IEEE Transactions on Power Delivery, Vol. 11, No. 1, January 1996

105°C/140°C RATED EPR INSULATED POWER CABLES

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ABSTRACT

The excellent long-term operation and field performance of existing EPR cables under the current industry[1] [2] operating temperatures of 90°C normal and 130°C overload is well known.

This paper describes a study for the implementation of a higher temperature rated EPR cable system including accessories up to a range of 105° continuous service and 140° emergency operation.

The investigation has been carried out into the electrical, mechanical, and thermal behavior of the system as a function of temperature. Compatibility has been studied under higher temperature in relation between conductor filling compound and the semi-conducting stress control layer. The results indicate that insulation degradation does not occur under accelerated and elevated temperature testing, concluding that properly formulated and selected materials are both compatible and suitable for the higher temperature ratings.

INTRODUCTION

Soon after the first synthesis of the ethylene-propylene copolymer in 1955, R&D laboratories of compound and cable manufacturers began to study the possibilities offered by this new material in cable applications, well in advance of the industrial production of the polymer. Since its appearance in an environment dominated by natural rubber, synthetic rubber and butyl rubber, the new EPR copolymer immediately appealed as a cable insulation for its significant advantages over the then current materials; low gas permeation, good heat aging, excellent corona and ozone resistance, excellent mechanical properties and improved electrical properties (wet and dry).

In 1962 the first technical paper was published[3] summarizing the successful testing of a 15 kV prototype cable and concluded at that time the possibility of producing medium voltage cable up to 50 kV. This resulted in further investigation culminating in the installation of the first 45 kV EPR cable system[4] in 1964 which was operational for 20 years without any problems prior to being removed from service due to plant renovation.

Since then, the industry's experience in EPR insulation has continued to grow into high voltage cable subsequently leading to the first 245 kV EPR prototype in 1988[5].

Further Developments

The advantages of EPR insulation over the more current extruded dielectric alternatives, namely XLPE and PE, are also quite evident particularly in terms of endurance in the most severe conditions where the presence of water, high temperatures, high stress fields, in combination, etc., are present [6] [7] [8].

While it has long been known that the thermal operating capabilities of EPR exceed those of other insulations[9] [10] [11] [12], EPR cables have been shown to operate well at high temperatures offering the end user a thermally stable cable structure in the occurrence of emergency and short circuit operation [13].

A further study has now been completed including a total system evaluation relative to the use of EPR at a continuous operating service temperature of 105°C and an emergency overload temperature of 140°C.

The results conclude that EPR insulated medium voltage cables including the system accessories are suitable for the higher ratings. The following are the major points of the findings:

1. EPR insulation systems are practically unaffected both thermally and electrically under extended testing at the higher temperature ratings.

95 WM 016-6 PWRD A paper recommended and approved by the IEEE Insulated Conductors Committee of the IEEE Power Engineering Society for presentation at the 1995 IEEE/PES Winter Meeting, January 29, to February 2, 1995, New York, NY. Manuscript submitted July 29, 1994; made available for printing December 8, 1994.

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2. Properly formulated ethylene copolymer insulation shields are thermally stable and suitable for 105℃/140℃ operation.

3. When tested to the AEIC[1] Thermomechanical Test @ 140℃, linear low density polyethylene jackets can withstand the higher rating with EPR insulated cables.

4. With increased current-carrying capacity, a reduction in conductor size may be possible depending on actual load requirements.

Thermal Aging Characteristics

The thermal aging behavior of EPR has been proven in tests to perform well beyond the current industry standards temperature rating of 90℃/130℃.

Thermal aging tests such as the Arrhenius model[14] is well known in the evaluation of cable life under thermal and oxidative behavior. According to the Arrhenius law, the overload period of 1500 hours at 140℃ represents two years continuous aging at 105℃. Under Arrhenius testing, compounds are considered to be at their "end of life" when the elongation reaches 50%.

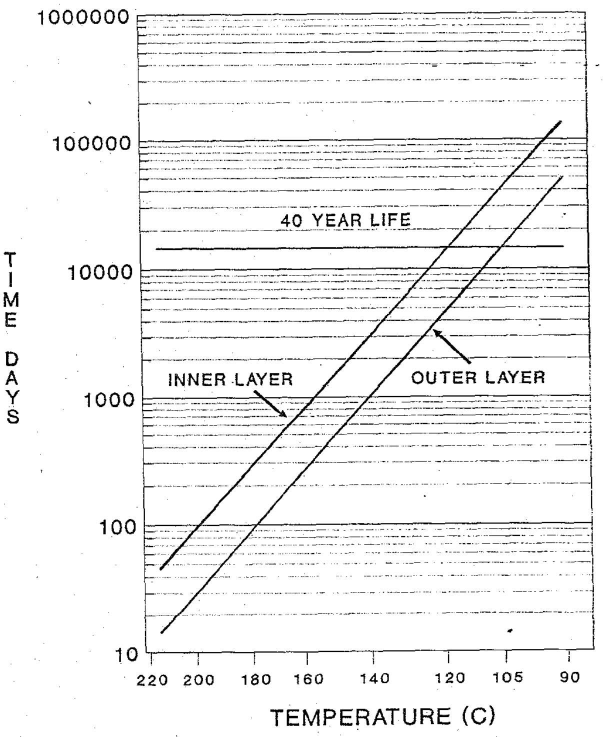


Fig. 1. EPR Insulation Arrhenius Life Curve
15 kV Cable Agings

Fig. 1 exhibits the results of full scale cable testing with the outer jacket and metallic screen removed. At each aging interval the mechanical characteristics were tested on samples taken at the inner surface of the insulation and the outer surface of the insulation. Comparative analysis of the inner portion of the insulation wall versus the outer portion of the insulation wall concludes that the differences in the results are the effect of oxidative aging at the outer wall, since the oxygen diffusion rate is greatly controlled through the insulation wall. In actual cable installation and operation, an outer jacket will provide additional protection for the outer insulation wall. The inner and outer semiconducting shields of the EPR insulation system exhibits similar aging characteristics of the adjacent insulation walls.

As noted in Fig. 1, EPR insulation exhibits an extended cable life; therefore, thermal aging is considered a negligible factor under conductor temperatures of 105℃ continuous and 140℃ overload.

Further, oxidative-thermal aging characteristics of EPR insulation exhibit results which are supportive of the higher 105℃/140℃ temperature rating. After 7 days air oven aging at both 121℃ and 150℃, the tensile strength and elongation display a percent retention of 100%, respectively. After extended air oven aging of 12 months at 121℃, substantially beyond any industry standard test, EPR insulation continues to show excellent results of 85% retention in tensile strength and 70% retention of original elongation.

As a result of formulation, selection of ingredients, and state-of-the-art mixing technology, the EPR insulation in this rigorous test program typically exhibits the stringent performance characteristics shown in Table 1.

Compatibility of Conductor Filling Compound

The effect of water (reduction of cable life) in the conductor of insulated (EPR, TRXLPE and XLPE) medium voltage power cables has been well documented by many authors throughout the past twenty years[15]. With the introduction of normal conductor operating temperatures in-excess of 100℃ for medium voltage power cables, it now becomes even more critical to assure that water will not enter the conductor during the cable's life. If water is present in the conductor while the cable's operating temperature goes above 100℃, the steam generated may damage the splices and terminations in the cable system. Therefore, it is essential to utilize either a solid conductor or a stranded conductor with a filling compound to impede the entrance of water when contemplating operating the cable system at a normal operating temperature above 100°C.

TABLE 1

PHYSICAL AND ELECTRICAL REQUIREMENTS OF EPR

Physical Requirements	Typical Value	ICEA Requirement*
Unaged		
Tensile strength, psi, min.	1850	700
Elongation at rupture, %, min.	300	250
Tensile stress at 200% elongation, psi, min. at room temperature	1500	---
After Air Oven Aging at 150° for 7 days (168 hours)		
Tensile strength, % of unaged value, min.	100	75**
Elongation at rupture, % of unaged value, min.	100	75**
Electrical Requirements	**Typical Value**	**ICEA Requirement**
Mechanical Water Absorption		
After 7 days (168 hours) in water at 82°C, mgms/sq. in., max.	5.0	---
Electrical Characteristics at Room Temperature (15.6°C)		
SIC at 80 V/mil, max.	2.7	4.0
% Dissipation Factor at 80 V/mil, max.	0.2	2.0
Insulation Resistance (K), min.	100,000	20,000
Electrical Stability in 90°C Water at 80 V/mil		
Dielectric Constant after 24 hours, max.	2.7	4.0
Dielectric Constant after 26 weeks, max.	2.7	---
Dissipation Factor after 24 hours, max., %	0.5	---
Dissipation Factor after 26 weeks, max., %	0.5	---
Stability Factor after 26 weeks, max.	0.2	---

*Type 1
**Requirement for aging at 121°C.

The compatibility of the conductor filling compound with the associated conductor stress control layers has been well established by both laboratory testing and its excellent field service record.

The conductor filling compound in conjunction with the conductor shield was subjected to compatibility testing as defined in ICEA Publication T-32-645[16] with the modification to 140°C emergency temperature. The resistance measurements of both the test specimens and the control were measured as a function of time while in the air oven. Time to stability of the test specimens and the control were achieved in the standard 42 days demonstrating no adverse effect to the conductor shield when tested to 140°C.

To further verify the compatibility of the conductor filling compound with the conductor shield, a layer of filling compound was sandwiched between two plaques of the inner semiconductive compound. The samples were placed inside an oven at 150°C and the electrical conductivity of both semiconductive plates was measured as a function of time. For comparison, the same measurements were performed on two plaques of the semiconductive material without the filling compound applied. The results are shown in Fig. 2. As can be seen, when tested out to 500 days, stability of the test specimens remained extremely constant.

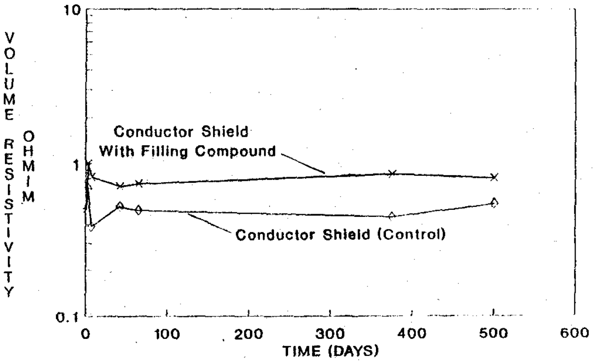


Fig. 2. Conductor Filling Compound and Conductor Shield Compatibility Testing @ 150°C

Semiconductive Shields

For extended life performance, it is necessary that the conductor shield and insulation remain totally bonded even if the conductor reaches the short circuit temperature of 250°C. For this reason, the choice of a conductor shield must be one which has a strong affinity to the EPR insulation. Typically, an ethylene based polymer is employed for this purpose. The criteria for the selection of the polymer base for use as a conductor shield are that it should 1) be capable of accepting the large quantity of carbon black required to achieve low resistivity, 2) be free stripping from the conductor, 3) develop an inseparable bond to the insulation and 4) have comparable heat aging characteristics to that of the insulation.

The criteria for the selection of the polymer base for use as an insulation shield are that it should 1) possess low and stable resistivity with temperature, 2) be compatible with the underlying insulation, i.e.,chemical, thermal, etc., 3) be resistant to deformation of the metallic shield, 4) possess comparable heat aging characteristics to that of the insulation, 5) be resistant to mechanical damage and 6) be free and clean stripping from the insulation.

An ethylene based copolymer is generally used as the base for an insulation shield compound for triple extrusion and in-line crosslinking with the conductor shield and insulation.

The ethylene based copolymer which yields a clean smooth interface with the insulation in the triple extrusion mode, provides controlled adhesion between the insulation and insulation shield while permitting the insulation shield to be removed for splicing and terminating leaving the insulation surface free of any conducting material. An EPR based polymer when used as an insulation shield compound would adhere firmly to the EPR insulation when applied in the triple extrusion process unless a lubricating agent is applied between the two layers.

In order to evaluate the compatibility between the insulation and insulation shield, one method of test is Thermal Gravimetric Analysis (TGA) of the insulation shield compound. Under isothermal conditions, the TGA scan will exhibit the weight loss characteristics of a material versus time. The actual plot from the TGA scan on the ethylene copolymer insulation shield formulated for this application and on EPR based insulation shields exhibit very similar weight loss characteristics as shown in Fig. 3. These weight loss characteristics are extremely low for temperatures in which EPR cables can be reasonably expected to operate, concluding that no harmful volatiles (acetic acid, etc.) are emitted from either insulation shield at temperatures well above the overload range. In addition, long term wet aging at operating temperatures have shown no harmful volatiles were emitted from ethylene copolymer insulation shields[17]. Both ethylene copolymers and EPR based insulation shields can exhibit thermal instability at higher temperatures; therefore, selection of a material should not be predicated on the base material but on test proven design parameters.

Thermomechanical Testing

The Thermomechanical Qualification Test introduced into the AEIC Specifications in 1987 was adopted as a means of ascertaining that each cable design will withstand the emergency operating temperature or whether a design would need to be derated. Failure in this test is indicated by cracking of the jacket or failure to comply with partial discharge and/or dissipation factor.

To demonstrate the 140°C emergency temperature capability of the EPR insulation system, the AEIC Thermomechanical Qualification Test was performed at a modified conductor temperature of 140°C.

The cable tested was a 500 kcm copper, 345 mils EPR insulation, copper concentric wires and an overall encapsulated polyethylene jacket, rated 35 kV. Additional designs are currently under test.

The test fixture used during this procedure was in accordance with AEIC CS6. The cable was installed in the two parallel, 15 ft long, 4 inch rigid, PVC conduits, which were joined at one end by a 16 inch radius, PVC U-Bend. The ends of the test fixture were sealed and adequate insulation was applied to the conduit to maintain the desired temperatures.

A total of 28 thermal cycles (twice the AEIC requirement) were completed, with each cycle consisting of the following: a load current of 950 amperes was applied to the conductor

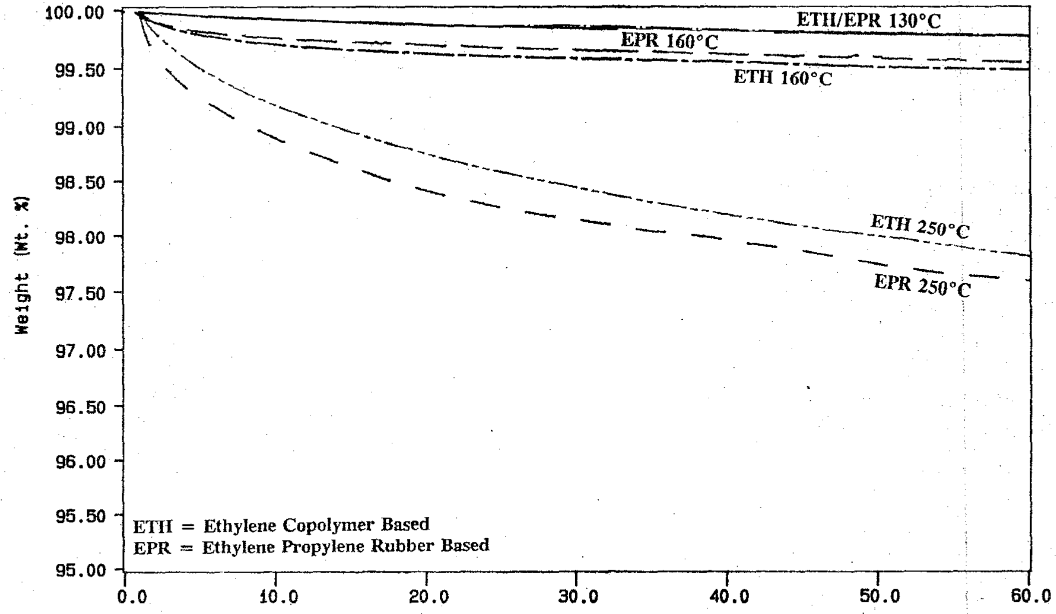


Fig. 3. Insulation Shield Isothermal TGA Studies

for approximately 10 continuous hours each working day. This load current produced a steady-state, emergency operating temperature of 140℃ for a period of not less than 6 hours per working day. These conditions produced an outside jacket temperature of 105℃. No voltage was applied during the thermal cycles.

After completion of the conditioning and electrical testing, the jacket was examined visually, and five (5) one foot samples were taken from the U-Bend for dimensional analysis, as outlined in AEIC CS6.

Evaluation concludes that the insulation was neither adversely affected or distorted while exposed to the 140℃ emergency temperature and no damage was exhibited to the external jacket while exposed to a maintained temperature of 105℃.

Electrical Testing

Samples of 15 kV cable were preconditioned for 72 hours at 140℃ to simulate in-service conditions and submitted to tan delta testing as a function of temperature. The samples were then subjected to two complete accelerated aging cycles each cycle consisting of continuous heating of 50 days at 105℃, 7 days at 140℃ and 0.5 hours at 250℃. Tan Delta was measured at the completion of each aging cycle at both rated voltage and 4 times rated voltage to ground. Dissipation factor measurements at the end of each aging cycle were virtually identical.

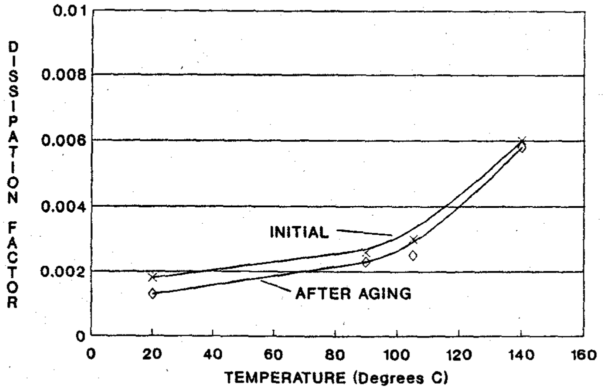


Fig. 4. Dissipation Factor vs. Aging
EPR Insulation with Strippable Insulation Shield

Fig. 4 displays the dissipation factor as a function of temperature and shows that the tan delta measurements after aging were slightly better than those obtained in the initial measurements. This excellent stability of dissipation factor versus aging further confirms the compatibility of the insulation shield utilized in the EPR insulation system.

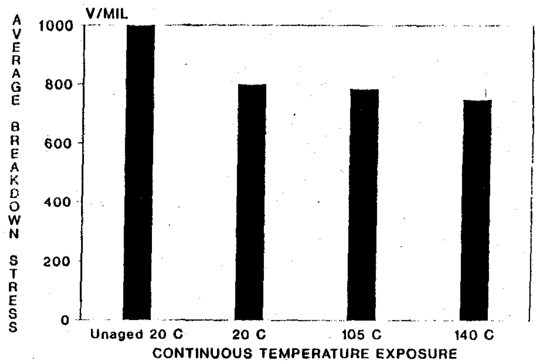


Fig. 5. EPR Insulation - AC Breakdown
vs. Temperature

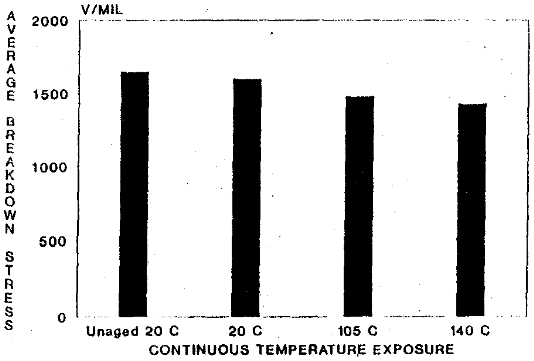


Fig. 6. EPR Insulation - Impulse Breakdown
vs. Temperature

Additional samples were preconditioned for 100 hours at 140℃ and subjected to dielectric tests both at power frequency and impulse at continuous temperatures of 20℃, 105℃ and 140℃. For the ac breakdown tests, 100 kV was applied for 10 minutes and increased 10 kV in 10 minutes steps until failure. The impulse tests consisted of 140 kV BIL followed by 25% increments of 10 negative impulses until failure. The results are shown in Fig. 5 and 6.

As can be seen the cables do not show any decrease of the dielectric strength up to 140℃. In impulse testing the cables show a limited decrease of their impulse dielectric strength from room temperature to 140℃.

Voltage Life Testing

The electrical breakdown of extruded dielectric cables is characterized by a scatter of failure levels and for this reason their reliability is most effectively predicted by means of a statistical approach. The choice of a suitable mathematical model to be applied to the distribution of breakdown stresses has been presented by many authors and in most cases the Weibull Distribution has been considered the most reliable [18][19]. Using this model it is possible to describe the breakdown probability of cable in terms of the magnitude and duration of the electric stress.

The "life curve" has been determined by submitting groups of 15 kV EPR insulated cable to various electrical gradients while continuously load cycling the cable at 110℃, 8 hours on, 16 hours off, which is 5℃ higher than the maximum continuous operating temperature. The upper curve in Fig. 7 represents the breakdown values at 63% of probability for 15 meter lengths of the 15 kV cables and based upon these results exhibits a life coefficient of 18.5 (inversely related to the slope of the curve) which has been found to be quite comparable to life tests determined at room temperature.

Considering other statistical parameters obtained in previous voltage life tests the survival probability of a 60 kilometer length is shown in the lower curve of Fig. 7. This curve represents an out of service probability of 1% exhibiting an extended cable life when operated at a continuous temperature of 105℃ and an average working stress over 125 volts/mil (5 kV/mm), i.e., maximum design stress at the conductor over 175 volts/mil (7 kV/mm).

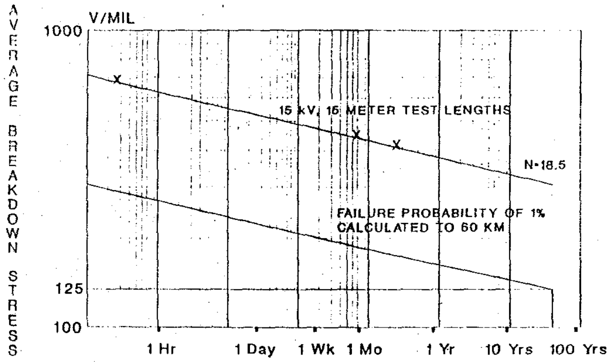


Fig. 7. EPR Voltage Life Curves @ 110℃

Maximum Design Stress

As medium voltage EPR insulated cables are normally constructed with a maximum design stress at the conductor of 60 to 80 volts/mil (2 to 3 kV/mm) at 90℃ operation, it is clear from the voltage life statistics that the reliability of EPR insulation is significant. The breakdown values at 63% of probability and the slope of the curves in Fig. 7 are indicative of exceptionally high quality cable with notable margin of safety at low probability of failure as compared to the operating conditions, i.e., 105℃ operation.

Based upon these results and the fact that EPR cables for high voltage operation are normally designed with a working gradient of 100 to 150 volts/mil (4 to 6 kV/mm) at the conductor, high voltage type EPR as tested in this program is suitable for higher operating design stress in medium voltage applications. The opportunity does exist for a maximum design working stress at the conductor of 100 volts/mil (4 kV/mm), resulting in a significant reduction in cable dimensions and cost to the users.

Wet Aging

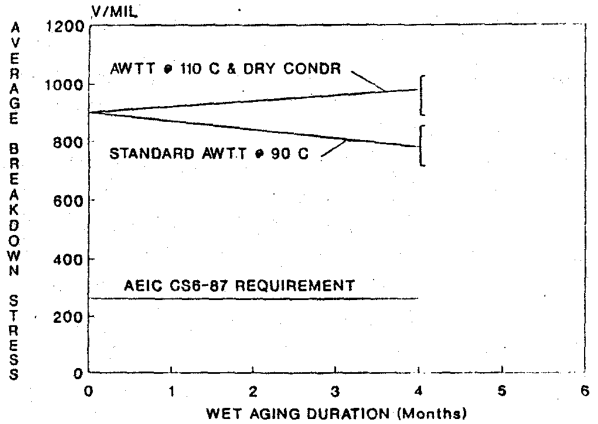
To demonstrate the wet aging stability, 105°/140° EPR insulated power cables were subjected to a modified version of the AEIC Accelerated Water Treeing Test (AWTT). As it was not practical to maintain liquid water both inside and outside the cable at a conductor temperature above 100℃, the AWTT Test was modified to run with a conductor temperature at 110℃, dry conductor, and water outside the cable in the AWTT tubes. This would be the case of a filled strand application. The test cable consisted of the standard #1/0 AWG aluminum, 175 mils EPR, rated 15 kV with 6 #14 copper concentric neutral wires and no overall covering.

Samples were preconditioned under the AEIC 14-Day Cyclic Aging Test @ 140℃ emergency temperature in lieu of the standard 130℃. Subsequently, the AWTT tubes were flooded with water for wet aging. Fig. 8 displays the 4-month AWTT test results of identical cables subjected to the modified AWTT @110℃ and dry conductor and standard AWTT @90℃ with wet conductor, with both conditions exposed to water on the outside. The samples at 110℃ exhibited AC breakdowns at 1020, 980 and 880 volts/mil while the standard AWTT exhibited AC breakdowns of 780, 700, and 840 volts/mil. The testing is continuing to twelve months.

Splices and Terminations

As the total cable system must be considered in the evaluation of higher operating temperatures, it is necessary to include suitable accessories in the test program.

Between the two accessories, the splice is the one which is subjected to more stringent operational conditions as they normally operate at temperatures slightly higher when compared to the cable. The opposite applies for the



Note: Initial Breakdown Values are After Cyclic Aging

Fig. 8. Modified AWTT @110℃

terminations. Compared to the terminations, the elastic stress relief of the operating splices can be stressed by expansion of 60 to 70%. Therefore, it was decided to verify the degradation of the mechanical parameters of the stress reliefs of the splices, particularly the tensile strength after extended durations at high temperatures. Similar materials can be employed in the terminations.

For this purpose, premolded stress reliefs made of EPR based compounds were chosen for the high temperature testing. 15 kV class stress reliefs were dilated on supports up to 100% and then aged at various temperatures. Testing continued at each temperature until lacerations were present in the elastic stress reliefs. Similar to the EPR insulation, the Arrhenius curve was plotted for the splices based upon a 100% stress relief expansion and is presented in Fig. 9. As can be seen, the system accessories also exhibit an extended cable life and excellent thermal aging characteristics at temperatures of 105℃ continuous and 140℃ overload.

The premolded stress reliefs were also subjected to AC withstand and impulse testing at ambient, 105℃ and 140℃ with the following results.

TABLE 2

DIELECTRIC WITHSTAND RESULTS

	Ambient	105℃	140℃
AC Withstand (5 minute steps)	135 to 145kV	130 to 140kV	120 to 135kV
Impulse	200 to 210kV	200 to 210kV	200 to 210kV

Ampacity Ratings

The higher temperature capability of the EPR insulation system will provide higher ampacity ratings for both copper and aluminum conductors of approximately 10 to 11 percent as shown in Tables 3 and 4. The present increase in ampacity rating may vary based upon other installations and operation conditions. While the benefit of increased current-carrying capacity may not allow a reduction to the next standard conductor size based on calculated ampacities, a reduction in conductor size may be passible relative to actual ampacity requirement. Nonetheless, a gain can easily be made by a system upgrade. The opportunities for higher operating design stress cables of 100 volts/mil (4 kV/mm) can substantially increase these benefits.

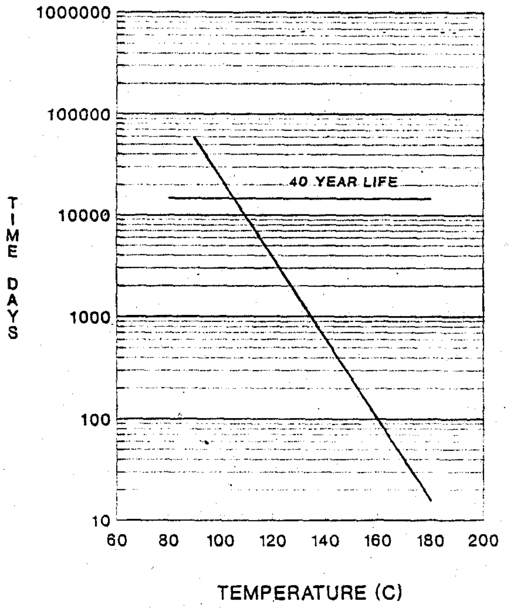


Fig. 9. Premolded Splice Arrhenius Life Curve
15 kV Class Agings

TABLE 3

25 kV 3-1/C EPRotenax, 1/3 Concentric Neutral and Jacketed Single Circuit, Underground Duct, 25℃ Ambient, 75% Load Factor
Copper Conductor

Conductor Size	Ampacity Rating (Amps)		Duct Sizes (Inches)
	90°	105°	
1	185	205	3.5
1/0	210	230	3.5
2/0	240	265	4
3/0	275	300	4
4/0	310	340	4
250	345	385	5
350	410	455	5
500	495	550	6
750	580	650	6
1000	635	710	6

TABLE 4

25 kV 3-1/C EPRotenax, 1/3 Concentric Neutral and Jacketed Single Circuit, Underground Duct, 25℃ Ambient, 75% Load Factor
Aluminum Conductor

Conductor Size	Ampacity Rating (Amps)		Duct Sizes (Inches)
	90°	105°	
1	145	160	3.5
1/0	165	180	3.5
2/0	185	205	4
3/0	215	235	4
4/0	245	270	4
250	275	300	5
350	330	360	5
500	395	440	5
750	495	550	6
1000	560	620	6

Note: Ampacities calculated per J. Neher, M. McGrath Method, AIEE Transactions, Power and Apparatus, Volume 76, October, 1957, pp. 752-772.

Summary and Conclusions

EPR insulated power cables have over thirty years experience in worldwide production and applications and has become recognized as a particularly suitable insulation compound for use in extremely hard environmental conditions. [3][6][8][10][11][12]

The test program and results presented conclude that medium voltage EPR insulated power cables are practically unaffected at the higher temperature rating of 105℃/140 ℃. The use of a properly formulated ethylene copolymer insulation shield has been shown to be quite compatible with the EPR insulation.

For installations in wet environments, filled strand or solid is the conductor of choice as water in the conductor is both undesirable and intolerable when the conductor operates at normal temperatures above 100℃.

Finally, cable selection for 105℃/140 ℃ operation must be one of total system design which includes the use of filled strand or solid conductor, properly formulated insulation system, appropriately selected splices and terminations, and an evaluation of system installation and operation.

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Frank L. Kuchta (M'84) received his BSEE Degree from Fairleigh Dickinson University in 1982. Upon graduation, he joined Pirelli Cable Corporation and has held various positions in design and application engineering. He is currently Supervisor of Application Engineering in the Research, Development and Engineering Department. His work has included specialized projects in computer aided design where he developed the computer program and user guide for the EPRI sponsored project, "Maximum Safe Pulling Lengths For Solid Dielectric Insulated Cables".

Mr. Kuchta is an active participant in IEEE-ICC and the Insulated Cable Engineers Association where he is Chairman in the development of a new concentric neutral cable specification. He currently holds one patent in the area of water blocked cable designs.

Mujibar M. Rahman received his BSME Degree, Mechanical Engineering, from Bangladesh University of Engineering and Technology, 1963, and his Dipl. Ing., from the Technical University of Darmstadt, Germany, 1967. He is currently Vice President and Chief Engineer for Pirelli North America and is responsible for RD&E of all cable products and accessories in USA and Canada.

After working as a teacher in the Technical University in Berlin, he joined Siemens, Germany in 1968 and worked in the RD&E of Telecommunication from 1968 to 1971. During 1971-76, he worked in the Energy Cable division of Siemens Austria in Vienna. Mr. Rahman joined Canada Wire and Cable in Montreal from 1977 to 1980 developing fiber optics. In 1981, he joined Pirelli-Canada and was responsible for optical fiber cable and facility development in Vancouver. In 1986, he was transferred to Pirelli USA and was responsible for RD&E-Telecommunications for Pirelli North America. Mr. Rahman is a member of various professional organizations and has several publications and patents.

Franco Ruffinazzi was born in Broni (Italy) on January 29, 1954. He received his Degree in Electrical Engineering from the University of Pavia, Italy, in 1979. In the same year, he joined Pirelli Cavi Ltd. Italy. He has been engaged in the Research and Development of high-voltage power cables and submarine cables for twelve years.

Mr. Ruffinazzi is currently a Manager of Extruded Insulated Power Cables, R&D Department.

Antonio Zaopo received his Degree in Chemistry from Padova University in 1975. After a short experience at the University working in the Physical-Chemistry Department, he joined Pirelli Cavi where he has been engaged in the R&D Department.

He is currently responsible for Materials R&D for all cable products. Mr. Zaopo is an active member of different IEC Working Groups related with materials for cables and has contributed several publications and patents.

DISCUSSION

J.C. CHAN, L.J. HIIVALA
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The increase in the temperature rating of EPR power cables from 90°C/130°C to 105°C/140°C raised a number of concerns relative to system stability, long-term performance reliability and economic impact due to increased conductor and dielectric losses.

Jackets

The increased temperature rating necessitates the use of jacket materials that are rated 90°C versus 75°C. Thus, low density PE will not be a suitable material according to ICEA, IEC and AEIC standards. Although the authors reported good performance of the PE jacket at 105°C in ideal laboratory conditions, it has not been demonstrated that the jacket can withstand rigorous service conditions such as high sidewall bearing pressures, mechanical clamping and thermomechanical bending forces.

System Accessories

There is a lack of published data in the area of accessories testing to demonstrate the performance reliability of the cable accessories at the continuous operating temperature of 105°C and emergency temperature of 140°C. For instance, no comprehensive testing has been performed to qualify the terminations to IEEE Std. 48-1990 or the splices to IEEE Std. 404-1993 at these elevated temperatures. Higher operating temperatures can only mean greater cable component migration problems due to expansion, greater mechanical stresses on fittings, clamps, connectors, stress cones, etc. resulting in accelerated deterioration of the cable/accessories components.

Also, what is the impact on terminal equipment connected to the ends of the cable (eg. switchgear, fuses, circuit breakers, lightning arrestors and transformers)?

Cable Surroundings

What studies have been done to ensure that the higher temperature ratings will not have an adverse effect on the thermal properties of the cable surroundings? For instance, will the higher temperature rating give rise to accelerated drying of the soil or backfill which can alter the thermal characteristics of the soil or backfill leading to possible thermal runaway?

Conductor Losses

The main reason given by the authors for the higher temperature ratings is to increase cable ampacity by about 10%. It should be borne in mind that increasing the conductor temperature from 90°C to 105°C also increases the conductor losses. Table 1 shows that the increase in conductor losses can be as high as 25% for a gain of ≈ 10% in ampacity. For a #1/0 or 4/0 Al conductor 25 kV cable, the increase in conductor losses is about 15 kW/cct.km. This translates into an energy loss of 360 kWh per day or 131 MWh per year for a 1 km circuit length. Can this be justified?

Dielectric Losses

A key difference between EPR and XLPE is the loss factor (i.e. the product of dissipation factor and dielectric constant) which is a measure of dielectric losses in a cable. Unlike XLPE, EPR exhibits a greater dissipation factor sensitivity with respect to temperature; and different EPR formulations display different dissipation factor characteristics as shown in Figure 1 [1]. Table 2 shows that dielectric losses become more significant at higher voltage levels. By increasing the cable operating temperature from 90°C to 105°C, the dissipation factor increases from 0.35 to 0.45% [Ref. 1] or from 0.26% to 0.33% [this paper], representing at least 25% increase in dielectric losses.

Validity of Conclusions

In the introduction, reference is made to the use of EPR-insulated power cables up to 245 kV. On the other hand, the authors present the results of tests carried out on 15-25 kV cables.

For high-voltage cables having larger conductor sizes and thicker insulations, consideration must be given to increased dielectric losses, thermomechanical effects, etc.

Do the authors consider their conclusions to be valid for all conductor sizes, insulation thicknesses and voltage classes? If not, what do they consider the appropriate limits to be?

1. J. Lasky & R. LaBozetta, "EPR Power Cables, Rated 105°C/140°C", 1993 IEEE Rural Electric Power Conference, Paper No. 93C2.

Table 1 Conductor Losses 90°C vs. 105°C

3−1/c Aluminum 25 kV EPR (1/3 CN) Jacketed, single circuit, Buried Duct

Conductor Size	Ampacity [A]		Cond. Resistance [Ohm/km]			Cond.Losses [kW/km]		Increase in losses [%]
	90°C	105°C	20°C	90°C	105°C	90°C	105°C	
1/0 AWG	165	180	0.551	0.706	0.740	19.2	24.0	25
4/0	245	270	0.274	0.352	0.368	21.1	26.8	27
250 Kcmil	275	300	0.232	0.298	0.312	22.5	28.1	25
500	395	440	0.116	0.149	0.156	23.2	30.2	30
750	495	550	0.077	0.099	0.104	24.3	31.4	29
1000	560	620	0.058	0.074	0.078	23.3	30.0	28

3−1/c Copper 25 kV EPR (1/3 CN) Jacketed, Single circuit, Buried Duct

Conductor Size	Ampacity [A]		Cond. Resistance [Ohm/km]			Cond.Losses [kW/km]		Increase in losses [%]
	90°C	105°C	20°C	90°C	105°C	90°C	105°C	
1/0 AWG	210	230	0.335	0.427	0.446	18.8	23.6	26
4/0	310	340	0.167	0.213	0.223	20.5	25.8	26
250 kcmil	345	385	0.142	0.181	0.189	21.5	28.0	30
500	495	550	0.071	0.090	0.095	22.1	28.6	29
750	580	650	0.047	0.060	0.063	20.3	26.6	31
1000	635	710	0.035	0.045	0.047	18.2	23.8	31

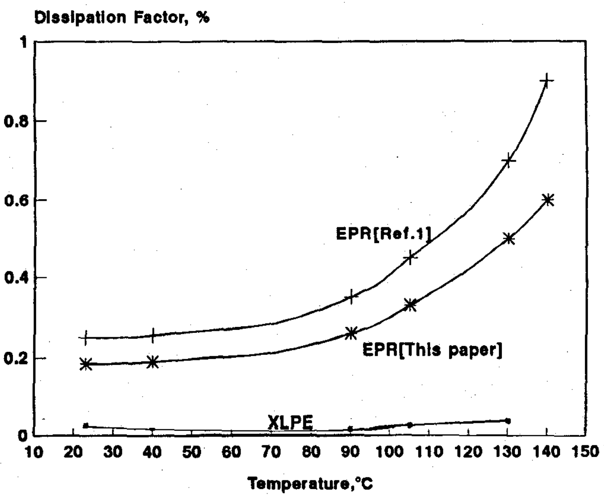

Figure 1 Dissipation Factor of EPR vs. XLPE

Table 2 Dielectric Losses in Power Cables

EPR Insulation

Cable Class [kV]	Uo [kV]	Cond. Size [Kcmil]	Cond. Dia. [in]	Ins. Wall [in]	Diel. Const	Cap. C [pF/m]	Diss. Factor [%]	Diel. Losses [W/m]	Diel. Losses [W/cct.km]
69	40	500	0.79	0.650	3.00	171.43	0.30	0.310	931
	40	750	0.97	0.650	3.00	196.05	0.30	0.355	1064
	40	1000	1.12	0.650	3.00	216.25	0.30	0.391	1174
35	20	1/0	0.36	0.345	3.00	156.47	0.30	0.071	212
	20	4/0	0.51	0.345	3.00	195.59	0.30	0.088	265
	20	250	0.56	0.345	3.00	207.37	0.30	0.094	281
	20	500	0.79	0.345	3.00	265.65	0.30	0.120	361
	20	750	0.97	0.345	3.00	310.18	0.30	0.140	421
	20	1000	1.12	0.345	3.00	347.01	0.30	0.157	471
15	8.7	1/0	0.36	0.175	3.00	246.76	0.30	0.021	63
	8.7	4/0	0.51	0.175	3.00	320.43	0.30	0.027	82
	8.7	250	0.56	0.175	3.00	342.83	0.30	0.029	88
	8.7	500	0.79	0.175	3.00	454.65	0.30	0.039	117

XLPE Insulation

Cable Class [kV]	Uo [kV]	Cond. Size [Kcmil]	Cond. Dia. [in]	Ins. Wall [in]	Diel. Const	Cap. C [pF/m]	Diss. Factor [%]	Diel. Losses [W/m]	Diel. Losses [W/cct.km]
69	40	500	0.79	0.650	2.30	131.43	0.03	0.024	71
	40	750	0.97	0.650	2.30	150.30	0.03	0.027	82
	40	1000	1.12	0.650	2.30	165.79	0.03	0.030	90
35	20	1/0	0.36	0.345	2.30	119.96	0.03	0.005	16
	20	4/0	0.51	0.345	2.30	149.95	0.03	0.007	20
	20	250	0.56	0.345	2.30	158.98	0.03	0.007	22
	20	500	0.79	0.345	2.30	203.66	0.03	0.009	28
	20	750	0.97	0.345	2.30	237.81	0.03	0.011	32
	20	1000	1.12	0.345	2.30	266.04	0.03	0.012	36
15	8.7	1/0	0.36	0.175	2.30	189.19	0.03	0.002	5
	8.7	4/0	0.51	0.175	2.30	245.66	0.03	0.002	6
	8.7	250	0.56	0.175	2.30	262.84	0.03	0.002	7
	8.7	500	0.79	0.175	2.30	348.56	0.03	0.003	9

Dielectric Loss in EPR cable is about 13 times that of XLPE cable

Manuscript received February 22, 1995.

P. Cinquemani, F. Kuchta, M. Rahman, R. Ruffinazzi, A. Zaopo The authors wish to thank Messrs Chan and Hiivala for their discussion. We would like to emphasize the objective of the test program and the paper. The objective was to determine the suitability of Pirelli's EPR for medium voltage cables to operate normal and emergency temperatures of 105°C and 140°C, respectively. Additionally we confirmed that acceptable accessories are available for this operation.

The following comments are called to the discussers' attention:

Jackets

The use of linear low density polyethylene (LLDPE) jackets have tested very positively under extended durations of the AEIC Thermomechanical Test at 140°C conductor loading and 105°C jacket temperature. While this material has not demonstrated any deficiency under industry accepted testing at these higher temperatures, we agree LLDPE may not be suitable for all applications and service conditions. Depending upon the application other materials may show additional benefits.

System Accessories

The premolded stress reliefs reported within this paper have been fully qualified to IEEE Standard 404-1993 at an independent testing laboratory. To further ensure suitability at the higher temperature ratings, the EPR premolds were subjected to cyclic aging in air for 12 cycles at 105°C and 12 cycles at 140°C, each cycle consisting of 12 hours current on, 12 hours current off. A continuous voltage of 2Vg was applied throughout the cyclic aging. The results provided in Table 2 of the paper exhibited ac withstand and impulse levels of 50% and 40% higher, respectively, than required for the rated cable. Additionally, the cable and accessory components evaluated in this test program demonstrated excellent compatibility and life expectancy for the intended application.

Cable Surroundings

You have made an excellent point relative to cable surroundings. It is a known fact that the higher temperature ratings may have an effect on the thermal properties of the cable surroundings, particularly accelerated drying of the soil. This information is well documented in EPRI Report EL-5090, "Thermal Stability of Soils Adjacent to Underground Power Cables" and "CEA Workshop on Thermal Design of Power Cables, June 1994". Critical factors which must be considered for direct buried cable is the interface temperature between cable and earth, quality and composition of the soils a cable backfill, thermal stability of the backfill, and the effect of soil/backfill moisture and compaction, whereas cable tray will have a completely different consideration. Proper engineering of the cable and system design will ensure the desired performance at these temperature. **We wish to reaffirm that one of the final conclusions in the technical paper was that "cable selection for 105°C/140°C operation must be one of total system design ......including the cable installation and operation."**

Conductor and Dielectric Losses

All material shows higher conductor and dielectric losses as temperature increases. The feasibility of operating at higher temperature must consider the total system loss over the designed life span. Therefore the decision to operate a system at a higher temperature needs to be based on the economics of the "total system" as a function of operating temperature, e.g. 35°C vs 90°C vs 105°C.

When designing an EPR system one should consider the low dielectric loss factor of the EPR insulation. This paper did not describe the performance of XLPE at 105°C/140°C.

Manuscript received May 8, 1995.