FURTHER SERVICEABILITY OF 40 YEAR OLD PILC CABLE

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Background - To assure the reliability of the electric power service to a large medical center in Houston, Texas, Houston Lighting and Power (HL&P), opted to remove from service and establish the aging condition of several paper insulated, lead covered (PILC) feeder cables that had been in operation from 40 to 45 years. All of the cables operated in a common environment. Six cables from four circuits were evaluated.

Characteristics of the Installation Site - The cables were installed in concrete encased polyvinyl chloride (PVC), 6 in. diameter conduits. Three cables in one conduit. The conduit system is filled with water the majority of the time, with the load on the cables being about 50% of their capacity, and operating consistently at that level. In the past one or more of the circuits had a significantly higher loading.

The service area is flat, approximately 40 ft. above sea level. It has a very high lighting isokeraunic level. The soil average temperature, at the depth of the duct system is approximately 10°C with the average year round ambient air temperature being approximately 28°C.

Description of the Cables - The main characteristics of the six cables are outlined in Table No. 1. All cables were made with compact round copper conductor, carbon black paper conductor shielding, 0.75 in. wide by 6 to 7 mils thick cellulose paper tapes, with overall thicknesses as indicated in Table No. 1. The insulating paper tapes were followed by a perforated foil baked paper tape, copper shielding tapes, and a lead sheath. The cables had been impregnated with Sun XX oil and were all manufactured by General Cable Corp., at its St. Louis, Missouri, or Bayonne, New Jersey plants.

Tests - The following tests were performed on each cable as per AEIC CS1-68 specification requirements.

TABLE 1.- CABLE CHARACTERISTICS

Sample No.	Circuit No.	Time In-Service Years	Rating kV	Insulation Thickness mils	Lead Sheath Thickness mils	Length ft
1	GN9	45	22	215	140	38
2	GN9	45	22	215	140	44
3	GN6	44	22	215	140	37
4	GN17	44	22	215	140	108
5	GN17	44	22	215	140	108
6	GN14	41	15	165	120	104
All cables made with 500 kcmil, compact round copper conductor.						

- Power factor vs. voltage stress (ionization factor) at ambient temperature
- Power factor vs. uniform insulation temperature (at 25, 70, and 90°C), at rated voltage
- High voltage time test
- Dissection

Results - The test results are shown in Figures 1 and 2, and Tables 2 and 3. Figure 1 shows the power factor vs. voltage stress characteristic for each of the 6 cables evaluated together with the corresponding ionization factors. For reference purpose this figure also shows the nominal operating voltage stress for 15 and 22 kV PILC cables (50 and 60 V/mil, respectively). Of the six cables evaluated, only Cable No. 4 has an ionization factor that still meets the specified requirement for new cables. The ionization factor of the other cables can be classified from moderately high to high.

Figure 2 shows the power factor vs. temperature characteristic for the six cables. The emergency temperature level (110°C) is indicated in this graph to allow for an estimation of the corresponding power factors. It is likely that under conditions of continued operation at a high temperature, one or two of the cables could go into a thermal run-away condition. After more than 40 years in service, 3 of the 6 cables still meet the power factor requirements for new cables, in the entire range of temperatures. The other 3 cables are degraded and sensitive to the higher temperatures.

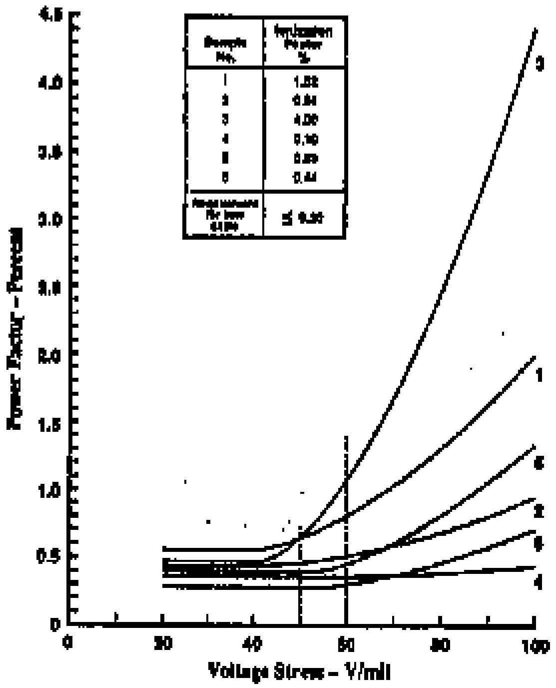

FIG. 1.- POWER FACTOR VS VOLTAGE STRESS
(at ambient temperature)

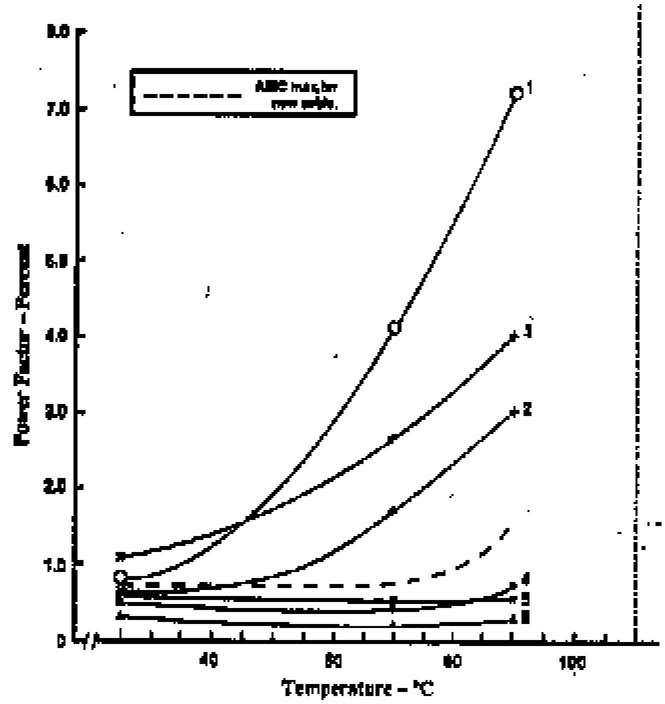

FIG. 2.- POWER FACTOR VS TEMPERATURE
(at rated voltage)

Table 2 provides the results of the high voltage time tests performed on each of the cables. All the cables passed the first step of 6 hours at 212 V/mil. This is an AEIC CS1-68 requirement for new cables. Only one of the cables passed the follow-up test, of keeping the cables for 7 hours, under a voltage stress of 400 V/mil. Passing this step is not a requirement. It is of interest to note that there is a significant correlation between the time each of the samples

TABLE 2.- HIGH VOLTAGE TIME TESTS

Sample		1	2	3	4	5	6
Age – Years		45	45	44	44	44	41
Phase		A-1	B-1	A-1	A-2	B-2	A-1
Step	Applied Voltage stress – V/mil	Time – Hours (withstand or to failure)					
1	212	6.00	6.00	6.00	6.00	6.00	6.00
2	400	0.01	0.68	0.01	0.72	2.42	7.00
AEIC CS1-68 Requirement: Pass 212 V/mil step for 6 hours.							

was able to withstand the 400 V/mil stress and the power factor of the cable samples at elevated temperature (90°C). Cables 1 and 3 failed between a very short time of reaching the 400 V/mil level. Samples 2 and 4 failed after about 35-40 minutes at this voltage stress, while Sample 5 lasted about two and a half hours. The only samples that passed the test was Sample 6, which also had the lowest power factor at all temperatures, and one of the lowest ionization factors.

Subsequent to the high voltage time tests, a short sample (about one foot long) of each of the cables, adjacent to the point of failure, was dissected. Except for the presence of wax in some of the bud spaces, no other abnormalities were encountered. Table 3 provides a record of the findings. Samples 1 and 2 had wax throughout the cable insulation wall, while Sample 3 showed wax only in the inner part of the insulation.

TABLE 3.- RESULTS OF DISSECTION

Sample	1	2	3	4	5	6
Age – Years	45	45	44	44	44	41
Phase	A-1	B-1	A-1	A-2	B-2	A-1
Tape Number from Outside	Wax on Paper Tapes					
1	Yes	Yes	No	No	No	No
2 – 5	Yes	Yes	No	No	No	No
6 – 15	Yes	Yes	No	No	No	No
15 – 25	Yes	Yes	Yes	No	No	No
26 – 29	Yes	Yes	Yes	No	No	No
30 – 40	Yes	Yes	Yes	No	No	No

In conclusion, all 6 cables are in acceptable condition, however, Samples 1 and 3 require to be operated at temperatures below 90°C. Higher temperatures quite likely will cause the power factor to rapidly increase. Cables 1, 2 and 3 can probably be operated safely with conductor temperatures up to 70°C and for limited periods up to 90°C. The instability of the power factor of these cables is shown by the fact that they failed shortly after applying the second step during the high voltage time test. This additionally is confirmed by the results of the dissection which shows a significant accumulation of wax in these cables. Cables 4, 5 and 6 are in good condition and can be operated safely at all temperatures: they have the likelihood of long service survival, provided moisture does not penetrate the cables due to corrosion of the lead sheath.