Experimental Investigation of Aging Effects of Dry-Band Arcing on ADSS Fiber- Optic Cables

George G. Karady
Yun Lei
Devarajan Srinivasan
Arizona State University

Monty Tuominen
Bonneville Power Administration

Brian G. Risch
Alcatel Optical Fiber Division

***Abstract*—A testing method for evaluating the quality of ADSS fiber optic cable is presented. Aging effect due to arcing under different voltage and pollution levels (heavy and light) is described. Measurement of area and depth of damaged cable is conducted to analyze the damage severity. Experiments show that 2 mA and 7 kV are threshold current and voltage which might cause cable failure. Cycle to failure of the cable decreases from 330 to 65 when voltage changes from 11 kV to 14 kV, and it is inversely proportional to the damage area of the cable.**

***Index Terms*—ADSS, Dry-band arcing.**

I. INTRODUCTION

THE ADSS(All Dielectric Self-Supporting) fiber-optic cables are frequently installed on transmission lines below the high voltage conductors by utilities. The failure of ADSS fiber-optic cables in high electric field environments is an industry-wide problem. Field observation shows problems ranging from simple discoloration of the cable surface to burning, which causes cable dropping[1]. The experimental results and the review of literature indicated that dry-band arcing, due to longitudinal electric fields and pollution along wet cables, caused most of the cables to fail[2][3]. Experiments were performed to identify the severity of corona discharge-caused deterioration of fiber-optic cables[4]. Fiber optic cables strung in electrically hostile environments need to last for a predicted life in excess of 25 years[5]. The object of this paper is to develop a testing method for the evaluation of quality of ADSS fiber optic cables, and to study the aging effects of dry-band arcing on ADSS fiber-optic cables. A new test method that represents quasi-environmental conditions experienced by fiber-optic cables strung along high-voltage transmission lines is introduced. The study of the effect of current-limiting impedances representing heavy and light pollution levels are also described. The effects of open circuit voltage and short circuit current on failure of the cable are introduced. The measurement of damaged area and depth on the cable is discusseded.

II. TEST EQUIPMENT FOR TESTING ADSS CABLES TO DRY-BAND ARCING

Armor rod assemblies are attached to grounded transmission line structures and support the fiber optic cables. If the cable is polluted and wet, a leakage current will flow through the cable jacket. The magnitude of the current depend on the placement of the cable with respect to the high voltage conductors, the conductor's voltage, and pollution on the cable's sheath. The current dries the wet pollution layer leading to the formation of dry-bands. A high voltage appears across the dry-bands and causes arcing. Dry-band arcing degrades the jacket material over a period of time and can lead to mechanical cable failure. ASU has developed test equipment and test procedures suitable for testing the ADSS cable jackets under dry-band arcing. The test method represents quasi-environmental conditions experienced by fiber-optic cables strung along high-voltage transmission lines in coastal areas, such as near the sea.

A. Test Setup

The electric circuit diagram of the test setup is shown in Figure 1[6]. A 18" length cable to be tested is prepared by sealing its end and fixing electrodes on the cable jackets. One electrode is grounded through a shunt resistor (for current measurement). The other electrode is energized with high voltage. The current is limited using a series RC limiting impedance. The cable is sprayed with salt water between the electrodes. The salt water forms a conducting layer on the cable surface. This generates a current on the surface of the jacket. When the spray is turned off, the current dries the jacket and a dry-band is formed. High voltage appears across the band resulting in arcing. The arc extends and then extinguishes. After allowing sufficient time for the arc to extinguish, the spraying process is started again. The test is repeated till the cable fails. Failure is defined as a puncture of the jacket. The number of cycles to failure is recorded. The test fixture can simultaneously test five cables. Figure 2 shows the test setup.

0-7803-8110-6/03/$17.00(C)2003 IEEE

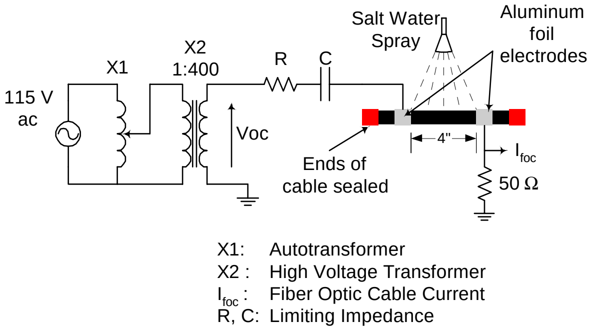

Figure 1. Test Setup Circuit Diagram[6]

Figure 2. Test Setup

B. *Water Cycling System*

A stainless steel tank was built for providing mechanical support to the cables and other test equipment. The tank has a drain hole at the center of its base. This drain will remain plugged during normal operation and will be used for periodic cleaning of the tank. The flow diagram of the spray system is shown in Figure 3. A plastic bucket is used to hold the salt water. A 0.5 hp self-priming pump is used to circulate the water through the system. There is a commercial, nylon in-line water filter with 40 mesh, 420 microns, stainless screen which is attached at the input of the pump. Water flow is measured and controlled by a flow meter with a valve. The flow rate (in our case, it is 3.5 gallon per minute) and salinity (1.5%) of the salt water are kept constant during the test. Each cable is sprayed by a nozzle arrangement. On the sides of the tank about 1" of water during normal operation, there are two drain holes. If a burning cable falls into the water, the water will extinguish the fire. Excess water is returned to the water bucket. A wet, conductive layer on the cable jacket between the electrodes is generated by the spray system. The cable surface was saturated by water spray in order to achieve some uniformity between spray cycles. The current through the saturated layer is very close to the short-circuit current since the layer resistance of the saturated cable is small compared to the limiting impedance. The time required for saturation depends on the flow rate of the water. Sprinkler nozzles can be used to spray salt water on the cable sample. The nozzles are mounted on ½" brass pipes, which connect to the plumbing system through a ½" flexible plastic pipe.

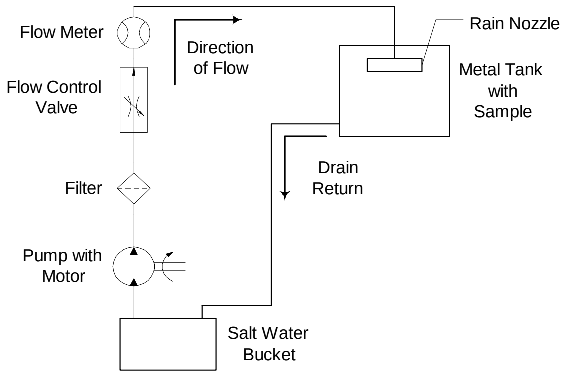

Figure 3. Flow Diagram of the Spray System

C. *Electric Setup*

The body of the tank is grounded. Insulators are mounted on the tank to isolate the high voltage from the tank(Figure 2). Each cable is energized through a RC limiting impedance. The RC limiting impedance is built on a printed circuit board. Non-inductive resistors with 12.5 wattage and maximum voltage ratings of 6kV are used to prevent damage due to high frequency components of the arcing current. The values of resistance and capacitance are determined by the pollution level (See Table 1). Current is measured by a shunt (50Ω) resistor with parallel voltage suppression devices. The resistors are terminated using co-axial connectors. The RC circuit is connected to the high voltage transformer through bare or insulated wire. An acrylic 'splash guard' is used to protect the resistance, voltage suppressors, and co-axial connectors from the water spray. High voltage wires are used for the connection of RC impedances to the insulators. Solid, bare copper wires are used to connect the insulators to the electrodes on the cable samples.

D. *Making the Cable Samples*

For making the cable samples, an aluminum foil is wrapped around each cable to act as electrodes. The electrodes should ensure that arcing occurs at the surface of the cable. It is believed (and indicated by laboratory tests) that dry-band arcing occurs in natural conditions between one of the electrodes and a boundary formed by a wet layer or between two wet layers. To simulate this, the electrodes should be spaced to prevent arcing between the electrodes at the maximum voltage level in the test. Experiments have determined that a 4"gap is sufficient for a system voltage of 40 kV. In addition, samples are long enough(18") to ensure that the ends do not get wet. Wires are connected to the electrodes using hose clamps. The cables are hung using a string.

E. *Protection Systems*

The high voltage transformer, metal tank, and all other components are placed inside a grounded, fenced cage to protect the operator from high voltage. All metal parts are connected together and grounded at the transformer terminal. The transformer is protected against short circuits. Protection circuitry ensures that the high voltage is switched off if the cage door is opened. All components(pump, valve, filter, water bucket, etc.) of the spray system are inside the grounded cage. Salinity, flow rate, or other adjustments are made only with the high voltage turned off. A standard high voltage grounding stick is used to ground the transformer high voltage terminal before working inside the cage. The 110 V auto transformer is protected by a fuse and circuit breaker. Dry-band arcing can cause certain jacket materials to ignite. To ensure 24 hr unsupervised operation, fire protection schemes were implemented. The metal tank contains the fire. Bare wires are used to connect to the cables. Fishing wire, which burns easily, is used to hold the cables. If the cable catches fire, the cable drops to the bottom of the tank. A wire mesh covers the tank above the cables. This mesh prohibits fire outside the tank. Two fire detectors are strategically placed over the mesh. In the event of a fire, the detectors trip a normally closed relay, which switches off the low voltage supply to the high voltage transformer. The mesh and fire detectors were thoroughly tested by intentionally setting cables on fire in the tank. The fire mesh and fire alarms are shown in Figure 4.

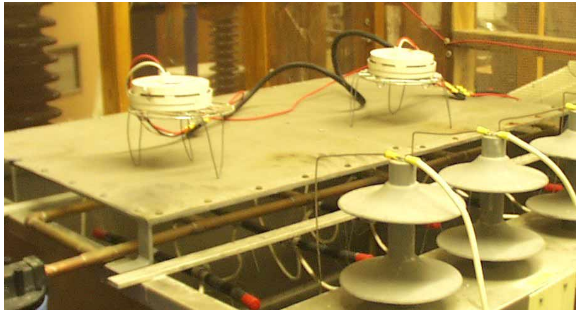

Figure 4. Fire mesh and fire alarm

F. *Test Procedure*

The test is performed under normal room temperature and humidity conditions. A sufficient quantity of the salt solution was prepared. The cable sample was installed in the test fixture and the required electrical connection was made. The control valve was set to get the desired flow rate from the nozzles. The setup was energized with the required high voltage. The cable was observed visually for failure. The current can be periodically checked to verify proper operation and recorded, if needed, for additional analysis.

G. *Data Acquisition And Control*

The test samples are continuously energized. The cables are wetted periodically and allowed to dry in cycles. An electronic or mechanical timer controls the pump for wetting the cable. Dry-band arcing occurs during the drying period. The discharge deteriorates and ultimately punctures the cable. The failure of the cable is determined by visual observation. The number of cycles to failure is counted. Visual observation can detect the failure with sufficient accuracy. However this requires the operator to inspect the cable regularly and stop the operation when discharge punctures the cable. Figure 1 shows that the test electrode is grounded through a 50 Ω resistance. The resistance is protected by a MOV or other surge suppression device. The voltage across this resistance is proportional with the current and can be connected to a data recorder or oscilloscope with a coaxial cable to observe or measure the cable current. The current measurement is not needed for the routine testing of ADSS cables. However, an experienced operator can determine if the system is operating properly by observing the current wave shape. During wetting, the current is sinusoidal and its rms value should be equal to the short circuit current level. Dry-band arcing distorts the current waveform. If the cable fails, the current waveform changes in an unpredictable way.

H. *Typical Test Results*

The critical electrical parameters for the dry-band arcing are the open-circuit voltage and short-circuit current. The test voltage must be high enough to generate dry-band arcing, but higher voltages are desirable to decrease times-to-failure of the cables. The short circuit current is determined by the pollution level. The limiting impedance values for different pollution levels are shown in Table 1.

Table 1. Limiting Impedance for Different Pollution Levels

Level	**Pollution Resistance Ω/m**	**R MΩ**	**C PF**
Heavy	10^5	5	600
Light	10^7	43	66.7

Under heavy pollution, open-circuit voltage levels of 14.66kV, 11kV, 7.33kV, 3.67kV are selected respectively. The short circuit current are 2.19mA, 1.65mA, 1.098mA, 0.55mA respectively. Under light pollution, the open circuit voltage level is 25kV and 14.66kV. The short circuit currents are 0.4mA and 0.24mA, respectively. The flow rate and water salinity are kept constant during the tests. A salinity of 1.5% is maintained. Tests have shown that water salinities above 0.75% does not effect the test results. A mechanical timer is used to control the pump. A typical cycle time is 15 minutes. The cable is wetted for 2 minutes and allowed to dry for 13 minutes. Cable failure is determined by visual observations. Five samples of the same cable are tested simultaneously. The average number of cycles to failure is recorded. Figure 5 and Figure 6 show typical test results obtained by testing three different cable types from the same manufacturer.

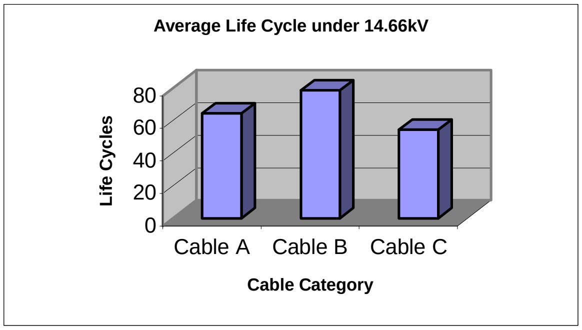

Figure 5. Life Cycles under 14.66kV, Heavy Pollution

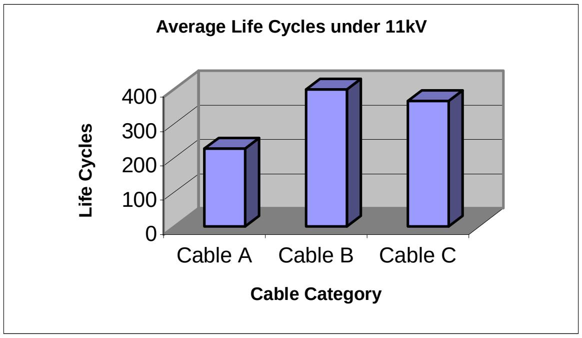

Figure 6. Life Cycles under 11kV, Heavy Pollution

I. *Analysis Based on the Measured Data*

From the above graph, we know that on an average it takes 65 cycles for the cable to fail or become damaged under 14.66kV(2.19mA), heavy pollution circumstance. For 11kV(1.649mA) of heavy pollution, it takes 330 cycles to fail or be punctured. For 7.33kV(1.098mA) and 3.67kV(0.55mA), there are no cable to failures. Under light pollution, for 25kV(0.4mA) and 14.66kV(0.24mA), there is not one cable failure or puncture. Possible reasons for not being damaged is the low short circuit current value of only 0.4 and 0.24mA. From the above data, it is found that in the general case, cable B is a better quality cable compared with cable A and cable C.

III. ANALYSIS BASED ON THE VOLTAGE AND CURRENT RELATIONSHIP

During the test, it is concerned that whether the open circuit voltage or short circuit current will play the key role in the failure process of the fiber optic cable. There is a test table to determine this.

Table 2 Test Results

Test Results(Cycles)		Short Circuit Current	
		1mA	2mA
Open Circuit Voltage	21kV	400	10
	14kV	400	23
	7kV	×	400

From the above test, it is found that the fiber-optic cable can endure 7kV, 2mA 400 cycles, there is generally a long narrow failure crack mark distributed along the longitudinal direction of the surface on some cable samples. For 14kV, 2mA test, the cable fails very fast, only 23 cycles. For 14kV, 1mA test, the cable still endures 400 cycles without failure or puncture of the cable. For the 21kV, 2mA test, there is a long duration time of dry band arcing on the surface of the cable. From phenomenon, the arc length is longer than the one of 14kV, 2mA's. It fails very fast (10 cycles on the average scale). From the above data, it is concluded that 2 mA is a kind of threshold short circuit current value under which the cable will fail or be damaged if dry band arcing occurs. 6-7kV is a kind of threshold open circuit voltage value under which there will be dry-band arcing on the surface of the cable. 1mA does not cause failure or even damage the cable. If the open circuit voltage is as high as 14kV and the short circuit current reaches 2mA, there will definitely be damage and the cable will fail.

IV. DEPTH AND AREA MEASUREMENT OF THE DAMAGED CABLE

In order to get a relationship between the failure life cycles and the damage of the cable, we measured the depth and area of the damaged cable. A microscope was used to measure the depth of the damaged cable. A digital camera was used to take photos of the damaged cable. In measuring the damaged surface area of the cable, a computer aided area measurement method was used while processing the digital photos.

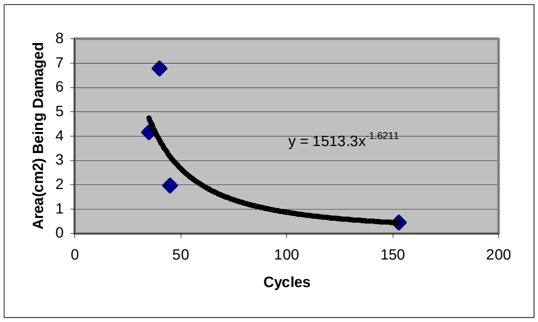

Figure 7. Damaged Area Measurement under 14.66kV for Cable A

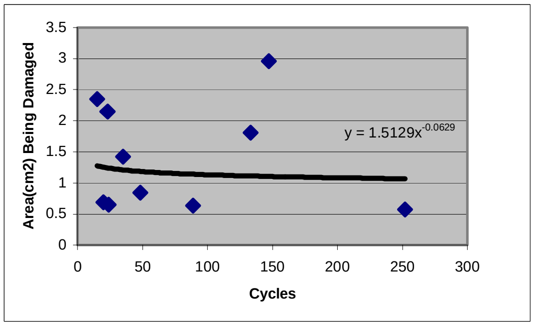

Figure 8. Damaged Area Measurement under 14.66kV For Cable B

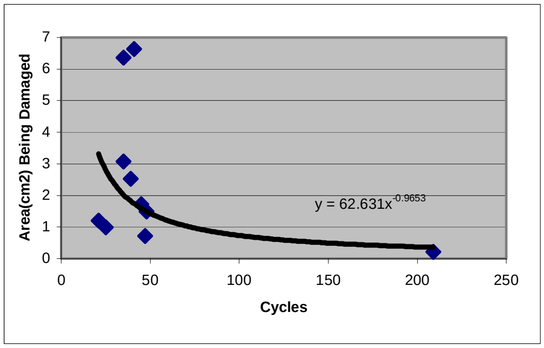

Figure 9. Damaged Area Measurement under 14.66kV for Cable C

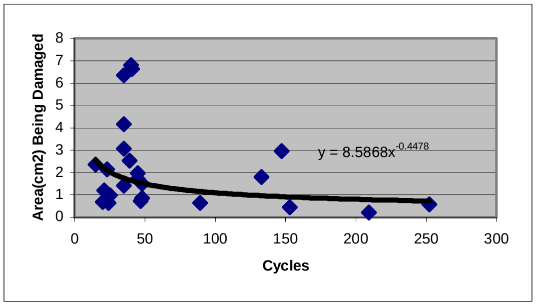

Figure 10. Overall Data of Damaged Area Measurement under 14.66kV

From the above graphs, it is found that, under 14.66kV(2mA), according to the power fit curve, the area damage of the cable is inversely proportional to the life cycles of the cable. There are spread errors among the data. In general, it tells us that if the cable fails very fast, dry band arcing would happen over a large area instead of focusing to one certain place. If the dry-band arcing focuses to a certain small place, the life cycle (to make the cable fail or to be punctured) will become longer. This case will also be seen at the test under 11kV(2mA) circumstance. Figure 11 shows that the power fit curve still give an inversely proportional relationship between the life cycles and damaged area of the cable A under 11kV(2mA). For the cable B and C under 11kV 2mA case, since they didn't fail or become punctured at 400 cycles(cut off cycle), there are only some small damage on the surface, we can not correlate the life cycles with the damaged area and depth measurement.

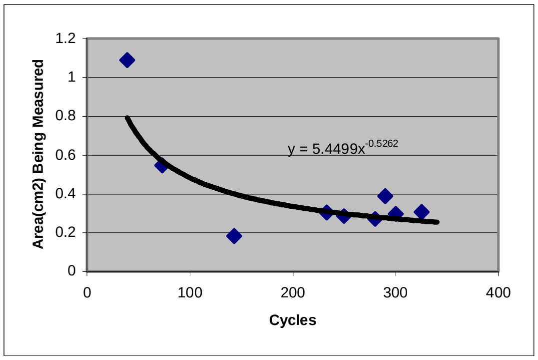

Figure 11. Damaged Area Measurement under 11kV for Cable A

For the depth measurement, there is no obvious relationship between the life cycle and depth of being damaged. This can be shown from Figure 11 to Figure 14.

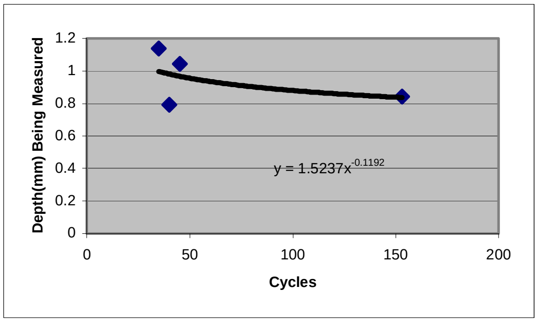

Figure 12. Damaged Depth Measurement under 14.66kV for Cable A

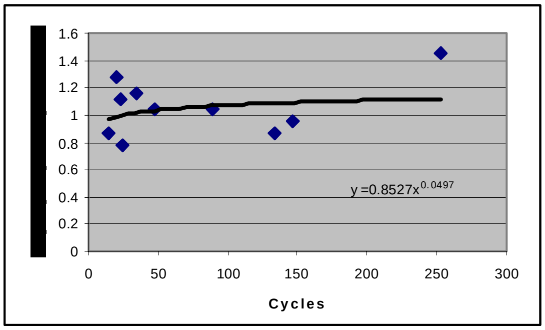

Figure 13. Damaged Depth Measurement under 14.66kV for Cable B

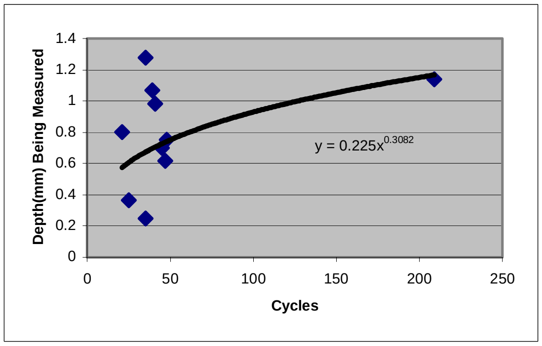

Figure 14. Damaged Depth Measurement under 14.66kV for Cable C

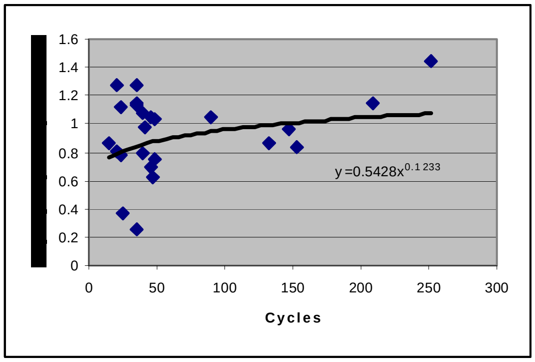

Figure 15. Overall Data of Damaged Depth Measurement under 14.66kV

Under 14.66kV(short circuit current is 2mA), the average area damage ranges from 1.4 cm^2 to 2.6 cm^2, the average depth damage ranges from 0.7mm to 1.05mm. Under 11kV(short circuit current is 1mA), the average area damage ranges from 0.05 cm^2 to 0.40 cm^2, the average depth damage ranges from 0.06 mm to 0.7 mm. It shows that the area and depth damage will increase with the open circuit voltage and short circuit current.

V. CONCLUSION

A. A new test method has been developed which will represent environmental conditions experienced by fiber-optic cables strung along high-voltage transmission lines in coastal areas, such as near the sea.

B. The effect of current-limiting impedances representing heavy and light pollution levels has been studied. Under heavy pollution, on average, when open circuit voltage is 14.66kV(short circuit current 2mA), the cycle to failure is 65, when open circuit voltage is 11kV(short circuit current 1.65mA), the cycle to failure is 330. For 7.33kV(1.098mA) and 3.67kV(0.55mA), the cable does not fail, life cycle reaches 400. Under Light pollution, for the case of 25kV(0.4mA) and 14.66kV(0.24mA), the cable does not fail. The life cycle reaches 400 also. The possible reason is the low current value.

C. Attempted to determine the effects of open circuit voltage and short circuit current on dry band arcing of cable failure process. It is found that in the test, 2mA is enough short circuit current to cause cable failure. The threshold open circuit voltage for forming dry band arcing is 6-7kV.

D. Material related measurements were conducted such as depth and area measurement of damaged area of the cable. The life cycle of the cable is inversely proportional to the damaged area on the surface of the cable. This shows that if the cable fails fast, the dry band arcing would have happened many places on the surface of the cable instead of focusing on one certain spot.

References:

[1] S.M. Rowland, K. Craddock, et. al., "The development of a metal-free, self supporting optical cables for use on long span high-voltage overhead power lines," *Proceedings of the 36th International Wire and Cable Symposium*, Arlington, 1987, pp. 449-456.

[2] Jurdens, H. Haag, R. Buchwald, "Experience with optical fiber aerial cables on high tension power lines," *1988 CIGRE Conference*, Paris, Paper 22-11.

[3] C.N. Carter, "Dry band electrical activity on optical cables separately strung on overhead power lines," *Proceedings of the 37th International Wire and Cable Symposium*, Reno, NV, November 1988, pp. 117-121.

[4] Karady, G.G.; Besztercey, G.; Tuominen, M.W., "Corona caused deterioration of ADSS fiber-optic cables on high voltage lines," *IEEE Transactions on Power Delivery*, Volume: 14, Issue 4, Oct. 1999 pp 1438 -1447.

[5] Rowland, K. Craddock, et. al., "The development of a metal-free, self supporting optical cables for use on long span high-voltage overhead power lines," *Proceedings of the 36th International Wire and Cable Symposium*, Arlington, VA 1987, pp. 449-456.

[6] Brian G Risch, Swati Neogi, George Karady, Yun Lei: "Evaluation of ADSS Jacketing Compounds and environmental Exposure Effect Using a New Dry Band Test Methodology". Proceeding of the 51 IWCS, International Wire & Cable Symposium, pp:551-559, November 2002.

VI. BIOGRAPHIES

George G. Karady (SM'70, F'78) received BSEE and Doctor of Engineering degree in electrical engineering from Technical University of Budapest. Dr. Karady was appointed to Salt River Project Chair Professor at Arizona State University in 1986, where he is responsible for the electrical power education and performs research in Power Electronics, High Voltage Techniques and Electric Power. Previously, he was with EBASCO Services where he served as Chief Consulting Electrical Engineer. He was Electrical Task supervisor for the Tokomak Fusion Test reactor project in Princeton. He worked for the Hydro Quebec Institute of Research as a Program manager. He worked for the Technical University of Budapest where he progressed from Post Doctoral Student to Deputy Department Head. Dr. Karady is a registered professional engineer in New York, New Jersey and Quebec. He is the author of more than 100 technical papers.

Yun Lei was born in Xining, China. He received his B. S in 1993 and the M.S degree in 1996 at Xi'an Jiaotong University, Xi'an, China. He is currently a graduate student at Arizona State University.

Devarajan Srinivasan was born in Baroda, India and is a student member of IEEE since 1993. He received his B. Tech degree from the Regional Engineering College, Calicut, India in 1992 and the MS degree from Arizona State University in 1997. He is currently a graduate student in the Ph.D. program at Arizona State University.

Monty W. Tuominen A native of Washington State, attended Washington State University in Pullman receiving a BSEE (with distinction) in 1968 and an MSEE in 1974. Military service (1969 through 1971) included one year as an electronics instructor at Ft. Monmouth, New Jersey and a year in Nha Trang, Vietnam as an electronic technician. After seven years of designing controls for the forest products industry he came to BPA in 1981. He is presently an electrical engineer in Technical Services of BPA's Transmission Business Line. His work encompasses the Corona and Field aspects of both AC and DC transmission lines and substations. He is currently responsible for properly locating fiber-optic cables on transmission structures relevant to the electrical environment. Mr. Tuominen is a member of the IEEE WG on Corona and Field Effects and is chair of the task force on Corona on Fiber-optic Cables. He is the chair of EPRI's Fiber-optic WG. He has authored several BPA reports and American Power Conference reports concerning fiber-optic cables on high voltage towers. He is registered as a Professional Electrical Engineer in the state of Oregon.

Brian G. Risch is the Cable Materials Manager at Alcatel. He holds a B.A. degree in physics from Carleton College and a Ph.D. in Materials Science and Engineering from Virginia Polytechnic Institute and State University. His Ph.D. research was in the area of polymer crystallization and structure-property relationships in polymers. Since 1996 Brian has worked for Alcatel's Optical Fiber Cable R&D center specializing in cable materials and fundamental material reliability studies.