HIGH VOLTAGE VLF TESTING OF POWER CABLES

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Abstract **– This publication describes a laboratory test program conducted with the objective to develop a test that would replace the existing dc withstand test. The article describes the methodology used to establish the voltage duration and magnitude of VLF (0.1 Hz) high voltage field tests suitable for crosslinked polyethylene (XLPE) insulated power cable. The results show that the voltage breakdown of laboratory aged XLPE cable at 0.1 Hz is approximately equal to that at 60 Hz, that proof tests at 0.1 Hz cause very little damage to the cable, and that 0.1 Hz testing appears to be a satisfactory alternate to dc testing. Preliminary values are suggested for voltage magnitude and time duration of cable acceptance, main-tenance and proof tests at 0.1 Hz for XLPE cable rated up to 35 kV. A program is underway to similarly evaluate samples of service-aged XLPE cable; as well as to demonstrate the use of the preliminary test values at typical utility installations.**

I. INTRODUCTION

During service, water trees form in the insulation of extruded cables and reduce dielectric strength [1]. The reduction in dielectric strength in many cases is sufficient to cause failure by normal system voltage.

In addition to lowering ac, dc and surge breakdown voltages, water and water trees tend to increase dissipation factor, modify leakage currents and modify dc absorption current. Field measurements of some of these parameters have proven to be a suitable means to detect degradation and the presence of water trees [2,3]. However, each measurement technique has disadvantages which have prevented their widespread use. Some have the disadvantage that the measurement integrates the entire length of cable. This tends to mask the changes created when the degraded section of the cable is small, preventing detection of localized degradation. Furthermore, leakage current at joints and terminations may modify the cable leakage current. Also, wet cables often have partial discharges detectable with commonly used equipment for only a relatively short time prior to cable failure. The existing dc withstand test possesses some of these disadvantages and in addition, there is some evidence that dc testing can cause damage to XLPE cable [4,5]. This laboratory test program has the objective to develop a test that would replace the existing dc withstand test.

In view of these disadvantages some attention has been given to proof testing cable systems using high voltage 0.1 Hz [6, 7]. A high voltage proof test will detect the weakest spot in the cable, no matter where it is located. Furthermore, an ac voltage proof test, as opposed to a dc voltage proof test, subjects the cable to voltage stresses similar to those applied when the cable is in operation. Because the charging current of the cable at 0.1 Hz is 600 times less than at 60 Hz the volt-ampere capacity is small, similar to the capacity of a dc test set.

An earlier investigation indicated that flashovers at cable ends or a cable failure during dc voltage testing further damages polyethylene insulated cables degraded by water trees [8]. Current AEIC Specifications CS-5 and CS-6 for crosslinked polyethylene (XLPE), and ethylene propylene rubber (EPR) insulated power cable, respectively, recommend lowering the magnitude of the dc test voltage as the cable ages in service (becomes weaker), because high voltage dc testing may cause damage.

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This paper covers work which is part of a program being sponsored by the Electric Power Research Institute (EPRI) and the Canadian Electrical Association (CEA). The objective is to develop a field test method for 5-46 kV cable having water trees that will determine when in-service cable is unsatisfactory for continuous service. The field test shall not cause significant damage to adjacent cable. The work has been performed on XLPE cable aged in the laboratory.

II. LABORATORY TEST PROGRAM ON XLPE CABLE

A laboratory study was conducted on cables having a high content of water trees in order to determine 1) the comparative 0.1 Hz and 60 Hz voltage breakdown strength, 2) the effect of 0.1 Hz testing on subsequent cable performance, and 3) suitable 0.1 Hz proof test voltage levels and time of voltage application. Selected additional tests were conducted to provide a comparison with conventional dc proof testing. Analysis of water trees in the cables confirmed the character of the degradation.

Cables Tested - Model and 15 kV XLPE cables were evaluated. The model cable has a 34 mm² (No. 2 AWG) copper conductor, 0.6 mm HFDA 0580 conductor shield, 1.5 mm HFDE 4201 insulation and 0.9 mm DHDA 7704 insulation shield. The 15 kV cable has a 34 mm² (No. 2 AWG) copper conductor, 0.55 mm HFDA 0581 conductor shield, 4.5 mm HFDE 4201 insulation and 0.9 mm HFDA 0692 insulation shield. The cables were subjected to tests for shield resistivity, insulation shield strippability, dimensional analysis, voids, contaminants, and shield protrusions and found to comply with requirements.

Accelerated Aging of Cables - The two cables were subjected to accelerated aging in the laboratory. Coils of each type of cable were placed in tanks containing tap water. Tap water also was kept in the interstices of each cable conductor. The degree of aging was characterized by periodically removing samples for voltage breakdown and water tree examination.

The model cable was aged for 38 months with 8 kV applied continuously between conductor and ground. For the first six months the water in the tanks was at ambient temperature, for the next 16 months the water temperature was cycled between 40 and 65°C each 48 hours, and for the remaining 16 months the temperature was reduced to ambient because 3 coils failed between 18 and 22 months of aging. During aging a total of 169 40 kV and 130 27 kV impulses, each having a 1.5x40 μs wave shape were applied to the cable.

The 15 kV cable was aged for 28 months. Initially 20 kV was applied continuously between conductor and ground. The voltage was reduced to 17, 12 and finally 8 kV due to 9 cable failures. The water in the tanks was cycled between 40 and 65°C each 48 hours for the first 9 months then kept at ambient temperature for the remaining time because of the cable failures. During aging a total of 140 80 kV impulses, each having 1.5x40 μs wave shape were applied to the cable.

A summary of the water tree count at the end of aging is given in Table 1 for model and 15 kV cables. The length and the number of bow tie and vented water trees found in a typical 20 mm length of cable is provided.

High Voltage 0.1 Hz Equipment - The equipment used in this program generates a voltage signal having a trapezoidal wave shape. The wave is formed by using a mechanical commutating device. The signal has polarity reversals at 5 second intervals with the rate of change of the voltage during reversals having a 60 Hz cosinusoidal shape with 2 to 6 milliseconds duration. A drawing of the trapezoidal wave is shown in Figure 1. In the trapezoidal wave, which mathematically approximates a square wave, the peak and rms values of voltage are equal. The maximum output of the test equipment is 52 kV.

III. LABORATORY TEST RESULTS

Voltage Breakdown Tests - The active length of the test samples was 5 m. The time interval between the end of the aging period and the

TABLE 1. - TREE COUNT OF XLPE CABLES AFTER AGING*

Length of Trees mm	Number of Water Trees	
Model Cable - Aged 38 Months		
	Bow Tie	Vented
0.05 - 0.13	240,000**	1,300
0.13 - 0.25	36	51
0.25 - 0.50	5	0
0.50 - 0.75	1	0
Total/cm³	250,000	–
Total/cm²	–	260/310***
15 kV Cable - Aged 28 months		
	Bow Tie	Vented
0.05 - 0.13	1,500,000**	28,000**
0.13 - 0.25	420,000**	6,000**
0.25 - 0.50	164	78
0.50 - 0.75	83	16
0.75 - 1.00	30	–
1.00 - 1.50	8	–
Total/cm³	500,000	–
Total/cm²	–	2,000/1,800***

* Length and number in 20 mm of cable
** Estimate based on examination of 2.5 x 2.5 mm area
*** At conductor shield/at insulation shield

TABLE 2. - VOLTAGE BREAKDOWN STRESS OF MODEL XLPE CABLE

Type of Voltage	Voltage Breakdown Stress* kV/mm	Relative Breakdown Strength
Unaged		
60 Hz	51	1.0
0.1 Hz	34**	–
Aged 11 Months		
60 Hz	28	1.0
0.1 Hz	25	0.9
dc	48	3.1
Aged 23 Months		
60 Hz	21	1.0
0.1 Hz	20	0.9
dc	64	3.0
Aged 38 Months		
60 Hz	20	1.0
0.1 Hz	23	1.1
dc	76	3.7

* Voltage increased in 5 minute steps
** Limit of test equipment - samples did not break down

test was minimized. For the initial breakdown step the voltage was one-half of the expected breakdown and applied for a period of 5 to 60 minutes, depending on the particular test. The voltage was increased 0.8 kV/mm for each additional 5-60 minute step until breakdown occurred. Each type of breakdown test was performed on 5 or more samples. The 63% probability of breakdown voltage was established on the basis of Weibull plots of the individual breakdown value of each sample. The voltage stress was calculated after measuring the insulation thickness at the point of failure. The breakdown voltage (63% probability) for each set of tests on the model cable is given in Table 2 and plotted in Figure 2. The 0.1 Hz breakdown voltage for the unaged model cable exceeded 52 kV. Table 3 presents the breakdown values at 0.1 Hz, 60 Hz and dc voltages for the 15 kV cable.

The 0.1 and 60 Hz breakdown voltage stresses are not significantly different for all the aging times. Both are much lower than the dc breakdown voltage stress. Based on this it is to be expected that the response of an aged XLPE cable to 0.1 and 60 Hz acceptance, proof, etc. tests, would be similar.

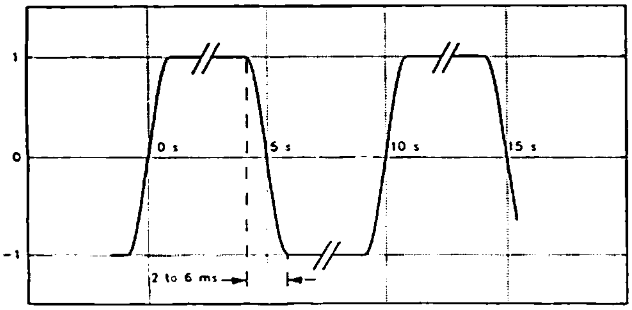

Fig. 1 - Schematic representation of 0.1 Hz trapezoidal wave shape.

0.1 Hz Voltage-Time Breakdown Characteristics - In order to establish the effect of time of application of a proof test on the condition of XLPE cable containing severe water treeing, 0.1 Hz voltage breakdown tests were conducted using different step times. The results of this series of tests are given in Figure 3. The equivalent constant voltage stress for cable breakdown at 1, 5 and 60 minutes was calculated in accordance with the following procedure and the values are plotted in Figure 4. These data provide useful information when deciding upon the duration of the proof test.

The procedure used was to first obtain the value of "C" for each breakdown sample using equation (1) [9]. The values of C were plotted on a Weibull distribution graph and the 63% probability obtained.

$$C = (E^n + g^n E^n + ... + g^{n(z-1)} E^n)t + g^{nz}E^n t_b \qquad (1)$$

where:
- E = voltage stress of first voltage step
- z = number of voltage steps until breakdown
- t = duration of each step
- t_b = time to breakdown at the last step
- g = factor of voltage increase in each step
- n = voltage endurance coefficient

Calculations for the constant "C" were made assuming "n" = 6. For the determination of the most probable value of "C" the value of the coefficient "n" is not critical. The voltage stress corresponding to the 63% probability of "C" and the time of a single step duration utilized in

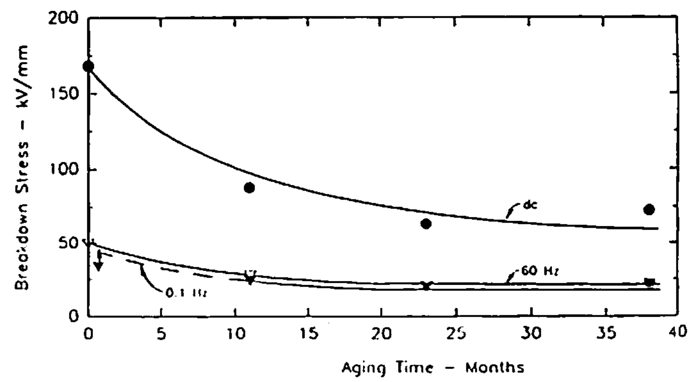

Fig. 2 - Voltage breakdown of model cable (5 minute steps).

TABLE 3. - VOLTAGE BREAKDOWN STRESS OF 15 KV XLPE CABLE

Type of Voltage	Voltage Breakdown Stress - kV/mm: 5 min. steps	Voltage Breakdown Stress - kV/mm: 60 min. steps	Relative Breakdown Strength 5 min. steps
Unaged Cable			
60 Hz	49	–	–
0.1 Hz	11*	11*	–
Aged 14 Months			
60 Hz	14.5	–	1.0
0.1 Hz	11*	8.5	>0.8
dc	58	–	4.2
Aged 28 Months			
60 Hz	14	13.2	1.0
0.1 Hz	11*	7.8	>0.8
dc	48	–	3.3

* Limit of test equipment - samples did not break down.

a particular test were calculated using Equation (2) derived from the inverse power law [9].

$$C = E_{avg}^{n} t \tag{2}$$

where:

E_{avg} = the equivalent constant voltage stress for cable breakdown in time t

Effect of 0.1 Hz Voltage Proof Tests on XLPE Cable - This series of tests was performed to establish the suitability of a 0.1 Hz proof test for detecting cable deterioration without inducing incipient damage to XLPE cable containing water trees. Tests were performed on model and 15 kV cables.

A model cable aged 23 months was subjected to a proof test in combination with a flashover at 13.3 kV/mm. The flashover simulated the occurrence of a cable failure or termination flashover during proof testing. Samples were subsequently taken to 60 Hz breakdown using 5 minute steps to determine whether proof testing caused any cable degradation. During testing the cable was energized at 13.3 kV/mm, 0.1 Hz for 5 minutes before the flashover. The simulated flashover was generated by a triggered discharge of a sphere gap connected across the voltage source to ground. This procedure was repeated 10 times. Similar tests also were performed without flashovers. The results indicate that proof tests at 13.3 kV/mm did not affect this cable.

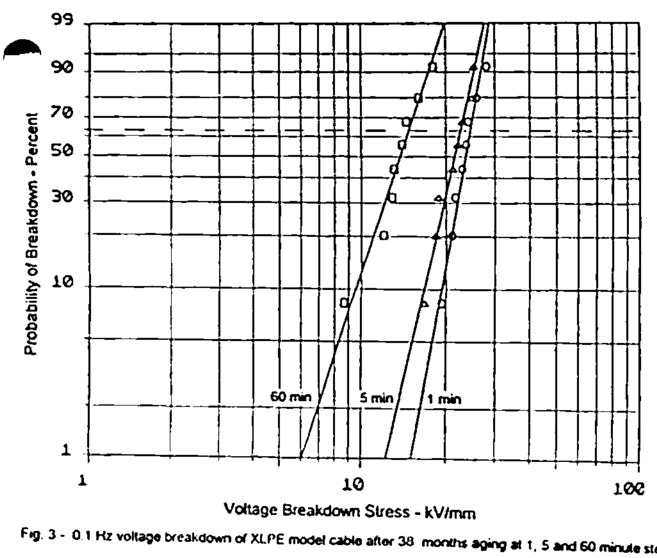

Fig. 3 - 0.1 Hz voltage breakdown of XLPE model cable after 38 months aging at 1, 5 and 60 minute steps.

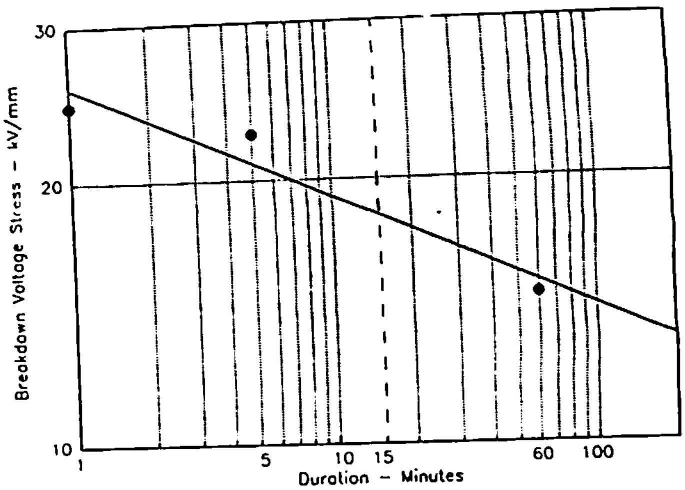

Fig. 4 - 0.1 Hz Voltage-time characteristic for XLPE model cable after 38 months aging.

After aging the model cable for 38 months, 0.1 Hz proof tests were conducted at applied voltage stresses prior to flashover of 8.0 and 12.0 kV/mm. The results of 60 Hz tests, after proof tests at 0.1 Hz with flashover, are given in Figure 5. The duration of the proof tests was 5 minutes and the magnitude of voltage stress was 12 kV/mm. The results indicate that proof testing at the specified levels and time affects only slightly the voltage breakdown stress of XLPE cable having severe water treeing.

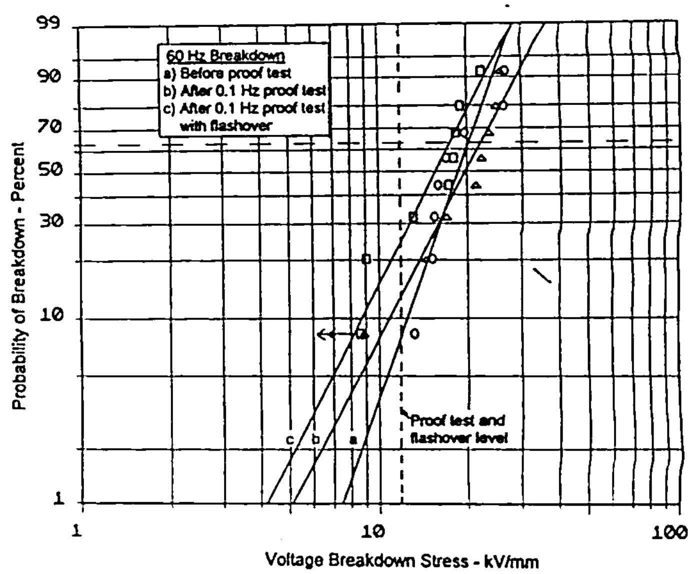

Fig. 5 - Effect of 0.1 Hz proof test on model cable aged 38 months.

After aging 14 and 28 months the 15 kV cable was subjected to a series of 0.1 Hz proof tests with and without flashovers. The test results are given in Table 4. The 0.1 Hz proof test voltage, corresponding to a nominal average stress level of 10.9 kV/mm (52 kV), was applied to the sample for a time duration of 5 minutes. The cables were subsequently subjected to a 60 Hz voltage breakdown test, to establish any damage caused by the proof testing. The results show that a 0.1 Hz proof test at 10.9 kV/mm reduces the 60 Hz dielectric strength to about 75% of the level prior to proof testing, indicating that this level of 0.1 Hz proof testing initiated (or enhanced) weak points which are present in the aged cable insulation.

Tests with flashovers were performed after 14 months aging on 15 kV cables at 0.1 Hz voltage stresses of 5.1, 5.9 and 6.5 kV/mm. These levels correspond to nominal 0.1 Hz voltages of 24, 28 and 32 kV respectively. The results of the subsequent 60 Hz breakdown levels were 13.4, 15.6 and 16.1 kV/mm, respectively. The results indicate that proof tests with and without flashover at levels as high as 6.5 kV/mm do not degrade cable after 14 months aging (Table 4).

TABLE 4. - 60 HZ BREAKDOWN STRESS OF AGED 15 KV XLPE CABLE AFTER 0.1 HZ PROOF TEST

Proof Test*			60 Hz Breakdown Stress - kV/mm	
Duration min.	Number of Flashovers	Voltage Stress kV/mm	Aged 14 months**	Aged 28 months**
5	0	3.7	–	13.3
5	1	3.7	–	13.3
5	1	5.1	13.4	–
5	0	5.9	15.6	11.7
5	1	5.9	15.6	12.0
5	0	6.5	14.6	–
5	1	6.5	16.1	–
5***	0	10.9	10.4	10.9

* Repeated 10 times
** The 60 Hz breakdown stress before 14 and 28 months proof testing was 14.5 and 14.0 kV/mm, respectively
*** Only one voltage application

Effect of DC Voltage Proof Test on Aged XLPE Cable - Tests similar to the 0.1 Hz proof tests except using dc voltage were conducted on model and 15 kV cables to confirm the fact that dc testing with flashovers can damage XLPE cable, as was found to be the case in an earlier program [8]. The test circuit used in these tests charges the test sample with a dc voltage through a current limiting resistance [8]. After a specific charging time a variable air gap is triggered bringing the cable voltage rapidly to zero. In this way a cable failure is simulated.

The 15 kV XLPE cable after 14 months aging was subjected to a series of dc breakdowns and proof tests with flashover at applied dc voltage stresses of 7.5, 13.4, 21.0 and 31.0 kV/mm. These stress levels correspond to applied voltages of approximately 33, 59, 92 and 138 kV, respectively. The test samples were held at the specified dc proof test voltage for 5 minutes prior to flashover.

A summary of the results of dc proof testing is given in Table 5. After 14 months of aging the test data show that at 7.5 kV/mm no damage occurred as a result of the dc proof test (the 60 Hz breakdown level is unchanged). At higher dc proof test levels of 13.4, 21.0 and 31.0 kV/mm, some degree of damage is caused by the proof testing. A typical Weibull plot at the pre-stress level of 31.1 kV/mm is given in Figure 6.

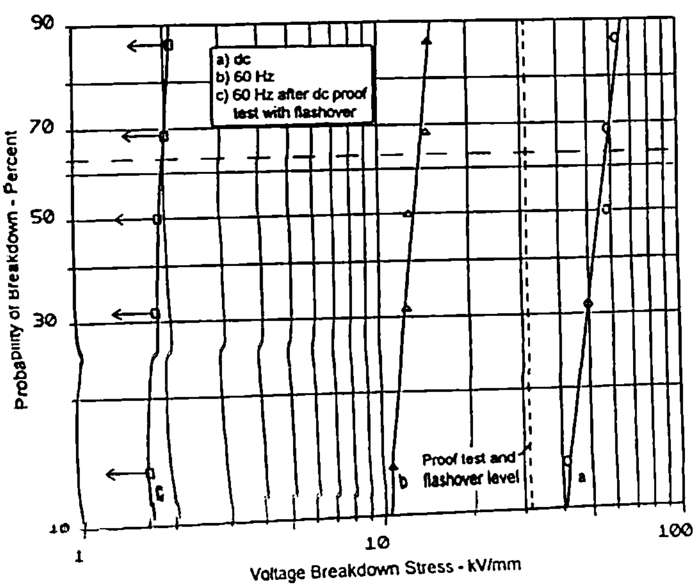

Fig. 6 - Effect of dc proof test on 15 kV XLPE cable aged 14 months.

After 28 months the 15 kV XLPE cable was subjected to another series of dc voltage proof tests followed by 60 Hz voltage breakdown tests. The data also is summarized in Table 5. In this case the dc proof tests were conducted at pre-stress levels of 10.4 and 16.6 kV/mm with flashovers. The dc proof testing in each case affected the cable.

TABLE 5. - 60 HZ BREAKDOWN STRESS OF AGED 15 KV XLPE CABLE AFTER DC VOLTAGE PROOF TEST

Proof Test*		60 Hz Breakdown Stress - kV/mm	
Duration min.	Test Stress kV/mm	Aged 14 months**	Aged 28 months**
5	7.5	13.7	–
5	13.4	11.0	–
5	21.0	11.8	–
5	31.0	>2.0	–
5	10.4	–	12.8
5	16.6	–	12.0

* Repeated 10 times
** The 60 Hz breakdown stress before 14 and 28 months proof testing was 14.5 and 14.0 kV/mm, respectively

IV. DISCUSSION

The water tree count and the sharp decrease in dielectric strength demonstrate that the XLPE cables studied were highly aged. The number of water trees found, particularly the bow tie type, is so numerous only a rough estimation of the quantity could be made.

The magnitude of the voltage breakdown at 0.1 Hz and at 60 Hz is approximately equal and is a fraction of the dc voltage breakdown. AEIC cable specifications imply a lower breakdown level for ac voltage when suggesting dc proof testing at 2.8 times ac, as an alternate to the recommended 60 Hz proof test voltages. It was expected that the magnitude of the 0.1 Hz breakdown voltage would be more like that at 60 Hz because of polarity reversals. For solid paper insulated 15 kV cable, Specification AEIC CS1-90 requires the factory final 60 Hz voltage test to be approximately 3.9 times the cable operating voltage [10]. If this ratio of final factory to rated operating voltage is extended to 15 kV polyethylene cable, the factory final 60 Hz voltage test would be equal to 33.6 kV, the same as in Specification AEIC CS1-90. Thus, Specification CS1 provides a precedent if and when ac proof testing in the field is incorporated into the AEIC CS5 Specification.

After installation of a cable, but before placing in service, the magnitude of the 60 Hz high voltage test would be 26.8 kV if a 20% reduction is taken, as suggested for high voltage dc testing in Specification AEIC CS-5. Because the breakdown voltage of XLPE cable is approximately the same at 0.1 and at 60 Hz it would seem logical to conduct the high voltage 0.1 Hz field test for 15 kV XLPE cable at 26.8 kV after installation but before placing in service.

Step voltage breakdown tests at 0.1 Hz on aged XLPE cable were performed using steps from 1 to 60 minutes duration. This was done to provide information on the effectiveness of the time of voltage application during the high voltage field test. The results are shown in Figure 4. The data provide information when selecting proof test voltage magnitude and duration for aged XLPE cable.

The series of tests on aged XLPE cable was conducted to provide data to establish suitable proof test voltages and time durations for field tests. Cables with different levels of aging were tested to establish 0.1 Hz voltage magnitudes that could be used without damaging the insulation. The cable characteristic chosen to establish the extent of damage was 60 Hz step voltage breakdown strength. This characteristic is very sensitive to insulation degradation. Realistic proof voltage time durations were chosen so that the data could be used to define this parameter. Flashovers that simulate cable failure were used to provide the worst damaging case during 0.1 Hz proof tests. This was found to be the case with dc voltage proof tests. It is felt that the data presented is useful when defining a realistic 0.1 Hz high voltage field test for cables of different levels of degradation.

The 0.1 Hz voltage-time characteristic data, presented in Figure 4, obtained on XLPE model cable, is useful to establish suitable field proof test voltage magnitudes for 15 kV XLPE cable. This was done with the curves presented in Figure 7 where the data obtained on model cable is replotted as a base. From this base curve, the laboratory proof test level for 15 kV cable is approximated. Taking into consideration that the breakdown voltage decreases as the length of the cable tested increases, the field proof test level can be determined approximately. The characteristic shown in Figure 7 assumes the proof test is made on a typical cable length of 150 m. The proof test voltage of short laboratory samples must be adjusted for the longer lengths of cable in typical field circuits. Equation 3 is an approximation for this adjustment [9].

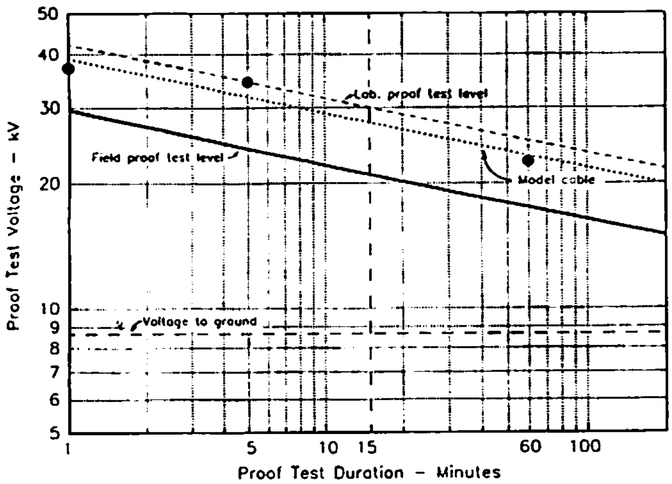

Fig. 7 – 0.1 Hz field proof test level for 15 kV XLPE cable.

$$\frac{E_f}{E_s} = \left[\frac{L_s}{L_f}\left(\frac{r_s}{r_f}\right)^2\right]^{1/m} \qquad (3)$$

where:
- E = voltage stress
- L = length
- r = conductor radius
- m = a factor (in this case 8) determining statistical distribution of breakdown with respect to variation of voltage stresses
- s = laboratory cable
- f = field cable

The magnitude of the 0.1 Hz field proof test voltage for a duration of 5 minutes indicated by Figure 7 is approximately 24 kV for an aged 15 kV XLPE cable.

The magnitude of a proof test voltage must not be unrealistically high. If too high, a cable in good condition, with long life remaining, would fail and be removed prematurely. Conversely an unrealistically low proof test voltage would not cause a cable on the verge of failure to be removed. For routine maintenance testing, the higher the voltage magnitude, the greater the cost advantage, because this would increase the elapsed time between maintenance tests. Based on knowledge gained during the laboratory program, suggested preliminary values for 0.1 Hz high voltage field tests are given in Table 6. It must be recognized however, that more experience needs to be gained before final values are established.

TABLE 6. - SUGGESTED FIELD TEST VOLTAGES FOR SHIELDED POWER CABLE

System Voltage (kV rms) (phase-phase)	0.1 Hz Test Voltage			
	Installation kV (cond-gnd)	Acceptance kV (cond-gnd)	Maintenance kV (cond-gnd)	Proof kV (cond-gnd)
5	12	14	10	10
15	25	28	22	22
25	38	44	33	33
35	55	62	47	47
Maintenance and proof test voltage duration suggested 15 minutes until some field experience gained				

V. CONCLUSIONS

a) The voltage breakdown magnitude of laboratory aged XLPE cable using a frequency of 0.1 Hz is approximately equal to that at 60 Hz. Both are significantly less than dc voltage breakdown.

b) The voltage-time breakdown characteristic at 0.1 Hz of XLPE cable has been obtained in the time range of 1 to 60 minutes. This range is expected to cover a realistic time duration for high voltage field tests.

c) Proof tests at 0.1 Hz affect laboratory aged XLPE cable less than do tests with dc. A 60 Hz step voltage test was used to judge the extent of the effect.

d) Suggested voltage magnitude and time duration for 0.1 Hz field proof tests have been developed based on evaluation of laboratory aged XLPE insulated cable. Service aged cable presently under evaluation will provide additional data.

e) Based on tests of laboratory aged model cables, it is estimated that the 0.1 Hz proof voltage test level for 150 m, 15 kV, XLPE cable should be 22 kV for 15 minutes.

f) In-service proof testing at 0.1 Hz appears to be a satisfactory alternate to dc proof testing. Planned field trials should provide further confirmation.

g) The required KVA output of the 0.1 Hz test equipment is much less than that of a 60 Hz unit because of low frequency. The 0.1 Hz unit is comparable in size to a dc unit.

VI. ACKNOWLEDGEMENT

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10. AEIC Cable Specifications

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CS-5 Specifications for Thermoplastic and Crosslinked Polyethylene Insulated, Shielded Power Cable, Rated 5 kV through 46 kV, November 1987.

VIII. BIOGRAPHIES

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He is past Chairman of the Insulated Conductor Committee, IEEE Power Engineering Society; and of the Conference on Electrical Insulation and Dielectric Phenomenon. He is the author of 30 technical papers and holds 20 U.S. patents in the field of underground power cables.

Carlos Katz (M'70-SM'78-F'87) Born in West Germany on August 18, 1934. Received an Electrical Engineering degree from Polytechnic Institute of Quito, Ecuador in 1961 and a MS degree from Stevens Institute of Technology, Hoboken, New Jersey in 1970.

From 1962 to 1971 he was associated with General Cable Corporation Research Center and from 1971 to 1974 with the laboratories of Phelps Dodge Wire & Cable. In 1974 he became Assistant Director of R&D at General Cable Corp., and later Technical Director Power and Control Cables for General Cable International. He has been with Cable Technology Laboratories as Chief Research Engineer since its founding 1978. Mr. Katz's special field of activity is the investigation of extruded and laminar dielectric high voltage power cables, the manufacture and properties of such cables and the extension of service life of installed cables.

Mr. Katz is the author of 31 technical papers and holds 16 U.S. patents related to high voltage cables. He is a voting member of ICC and a member of CIGRE.

Bogdan Fryszczyn. Born in Poland on April 24, 1943. Received his M.S. and Ph.D. degrees in Nuclear Physics from the University of Warsaw in 1965 and 1974, respectively. From 1965 and 1978 he worked as Research Associate at Warsaw University, Warsaw, Poland. While associated with Warsaw University he performed research work at the Joint Institute for Nuclear Research in Dubna, USSR (1966-1971) and at the University of Groningen, Holland (1973-1974). He has been associated with Cable Technology Laboratories since 1979 where at present he is a senior Research Engineer.

Dr Fryszczyn's special field is the investigation of extruded distribution cables and their components, the behavior of cables in service and the extension of life of these cables. Dr. Fryszczyn is the author of numerous technical papers on high voltage extruded power cables and of several related U.S. patents.

John Densley Born in Swansea, Wales in 1943. He received a B.Sc. (Eng.) and Ph.D. degrees from Queen Mary College, University of London in 1964 and 1967, respectively. In 1968 he joined the Power Engineering Section of the National Research Council of Canada. He worked there for 23 years on electrical aging phenomena in polymeric insulation systems. In 1991, he moved to Ontario Hydro Technologies where he is actively engaged in research into diagnostic and condition monitoring techniques for high voltage equipment. He has published over 60 papers on partial discharges, and electrical and water treeing in cable insulation.

Dr. Densley is a Fellow of the IEEE, and is active in the PES Insulated Conductors Committee and the Dielectrics and Electrical Insulation Society. He is the Canadian representative on CIGRE SC15 (Materials for Electrotechnology) and also the International Electrotechnical Commission (IEC) TC 98 (Insulation Systems).

Bruce S. Bernstein (F'92) is technical advisor with the Power Delivery Group of the Electric Power Research Institute (EPRI) headquartered in Washington, DC. He joined EPRI in 1977 and has been involved in guiding extruded cable and material studies for several ESD programs and for the Office of Exploratory Research. He has coordinated several EPRI workshops on extruded cable subjects. Before joining EPRI Mr. Bernstein was Materials Section Manager at Phelps Dodge Cable and Wire Co. in Yonkers, NY. Earlier he guided contract research on the subject of radiation effects on polymers, including efforts to effectively crosslink polyethylene. Mr. Bernstein was born in New York City, attended City University of New York, Brooklyn Polytechnic Institute and has a M.S. degree from Iowa State University. He is a Fellow of IEEE, the U.S. representative to CIGRE Study Committee 15, a U.S. representative on the CIGRE SC-15-06 Solid Dielectrics Working Group, former member of DEIS ADCOM. He is also a member of the American Chemical Society and the Society of Plastic Engineers. He has authored or co-authored about 45 publications and patents on polymeric materials.