LIGHTNING PROTECTION OF ELECTRIC DISTRIBUTION LINES

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INTRODUCTION

This paper is a report of methods used by Southwestern Public Service Company to reduce momentary interruptions due to lightning. This required the determination of the optimum spacing of arresters to protect distribution lines from lightning by applying arrester stations to two different locations in the same area. Each line represents a different average spacing of arrester stations. These lines are compared to a shielded line and an unprotected line, also in the same area.

DESCRIPTION OF PROJECT AREA

Four distribution lines radiating from the Kress Rural Substation were selected for the study. The Kress Rural Substation transformer is a 7500 kva, 69 kv delta primary to 7.2/12.47 kv 4-wire grounded wye secondary. Only one of the circuits in this study has a system neutral. The four circuits are described below.

1. KR 140 is a circuit with an overhead neutral (shielded), framed DS-5-40, for the main line. The laterals are flat construction, framed DS-5-52, without a neutral and are fused from the main line. There are about 12 mi of shielded line and a little over 10 mi of nonshielded laterals. This circuit extends west from Kress Rural Substation 1-1/4 mi, then north with laterals both east and west.
2. KR 202 is an arrester-protected circuit where the maximum spacing between arrester stations is three spans (average 1125 ft). Some transformer stations are only one and two spans apart, and some transformer stations have been set in mid-span, making the average spacing between arresters 758 ft. This circuit is framed DS-5-52 and extends north of the substation approximately 5 mi. The laterals are not fused from the main line. The total circuit of 16.91 mi is framed DS-5-52 and has arresters installed.
3. KR 203 is an arrester-protected circuit where arrester stations are on every structure and the spacing averages 313 ft. This circuit extends east and north from the substation and is just under 16 mi in length. Laterals are not fused.
4. KR 242 is divided into two circuits, each with a three-phase sectionalizer. KR 243 (sectionalizer) portion of the circuit is line that has been converted from 23 kv to 12.47 kv and has two 5 ft 7 in. arms with one phase on the top arm and the other two phases on the bottom arm. This circuit extends approximately 4-1/4 mi south with the last 1-1/2 mi on the south end being shielded (DS-5-40). The laterals are fused and are flat construction (DS-5-52). The other sectionalizer (KR 204) circuit extends south and west approximately 5 mi. This circuit is flat construction (DS-5-52) and the laterals are fused.

EQUIPMENT AND PROCEDURES

Aside from the arresters and associated hardware that were installed on KR 202 and KR 203, the equipment utilized for record-gathering consists of an OCB, KR 140, and an electronic OCR on each of the other three circuits, KR 202, KR 203, and KR

242. All four circuits have a potential transformer and a recording voltmeter (with a spring-wound carry-over feature) mounted near the load side of the OCB or OCR to record the time and duration of each interruption. On circuit KR 202, there is a lightning arrester discharge counter connected in series with the ground lead on all but three arrester stations. There are six counters installed on circuit KR 242.

The procedures for this study have followed, roughly, the following schedule:

1. In the latter part of 1970, initial maintenance of lines was performed to increase BIL levels to acceptable standards; slack spans with excessive sags were corrected; and guys and cracked arresters were replaced. This does not include KR 242 circuit.
2. In 1971, the operating sequence of the OCR's was changed from one fast and three retarded to all retarded time-current curve similar to OCB relay curve (very inverse).
3. Lightning arrester discharge counters were installed in June, 1972. Because of the excessive count, at the end of 1973, one-third of the counters were partially desensitized and another one-third were desensitized to a greater extent.
4. Record-keeping consists of reading and recording the OCB and OCR counters each time a patrolman is at the substation, generally weekly, replacing the voltage charts on a weekly basis, and reading the discharge counters on an annual basis. Rainstorms in the Kress area are detected by: personnel in Plainview, Amarillo radar, and from customers if a sustained interruption occurs.

DISCUSSION OF RESULTS

Tabulations referred to below are presented at the end of the paper.

Table 1 shows rate of momentary interruptions due to lightning in the years before and after the arresters were installed. On the basis of interruptions per 100 mi, the rate varied from 15 to 52 before the improvements were made. The last four years, the rate has varied from 0 to 7. Reclosers have several short-time, low-current opening schedules which may be used to open the OCR before momentary faults on a branch line will blow the fuse ahead of that branch line. The short-time, low-current schedule made the OCR's operate unnecessarily. They opened due to power follow current in the arrester, and we think the OCR will open whenever a "normally self-clearing" arc-over occurs along a wood arm. The short-time, low-current schedule to prevent lateral fuse blowing has not proven to be necessary.

The unprotected line, KR 242, has a very good interruption record. The six counters on KR 242 circuit indicate storms passed over the circuit in 1974 and 1975.

Tables 2A and 2B give the approximate number of storms. Discharge counters and the effect of modification are also included.

Table 3 is a record of damage due to lightning. There was more equipment damage in 1971.

Tables 4A and 4B show interruptions grouped according to year, circuit and cause.

Table 5 shows interruptions grouped according to cause.

Table 6 presents distribution line data.

TABLE I

Number of Momentary Interruptions Due to Lightning
(Numbers in parenthesis are per 100 miles of line)

Before Arresters Were Installed

Years	KR 140 OCB 29.0 Miles	KR 120 OCB 42.4 Miles	Totals 71.4 Miles
1965	4 (14)	7 (17)	11 (15)
1966	9 (31)	15 (36)	24 (34)
1967	12 (41)	24 (58)	36 (50)
1968	7 (24)	15 (36)	22 (31)
1969	8 (28)	29 (70)	37 (52)
1970	5 (17)	12 (29)	17 (24)

Note: The circuits were improved and split into four types of protection early in 1971. The results since then are tabulated below:

After Arresters Were Installed

Years	KR 140 OHN & Flat 22.35 mi.	KR 203 A.E.P. 15.86 mi.	KR 202 A.3.P. 16.91 mi.	KR 242 16.43mi.	Totals 71.55 mi.
1971	0	7*(44)	9*(53)	15*(91)	31*(43)
1972*	0	0	0	0	0
1973	0	0	1?(6)	0	1?(1)
1974	1?(4)	0	0	2(12)	3(4)
1975	1?(4)	0	2?(12)	2(12)	5(7)

*OCR sequence of one fast and three retarded operations was changed to all retarded operations prior to storm period of 1972.

TABLE 2A

Approximate Number of Thunderstorm Days
and Number of Arrester Discharges Counted

Years	Approx. Number of Thndrstrm Days	On KR202 Number of Discharge Counters	On KR202 Number of Discharges Counted	On KR242 Number of Discharge Counters	On KR242 Number of Discharges Counted
1971	19	--	--	--	--
1972	26	114	797 (1)	--	--
1973	24	114	1137 (2)	--	--
1974	22	117	636 (3)	6	9 (3)
1975	24	116	369	6	24

(1) Installation of discharge counters was completed on June 19, 1972.

(2) It is believed some of the discharges counted were due to induced strokes caused by lightning strokes to earth near the line.

(3) At the end of 1973 approximately one third of the discharge counters were modified to de-sensitize them and another one third received additional modification to de-sensitize them to a greater extent. The results are shown in Table 2B.

TABLE 2B

Effect of Modifying Discharge Counters to
Reduce Their Sensitivity. Year 1974

Counter Modification	On KR202 Number of Discharge Counters	On KR202 Number of Discharges Counted	On KR242 Number of Discharge Counters	On KR242 Number of Discharges Counted
No Modification	43	434	2	6
Gap Shorted	37	141	2	0
Gap Shorted plus Resistor	37	61	2	3

TABLE 3

Record of Damage Caused by Lightning

Year	OHN & Flat KR 140	A.E.P. KR 203	A.3.P. KR 202	No. A KR 242
1971	1 Fuse	--	1 35' pole 2 X-Arms	6 35' poles 6 X-Arms 1 Fuse
1972	1 Fuse	--	3 L.A.'s	--
1973	--	--	--	--
1974	3 Fuses	--	--	2 L.A.'s
1975	5 Fuses 2 arresters	1 insulator 3 arresters	2 arresters	2 Fuses 2 insulators

Table 3 indicates lightning was less damaging in 1972, 1973 and 1974.

TABLE 4A

Number of Interruptions Grouped According to
Year, Circuit, and Cause

For the Period 1965-1970

	Circuit No.	Momentary 'Ltng.	Momentary Other	Sustained	Total	Totals w/o Ltng.
1965	140+	4	2	3	9	5
	120+	7	7	9	23	16
	Totals	11	9	12	32	21
1966	140	9	0	0	9	0
	120	15	7	2	24	9
	Totals	24	7	2	33	9
1967	140	12	0	0	12	0
	120	24	11	0	35	11
	Totals	36	11	0	47	11
1968	140	7	0	1	8	1
	120	15	3	2	20	5
	Totals	22	3	3	28	6
1969	140	8	0	2	10	2
	120	29	1	2	32	3
	Totals	37	1	4	42	5
1970	140	5	0	0	5	0
	120	12	0	2	14	2
	Totals	17	0	2	19	2

+ Circuit lengths were: KR 140 - 29.0 Miles and
KR 120 - 42.4 Miles

TABLE 4B

Number of Interruptions Grouped
According to Year, Circuit and Cause

For Period 1971-1975

Year	Circuit No.	Momentary Ltng.	Momentary Other	Sustained Ltng.	Sustained Other	Totals	Total w/o Ltng.
1971 #	140+	0	0	0	1	1	1
	202+	9*	0	0	1	10	1
	203+	7*	0	0	1	8	1
	242+	15*	7	0	3	25	10
	Totals	31	7	0	6	44	13
1972	140	0	4	0	0	4	4
	202	0	1	0	1	2	2
	203	0	2	0	1	3	3
	242	0	2	0	2	4	4
	Totals	0	9	0	4	13	13
1973	140	0	1	0	1	2	2
	202	1?	4	0	0	5	4
	203	0	5	0	0	5	5
	242	0	2	0	0	2	2
	Totals	1?	12	0	1	14	13
1974	140	1?	3	0	1	5	4
	202	0	6	0	1	7	7
	203	0	1	0	0	1	1
	242	2	0	1**	1	4	1
	Totals	3	10	1	3	17	13
1975	140	1	0	0	0	1	0
	202	2	5	0	0	7	5
	203	0	0	0	1	1	1
	242	2	9	0	0	11	9
	Totals	5	14	0	1	20	15

Arresters, reclosers and guy insulators were added in spring of 1971.

* The recloser was opened by arrester power follow current.

** Sectionalizer KR 204 opened during a thunderstorm giving a sustained outage to part of KR 242.

+ Circuit lengths are: KR 140 - 22.35 miles
KR 202 - 16.91 miles
KR 203 - 15.86 miles
KR 242 - 16.43 miles

TABLE 5

Interruptions by Circuits According to Causes

For Period 1971-1975

Year	Ckt. No.	Ltng.	Wind	Animals	Public	Equipment	Unkn.	Ice	Total
1971	140	0	1	0	0	0	0	0	1
	202	9	1	0	0	0	0	0	10
	203	7	1	0	0	0	0	0	8
	242	15	3	0	5	1	1	0	25
	Totals	31	6	0	5	1	1	0	44
1972	140	0	2	0	1	1	0	0	4
	202	0	1	0	0	1	0	0	2
	203	0	0	0	0	1	2	0	3
	242	0	0	0	0	2	2	0	4
	Totals	0	3	0	1	5	4	0	13
1973	140	0	1	0	1	0	0	0	2
	202	12	1	1	0	0	2	0	5
	203	0	0	1	0	0	4	0	5
	242	0	2	0	0	0	0	0	2
	Totals	12	4	2	1	0	6	0	14
1974	140	12	3	0	0	0	0	1	5
	202	0	5	0	0	0	1	1	7
	203	0	1	0	0	0	0	0	1
	242	3	0	0	0	0	0	1	4
	Totals	4	9	0	0	0	1	3	17
1975	140	1	0	0	0	0	0	0	1
	202	2	2	0	0	0	3	0	7
	203	0	1	0	0	0	0	0	1
	242	2	0	0	0	0	9	0	11
	Totals	5	3	0	0	0	12	0	20

TABLE 6

Distribution Line Data

For the Period 1971-1975

Circuit No.	KR 140	KR 202	KR 203	KR 242
Length, Mi.				
Flat, DS-5-52	10.26	16.91	15.86	14.91
OHN, DS-5-40	12.09	--	--	1.52
Total	22.35	16.91	15.86	16.43
Avg. Span, Ft.		304	313	284
Ltng. Arr. Stas. No.		117	268	--
Avg. Spacing, Ft.		762*/758	313	--
Max. Spacing, Ft.		1502*/1380	425	--

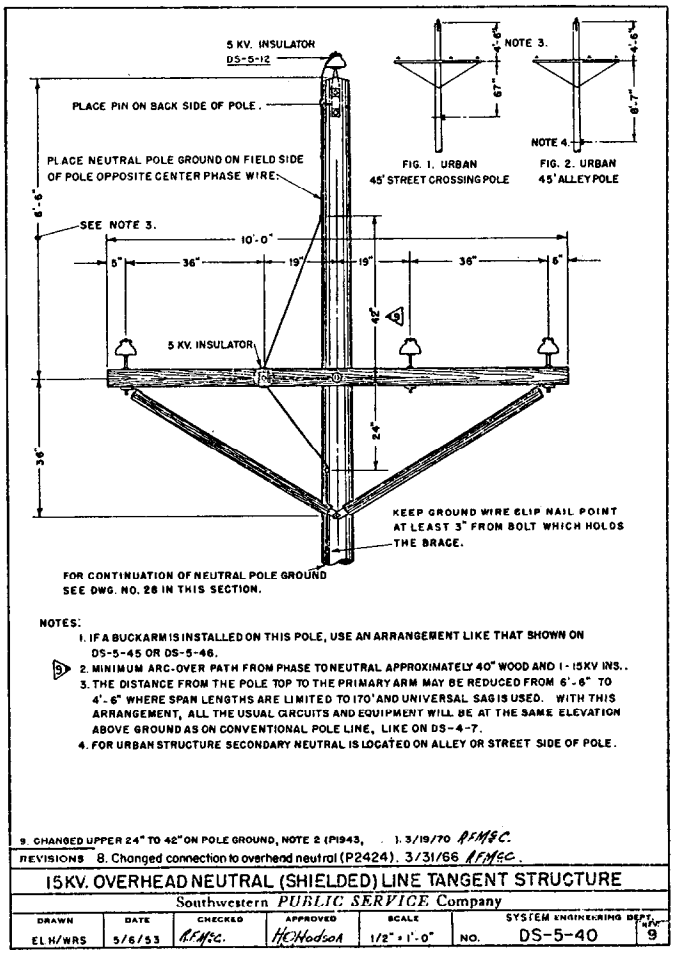
*Applies only to 1971 and 1972 conditions.

For the Period 1965-1970

Circuit No.	KR 140	KR 120
Length, Miles	29.0*	42.4#

* In this period KR 140 had about nine miles of what was transferred to KR 242 in 1971.

\# In this period KR 120 was an OCB that fed three sectionalizers which were replaced with electronic OCR's in 1971.



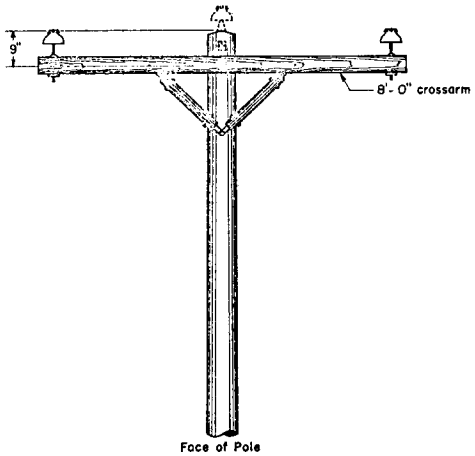
NOTES:
1. IF A BUCKARM IS INSTALLED ON THIS POLE, USE AN ARRANGEMENT LIKE THAT SHOWN ON DS-5-45 OR DS-5-46.
2. MINIMUM ARC-OVER PATH FROM PHASE TO NEUTRAL APPROXIMATELY 40" WOOD AND 1-15KV INS..
3. THE DISTANCE FROM THE POLE TOP TO THE PRIMARY ARM MAY BE REDUCED FROM 6'-6" TO 4'-6" WHERE SPAN LENGTHS ARE LIMITED TO 170' AND UNIVERSAL SAG IS USED. WITH THIS ARRANGEMENT, ALL THE USUAL CIRCUITS AND EQUIPMENT WILL BE AT THE SAME ELEVATION ABOVE GROUND AS ON CONVENTIONAL POLE LINE, LIKE ON DS-4-7.
4. FOR URBAN STRUCTURE SECONDARY NEUTRAL IS LOCATED ON ALLEY OR STREET SIDE OF POLE.

9. CHANGED UPPER 24" TO 42" ON POLE GROUND, NOTE 2 (PI943,). 3/19/70 RFMSC.
REVISIONS 8. Changed connection to overhead neutral (P2424). 3/31/66 RFMSC.

15KV. OVERHEAD NEUTRAL (SHIELDED) LINE TANGENT STRUCTURE

Southwestern PUBLIC SERVICE Company

DRAWN	DATE	CHECKED	APPROVED	SCALE	SYSTEM ENGINEERING DEPT. NO.	REV.
ELH/WRS	5/6/53	RFMSC.	H.O. Hodson	1/2" = 1'-0"	DS-5-40	9



3. Changed references and dwg. number. 2/7/57. RFMSC.
2. Changed title and pole top pin reference. 11/15/55. RFMSC. HOH 12/8
REVISIONS 1. Added reference, omitted Property Side. ELH/WRS-4/5/54 RFMSC 4-3-54, HOH 4-6

TANGENT STRUCTURE, RURAL-3 WIRE CONSTRUCTION

Southwestern PUBLIC SERVICE Company

DRAWN	DATE	CHECKED	APPROVED	SCALE	SYSTEM ENGINEERING DEPT. NO.	REV.
ELH/WRS	2/24/54	RFMSC 3-2-54	3-3-54 H.O. Hodson	1/2" = 1'-0"	DS-5-52	3