintenance program has only 13 percent more failures added by inadequate maintenance, while a poor maintenance program has 49 percent more failures added by inadequate maintenance.

It is apparent from the data that excellent maintenance quality is very important on open wire and on motors.

It would also appear from the data in Table 65 that essentially everyone in the survey did excellent or fair maintenance on transformers, generators, and switchgear bus—bare. However, on circuit breakers 15 percent of the population had "none" and 4 percent had "poor" on maintenance quality. On motor starters 10 percent had "poor" on maintenance quality. Thus, it would appear that everyone did not maintain circuit breakers and motor starters as well as transformers, generators, and switchgear bus—bare.

One of the drawbacks to the results reported under maintenance quality was that there was no objective definition of "excellent," "fair," or "poor." There are no standards for maintenance quality, and thus this data must be considered to be individual judgment. However, data reported under "failure, months since maintained" does not have this same drawback; this data can be considered factual.

DISCUSSION—FAILURE, MONTHS SINCE MAINTAINED

The data in Table 80 show for all equipment classes combined that there is a close correlation between the percent of failures due to inadequate maintenance and the failure, months since maintained.

Failure, Months Since Maintained	Percent of Failures Due to Inadequate Maintenance
Less than 12 months ago	7.4
12–24 months ago	11.2
More than 24 months ago	36.7

Data from Tables 67 through 78 can also be used to calculate similar correlations for several equipment categories; however, in some cases the sample size is smaller than desirable for adequate statistical confidence.

COMMENTS—NORMAL MAINTENANCE CYCLE

A detailed analysis has not been made of the "maintenance, normal cycle" data in Tables 64 and 66. It is possible that some interesting conclusions could also be drawn from an analysis of this data.

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[3] W. H. Dickinson *et al.*, "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 Trans. Ind. Appl.*, vol. 1A-10, pp. 242–249, Mar./Apr. 1974.