Annex I

Reliability Study of Cable, Terminations, and Splices by Electric Utilities in the Northwest

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Reliability Study of Cable, Terminations, and Splices by Electric Utilities in the Northwest

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Abstract—**The results for cable, terminations, and splice reliability are summarized from a reliability report prepared annually by the Northwest Electric Light and Power Association (NELPA). Failure rates are given for primary cable, secondary cable, plug-in elbow connectors, primary splices and loadbreak junctions, pole top terminators, and secondary connections. Pertinent factors that affect the failure rates are identified.**

INTRODUCTION

FOR THE PAST 18 years the Northwest Underground Distribution Committee[1] of the Northwest Electric Light and Power Association (NELPA) has prepared an annual report titled "URD equipment and materials reliability in the Northwest" [1].

Of particular interest to the IEEE Power Systems Reliability Subcommittee on Industrial and Commercial Power Systems is the portion of the report pertaining to cables, terminations, splices, and connections, since similar equipment is often used on industrial or commercial power systems.

The data in the NELPA report appears to be more complete and represents a much larger sample size than the data from the IEEE reliability survey of industrial plants [2] that was published in 1973–1974 and incorporated into the present ANSI/IEEE Standard No. 493-1980 [3]. The standard is being revised and updated in 1986. This paper will sumarize the NELPA report with the intent of using it as a source for the 1986 revision of ANSI/IEEE Standard No. 493.

BACKGROUND

NELPA companies serve most of the Northwest areas of the United States. Because the geographical makeup of this area consists of some very wet areas, some very dry areas, some very hot areas, and some very cold areas, the data from the report should be valuable for evaluating URD equipment for use around the country, particularly for such items as corrosion resistance and insulation failure.

NELPA consists of the following member companies.

Idaho Power Company
Montana Power Company
Pacific Power & Light Company
Portland General Electric Company
Puget Sound Power & Light Company
Utah Power & Light Company
Washington Water Power Company

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[1] Kenneth W. Prier of Portland General Electric Company was Chairman of the Northwest Underground Distribution Committee in 1984, when Report No. 17 was issued. Richard M. Snell of Montana Power Company is the present Chairman.

TABLE I
CABLE FAILURE RATES—ALL VOLTAGE CLASSES
(Failures per 100 Conductor Miles)

1969	0.67	1977	0.98
1970	1.11	1978	1.47
1971	0.73	1979	1.82
1972	0.91	1980	1.68
1973	1.00	1981	2.55
1974	1.03	1982	2.51
1975	0.89	1983	2.27
1976	1.10		

FAILURE DATA REPORTING

The report is only concerned with natural failures of equipment or materials. All failures caused by abnormal external means, such as through dig-ins or damage prior to installation, are not intended to be included in the data. In the cases where the cause of a failure could not be determined, the cause of the failure is assumed and reported in that way.

The member utilities are continuously improving their efforts to accumulate basic data. However, there are still problems with field people not reporting the material failures. All failure rates in this report should be considered on the low side.

PRIMARY CABLE

Table I lists the failure record for all voltage classes (15 kV, 25 kV, and 35 kV) and insulation types of primary cable used on the systems.

In general the failure record is excellent, although high molecular weight polyethylene (HMWPE) insulated cable is failing at a much greater rate than crosslinked polyethylene (XLPE). (See Tables IIIA and IIIB for complete data.)

The failure rates for the last few years are high because one utility has just started reporting failures and they have been having problems with 175-mil 15-kV cable.

A comparison was also made between 15-kV HMWPE and 15-kV XLPE cable for the last ten years. (See Table II.)

TABLE II
15-kV CLASS CABLE
(Failures per 100 Conductor Miles of Cable)

Failure Year	175-mil HMWPE	220-mil HMWPE	175-mil XLPE	220-mil XLPE
1973	0.90	1.40	0.27	0.0
1971	0.41	1.41	0.53	0.56
1975	0.72	1.51	0.33	0.0
1976	1.19	1.28	0.47	1.72
1977	1.25	1.04	0.39	0.0
1978	2.07	0.69	1.06	0.08
1979	2.67	0.90	0.68	0.12
1980	3.42	0.65	0.03	0.0
1981	5.38	0.95	0.10	0.05
1982	4.77	1.69	0.07	0.0
1983	4.40	1.73	0.53	0.0

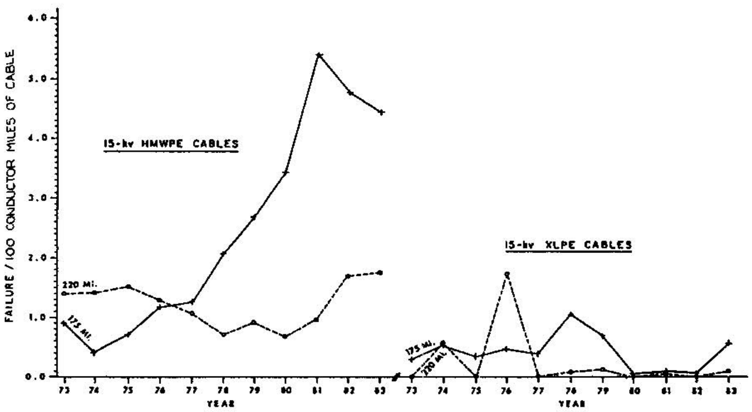

Fig. 1. Failure rates of 15-kV URD cables.

HMWPE cable seems to be failing at a much higher rate than XLPE cable. These failures seem to be related to treeing problems, which break down the insulation material. (See Fig. 1 for a plot of the data.)

Some member utilities have started to purchase tree-retardant insulation material. The usage has been limited and no failures have been reported.

In addition, 175-mil thickness insulation seems to have a much higher failure rate than 220-mil insulation. This is apparently due to the larger electrical stress capability of 220-mil insulation.

Secondary Cables

The failure rate for secondary low-voltage cables (600 V and below) has remained fairly constant for the last two years. The failure rates since 1969 are as follows.

1969	1.5	failures per 100 conductor miles
1970	1.25	failures per 100 conductor miles
1971	0.74	failures per 100 conductor miles
1972	0.62	failures per 100 conductor miles
1973	0.35	failures per 100 conductor miles
1974	0.50	failures per 100 conductor miles
1975	0.39	failures per 100 conductor miles
1976	0.53	failures per 100 conductor miles
1977	0.73	failures per 100 conductor miles
1978	0.71	failures per 100 conductor miles
1979	0.73	failures per 100 conductor miles
1980	0.48	failures per 100 conductor miles
1981	0.80	failures per 100 conductor miles
1982	0.70	failures per 100 conductor miles
1983	0.78	failures per 100 conductor miles

Failures of this cable seem to be related mostly to mechanical-type damage occurring during or after installation. Corrosion problems due to moisture do not seem to be a problem. (See Table IV for complete data.)

Plug-In Elbow Connectors

The failure rate for 15-kV, 25-kV, and 35-kV loadbreak elbows of 0.41 failures per 1000 units (unit defined as one

TABLE IIIA
PRIMARY CABLE—15 kV

Type	Company	Miles[a] Installed	Failures This Year	Failures to Date	Average Life Before Failure	Neutral Corrosion
(A) HMWPE 175 mil, 15 kV	A	18	0	23	Unknown	
	B	1170	34	118	7–8 yrs	
	C	1388	97	412		
	E	3161	86	545	13 yrs	8
	G	1085	83	529	12 yrs	10
Total		6822	300	1627		
(B) HMWPE 175 mil, 15 kV tree retardant	C	504	0	0		
	E	1106	0	0		
Total		1610	0	0		
(C) HMWPE 220 mil, 15 kV	A	1	0	0	12 yrs	
	C	74	16	86	Unknown	
	D	2373	31	255	Not reported	
	F	488	3	6	20 yrs	
Total		2896	50	351		
(D) HMW-Poly 220 mil, 15 kV tree retardent	D	60	0	0		
(E) XLP 175 mil, 15 kV	A	1960	21	117	Unknown	
	B	150	0	0		
	C	615	0	0		
	E	1519	0	14		
	G	60	1	3		
Total		4154	22	134		
(F) XLP 175 mil, 15 kV tree retardant	E	318	0	0		
(G) XLP 175 mil, 15 kV tree retardant with insulated jacket	E	90	0	0		
(H) XLP 175 mil jacket, 15 kV	G	149	0	0		
Total		149	0	0		
(I) XLP 220 mil, 15 kV	C	1	0	0		
	D	2417	0	10	Not reported	
	F	[b]	[b]	[b]		
Total		2418	0	10		
(J) Butyl-neoprene, 15 kV	A	1	1	1		
	D	10	0	1		
	E	79	2	15	21 yrs	
Total		90	3	17		
(K) EPR 175 mil, 15 kV	A	3	0	4		
GRAND TOTAL		18 610	375	2143		
LAST YEAR'S GRAND TOTAL		17 751	376	1768		

[a] Conductor miles (*not* circuit miles).
[b] Accurate data not available.
(Data from NUDC Report No. 17, October 8, 1984.)

TABLE IIIB
PRIMARY CABLE—25 AND 35 kV

	Type	Company	Miles[a] Installed	Failures This Year	Failures to Date	Average Life Before Failure	Neutral Corrosion
(A)	HMWP 260 mil, 25 kV	G	125	0	8		
(B)	HMWP 260 mil, 25 kV	B	80	8	15	8–10 yrs	
(C)	HMWP 260 mil, 25 kV	C	930	75	432		
(D)	HMWP 295 mil, 25 kV	C	108	26	67		
(E)	HMWP 280 mil, 25 kV	A	2	0	55	11 yrs	
	Total		1245	109	577		
(F)	HMWP 260 mil, 25 kV tree retardant	C	348	0	0		
(G)	XLP 260 mil, 25 kV	B	11	0	0		
(H)	XLP 260 mil, 25 kV	C	409	0	4		
(I)	XLP 295 mil, 25 kV	F	[b]	[b]	[b]		
	Total		420	0	4		
(J)	XLP 260 mil, 25 kV with jacket	B	326	0	0		
(K)	EP 295 mil, 25 kV	A	5	0	2		
(L)	HMWP 345 mil, 35 kV	C	74	0	22		
(M)	HMWP 345 mil, 35 kV tree retardant	C	31	0	0		
(N)	HMWP 345 mil, 35 kV tree retardant	E	98	0	0		
	Total		129	0	0		
(O)	XLP 280 mil, 35 kV	A	10	0	2		
(P)	XLP 345 mil, 35 kV	A	102	1	2	2 yrs	
(Q)	XLP 345 mil, 35 kV	C	34	0	0		
(R)	XLPE 345 mil, 35 kV	E	29	0	0		
(S)	XLPE 345 mil, 35 kV	G	5	0	0		
	Total		180	1	4		
(T)	XLP 345 mil, 35 kV tree retardant	E	48	0	0		
(U)	XLP 345 mil, 35 kV tree retardant with insulated jacket	E	17	0	0		
GRAND TOTAL			2792	110	609		
LAST YEAR'S GRAND TOTAL			2251	127	498		

[a] Conductor miles (*not* circuit miles).
[b] Accurate data not available.
(Data is from NUDC Report No. 17, October 8, 1984).

TABLE IV
LOW-VOLTAGE CABLE

Type Insulation	Company	Thickness	Miles[a] Installed	Failures This Year	Failures to Date	Average Life Before Failure	Neutral Corrosion
(A) Poly	C		0	0	0		
	D	(Sodium)	12	0	4[c]	2 ½ yrs	
	E		0	0	0		
Total			12	0	4		
(B) XLPE	A	70–110 mil	2983	165	543	Unknown	
	B	70–110 mil	1300	1	21		
	C	60–110 mil	11 295	87	914	Unknown[b]	All neutral
	D	80–95 mil	8128	5	89		
	E	Min. IPCEA	5520	5	47	(Failures[b] starting with 1976 data)	
	G	60–110 mil	2096	Unknown	Unknown		
Total			31 322	263	1614		
(C) Abrasion-resistant XLPE	E		9	0	0		
	G		0.2	0	0		
Total			9.2	0	0		
(D) Abrasion-resistant HMWP	A		46	0	0		
	E		697	0	0		
Total			743	0	0		
(E) PVC	A	80 mil	10	0	1		
	C		0	0	0		
	D		7.1	0	0		
	E		0	0	0		
Total			17.1	0	1		
(F) Rubber neoprene	C		195	0	0		
	D	65 & 65 mil	1162	0	11		
	E	5/64 in	99	0	3		
Total			1456	0	14		
GRAND TOTAL			33 550.1	263	1633		
LAST YEAR'S GRAND TOTAL			31 978.9	225	1370		

[a] Insulated conductor miles (*not* circuit miles).
[b] Some of these failures could have been rubber neoprene, but no record is available as to which type cable failed. More failures are being reported due to a computer-managed reporting system.
[c] Cable insulation failed due to mechanical stress placed on it by the design of the connector. (A stainless-steel hose clamp around the insulation makes a quick fix.)
(Data is from NUDC Report No. 17, October 8, 1984.)

single-phase terminator) has been fairly constant over the last four years. Many of the recent problems were due either to molding problems of one manufacturer, cross-threading of connectors, or bad compression joints. These failures include units that were improperly installed, which is a significant number. The failures also include units that were replaced during maintenance due to problems such as visible tracking overheating, etc. (See Table V for complete data.)

PRIMARY CONNECTIONS

This is the fifth year for the study of primary cable splices and primary load break functions. Since the data is relatively new the results should be used carefully.

The failure rate for 15-kV splices was 2.1 failures per 1000 units (unit defined as one single-phase splice), compared to last year's 2.4 failures; the failure rate for 15-kV primary junctions was 1.0 failures per 1000 units, compared to last year's 1.3 failures. Splice failures over the last couple of years have been due mostly to the molding problems experienced by one manufacturer and to improper installation by line crews. (See Table VI for completed data.)

POLE TOP TERMINATORS

The outstanding performer for all voltage classes (15 kV, 25 kV, and 35 kV) is the molded rubber terminator. The failure rate is 0.06 per 1000 units (unit defined as one single-phase

TABLE V
PLUG IN PRIMARY TERMINATORS (ELBOWS)

	Type	Company	Total Number on System	Failures This Year	Failures to Date	Average Life Before Failure
(A)	Non-LB rubber, 15 kV	A	65	0	0	
		C	1628	0	3	
		D	2302	0	41	
		E	6440	0	51	
		G	200	0	0	Unknown
	Total		10 635	0	100	
(B)	Non-LP rubber, 600 A–15 kV	A	707	0	0	
		C	0	0	0	
		D	322	0	2	
		E	1972	0	9	
		G	25	0	0	
	Total		3026	0	11	
(C)	Non-LB rubber, 600 A–25 kV	C	33	0	0	
		E	0	0	0	
		F	*	*	*	
	Total		33	0	0	
(D)	Non-LB rubber, 600 A–35 kV	E	30	0	0	
	Total		30	0	0	
(E)	Non-LB metal	A	40	0	0	
		C	15	0	1	
	Total		55	0	1	
(F)	LP rubber 15 kV	A	31 138	18	168	
		B	21 514	32	71	
		C	40 997	27	231	
		D	76 525	21	180	
		E	160 506	44	370	
		F	*	*	*	
		G	24 179	2	15	
	Total		354 859	144	1035	
(G)	LB rubber, 25 kV	B	797	4	19	
		C	24 311	5	27	
		E	0	0	0	
		F	*	*	*	
		G	565	0	4	
	Total		25 673	9	50	
(H)	LB rubber, 35 kV	A	2465	0	2	1 yr
		C	2293	5	19	
		E	730	0	0	
	Total		5488	5	21	
GRAND TOTAL			399 799	158	1218	
LAST YEAR'S GRAND TOTAL			371 119	160	1060	

* Accurate data not available.
(Data is from NUDC Report No. 17, October 8, 1984.)

TABLE VI
PRIMARY CONNECTIONS

Type	Company	Total Number on System	Failures This Year	Failures to Date	Average Life Before Failure
Primary splices—15 kV, molded rubber	A	13 454	48	443	10 yrs
	B	7484	68	149	
	C	17 624	6	15	
	D	21 481	4	35	
	E	18 990	65	389	
	G	11 813	3	25	
Total		90 846	194	1056	
Primary splices—25 kV, molded rubber	B	309	3	5	
	C	11 332	1	3	
	G	520	0	4	
Total		12 161	4	12	
Primary splices—35 kV, molded rubber	A	711	1	6	
	C	1057	0	16	
	E	437	0	0	
	G	32	0	0	
Total		2237	1	22	
GRAND TOTAL		105 244	199	1090	
LAST YEAR'S GRAND TOTAL		94 281	203	891	
Primary loadbreak junctions (lateral taps)—15 kV	A	3474	13	138	4–8 years
	B	3224	18	30	
	C	7321	3	9	
	D	8742	4	31	
	E	30 555	19	213	
	G	2103	0	2	
Total		55 419	57	423	
Primary loadbreak junctions (lateral taps)—25 kV	B	42	1	4	
	C	3587	3	7	
	G	16	0	0	
Total		3645	4	11	
Primary loadbreak junctions (lateral taps)—35 kV	C	306	1	2	
	E	261	0	0	
Total		567	1	2	
GRAND TOTAL		59 631	62	436	
LAST YEAR'S GRAND TOTAL		55 195	71	374	

Note: Data on taped primary splices has been discontinued due to lack of data.
(Data from NUDC Report No. 17, October 8, 1984.)

terminator). The porcelain elastomeric type has a rate of 0.43 per 1000 units. Overall the record for these devices is excellent. (See Table VII for complete data.)

SECONDARY CONNECTIONS

This is the sixth year of evaluating the different types of secondary connections 600 V and below made by the member utilities. This data should be used carefully due to the difficulty in tabulating failures from previous years. The section on taped-insulated connections has been discontinued since the data is not dependable. Even though the data is new, the numbers on heat-shrink connections appear to be particularly interesting due to the failure rate of 0.002 per 1000 units (unit defined as one single-phase connection) for 1983 on 513 280 units installed. This compares with the failure rate of 0.00 per 1000 units for 1982. The failure rate for the molded

TABLE VII
POLE TOP TERMINATORS

	Type	Company	Total Number on System	Failures This Year	Failures to Date	Average Life Before Failure
(A)	Porcelain compound	A	192	0	7	8 yrs
		C	125	0	3	
		D	115	0	0	
		E	75	0	3	17 months
	Total		507	0	13	
(B)	Porcelain epoxy	E	125	0	3	
(C)	Porcelain elastomer—15 kV	B	Unknown	1	10	
		C	1631	2	20	
		D	2732	0	2	
		E	25 522	11	230	Unknown
	Total		37 126	16	271	
(D)	Porcelain elastomer—25 kV	C	1320	2	12	
	Total		1320	2	12	
(E)	Porcelain elastomer—35 kV	A	137	0	0	
		E	448	0	0	
	Total		585	0	0	
(F)	Porcelain elastomeric compound 35 kV	C	18	0	1	
		A	37	0	0	
	Total		55	0	1	
(G)	Molded rubber—15 kV	A	1840	0	1	
		B	14 359	2	15	
		C	17 861	2	34	Unknown
		D	32 576	2	8	2 yrs
		F	*	*	*	
		G	10 045	0	12	
	Total		76 681	6	70	
(H)	Molded rubber—25 kV	B	600	0	0	
		C	12 064	0	7	
		F	*	*	*	
		G	369	0	2	
	Total		13 033	0	9	
(I)	Molded rubber—35 kV	A	1071	0	0	
		C	972	0	4	
		G	40	0	0	
			*	*	*	
	Total		2083	0	4	
(J)	Taped	A	7'	0	1	
		C	0	0	0	
		D	200	0	21	
	Total		229	0	22	
(K)	Scotch 83A3	A	227	0	23	
		F				
	Total		227	0	23	
(L)	Heat shrink—15 kV	E	9397	0	4	
		C	7	0	0	
	Total		9404	0	4	

TABLE VII
(Continued)

	Type	Company	Total Number on System	Failures This Year	Failures to Date	Average Life Before Failure
(M)	Heat shrink—25 kV	C	80	0	1	
	Total		80	0	1	
(N)	Heat shrink—35 kV	E	363	0	0	
		C	21	1	3	
	Total		384	1	3	
GRAND TOTAL			141 839	25	436	
LAST YEAR'S GRAND TOTAL			133 271	21	411	

* Accurate data not available.
(Data from NUDC Report No. 17, October 8, 1984.)

TABLE VIII
SECONDARY CONNECTIONS

	Type	Company	Total Number on System	Failures This Year	Failures to Date	Average Life Before Failure
(A)	Molded rubber/ plastic insulated connections	A	53 162	5	36	
		B	—	—	—	
		C	1093	0	2	
		D	292 399	6	242	
		E	155 284	2	171	
		F	*	*	*	
		G	44 245	0	10	
	Total		546 183	13	461	
(B)	Heat shrink connections	A	47 987	1	11	1 yr
		B	—	—	—	
		C	147 184	Unknown	Unknown	
		D	53 100	0	1	
		E	265 009	0	6	
		F	*	*	*	
	Total		513 280	1	18	
GRAND TOTAL			1 059 463	14	479	
LAST YEAR'S GRAND TOTAL			965 121	13	465	

* Accurate data not available.
(Data from NUDC Report No. 17, October 8, 1984.)

rubber-plastic units is 0.02 failures per 1000 units for 1983, which is the same as for 1982. (See Table VIII for data.)

REFERENCES

[1] Northwest Underground Distribution Committee of the Northwest Electric Light and Power Association (NELPA), "URD equipment and materials reliability in the Northwest," no. 17, October 8, 1984.
[2] IEEE Committee Report, "Report on reliability survey of industrial plants," published in six parts, *IEEE Trans. Ind. Appl.*, pp. 213-252, 456-476, 681, Mar./Apr., July/Aug., Sept./Oct. 1974. (Included as Appendices in [3].)
[3] ANSI/IEEE Standard No. 493-1980, "IEEE Recommended Practice for the Design of Reliable Industrial & Commercial Power Systems."

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