Annex D

Reliability of Electric Utility Supplies to Industrial Plants

By
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Industrial and Commercial Power Systems Committee
IEEE Industry Applications Society

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ABSTRACT

The paper summarizes the results of a 1974 survey of the reliability of electric utility supplies to industrial plants. Results include the average rates of occurrence and durations of power interruptions as a function of type of electric utility supply. This information should help industrial plant operators choose the types of electric utility supplies best suited to their plants.

INTRODUCTION

The electric utility supply reliability survey reported here is a followup to the 1972 survey of the reliability of electrical equipment in industrial plants.[1,2] The 1972 survey showed that the electric utility supply is the most fallible "component" of an industrial plant system and therefore deserves careful consideration.

Certain of the data in the earlier survey were subject to possible error due to misinterpretation of the survey form. Hence, a prime objective of the present survey was to improve the accuracy of data on electric utility supplies. A second objective was to provide more detailed and definitive data on electric utility supply interruption rates and average durations as a function of the number of supply circuits, the type of switching scheme, and the voltage of the supply circuits. A third objective was to obtain data from a larger number of plants than in the 1972 survey thereby permitting interruption rates and average durations to be determined with greater precision. A total of 87 plants provided usable data, almost triple the number of plants providing data on electric utility supplies in the 1972 survey. Survey response broken down by industry is as follows: cement = 2, chemical = 14, metal = 4, petroleum = 30, pulp and paper = 1, rubber and plastics = 4, and other manufacturing = 32.

It should be emphasized that electric utility supply reliability is a function of a number of factors not directly identified in the data presented here. Included in these reliability-influencing factors are line exposure, weather and other environmental conditions, and utility operating and maintenance practice. Thus, the electric utility supply reliability data given in this paper represents average performance and should not be used in preference to specific data when this is available. Methods are available for computing the reliability performance of an electric utility supply when the reliability performance parameters of utility system components are known.[3]

SURVEY QUESTIONNAIRE

The survey questionnaire requested the following data for each electric utility supply.

1. Type of industry
2. Type of electric utility supply
   a. Number of utility circuits supplying the plant
   b. Mode of operation if more than one supply circuit: all circuit breakers normally closed, manual throw-over scheme, or automatic throw-over scheme
   c. Voltage of utility circuits supplying the plant
   d. Type of supply circuits: overhead or underground
   e. A sketch of the electric utility supply system
3. The period of time covered by the survey report. (Respondents were asked to limit their response to the period January 1, 1968 to the present.)
4. The number of interruptions to the plant due to loss of the electric utility supply during the time period of (3).
5. The duration of each electric utility supply interruption, an indication whether service was restored to the plant by a switching operation or by repair or replacement of failed equipment, and, if known, the equipment which failed causing the interruption.

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SURVEY DATA SUMMARY AND DISCUSSION

Some respondents to the survey listed voltage dips which caused disruption of plant production as well as complete interruptions of electric utility service. Other respondents commented on production disruptions due to voltage dips without giving details. However, most respondents reported only on complete interruptions of service and this was the intent of the survey. The Subcommittee feels that the sensitivity to voltage dips is a rather unique characteristic of each plant and process and that average interruption rates including voltage dips would not be very meaningful. Therefore, all voltage dip events were removed from the survey data leaving only those interruptions due to complete loss of electric utility service. Hence, the interruption rates given in the summary tables reflect complete loss of electric utility service only. If a plant is sensitive to voltage dips, the rate of such events must be added to the reported interruption rates to obtain the total rate of production disruption due to utility supply troubles.

Almost all respondents indicated that utility supply circuits are overhead rather than underground. Hence, no effort was made to separate supplies with overhead and underground circuits. The data given in the summary tables essentially reflects overhead supply circuits due to the preponderance of such circuits in the survey response.

Preliminary analyses of utility supply interruption rates by industry category indicated no significant differences between industries. Further, there seems to be no good reason why utility supplies of the same type and voltage should differ between industries. Therefore, the data presented in the summary tables is not broken down by industry.

The survey response broken down by number of utility supply circuits, voltage of utility supply circuits, and mode of operation of multiple supply circuit utility supplies is given in Table I.

Table I
Number of Responding Plants
With Electric Utility Supplies
of Various Types

Number of Supply Circuits	
1 circuit	- 20 plants
2 circuits	- 56 plants
3 or more circuits	- 11 plants
Supply Circuit Voltage	
voltage ≤ 15 KV	- 22 plants
15 KV < voltage ≤ 35 KV	- 17 plants
voltage >35 KV	- 48 plants
Switching Scheme of Multiple Circuit Supplies	
all breakers closed	- 45 plants
manual throwover	- ·9 plants
automatic throwover	- 13 plants

Table I shows that two-circuit supplies are the most common among the responding plants. A much smaller number of plants reported three or more supply circuits. All multiple-circuit supplies are combined in the data tables which follow because such supplies are expected to have similar interruption rates and because of the relatively small sample of supplies with three or more circuits. Responses have been broken into three voltage categories corresponding roughly to distribution voltages, subtransmission voltages, and transmission voltages. This was done because electric utility design and operating practice is rather different at these three function levels. Hence, it can be expected that utility supply reliability will be a function of the system level at which service is provided.

Table I indicates that about two-thirds of the responding plants having multiple circuit utility supplies operate with all circuit breakers closed. That is, service is supplied simultaneously over all supply circuits. Service may also be lost, however, by failures in the plant substation or by a widespread failure in the supplying utility's system. Plants having throwover schemes operate with a single circuit providing normal service. Thus, such plants suffer an interruption any time the normal supply circuit fails. The duration of interruption to such plants is usually limited to the time required to reclose the normal supply circuit or to switch to the alternate supply circuit if the normal circuit is permanently faulted.

Table II summarizes interruption rate and average interruption duration data for single-circuit utility supplies broken down by voltage level. Interruption rates and average durations are given separately for interruptions reported terminated by utility switching operations and by repair or replacement of failed components. Also given are overall interruption rates and average durations.

Tables III and IV show interruption rates and average durations for multiple circuit utility supplies broken down by switching scheme and by voltage level. Table V shows interruption rates and average durations for multiple-circuit utility supplies which operate with all circuit breakers closed broken down by voltage levels. Similar breakdowns by voltage for throwover switching schemes were not possible due to lack of an adequate data base.

Interruption rates and average durations are given in Tables II through V for interruptions where service is restored by: (a) some switching operation or sequence of switching operations in the electric utility system, and (b) repair or replacement of components which failed in the electric utility system. If service can be restored by some automatic or manual switching action in the electric utility system, whether remote or within the utility switchgear at the plant, interruptions are usually much shorter than if repair or replacement of failed components is required to restore service. The reason for providing data on both short-duration switching-terminated interruptions and on long-duration repair-terminated interruptions is because of possible differences in impact on plant operations.

It should be mentioned here that interruption rates and average durations computed from a small number of observed interruptions should be regarded as less accurate than those computed from a larger sample of observations. In particular, Reference [1] shows that interruption rates computed from an observed number of interruptions less than about 8 or 10 may well be in error by plus or minus 50 per cent or more due to random variations alone.

The data of Tables II through V show the expected trends.

(1) Utility supply interruption rates are lowest for multiple circuit supplies which operate with all circuit breakers closed and highest for single-circuit supplies. Tables II and III show that the interruption rate for single-circuit supplies is about six times that of multiple circuit supplies which operate with all circuit breakers closed. Interruption rates for multiple-circuit supplies which operate with a throwover scheme are comparable to those for single-circuit supplies, but throwover schemes have a smaller average interruption duration than single-circuit supplies.

(2) Interruption rates are highest for utility supply circuits operated at distribution voltages and lowest for circuits operated at transmission voltages.

Direct comparisons between interruption rates determined in this survey and in the 1972 survey are not possible in every case, but where possible show somewhat higher values in the present survey. Since the present survey is believed to be more accurate, has a larger data base, and is more up-to-date, the values presented here are to be preferred over those presented in 1972 survey.

REFERENCES

1. Reliability Subcommittee Report, "Report On Reliability Survey of Industrial Plants, Part I: Reliability of Electrical Equipment", IEEE Transactions on Industry Applications, pp. 213-235, March/April 1974.

2. Reliability Subcommittee Report," 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", Ibid., pp. 242-252, March/April 1974.

3. R. Billinton, R. J. Ringlee, and A. J. Wood, Power-System Reliability Calculations, The MIT Press, Cambridge, Mass., 1973.

Table II
Single Circuit Utility Supplies

Voltage Level	Unit-years of History	Number of Interruptions Reported* N_S	N_R	Interruptions Per Year** λ_S	λ_R	λ	Average Interruption Duration, Minutes** r_S	r_R	r
v≤15KV	27.62	25	75	.905	2.715	3.621	3.5	165	125
15KV<v≤35KV	12.67	0	21	-	1.657	1.657	-	57	57
v>35KV	71.16	37	60	.527	.843	1.370	1.5	59	37
all	111.45	62	156	.556	1.400	1.956	2.3	110	79

Table III
Multiple Circuit Utility Supplies
All Voltage Levels

Switching Scheme	Unit-Years of History	Number of Interruptions Reported N_S	N_R	Interruptions Per Year λ_S	λ_R	λ	Average Interruption Duration, Minutes r_S	r_R	r
all breakers closed	246.17	63	14	.255	.057	.312	8.5	130	31
man. throw-over	42.33	31	5	.732	.118	.850	8.1	84	19
auto. throw-over	64.36	66	11	1.025	.171	1.196	0.6	96	14
all	352.86	160	30	.453	.085	.538	5.2	110	22

Table IV
Multiple Circuit Utility Supplies
All Swiching Schemes

Voltage Level	Unit-Years of History	Number of Interruptions Reported N_S	N_R	Interruptions Per Year λ_S	λ_R	λ	Average Interruption Duration, Minutes r_S	r_R	r
v≤15KV	81.31	52	12	.640	.148	.788	4.7	149	32
15KV<v≤35KV	78.00	39	5	.500	.064	.564	4.0	115	17
v>35KV	193.55	69	13	.357	.067	.424	6.1	184	34

Table V
Multiple Circuit Utility Supplies
All Circuit Breakers Closed

Voltage Level	Unit-Years History	Number of Interruptions Reported N_S	N_R	Interruptions Per Year λ_S	λ_R	λ	Average Interruption Duration, Minutes r_S	r_R	r
v≤15KV	45.61	8	4	.175	.088	.263	0.7	335	112
15KV<v≤35KV	52.61	18	1	.342	.019	.361	7.0	120	13
v>35KV	147.95	37	9	.250	.061	.311	11.0	203	49

*N_S and N_R are, respectively, the number of service interruptions terminated by switching and by repair or replacement.

**Interruption rates and average durations subscripted S and R are, respectively, rates and durations of interruptions terminated by switching and by repair or replacement. Unsubscripted rates and duration are overall values.

