Annex E

Report of Switchgear Bus Reliability Survey of Industrial Plants and Commercial Buildings

By
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Power Systems Support Committee
Industrial Power Systems Department
IEEE Industry Applications Society

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Abstract—The Power Systems Reliability Subcommittee of the IEEE Industry Applications Society has been conducting surveys of the reliability of electrical equipment in industrial plants and commercial buildings. Switchgear bus was included in a previous survey published in 1973 and 1974 [1] and generated some controversy concerning bare and insulated bus. For this reason, and also for an ongoing effect to continually update the 1973 and 1974 survey [1], switchgear bus reliability has been investigated in a new survey in 1977, and the results are presented. Reference is made to a paper [2] given at the 1977 Industrial and Commercial Power Systems Technical Conference on reasons for conducting the new survey.

INTRODUCTION

CURRENT reliability data on failure rate of electrical equipment can provide a valuable tool for the power systems designer or planner. These data can also be a valuable tool for the manufacturer of the equipment concerned.

Many parameters were included in this new survey in an effort to uncover the most influencing factors on the reliability of bare bus and insulated bus and to allow any new obvious and significant applications considerations to be identified. The questionnaire submitted was condensed to a practical and useful form to obtain optimum response in as short of time period as possible.

Results of the survey are presented in tabular form, and discussion is included primarily where adequate response and population data were obtained. Many questions and uncertainties still exist, and the intent of the following presentation is to report the results of the survey with some discussion, but drawing of definite conclusions is left to the reader.

SURVEY FORM

The questionnaire form (Fig. 1) and cover letter used in the survey are included in the Appendix. Total populations data categorize information into major areas of application. An area of primary concern is maintenance because of its obvious relation to failure rate. However, this is the most difficult datum to obtain in complete and uniform format for meaningful results. Responses in this survey did not permit these results to appear, partly due to the respondents' failure to submit information and partly due to the survey format.

Failed unit data were requested in the form shown in the second portion of the questionnaire. The major categories are causes of failure, types of failure, duration of failure, and failed components. This form is less extensive, but more specifically oriented for switchgear bus than in 1973 and 1974 survey [1].

SURVEY RESPONSE

Table I summarizes the survey response including number of buses, companies, and plants. In this survey, bus "unit-year" is defined as the product of the total number of switchgear connected circuit breakers and connected switches reported in a category times the total exposure time. In the previous survey, the unit-year did not include the number of connected switches; that is, only the connected circuit breakers were counted. Table II shows the 1973 and 1974 [1] survey and is included for comparison of responses. The total number of plants in the new survey response is considerably greater than in the 1973 and 1974 survey, but it is interesting to note that unit-year sample size is slightly less. Also some discrepancy appears in the total number of failures reported in Table I and those of some subcategories in tables to follow. This is due to all companies not responding to every category.

SURVEY RESULTS

Insulated and Bare Bus

A major controversy emerged in the results of the 1973 and 1974 survey [1] concerning bare and insulated switchgear bus. Insulated bus, 601-15 000 V, showed a higher failure rate than bare bus, above 600 V, but data were heavily influenced by the chemical industry. The new survey shows the opposite of this, as seen in Table I, with less chemical industry influence. Bare bus, above 600 V, shows a relatively high failure rate, but the sample size is not large, thus making this observation somewhat questionable. With more companies responding in the

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[1] Other members of the subcommittee are Phillip E. Gannon (Chairman), J. W. Aquilino, Carl E. Becker, W. H. Dickinson, Bruce Douglas, Ian Harley, C. R. Heising, Don Kilpatrick, D. W. McWilliams, R. N. Parisian, A. D. Patton, Dr. Chanan Singh, Wayne L. Stebbins, Harold T. Wayne, and Stanley J. Wells.

Company Name and Plant: ______________ ______________________________

Industry Type: ____

Period Reported - From: Month ______________ Year ______________

To: Month ______________ Year ______________

Plant Climate: Temperature __________ Relative Humidity __________

Contamination Level and Type: ______________________________

Total Population:

			Bus Type and Rating								System Application				Maintenance Data	
Bus No.	No. CB's & SW's	Age of Bus (YRS)	Bare	Insulated	Outdoor	Indoor	Copper	Aluminum	L-L Voltage (KV)	Current (KA)	L-L Voltage(KV)	Ungrounded	Solid Ground	Imped. Ground	Maint Cycle (MO)	Extent of Maintenance
1																
2																
3																
4																
5																
6																

Failed Unit Data:

			Type of Failure					Restore Data				
Bus No.	Failure Primary Cause	Failure Contributing Cause	Short L-G	Short L-L	Open	Other	Last Maint. (MO)	Round Clock	Normal Hours	Schedule Later	Failure Duration (Hrs.)	Failed Component and Material

Fig. 1. Switchgear bus reliability survey for metalclad and metal enclosed switchgear bus.

new survey but with less overall unit-year sample size, the failure rate for all bus shows to be slightly higher than in the previous survey. But on breaking this down further, bare bus failure rate is higher and insulated bus failure rate is lower in the new survey.

Table I shows the chemical industry data broken out since it is believed to be a major contributor in the controversy of the 1973 and 1974 survey [1]. In the new survey the chemical industry dominated the number of failures in each category, but did not dominate sample sizes. This supports the argument of some that bus utilized in the chemical industry should have a relatively high failure rate, especially in the use of bare bus.

Table I also shows median outage duration time after a failure of each category, in hours per failure. It is important to emphasize that these data are based on many factors, and without sufficient supplement from respondents concerning operating procedures, maintenance type, spare parts inventory, etc., the data relate to a very general or all-inclusive type of information.

Grounding Type

Survey results are shown in Tables III–V. Inadequate response and the general nature of the questionnaire format prohibit sufficient results for this category. It is believed that grounding type related to failures is important data, but data should be specific, for example, in types of failures in ungrounded systems and in impedance value of impedance grounded systems. This category may be pursued in greater detail in the next survey.

TABLE I
SWITCHGEAR BUS: INDOOR AND OUTDOOR

NUMBER OF COMPANIES	NUMBER OF PLANTS IN SAMPLE-SIZE	NUMBER OF BUSES	SAMPLE SIZE UNIT-YR	NUMBER OF FAILURES REPORTED	INDUSTRY	EQUIPMENT SUB-CLASS	FAILURE RATE FAILURE PER UNIT-YEAR	MEDIAN HOURS DOWNTIME PER FAILURE
39	56	444	51391	54	ALL	ALL	.001050	28
28	36	245	24855	28	ALL	INSULATED ABOVE 600V	.001129	28
25	35	199	26592	26	ALL	BARE (ALL VOLTAGES)	.000977	28
17	23	132	22420	18	ALL	BARE 0-600V	.000802	27
14	18	67	4172	8	ALL	BARE ABOVE 600V	.001917	36
14	19	92	7425	15	PETROLEUM CHEMICAL	INSULATED ABOVE 600V	.002020	40
11	13	135	7002	18	PETROLEUM CHEMICAL	BARE (ALL VOLTAGES)	.002570	28
10	11	83	4707	13	PETROLEUM CHEMICAL	BARE 0-600V	.002761	22
7	8	52	2295	5*	PETROLEUM CHEMICAL	BARE ABOVE 600V	*	48

* Small sample-size.

TABLE II
RESULTS OF PREVIOUS SURVEY PUBLISHED IN 1973 AND 1974 [1]
SWITCHGEAR BUS: INDOOR AND OUTDOOR

NUMBER OF PLANTS SAMPLE-SIZE	SAMPLE SIZE (UNIT-YEAR)	NUMBER OF FAILURES REPORTED	INDUSTRY	EQUIPMENT SUB-CLASS	FAILURE RATE FAILURES PER UNIT-YEAR	ACTUAL HOURS DOWNTIME/FAILURE INDUSTRY AVERAGE	MINIMUM PLT. AVG.	MEDIAN PLT. AVG.	MAXIMUM PLT. AVG.
12	11740	20	ALL	INSULATED 601-15000V	0.001700	261	5	26.8	1613
12	32280	11	ALL	BARE 0-600V	0.000340	550	2	24	2520
5	20560	13	ALL	BARE >600V	0.000630	17.3	6.9	13	48
5	4003	15	PETROLEUM CHEMICAL	INSULATED 601-15000V	0.003750	340	18	26.8	1613
3	17270	10	PETROLEUM CHEMICAL	BARE >600V	0.000580	19.3	6.9	42	48

TABLE III
TYPE OF GROUNDING OVERALL, BUS INSULATED AND BUS BARE

	UNGROUNDED	SOLID-GROUND	IMPEDANCE-GROUND	NOT REPORTED	TOTAL
(Unit-Year) Sample-Size	20262	9787	17280	4062	51391
# FAILURE	17	12	23	2*	54
FAILURE RATE	.000839	.001226	.001331	-	.001050

* Small sample size.

TABLE IV
BUS INSULATED

	UNGROUNDED	SOLID-GROUND	IMPEDANCE-GROUND	NOT REPORTED	TOTAL
(Unit-Year) Sample-Size	4626	4274	14270	1685	24855
# FAILURE	7*	4*	16	1*	28
FAILURE RATE			.001121	-	.001126

* Small sample size.

TABLE V
BUS BARE

	UNGROUNDED	SOLID-GROUND	IMPEDANCE-GROUND	NOT REPORTED	TOTAL
(Unit-Year) Sample-Size	15636	5513	3010	2377	26536
# FAILURE	10	8	7*	1*	26
FAILURE RATE	.000640	.001451			.000980

* Small sample size.

TABLE VI
AVERAGE AGE OF SWITCHGEAR BUS

	ALL	INSULATED	BARE
AGE 1-10 yrs.	6526 unit-year	1899 unit-year	4627 unit-year
>10 yrs.	44596 unit-year	22887 unit-year	21709 unit-year

Age of Bus

Tables VI–VIII illustrate how failures of insulated and bare bus relate to age in this survey. An interesting observation here is that newer bus appears to experience a higher failure rate than older bus. This might be expected if one considers improper installation, new components failure rate, type of construction of new switchgear, etc. As discussed below under "causes" of failures, the logicality of this observation is not consistent.

As incoming data were analyzed, it became apparent that the period reported (it was assumed that the period reported was the period of best kept records) and the age of bus did not correlate as well as expected in every case, a fallacy in the questionnaire format perhaps. Note that the older bus sample size is much larger.

Indoor and Outdoor Bus

The results of this category are summarized in Tables IX–XI below. Table XI shows an overall result of outdoor bus failure rate versus indoor bus failure rate. Outdoor bus shows a higher failure rate than indoor bus, an observation not too surprising.

Failure Duration

Failure duration results are reported in Tables XII and XIII below and categorized into repair on a round-the-clock emergency basis and repair on a normal working hour basis. This adds more meaning to the data in Table I, but would be more meaningful if repair methods were known. Urgency of repair as shown in Table XIV reveals that most repairs were made on an emergency basis. The data of these tables compare very favorable with those of the previous survey.

Type of Maintenance

Response was disappointingly low in this category and results are presented in Tables XV and XVI. The tables show results of maintenance cycles and time since last maintenance in three groups: 1) less than 12 months, 2) 12-24 months, and 3) more than 24 months. This is a very important category regarding reliability, and hopefully the next survey will produce better results.

Causes of Failures

Primary and contributing causes of failures are summarized in Tables XVII and XVIII. As might be expected inadequate maintenance is a large contributor to failures. This does not necessarily follow from the observation above on age of bus. However, defective components are a large primary cause of failures, which is logical for new installations. Correlation between the two tables below is clearly evident from the contributing cause of exposure to contaminants and the primary cause of inadequate maintenance. Exposure to contaminants, which includes dust, moisture, and chemicals, also supports the data showing outside bus with a relatively high failure rate. Inadequate maintenance was reported as the single largest primary cause of failures in the 1973 and 1974 survey [1]. This prompted the effort to survey type of maintenance in the new survey.

TABLE VII
NUMBER OF FAILURES VERSUS AGE

	ALL	INSULATED	BARE
AGE 1-10 yrs.	15	5*	10
>10 yrs.	37	23	14

* Small sample size.

TABLE VIII
FAILURE RATE (FAILURE PER UNIT-YEAR)

	ALL	INSULATED	BARE
AGE 1-10 yrs.	.002298	*	.002161
> 10 yrs.	.000829	.001005	.000645

* Small sample size.

TABLE IX
SWITCHGEAR BUS INSULATED

	OUTDOOR	INDOOR
Sample-Size Unit-Year	4275	20356
FAILURE	7*	19
FAILURE RATE	*	.000933

* Small sample size.

TABLE X
SWITCHGEAR BUS BARE

	OUTDOOR	INDOOR
Sample-Size Unit-Year	2750	22339
FAILURE	8	11
FAILURE RATE	.002909	.000492

TABLE XI
SWITCHGEAR BUS (OVERALL)

	OUTDOOR	INDOOR
Sample-Size Unit-Year	7825	42695
FAILURE	15	30
FAILURE RATE	.001917	.000703

TABLE XII
FAILURE DURATION: ROUND CLOCK VERSUS NORMAL HOUR (HOURS DOWNTIME PER FAILURE)

FAILURE REPAIR URGENCY	BUS INSULATED MEDIAN	BUS INSULATED AVERAGE	BUS BARE MEDIAN	BUS BARE AVERAGE
ROUND CLOCK	24 hr.	87 hr.	32 hr.	39 hr.
NORMAL HOUR	240 hr.	430 hr.	24 hr.	154 hr.

TABLE XIII
FAILURE DURATION: ROUND CLOCK VERSUS NORMAL HOUR (HOURS DOWNTOWN PER FAILURE)

	BUS INSULATED ROUND CLOCK	BUS INSULATED NORMAL HOUR	BUS BARE ROUND CLOCK	BUS BARE NORMAL HOUR
25 PERCENTILE	8 hr.	8 hr.	3 hr.	4 hr.
50 PERCENTILE	24 hr.	240 hr.	32 hr.	24 hr.
75 PERCENTILE	48 hr.	350 hr.	48 hr.	48 hr.

TABLE XIV
FAILURE REPAIR URGENCY

	ROUND CLOCK	NORMAL HOUR	SCHEDULE LATER
BUS INSULATED	64%	28%	8%
BUS BARE	53%	41%	6%

TABLE XV
NUMBER OF SWITCHGEAR BUS-INSULATED FAILURES VERSUS MAINTENANCE CYCLE

	LESS THAN 12 MO.	12-24 MO.	MORE THAN 24 MO.
Sample-Size (Unit-Year)	3563	8812	7253
# FAILURE	2*	13	6*
FAILURE RATE	-	.001475	

* Small sample size.

TABLE XVI
NUMBER OF SWITCHGEAR BUS BARE FAILURES VERSUS MAINTENANCE CYCLE

	LESS THAN 12 MO.	12-24 MO.	MORE THAN 24 MO.
Sample-Size (Unit-Year)	980	10,455	6312
# FAILURE	2*	12	4*
FAILURE RATE	-	.001147	-

* Small sample size.

TABLE XVII
SUSPECTED PRIMARY CAUSE OF FAILURE

BUS INSULATED	BUS BARE	
26%	17%	1. Defective Component
4%	4%	2. Improper Application
7%	9%	3. Improper Handling
7%	13%	4. Improper Installation
19%	22%	5. Inadequate Maintenance
-	18%	6. Improper Operating Procedure
11%	4%	7. Outside Agency - Personnel
26%	-	8. Outside Agency - Other
-	13%	9. Overheating

TABLE XVIII
CONTRIBUTING CAUSE TO FAILURE

BUS INSULATED	BUS BARE	
6.6%	-	1. Thermocycling
3%	8%	2. Mechanical Structure Failure
6.6%	-	3. Mechanical Damage From Foreign Source
-	15%	4. Shorting By Tools or Metal Objects
3%	-	5. Shorting By Snakes, Birds, Rodents, etc.
10%	4%	6. Malfunction of Protective Device
	4%	7. Improper Setting of Protective Device
3%	-	8. Above Normal Ambient Temperature
3%	15%	9. Exposure to Chemical or Solvents
30%	15%	10. Exposure to Moisture
10%	19%	11. Exposure to Dust or Other Contaminants
6.6%	-	12. Exposure to Non-Electrical Fire or Burning
-	8%	13. Obstruction of Ventilation
10%	4%	14. Normal Deterioration from Age
3%	4%	15. Severe Weather Condition
-	4%	16. Testing Error

TABLE XIX
FAILURE TYPE

BUS INSULATED	BUS BARE	
57%	33%	1. Short L-G
40%	60%	2. Short L-L
-	7%	3. Open
3%	-	4. Other

Failure Type

The survey results on types of failures, shown in Table XIX, show a surprisingly high percentage of failures line-to-line.

GENERAL DISCUSSION

At this point it is well to note the confidence intervals of failure rate for bare and insulated bus. Table XX shows the limits for a 90 percent confidence interval. The table illustrates the statistical limits within which 90 percent of the failures could be expected to occur.

Lack of specific details limits the integrity of some data, and as previously indicated not all categories surveyed were reported in this paper, due primarily to small sample sizes and numbers of failures. As with most surveys, accurate data combined with large response are difficult to obtain since response definitely relates to simplicity in questionnaire format. Data of the effect of maintenance on failure rate are highly desirable for obvious reasons, and effort will be made to acquire this data in the future in a meaningful and usable form.

TABLE XX
CONFIDENCE INTERVALS FOR FAILURE RATE λ

FAILURE RATE (λ) FAILURE PER UNIT-YR	INSULATED BUS >600V	BARE BUS > 600V	BARE BUS ≤ 600V
λ L *	.000779	.000958	.000521
λ	.001129	.001917	.000802
λ U *	.001569	.003488	.001203
% DEVIATION - L	31%	50%	35%
% DEVIATION - U	39%	82%	50%

* Upper and lower limits of 90 percent confidence interval for λ

APPENDIX

A. D. Patton
Texas A & M University
Department of Electrical Engineering
College Station, Texas 77843

Dear Sir:

RE: Switchgear Bus Reliability Survey for Metalclad and Metal Enclosed Switchgear

The Reliability Subcommittee of the Industrial and Commercial Power Systems Committee requests your cooperation in a survey to determine the reliability of metal-clad and metal-enclosed switchgear bus in industrial plants. The survey is a follow-up to the general reliability survey of plant equipment in 1971 and is intended to provide more meaningful data on switchgear bus. Attached for your information is a report by the subcommittee on reasons for the survey.

The results of the survey will be published in an IEEE paper and are expected to be of value to system planners and designers in the reliability evaluation of alternatives. Individual responses will be held in confidence and only summaries published.

SURVEY INSTRUCTIONS

It is hoped that the survey form is reasonably self-explanatory. Nevertheless, a sample filled-out data sheet is attached for your guidance, and some brief instructions follow. We wish to emphasize that all requested data are important, but it is realized that some of the requested information may be unknown. In such cases, simply provide the information which is known and leave the other spaces blank. We also encourage you to provide explanatory comments on any of your data as you feel appropriate. If additional data sheets are needed, please duplicate the data sheet provided.

General Data

1) It is vitally important that the period reported be given.
2) The plant climate and contamination data should be your general estimates of the requested information.

Total Population Data

1) Using the total population data block, give requested data for all buses *in service during the period reported* whether or not failures have been experienced. (Note the period reported may not exceed the age of a bus. Use separate data sheets for newer busses.)
2) It is vitally important that the number of connected circuit breakers and switches be given for each bus.

Failed Unit Data

1) List each bus failure event separately.
2) Identify the bus in each failure event by specifying the bus number as assigned in the total population data block.
3) Specify failure cause and contributing cause, where known, using the code numbers on the attached sheet.
4) Specify months since bus was last maintained.
5) Check off urgency of restoration effort.
6) Specify time in hours from onset of failure until bus was restored to service.
7) Describe component which first failed, including component material.

Our schedule dictates that responses be received no later than April 1, 1977. Your participation in this project will be greatly appreciated.

Sincerely,

A. D. Patton
Chairman, Reliability Subcommittee

SURVEY QUESTIONNAIRE

Primary Cause of Failure:

1) defective component,
2) improper application,
3) improper handling,
4) improper installation,
5) inadequate maintenance,
6) improper operating procedures,
7) outside agency–personnel,
8) outside agency–other,
9) overheating.

Contributing Cause to Failure:

1) persistent overloading,
2) transient overvoltage,
3) overvoltage,
4) thermocycling,
5) mechanical structural failure,
6) mechanical damage from foreign source,
7) shorting by tools or metal objects,
8) shorting by snakes, birds, rodents, etc.,
9) malfunction of protective device,
10) improper setting of protective device,
11) above normal ambient temperature,
12) below normal ambient temperatures,
13) exposure to chemicals or solvents,
14) exposure to moisture,
15) exposure to dust or other contaminants,
16) exposure to non-electrical fire or burning,
17) obstruction of ventilation,
18) normal deterioration from age,
19) severe weather conditions,
20) loss or deficiency of cooling medium,
21) testing error.

Comments:

REFERENCES

[1] IEEE Committee Report, "Report on reliability survey of industrial plant," *IEEE Trans. Ind. Appl.*, Mar./Apr., July/Aug., and Sept./Oct., 1974. (Part 1–Reliability of electrical equipment; Part 3–Causes and types of failures of electrical equipment, the methods of repair, and the urgency of repair; Part 5–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 6–Maintenance quality of electrical equipment.)

[2] IEEE Committee Report, "Reasons for conducting a new reliability survey on switchgear bus-insulated and switchgear bus-bare," Industrial and Commercial Power System Tech. Conf., May 1977, Conf. Rec., p. 91–95.

