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June 1992

# **Waltz Mill Testing of 765-kV Paper-Polypropylene-Paper (PPP) Cable**

Prepared by  
Westinghouse Electric Corporation  
Ruffs Dale, Pennsylvania

## Waltz Mill Testing of 765-kV Paper-Polypropylene-Paper (PPP) Cable

A prototype 765-kV PPP-insulated pipe-type cable was subjected to a two-year accelerated test program at EPRI's Waltz Mill Cable Test Center. The cable performed well and demonstrated its suitability for commercial service. This report provides details of the installation, test program, and results.

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### INTEREST CATEGORY

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Underground cables

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### KEYWORDS

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Pipe-type cables  
Underground transmission  
Transmission cables  
Taped cables  
Joints  
Terminations

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**BACKGROUND** With the advent of 765-kV as a transmission voltage, underground cable system development (EPRI report EL-2196) proceeded as a complement to the more common overhead transmission system. At these higher voltages, a lower-loss cable insulating material is a necessity for economic operation. A three-layer tape laminate, composed of cellulose paper and polypropylene film (PPP), was chosen as the insulating material in the 765-kV prototype cable system. Short-term laboratory testing indicated that the system was well designed. Some reasonable assurance of system reliability through stringent long-term accelerated life testing was needed. The necessary testing was cosponsored by the Empire State Electric Energy Research Corporation and EPRI.

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**OBJECTIVE** To determine the integrity, reliability, usefulness, and life expectancy of a prototype 765-kV PPP pipe-type cable system.

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**APPROACH** Investigators acquired and installed a prototype 765-kV pipe-type cable system at EPRI's Waltz Mill Cable Test Center. The system was composed of approximately 250 m of cable, two joints, and two terminations. Suitable instrumentation for monitoring cable system conditions was installed. The investigators devised a two-year accelerated-life test program, operating the cable at conductor temperatures ranging from 85 to 105°C and phase-to-ground voltages from 464 to 607 kV. Both steady-state and cyclic loadings were imposed on the system. Dissipation factor measurements were made throughout the program.

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### RESULTS

- The cable, joints, and terminations endured the test program with no increase in dissipation factor, thus demonstrating sound designs suitable for commercial service.
- In view of the excellent performance of the cable, an extended test program was initiated in 1988 to enhance user confidence in the system's reliability. As of December 31, 1991, an additional 120 weeks of test time have accumulated with continuing stable performance.

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**EPRI PERSPECTIVE** This development project (EPRI report EL-2196), a seven-year effort, was followed by four calendar years of field testing at EPRI's Waltz Mill Cable Test Center. Eleven years and several back-to-square-one restarts were

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required before success was finally achieved. The research success at 765 kV led to the more important and economically rewarding commercial success at the 138- to 345-kV levels. PPP cable systems have been written into industry standards up to 765 kV, and they are a very attractive cost-saving option for new or retrofit underground transmission installations.

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**PROJECT**

RP7801-7

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Contractor: Westinghouse Electric Corporation

For further information on EPRI research programs, call  
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Waltz Mill Testing of 765-kV  
Paper-Polypropylene-Paper (PPP) Cable

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TR-100422  
Research Project 7801-7

Final Report, June 1992

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## ABSTRACT

A 765-kV PPP-insulated cable was subjected to a 27-month accelerated life test program at the EPRI Waltz Mill Cable Test Facility. Testing started in August 1981 and was successfully completed in January 1985. The program included conductor temperatures ranging from 85°C to 105°C and line-to-line voltages from 800 kV to 1050 kV. Cyclic testing was performed during 20 of the 27 months. Dissipation factor measurements were made throughout the program. The measurements indicated no deterioration of the cable or splices as a consequence of the high temperatures and voltages applied to them in this test program.



## CONTENTS

<u>Section</u>		<u>Page</u>
1	INTRODUCTION	1-1
	Scope of Test	1-1
	Waltz Mill Site	1-1
2	CABLE SYSTEM DESCRIPTION	2-1
	Cable	2-1
	Splices	2-2
	Potheads	2-2
3	TEST INSTALLATION	3-1
	Potheads and Risers	3-2
	Main Runs	3-4
	Splices	3-5
	Loop	3-6
	Load Current	3-7
	Temperature Measurements	3-8
	Temperature Control	3-9
	Temperature Safety	3-9
	Oil System	3-10
4	TEST PROGRAM AND PROCEDURES	4-1
	Test Program	4-1
	Conductor Temperature Settings	4-5
	Dissipation Factor Measurement	4-6
5	TEST RESULTS	5-1
	Main Runs	5-1
	Splices	5-3
	Gas-in-Oil Analysis	5-4

<u>Section</u>		<u>Page</u>
6	PROBLEM AREAS	6-1
	Short in Current Circuit	6-1
	Loop Insulation	6-2
	External Flashovers	6-3
	Standard Capacitor	6-3
7	CONCLUSIONS	7-1
8	EXTENDED TEST PROGRAM	8-1
APPENDIX	CHRONOLOGY OF TEST PROGRAM	A-1
REFERENCES		R-1

## ILLUSTRATIONS

<u>Figure</u>		<u>Page</u>
2-1	Waltz Mill 765-kV PPP Cable	2-1
2-2	Schematic of Waltz Mill 765-kV Splice Design	2-2
3-1	PPP Cable Arriving at Waltz Mill	3-1
3-2	Schematic of Waltz Mill Test Bay 34	3-2
3-3	Enclosure Arrangement During Cable Termination	3-3
3-4	Test Bay 34: Terminations and Risers	3-3
3-5	765-kV Terminations Viewed From EHV Substation	3-3
3-6	Installation of 765-kV PPP Cables in Main Run	3-4
3-7	Test Bay 34: Splice Enclosure and Main Run	3-5
3-8	Aerial View of Test Bay 34	3-6
3-9	Current Transformers Located Under the Pothead Stand	3-7
3-10	Thermocouple Locations on Cable Shield and Pipe	3-8
3-11	Attachment of Thermocouple During Cable Installation	3-9
4-1	Waltz Mill Test Profiles for 765-kV PPP Cable	4-5
4-2	Temperature Curves for 765-kV PPP Cable	4-6
4-3	Bridge Circuit for Dissipation Factor Measurements	4-8
5-1	Variation of Dissipation Factor over the Test Program for the Two Main Run Cables	5-2

<u>Figure</u>		<u>Page</u>
5-2	Variation of Dissipation Factor with Conductor Temperature for Main Run No. 2	5-2
5-3	Variation of Dissipation Factor over the Test Program for the Two Splices	5-3
5-4	Variation of Dissipation Factor with Conductor Temperature for Splice No. 2	5-4
6-1	Short in Current Circuit	6-2
6-2	Damaged 1600-kV Standard Capacitor	6-4
6-3	Installation of 1000-kV Standard Capacitor	6-4

## TABLES

<u>Table</u>		<u>Page</u>
4-1	Planned Waltz Mill Test Program for 765-kV PPP Cable	4-2
4-2	Actual Waltz Mill Test Program for 765-kV PPP Cable	4-3
5-1	Gas-in-Oil Measurements for Potheads	5-6
5-2	Gas -in-Oil Measurements for Splice and Main Run Areas	5-7



## Section 1 INTRODUCTION

### SCOPE OF TEST

In 1981, a 765-kV PPP-insulated cable manufactured by Phelps Dodge Cable and Wire Company was sent to the EPRI Waltz Mill Underground Transmission Test Facility for evaluation. Installation at Waltz Mill was finished in July 1981 and testing began the following month. In January 1985, the cable successfully completed an accelerated life test program designed to demonstrate its suitability for utility service.

This report documents the results of the test program and includes a description of the cable installation, the test program, thermocouple placement, and the results of dissipation factor measurements. There is a description of the cable and components, for reference purposes. Various problems encountered during the test program are also discussed.

The installation and test programs were similar to that utilized since 1969 for various newly developed cables ranging from 138 kV to 765 kV. Reference 1 describes earlier tests on high-pressure oil-filled cables.

The development of the 765-kV PPP cable is described in References 2-4. A summary of this development and the subsequent test programs is given in Reference 5.

### WALTZ MILL SITE

The EPRI Underground Transmission Test Facility at Waltz Mill, Pennsylvania, is a 29-acre outdoor test site, south and east of Pittsburgh, near the New Stanton exit of the Pennsylvania Turnpike. The primary purpose of the facility is accelerated life testing of newly developed cable systems with voltages ranging from 69 kV to 1200 kV. It is also available for other evaluations that require continuous high voltage, circulating load currents, and computerized test parameter control.



## Section 2 CABLE SYSTEM DESCRIPTION

The cable system that was tested included 285 meters of cable, two splices, and two terminations.

### CABLE

Figure 2-1 shows details of the cable construction. Main features are a 1013-mm<sup>2</sup> (2000-kcmil) compact segmental copper conductor and a 31.8-mm (1.250-in) wall of paper-polypropylene-paper (PPP) insulation impregnated with polybutene. For the Waltz Mill sample, nylon rather than metallic skid wires are used to electrically isolate the cable shield from the grounded pipe. This allowed us to make power factor measurements on the cable as described in section 4.

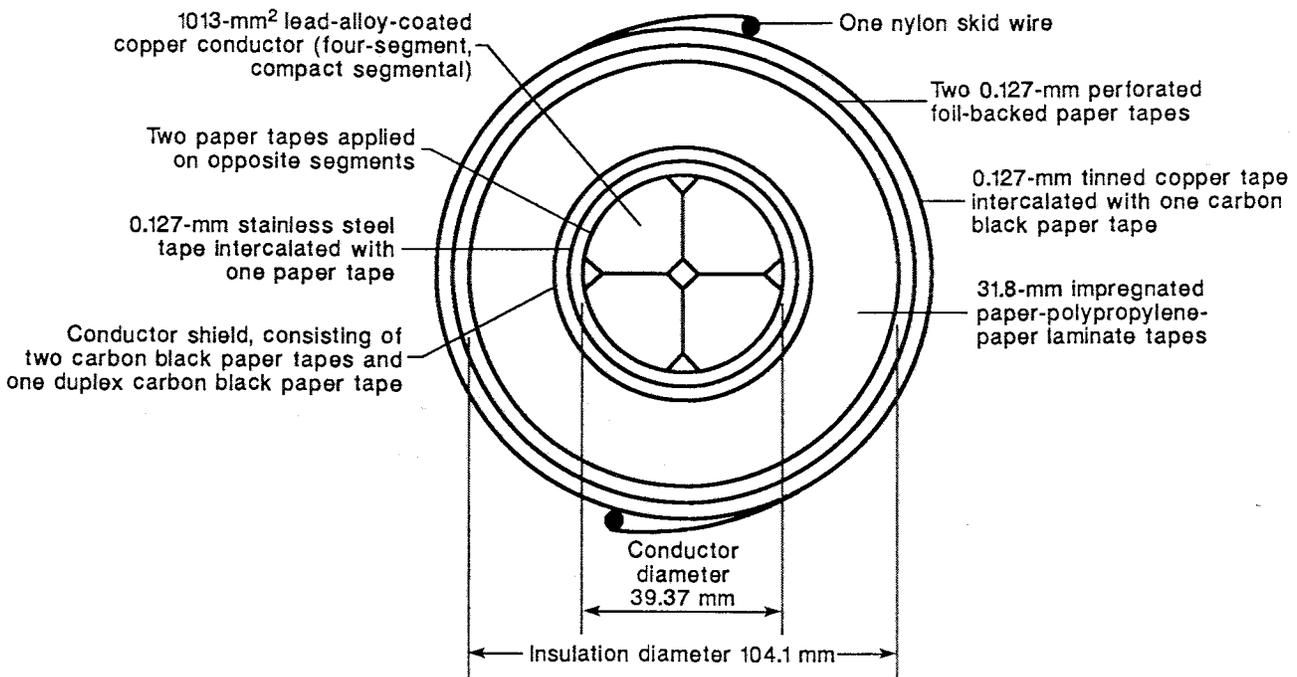


Figure 2-1. Waltz Mill 765-kV PPP Cable

## SPLICES

Each of the two splices as shown in Figure 2-2 has an overall length of 3.84 meters. The insulation thickness of 52 mm over the FM connector is constructed of impregnated PPP tapes.

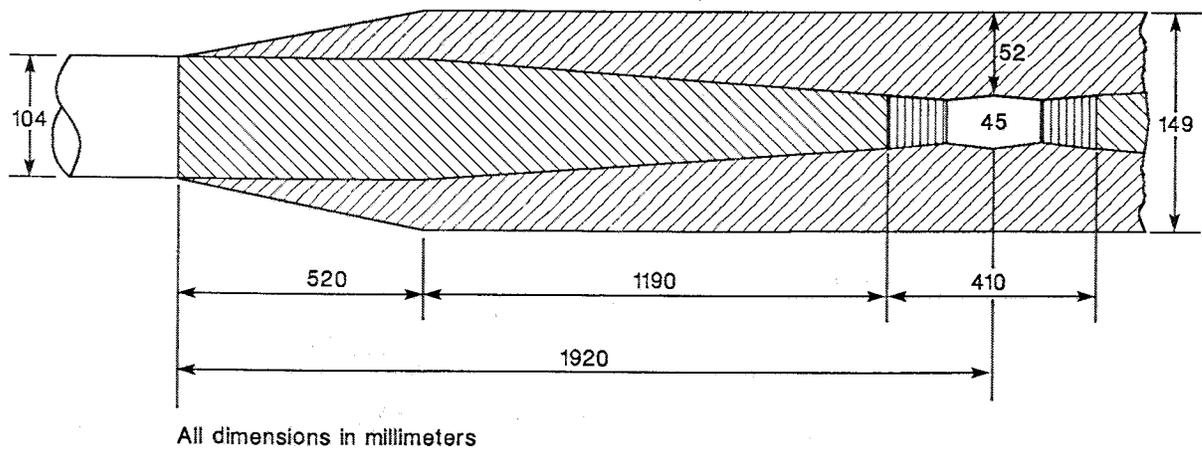


Figure 2-2. Schematic of Waltz Mill 765-kV Splice Design

## POTHEADS

The cable is terminated in two G&W capacitor-graded, 765-kV potheads. These oil-filled potheads have an overall height of 8.26 meters from the base plate to the top of the ferrule. The outside diameter of the porcelain is 0.632 meters.

### Section 3 TEST INSTALLATION

The cable was shipped to Waltz Mill on three reels, two of which are shown in Figure 3-1. Two of the reels were used for the main run and one for the loop segment.

The cable was installed in test bay 34, which had been used for testing a 500-kV sample when Waltz Mill was built in 1969. The test bay required only minor modifications, since the 765-kV PPP cable has virtually the same outer diameter as the 500-kV paper cable.

The installation was carried out under representative field conditions, i.e. using the same procedures and personnel that would be used in a commercial installation for this type of cable. It consisted of pulling the three lengths of cable into the test bay pipes and fabricating the splices and terminations. Shield interrupts were built into the cable, dividing it into seven distinct segments as shown schematically in Figure 3-2 and described below.

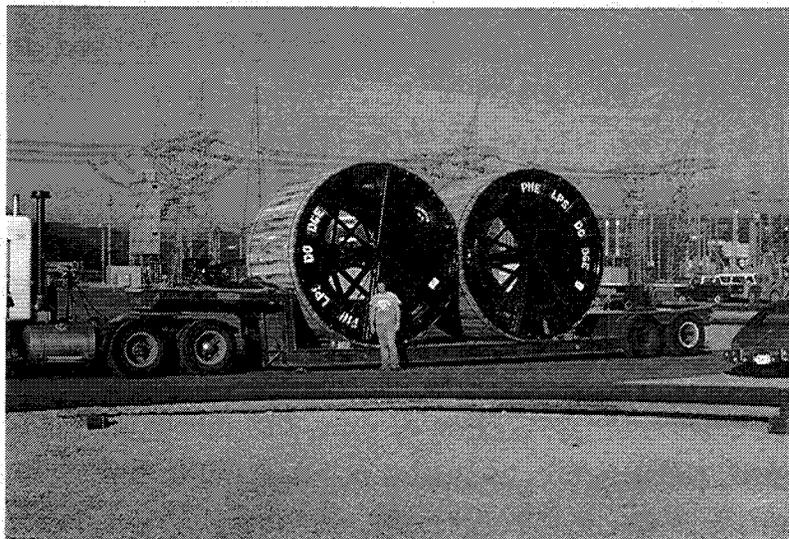


Figure 3-1. PPP Cable Arriving at Waltz Mill

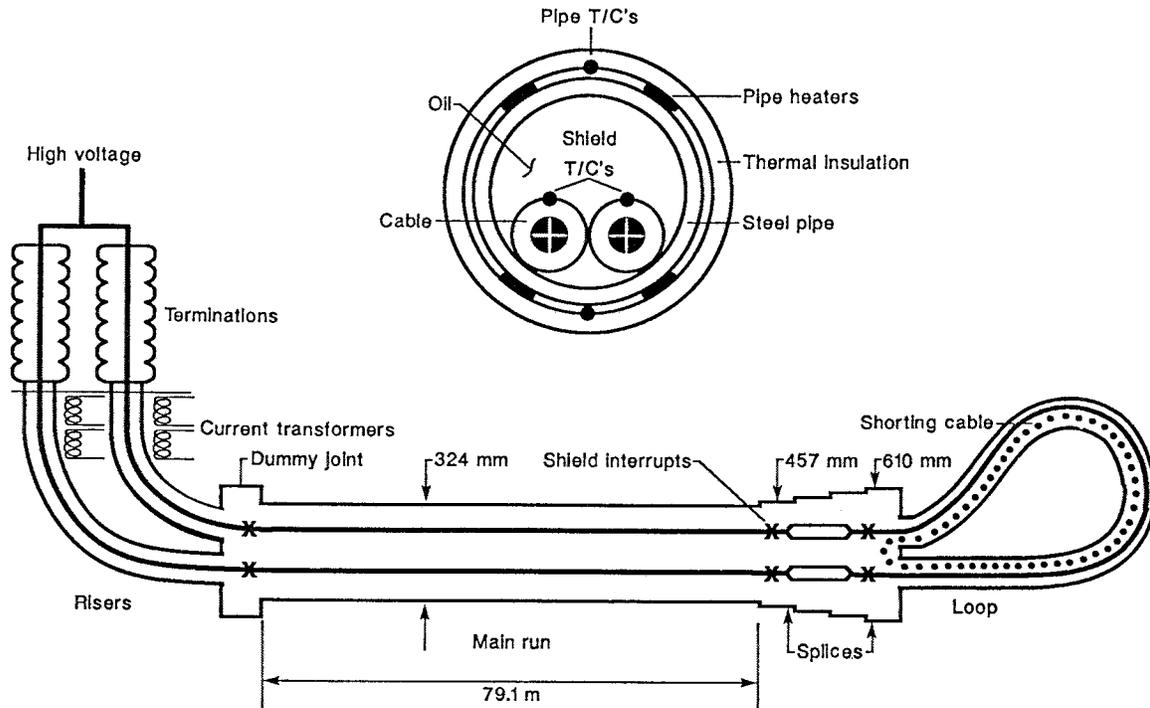


Figure 3-2. Schematic of Waltz Mill Test Bay 34

### POTHEADS AND RISERS

Two riser sections provide the transition from the terminations to the main run. The potheads were mounted on a steel structure 4.57 meters high. Figure 3-3 shows this structure with the air-conditioned enclosures that were used during termination of the cable. Two views of the completed potheads, along with the riser pipes, are shown in Figures 3-4 and 3-5. The stainless steel pipes that enclose the riser sections of cable are 219 mm in diameter and have a 3.05-meter radius of curvature. They extend 12.2 and 9.1 meters, respectively, from the base of each pothead to the dummy joint, and are covered with a 25.4-mm thickness of rigid urethane insulation.

The dummy joint is an enlarged section of pipe, 610 mm in diameter by 2.59 meters long, which permits construction of shield interrupts after the cable has been pulled into the main runs and risers. Thickness of the fiberglass insulation on the dummy joint is 38.1 mm.

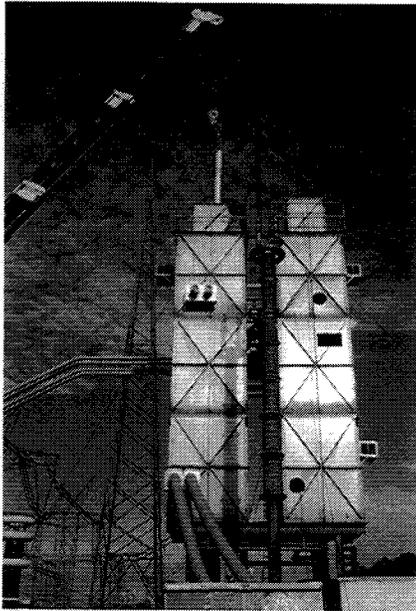


Figure 3-3. Enclosure Arrangement During Cable Termination

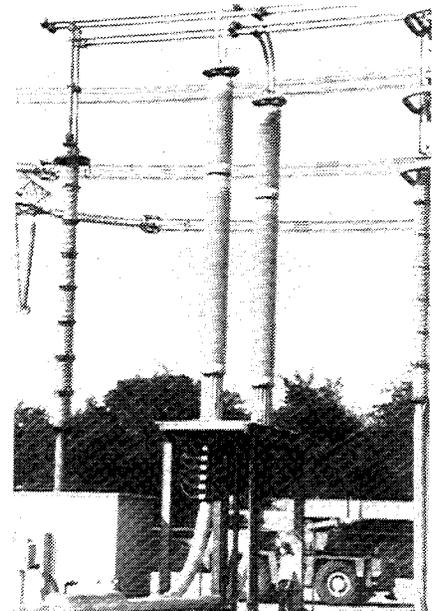


Figure 3-4. Test Bay 34 Terminations and Risers

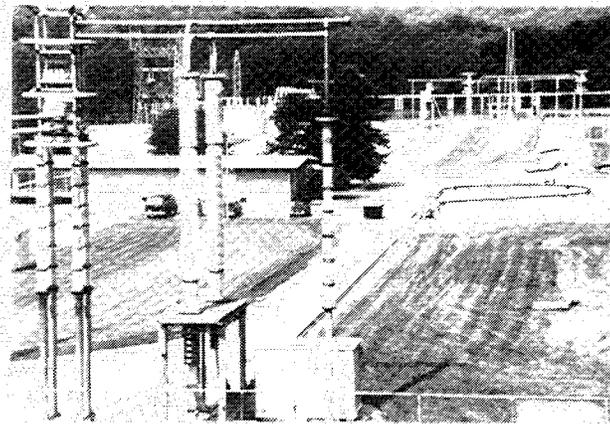


Figure 3-5. 765-kV Terminations Viewed from EHV Substation

## MAIN RUNS

The two main run cables are housed in a steel pipe 324 mm in diameter and 79.1 meters long. The pipe is equipped with electric heating elements that are separately controlled in three zones, each 26.4 meters long. The thermal insulation is 25.4 mm of fiberglass.

Figure 3-6 is a view of the two cable reels set up near the splice end, with the cables being pulled into the main run pipe. The completed installation of the main run piping is shown in Figure 3-7, with the splice enclosure in the foreground and the EHV substation in the background.

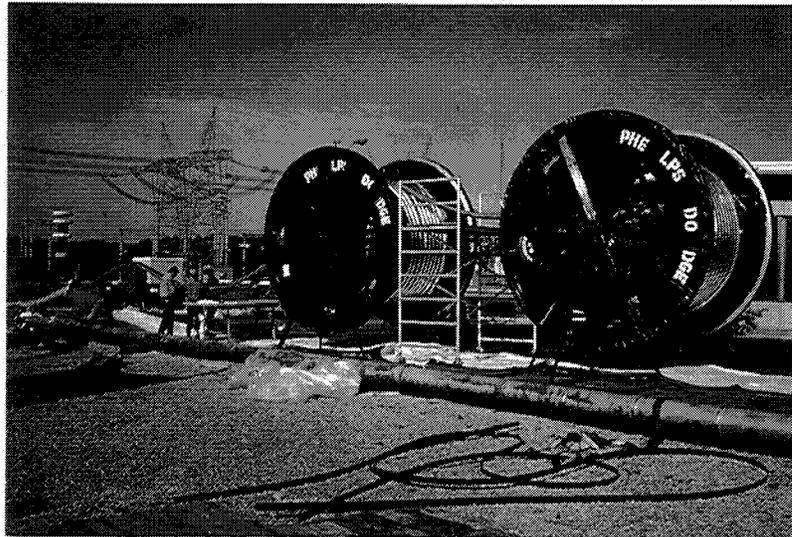


Figure 3-6. Installation of 765-kV PPP Cables in Main Run

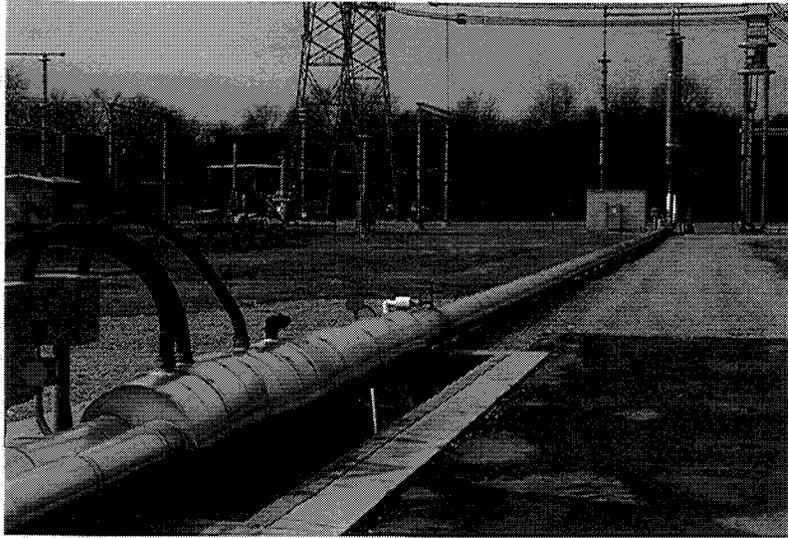


Figure 3-7. Test Bay 34: Splice Enclosure and Main Run

### SPLICES

A splice attaches each of the main run cables to the loop cable. Both splices are housed in the splice enclosure, which is also heated and insulated. This steel enclosure is made up of four pipe segments of different diameters: 610 mm, 559 mm, 508 mm, and 457 mm. The segments are nested during installation or disassembly. Overall length of the splice enclosure is 7.24 meters. The thermal insulation is 38.1 mm of fiberglass.

There is a shield interrupt on each side of each splice. Their locations are shown in Figure 3-2.

## LOOP

The loop section of cable is enclosed in a 219-mm diameter steel pipe, 80.2 meters long. A bare 1266-mm<sup>2</sup> copper cable is placed in this pipe with the test cable and is joined to itself in the splice enclosure to form a complete loop. Its purpose is to reduce the losses that would otherwise occur in the pipe.

The pipe is unheated, but was initially covered with 25.4 mm of rigid urethane insulation. The insulation was removed part way through the test program when the loop cable temperature began to exceed that of the main run on hot summer days. Only the first 4.5 meters of pipe next to the splice enclosure were left insulated.

The loop can be seen in the aerial view of the test bay in Figure 3-8.

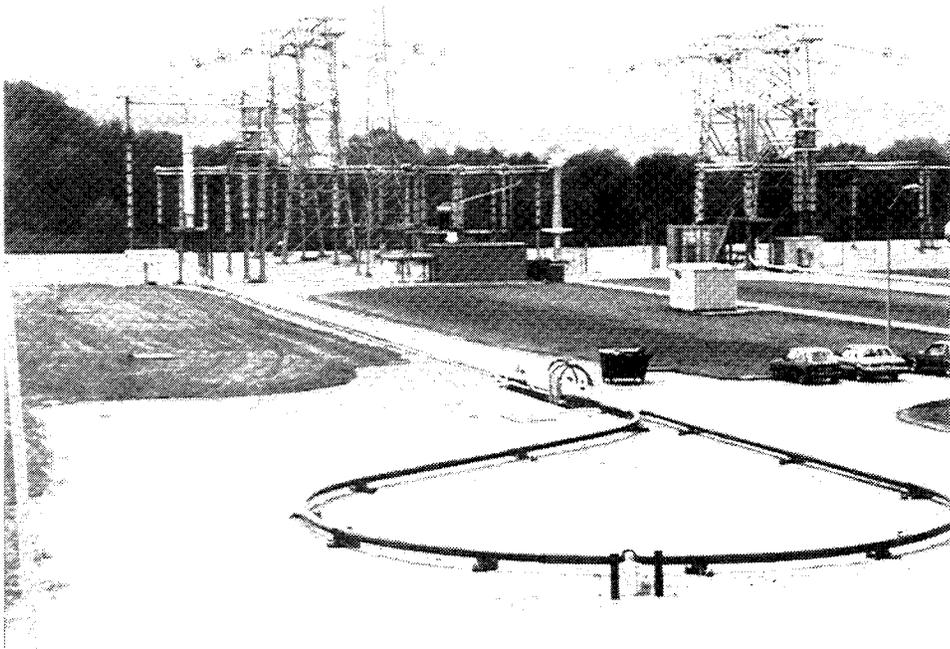


Figure 3-8. Aerial View of Test Bay

## LOAD CURRENT

The current circuit is completed on one end by the loop and on the other end by the connection of the potheads to a common bus, which in turn is connected to the high voltage bus. Load current is derived from eleven current transformers, each capable of inducing a potential of about four volts in the test loop. These current transformers, and a metering transformer, are installed around the cable under the two potheads. Figure 3-9 shows a close-up view of five of the current transformers, with the metering transformer at the bottom of the stack.

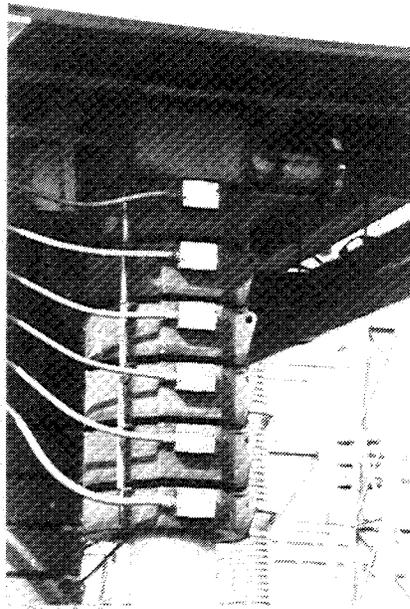


Figure 3-9. Current Transformers Located Under the Pothead Stand

The load current is controlled with magnetic amplifiers in conjunction with saturable core reactors. This arrangement makes it possible to control the conductor current while independently applying high voltage. In this way, each temperature and voltage level required by the test program can be established independently.

## TEMPERATURE MEASUREMENTS

The temperature of the test sample is monitored by 52 thermocouples attached to the pipe and cable shield, as shown in Figure 3-10. Twenty-two of these are attached to the top or bottom of the pipe. The other 30 are attached to the cable shield. An additional 6 thermocouples attached to the shield serve as spares, to replace any of the adjacent active thermocouples that might become disabled. The shield thermocouples are located on top of the cable, except as indicated in Figure 3-10. All thermocouples are routed to the station computer which scans them at five-minute intervals. Figure 3-11 shows a thermocouple attached to the main run cable during the pulling operation. All thermocouples are type E (Chromel/Constantan).

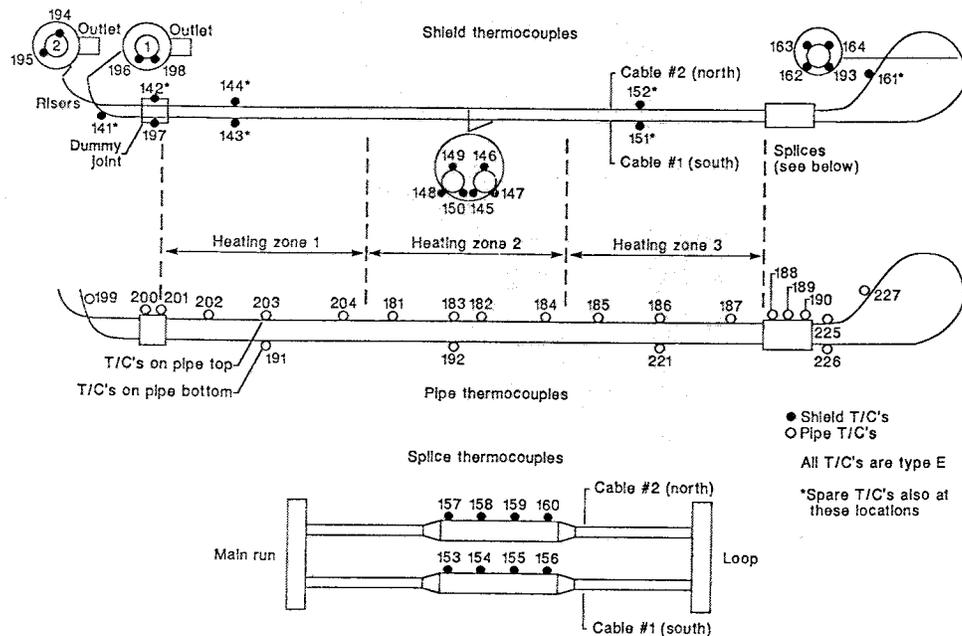


Figure 3-10. Thermocouple Locations on Cable Shield and Pipe

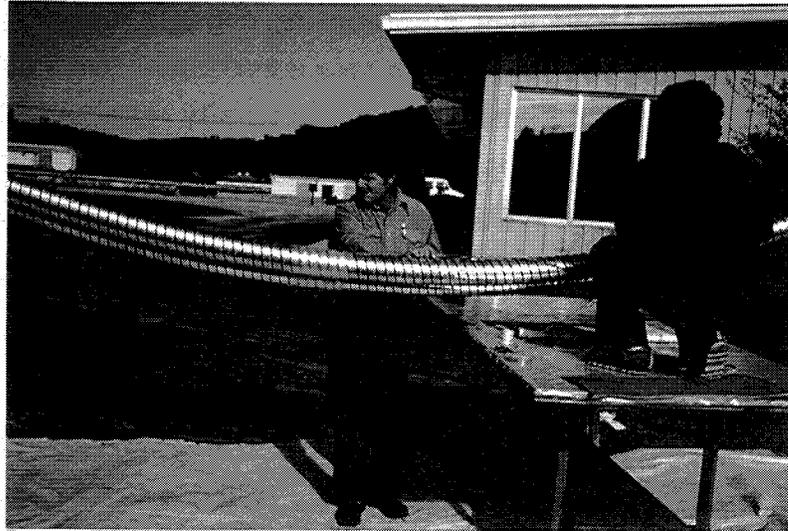


Figure 3-11. Attachment of Thermocouple During Cable Installation

#### TEMPERATURE CONTROL

The shield temperature of the cable in each zone of the main run, or in the splice enclosure, is controlled by the pipe heaters, which are cycled in response to the highest temperature indicated by the sheath thermocouples in that zone. For example, if the control temperature is set at 73°C, the pipe heater will remain on in a given zone until one or more of the shield thermocouples indicates 73.5°C. The pipe heaters are then shut off by the computer and remain off until all thermocouple indications in that zone are below 72.5°C, at which time the heaters are reenergized. Only the main runs and splices are equipped with pipe heaters and are subjected to the test temperature. The loop and riser sections run at lower temperatures and serve only to complete the current circuit.

#### TEMPERATURE SAFETY

Three independent safety measures are provided to prevent overheating of the cable during the test program. The primary method utilizes the computer to turn off all pipe heaters and current if preset temperature limits are exceeded. Any two

thermocouples indicating above their limits during a single time scan or the same thermocouple indicating above its limit on two consecutive scans (at five-minute intervals) will activate the trip. These limits are generally set about 10°C above the shield control temperatures. As a backup, one shield thermocouple for each heating zone is wired into an electronic temperature controller, which can also trip the current and heaters. The final backup is a mechanical thermostat attached to the main run pipe.

## OIL SYSTEM

The pipe filling oil is Cosden polybutene 0 SH electrical grade with 40 to 50 percent hydrogenation. The hydrogenation of the oil was believed to be necessary to minimize swelling of the PPP tapes. About 9440 liters are needed to fill the piping and potheads, with an additional 1135 liters required for the storage tank in the pumping plant. A nitrogen blanket at 136 kPa (5 psig) is used to pressurize the oil in the tank.

In order to minimize hot spots in the cable, an oil flow rate of about 38 liters per minute is maintained through the main run. Oil is circulated from the pumping plant into an insulated 33.4-mm pipe which is routed above ground next to the main run. The oil flows from the 33.4-mm line into the splice enclosure and back through the main run. It is removed at the dummy joint and returned to the pumping plant through another 33.4-mm pipe. Oil flow within the pumping plant bypasses the storage tank, with interchange to and from the tank occurring only when the oil temperature is changing.

While flowing through the pumping plant and the buried supply line, the oil was cooled by 2 to 8°C, depending on the time of year. This temperature drop caused the splice shield temperatures to be lower than the temperatures in the main run by varying amounts throughout the program. The effect is similar to the behavior of a commercial splice in a manhole, where the increased cooling generally offsets the higher conductor-to-shield temperature difference.

Oil pressure was maintained in the 1377-1550 kPa (185-210 psig) range throughout the test program.

## Section 4 TEST PROGRAM AND PROCEDURES

### TEST PROGRAM

The accelerated life test program established at Waltz Mill consists of operating the sample at voltage and temperature levels above rated values over a cumulative test time of approximately two years. The test parameters are gradually increased with each test period. In the beginning of the test program, these parameters are at, or only slightly above, rated conditions. By the end of the program, test parameters are substantially above the rated levels.

During some test periods, temperature is maintained continuously at the test condition, while during other periods, the sample is heated to the test condition, then allowed to cool to near ambient. These two periods are referred to respectively as "continuous" and "cyclic". Voltage is maintained at a constant level during each test period, regardless of the type of temperature control.

The planned test program for the 765-kV PPP cable is given in Table 4-1. It differs from the 550-kV tests run in the early 1970's in several respects. The earlier tests were run at temperatures of 75°C, 90°C, and 100°C, whereas the PPP cables were run at 85°C, 95°C, and 105°C. The higher temperatures were chosen because of a somewhat different interpretation of maximum temperatures in the US cable standards from the 1970's to the 1980's and the belief that testing of this cable should be done at the highest temperatures allowed by the standards [6] current at that time. In addition, the earlier tests consisted of 18 months of continuous temperature tests and six months of cyclic tests. For the PPP cable, the emphasis is on cyclic testing, with only seven months allotted to continuous tests and 17 months to cyclic tests. The greater emphasis was placed on cyclic tests because there was concern that the pipe filling oil might cause swelling of the PPP tapes. Cyclic testing would increase the amount of filling oil that could work its way into the cable structure.

Table 4-1

Planned Waltz Mill Test Program for 765-kV PPP Cable

<u>Test Period</u>	<u>Duration (Months)</u>	<u>Applied Voltage (%*)</u>	<u>Voltage (kV) Ø-Ø</u>	<u>Operating Mode</u>	<u>Conductor Temp. (°C)</u>
1	1	105	803	Continuous	85
2	1	105	803	Cyclic	85
3	1	125	956	Continuous	85
4	1	125	956	Continuous	95
5	10	125	956	Cyclic	95
6	1	125	956	Continuous	105
7	2	125	956	Cyclic	105
8	1	138	1052	Continuous	85
9	1	138	1052	Continuous	95
10	2	138	1052	Cyclic	95
11	1	138	1052	Continuous	105
12	2	138	1052	Cyclic	105

24

\* 100% Reference = 765 kV Ø-Ø

Table 4-2

## Actual Waltz Mill Test Program for 765-kV PPP Cable

Test Period	Duration (Months)	Applied Voltage		Operating Mode	Conductor Temp. (°C)	Actual Test Conditions**	
		(%*)	(kV) Ø-Ø			Shield Temp. (°C)	Current (Amps)
1	1	105	800	Continuous	85	65	800
2	1	105	800	Cyclic	85	65	800
3	1	125	956	Continuous	85	65	750
4	1	125	956	Continuous	95	65	980
5a***	9	125	956	Cyclic	95	65	980
5b	3	125	956	Cyclic	95	70	860
6	1	125	956	Continuous	105	80	850
7	2	125	956	Cyclic	105	80	850
8	1	138	1052	Continuous	85	70	550
9	1	138	1052	Continuous	95	70	840
10	3	138	1052	Cyclic	95	70	840
11	1	138	1052	Continuous	105	80	820
12	2	138	1052	Cyclic	105	80	820

27

\* 100% Reference = 765 kV Ø-Ø

\*\* There was some variation in test conditions in response to ambient conditions.

\*\*\* Test periods 1 through 5a were run with partially shorted current. See Section 6.

Several modifications were required during the course of the test program, the reasons for which are discussed in Section 6. Table 4-2 gives the actual test program and includes the shield temperatures and current levels that were used. Figure 4-1 represents graphically the information in Table 4-2. A detailed chronology of the entire test program is in Appendix 1.

The effect of temperature and voltage on the cable dielectric is based on the following empirical equation [7]:

$$T = T_p (E_p/E_o)^n e^{\alpha(t-85)}$$

where

- T is the total equivalent service life derived from a single test period
- T<sub>p</sub> is the length of the test period
- E<sub>p</sub> is test period voltage
- E<sub>o</sub> is the rated cable voltage t is the test period temperature
- n is the voltage aging exponent
- α is the temperature aging exponent

The generally accepted range for the voltage aging exponent, *n*, is 10 to 12 for oil-impregnated paper. The temperature aging exponent, *α*, is believed to be within the range of 0.069 to 0.087, equivalent to a doubling of the aging rate for each 10°C to 8°C increase in the dielectric temperature above the maximum continuous operating temperature of 85°C. The total equivalent service life for the entire test program is the sum of the T values calculated for each test period.

The aging effect of this test program on the cable was calculated in a conservative and in a liberal way with the following results:

- (a) Using a voltage coefficient *n* = 10, the 10°C rule for the temperature aging, and counting none of the cyclic time toward temperature aging, the aging effect is 40.7 years.
- (b) Using a voltage coefficient *n* = 12, the 8°C rule for the temperature aging and counting 100% of the cyclic time toward temperature aging, the aging effect is 164 years.

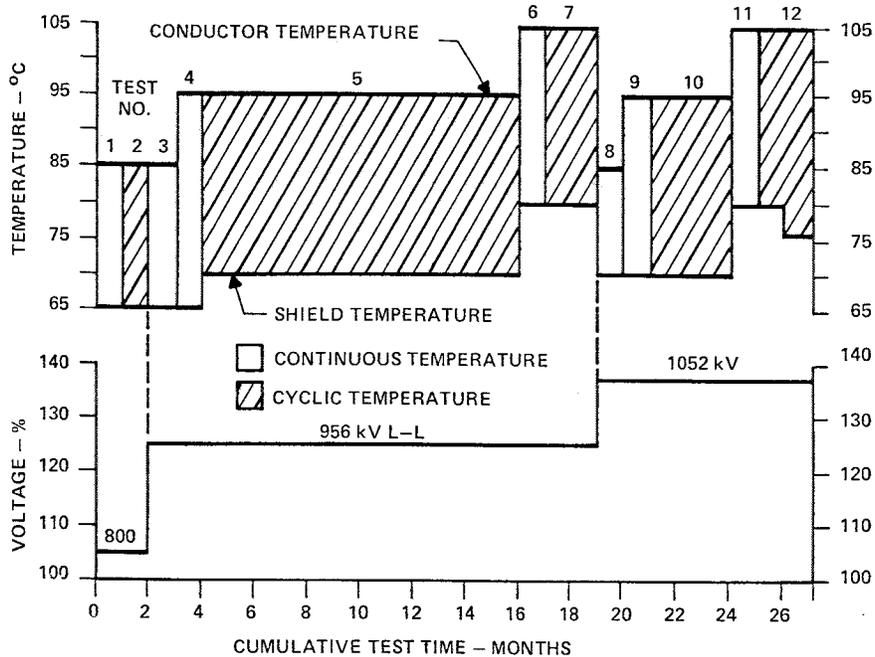


Figure 4-1. Waltz Mill Test Profiles for 765-kV PPP Cable

#### CONDUCTOR TEMPERATURE SETTINGS

Since the conductor temperature cannot be measured directly, its value is established by calculation, based on measurements made at the EPRI EHV Laboratory in Yonkers. Figure 4-2 shows the shield temperature and current required to achieve the conductor temperatures called for in the test program. The data shown are for a line-to-line voltage of 956 kV (125% of rated). For the 105% voltage level, shield temperatures about 1.5°C higher than those shown are required to achieve the same conductor temperature at a given current. For the 137.5% voltage level, shield temperatures 1°C lower are required. These numbers indicate the relatively small effect the dielectric losses have on a PPP-insulated cable, when compared with a paper-insulated cable.

The test conditions are not totally independent of ambient temperature. During cold weather, the set point is more readily achieved if it combines relatively high current with a lower shield temperature. During warm weather, however, a lower current is usually required to avoid overheating the cable.

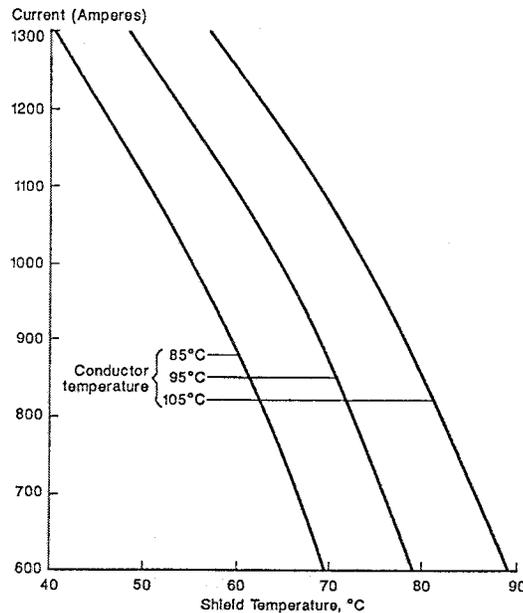


Figure 4-2. Temperature Curves for 765-kV PPP Cable Energized at 956 kV, Phase-to-Phase

#### DISSIPATION FACTOR MEASUREMENT

Since cable insulations are not perfectly lossless dielectrics, a small portion of the energy required to charge the cable insulation is dissipated in the form of heat. This energy is called the dielectric loss and is measured by the dielectric dissipation factor. This factor is slightly voltage dependent and extremely temperature dependent, but for a good insulation displays consistent readings at any time when measured under identical temperature and voltage conditions. Any increase in value with time is an indication that the insulation is being degraded. Dielectric dissipation factor serves as the primary means for monitoring the performance of paper-insulated cables.

A transformer ratio-arm bridge is used to measure dielectric dissipation factor and cable capacitance, with precision capacitors being the reference standard during these measurements. The shield interrupts installed at the six locations indicated in Figure 3-2 separate the cable system into seven distinct parts for measurements purposes: two main run cables; two splices; two riser/pothead segments; and the loop cable. A coaxial lead is soldered to each shield segment and connected to ground for normal operation of the cable system. For measurement purposes, the dissipation factor bridge is switched into each of these circuits in turn.

Figure 4-3 shows a schematic of the transformer ratio-arm bridge used to measure the dissipation factor of the cable insulation. The basic components of the instrument are a variable resistor,  $R_2$ , a precision capacitor,  $C_n$ , and an electromagnetically screened difference transformer, whose windings are indicated by  $W_1$ ,  $W_2$ , and  $W_3$ . The equivalent circuit of the insulation being tested is represented by  $R_x$  and  $C_x$ . By adjustments to  $R_2$  and the number of turns of  $W_1$  and  $W_2$ , the bridge can be balanced, as determined from the null indicator. The cable capacitance is calculated from:

$$C_x = C_n W_2/W_1$$

The dissipation factor is calculated from:

$$\text{Tan } \delta = \omega C_x R_x = \omega C_2 R_2$$

where  $\omega$  is the frequency of the voltage supply, expressed in radians per second (377 rad/sec).

Measurements are made at one-month intervals throughout the test program under the following guidelines:

1. Before the start of each new test period, measure dissipation factor at ambient temperature, all previous lower test temperatures, and the new test temperature. Repeat these measurements at the start of each subsequent month for all test periods lasting longer than one month.
2. At each temperature, measure dissipation factor at the voltage level of the current or upcoming test period, at all lower test voltage levels, and at 110 kV (phase-to-phase).

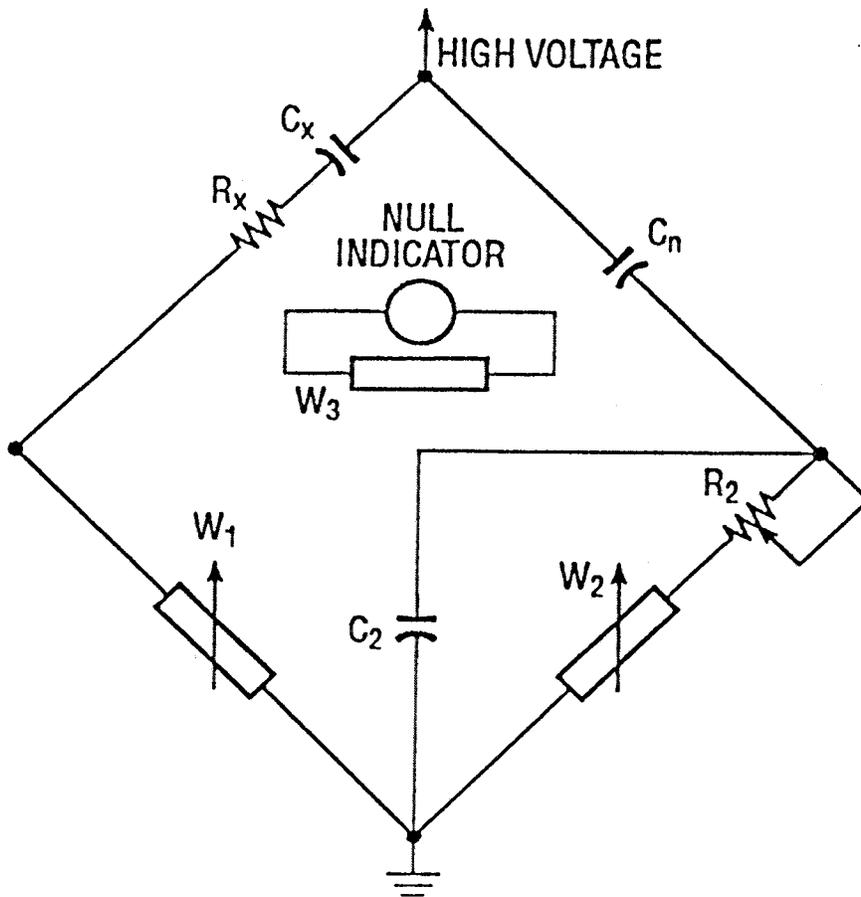


Figure 4-3. Bridge Circuit for Dissipation Factor Measurements

## Section 5 TEST RESULTS

The change in dissipation factor is the most important measure of the aging or deterioration of the cable insulation during the test program. The initial application of voltage and temperature is a conditioning process that normally causes a small reduction in dissipation factor. Later, this factor would be expected to remain constant, if measured at the same temperature and voltage, unless some deterioration were occurring. To evaluate this effect, we plotted the dissipation factor as a function of test time throughout the program. The data taken at 85°C conductor temperature were selected because of the large number of readings that were made at this temperature. Since there was no pattern to the generally small variation of dissipation factor with voltage, the measurements made at 520 kV and above were averaged for the purposes of this analysis.

Of the seven cable components measured (two risers, two mains, two splices, and the loop), only the mains and splices were subjected to the controlled temperatures called for in the test program. The other components were tested only to guard against the possibility of an unusual condition that might have led to a premature failure. Post-test data analysis was, therefore, confined to the mains and splices.

### MAIN RUNS

Figure 5-1 shows the dissipation factor measurements made on the two main run cables throughout the program. The figure shows some variation among the individual readings, but no upward trend that would indicate possible deterioration of the dielectric. There is actually a slight downward trend. Measurements averaged 0.067 percent for each of the main runs.

The effect of temperature on the dissipation factor of main run no. 1 is given in Figure 5-2. These data indicate the dissipation factor does not significantly increase with increasing temperatures until the normal operating temperature has been exceeded by 10°C or more.

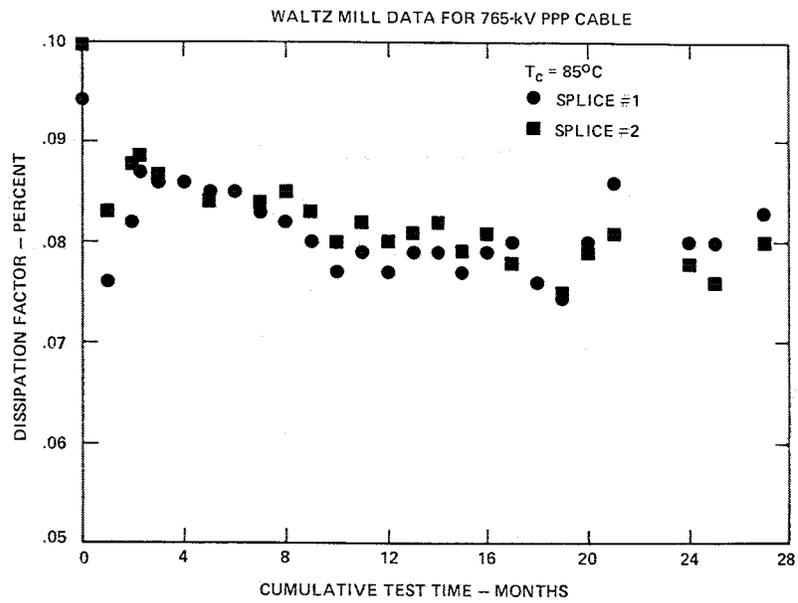


Figure 5-1. Variation of Dissipation Factor over the Test Program for the Two Main Run Cables

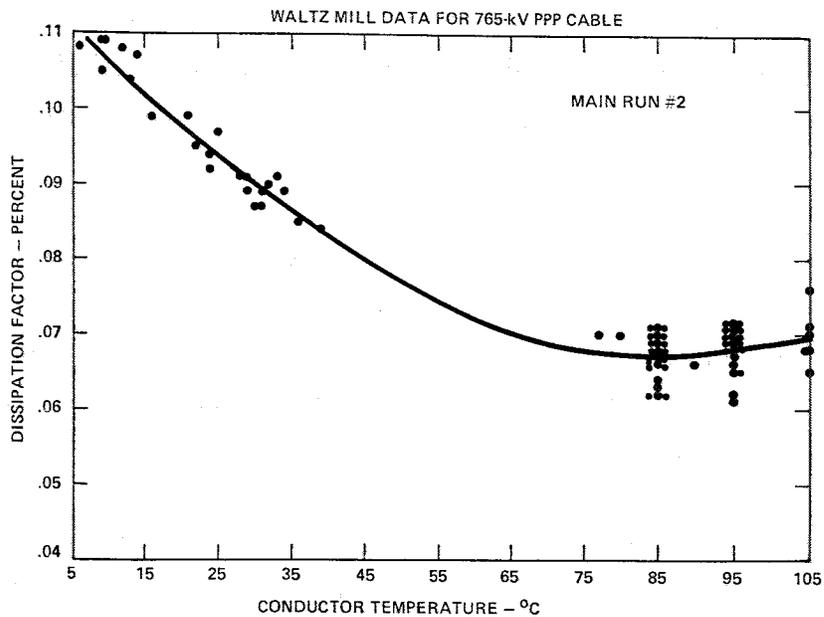


Figure 5-2. Variation of Dissipation Factor with Conductor Temperature for Main Run No. 2

## SPLICES

The behavior of the splices was slightly different, as shown in Figure 5-3. The measurements were initially high (though somewhat erratic), decreased as the test program progressed, and then, for splice no. 1 only, increased slightly toward the end of the program. There was little difference between the values for the two splices. Taking average values for the beginning (first 9 months), middle (months 10-18), and end (last 9 months) gives the following profile of the results.

<u>Time Period</u>	<u>Average Dissipation Factor(%)</u>	
	<u>Splice 1</u>	<u>Splice 2</u>
Beginning	.084	.087
Middle	.078	.080
End	.081	.078

During the final 18 months of testing, the dissipation factor averaged 0.079 percent for both splices. Figure 5-4 gives the variation of dissipation factor with conductor temperature for Splice No. 2.

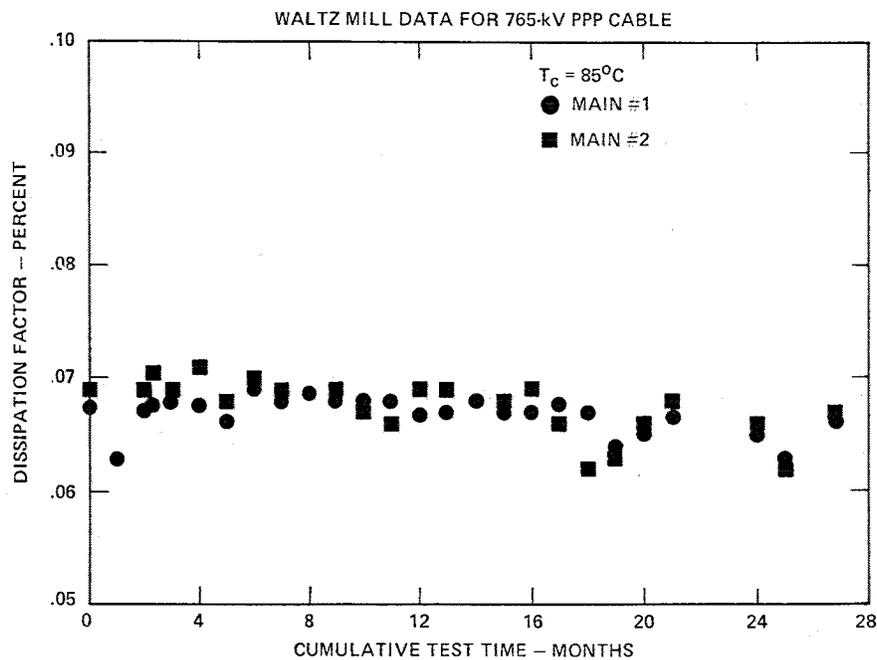


Figure 5-3. Variation of Dissipation Factor over the Test Program for the Two Splices

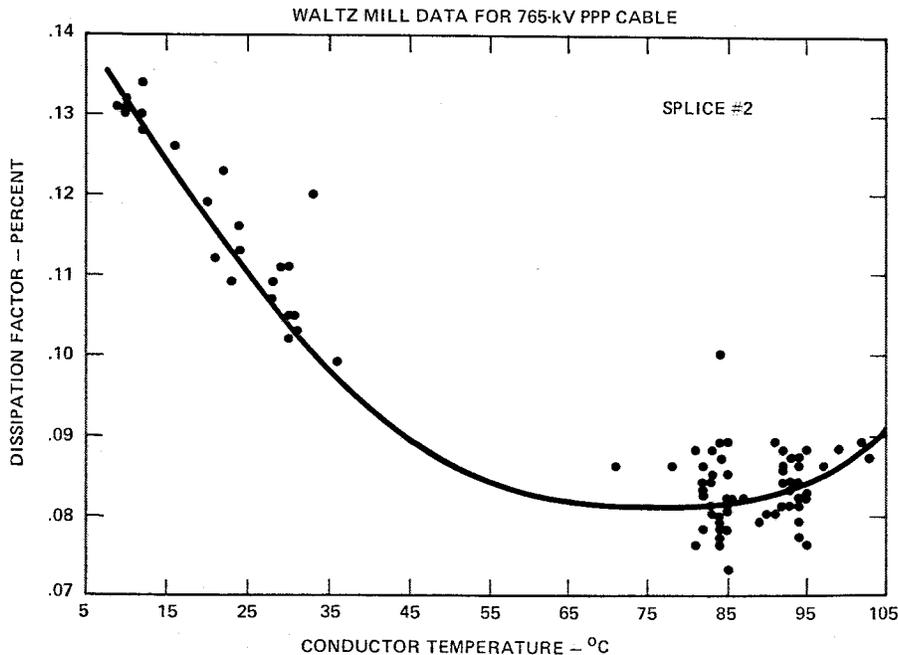


Figure 5-4. Variation of Dissipation Factor with Conductor Temperature for Splice No. 2.

#### GAS-IN-OIL ANALYSIS

Oil samples were taken three times during the test program from the potheads and twice from the main run and splice areas. Using a gas chromatograph, these samples were analyzed for the nature and quantity of dissolved gases. The results are given in Table 5-1 for the potheads and Table 5-2 for the splice and main run.

Gas-in-oil analysis has been used on transformer oils for many years but has only recently been applied to cable oils. The experience on transformers is not directly applicable to cables because of differences in operating temperatures and pressures, paper-to-oil ratios, and initial gas content. Cable insulations are generally operated at lower, less uniform temperatures, but higher electrical stresses. Cable oil temperatures are also generally lower, but oil pressure is much higher. The oil/paper ratio is somewhat lower for a cable than a transformer. The initial gas

distribution is also quite different, with a cable oil highly degassed, while transformer oil sometimes has an interface with air. Cable fluids are frequently polybutene, as in this case, rather than the mineral oil common in transformers, and do not have antioxidants or other additives. The polybutenes, in particular, need further study and experience to make the gas analysis techniques as successful for cables as they are for transformers.

Because of the lack of experience with this analysis for cable oils, the data are subject to some disagreement. However, review of the data shows no evidence of insulation deterioration. In particular, there is no evidence of hydrogen, carbon monoxide, or acetylene. The high nitrogen levels are a result of the nitrogen atmosphere maintained above the oil in the pump house storage tank. However, the reason for the increase in the nitrogen level for the last sample is not apparent.

Table 5-1

Gas-in-Oil Measurements for Potheads

Location:	<u>North Pothead</u>			<u>South Pothead</u>														
	Date of Sample:	PCT	PPM	Date of Sample:	PCT	PPM												
Nitrogen	4/4/1983	91.99	74557	12/7/1983	91.29	60714	6/6/1985	93.81	172671	4/4/1983	93.38	76019	12/7/1983	87.84	62788	6/6/1985	93.75	145299
Oxygen/Argon		3.32	2691		4.01	2667		1.80	3313		1.86	1514		8.92	6376		1.89	2929
Carbon Dioxide		0.66	535		0.60	399		0.40	736		0.70	570		0.50	357		0.40	620
Methane		1.11	900		0.89	592		0.84	1546		1.17	952		0.63	450		0.83	1286
Ethane		0.61	494		0.67	446		0.62	1141		0.61	497		0.41	293		0.63	976
Ethylene		0.75	608		0.66	439		0.74	1362		0.76	619		0.42	300		0.71	1100
C3 Hydrocarbons		1.56	1264		1.88	1250		1.79	3295		1.52	1237		1.28	915		1.79	2774
Total Combustibles		4.03	3266		4.10	2727		3.99	7344		4.06	3305		2.74	1959		3.96	6137

Notes: Hydrogen, Carbon Monoxide, and Acetylene were below detectable levels for all samples.

Sample Dates represent the following:

- 4/4/83: During the 10th month of test period 5
  - 12/7/83: During the 2nd month of test period 7
  - 6/6/85: After test period 12
- PCT = Percent by Volume of Gas  
 PPM = Parts Per Million of Solution

Table 5-2

Gas-in-Oil Measurements for Splice and Main Run Areas

Location:	<u>Splice</u>		<u>Dummy Joint</u>	
Date of Sample:	12/7/1983	6/6/1985	12/7/1983	6/6/1985
Nitrogen	<u>PCT</u> 87.78 <u>PPM</u> 65747	<u>PCT</u> 89.49 <u>PPM</u> 117633	<u>PCT</u> 91.30 <u>PPM</u> 76582	<u>PCT</u> 89.70 <u>PPM</u> 130244
Oxygen/Argon	7.87	5.42	4.20	5.62
Carbon Dioxide	0.74	0.45	0.64	0.40
Methane	0.81	0.93	0.88	0.76
Ethane	0.60	0.76	0.64	0.68
Ethylene	0.49	0.80	0.60	0.71
C3 Hydrocarbons	1.71	2.15	1.74	2.13
Total Combustibles	3.61	4.64	3.86	4.28

Notes: Hydrogen, Carbon Monoxide, and Acetylene were below detectable levels for all samples.

Sample Dates represent the following:

12/7/83: During the 2nd month of test period 7

6/6/85: After test period 12

PCT = Percent by Volume of Gas

PPM = Parts Per Million of Solution



## Section 6 PROBLEM AREAS

The Waltz Mill testing of the 765-kV cable was carried out with only minor deviation from the original plan. The only problem that directly affected the final outcome of the test program was a short in the current circuit. Other problems were associated with the thermal insulation on the loop, external flashovers across the EHV insulators, and replacement of the standard capacitor.

### SHORT IN CURRENT CIRCUIT

During the ninth month of test period no. 5, a point of contact was discovered between the pothead stand and one of the stainless steel riser pipes. As shown in Figure 6-1, this contact created a parallel circuit with the conductor current, and caused the metering CT (current transformer) to detect the sum of these two currents rather than just the conductor current. The immediate problem, which was caused by improper installation of an adapter plate below the pothead, was resolved by grinding the adapter plate to provide adequate clearance.

The end result of the short circuit was that the conductor current had been lower than planned for most of the test program up to that time, and, consequently, the conductor temperature was lower than had been intended. In periods when we thought the conductor temperature was 95°C it was actually closer to 88 or 89°C. In test periods where we were shooting for 85°C, it was closer to 80°C. When we simulated the short with a bolted connection, we found that the conductor current represented only 72% of the total current. Analysis of temperature data from the loop section indicated the problem had existed from the start of the test program and that the conductor current was about 75% of what we had thought it was.

It is somewhat fortunate that the majority of the previous test program was cyclic rather than continuous and the cyclic periods were more for mechanical aging than for thermal aging. In laying out the test program, there was no consensus about the equivalent aging of the cyclic test periods. As a compromise, it was estimated that

the equivalent thermal aging of the cyclic test periods would be 25 percent of the aging of continuous periods with the same maximum conductor temperature. In any case, the continuous test periods by themselves resulted in equivalent aging greater than the 30 or 40 years of normal service, which is the general objective of the test program. In view of this, it was decided that we would continue with the original test program, except that test period 5 was extended by two months. Test period 10 was also extended by one month.

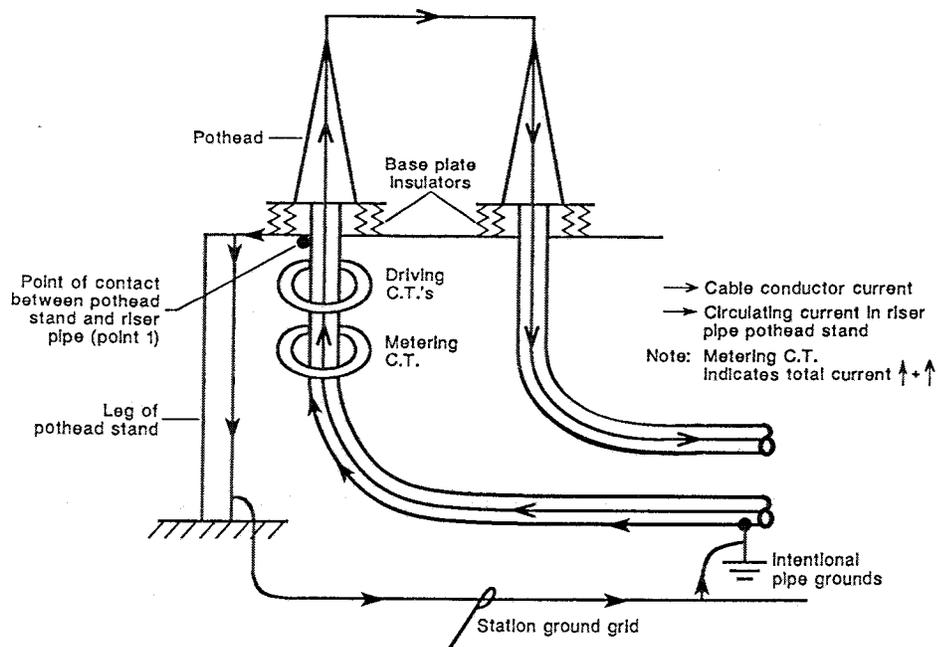


Figure 6-1. Short in Current Circuit

### LOOP INSULATION

For the original 500-kV test program, only the main runs and splice enclosure were thermally insulated, but when a forced cooling system was introduced in the mid-1970's, insulation was added to the loop and riser sections on two of the test bays, including bay 34. Both the loop and risers were to be part of the oil flow path, so the insulation was required.

For the first part of this test program, while the conductor current was lower than we had planned, the loop cable ran cooler than the main runs and splices, which were supplemented by the pipe heaters. However, after the short at the pothead stand was removed and the current was adjusted to its proper level, the loop cable began to run hotter than the main runs and splices. These higher temperatures were caused by the lack of oil circulation in the loop and the more effective thermal insulation that had been used there. The loop insulation was immediately removed, except for short lengths near the splice enclosure, and the loop temperature ceased to be a problem.

#### EXTERNAL FLASHOVERS

During test periods 8 through 12, when the peak voltage was applied, we experienced occasional flashovers across the insulators supporting the high voltage bus. The problem, which caused minor delays to the test schedule but no damage to the test sample, was eventually traced to a specific insulator stock and was resolved by adding another insulator to the stack. A view of this insulator is shown in the center of Figure 3-5.

#### STANDARD CAPACITOR

A standard capacitor, rated at 1600 kV, was installed in the EHV substation when the test facility was built and was used in making dissipation factor measurements on the 765-kV sample during the early portions of the test program. However, just after test period no. 7, severe cold weather (-30°C) created stresses that shattered the upper porcelain of the capacitor, as shown in Figure 6-2. Fragments were scattered up to 30 meters away. Fortunately, it was not energized at the time and no one was in the area.

An 800-kV standard capacitor, which was available from a previous project, was substituted for the remainder of the 765-kV test. A comparison of dissipation factor data taken immediately before and after the exchange showed there was no difference. A new 1000-kV standard capacitor was ordered, but arrived after the 765-kV program was completed. Figure 6-3 shows it being installed in May 1985.

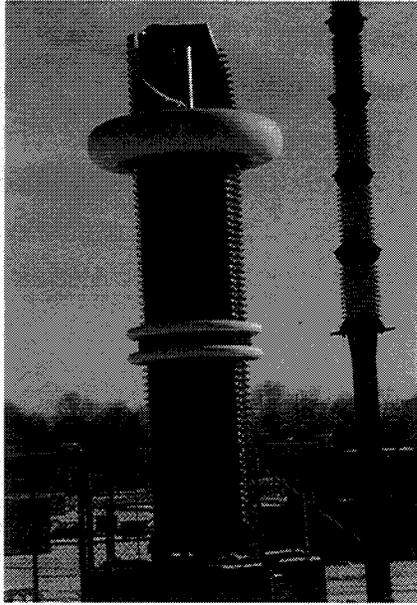


Figure 6-2. Damaged 1600-kV Standard Capacitor

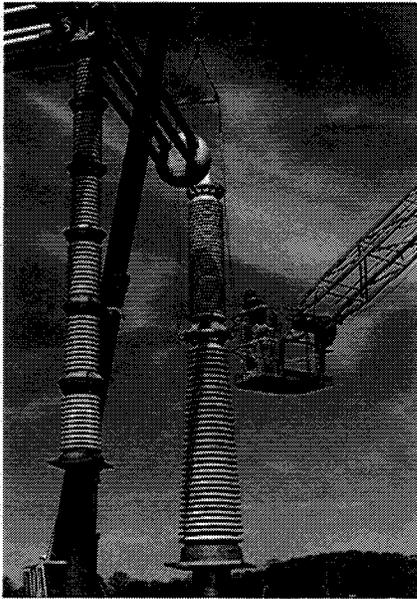
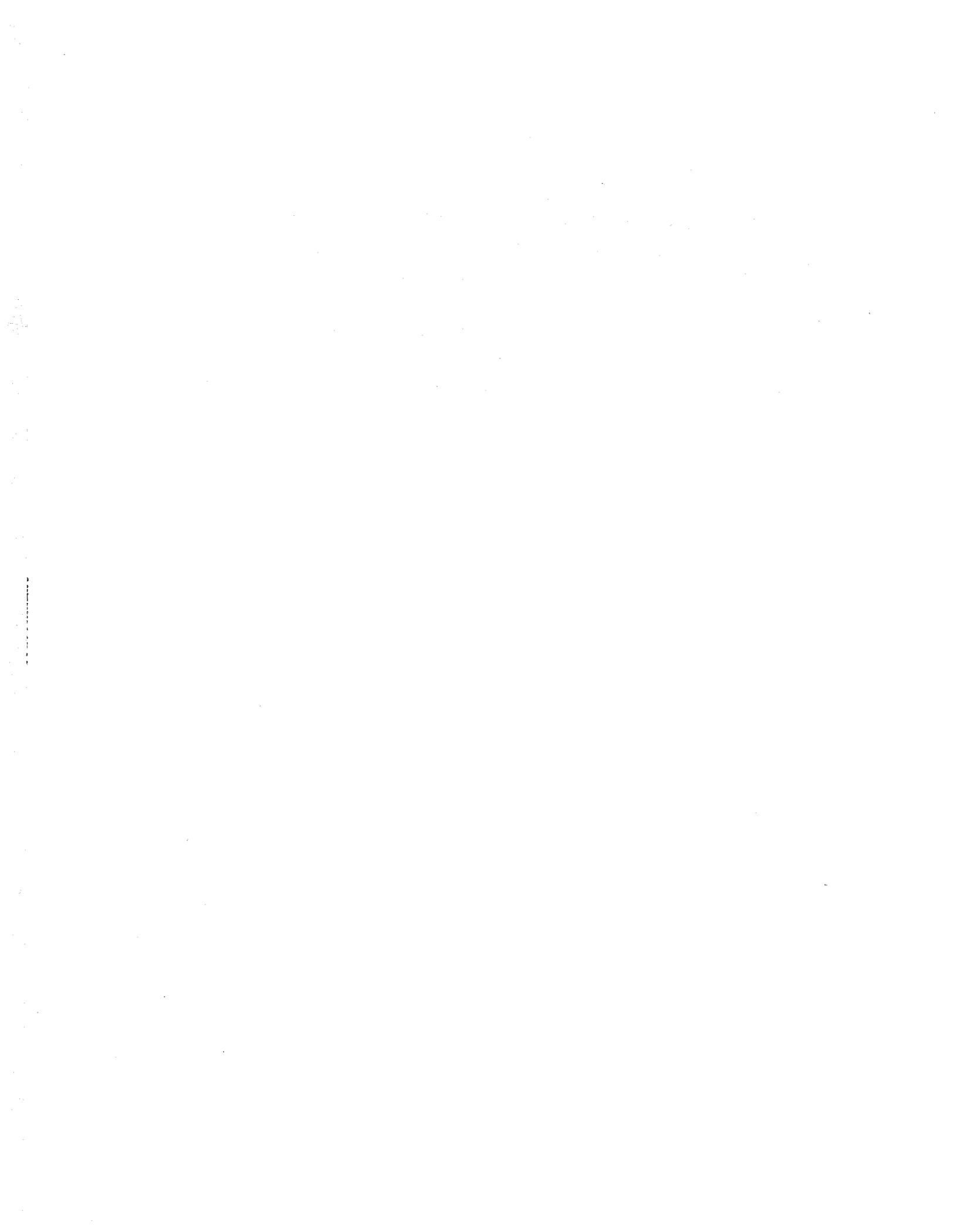


Figure 6-3. Installation of 1000-kV Standard Capacitor

Section 7  
CONCLUSIONS

The two main run cables were subjected to conductor temperatures as high as 105°C and voltages as high as 137.5 percent of their rated value during a two-year test program. The splices were subjected to the same voltage levels as the main runs and only slightly lower temperatures. The terminations also saw these high voltage levels and current levels greater than would be expected in commercial service. All of these components endured this program with no observable increase in dissipation factor characteristics, and, thus, demonstrated a sound design suitable for commercial application.



Section 8  
EXTENDED TEST PROGRAM

The 765-kV cable was left in its test bay after the test program described in this report was completed in January 1985, while consideration was given to possible follow-on testing. In May 1988, an extended test program was started under the following conditions:

Two-Day Temperature Cycle  
85°C Maximum Conductor Temperature  
800 kV (Ø-Ø) Voltage

Testing is to be continued under these conditions until cable deterioration is observed. Dissipation factor measurements on the cable and oil are scheduled to be performed on a regular basis to monitor the cable condition.

As of December 1991, the cable had undergone 120 weeks of extended testing under these conditions.



APPENDIX  
CHRONOLOGY OF TEST PROGRAM

SAMPLE 34: 765-kV PPP CABLE

- June 1981 The 765-kV PPP cable was installed in Waltz Mill Test Bay 34.
- 7-28-81 The cable was energized for the first time, to 30-kV for dissipation factor measurements.
- 8-03-81 The 24-hr. proof test was started, applying voltage at 800 kV ( $\emptyset-\emptyset$ ) for 24 hours with the cable at ambient temperature.
- 8-18-81 Test period no. 1 was started.
- 9-21-81 Test period no. 1 was completed.
- 9-23-81 Test period no. 2 was started.
- 11-05-81 Test period no. 2 was completed.
- 11-06-81 Voltage was raised to 956 kV ( $\emptyset-\emptyset$ ) for the first time and test period no. 3 was started.
- 11-17-81 A series of dissipation factor measurements were made to determine the effect of having the adjacent phase energized when making dissipation factor measurements.
- 12-09-81 Test period no. 3 was completed.
- 12-18-81 Conductor temperature was raised to 95°C for the first time and test period no. 4 was started.
- 1-19-82 Test period no. 4 was completed.
- 1-28-82 Test period no. 5 was started.
- 3-14-83 After 39 weeks of test time in test period no. 5, a short between the south riser and the pothead stand was discovered.

- 3-16-83 Thermal insulation was removed from the loop.
- 3-21-83 Test period no. 5 was resumed, with corrected current.
- 8-12-83 Test period no. 5 was completed, after 12 months of accumulated test time.
- 8-15-83 Conductor temperature was raised to 105°C for the first time and test period no. 6 was started.
- 9-21-83 Test period no. 6 was completed.
- 9-26-83 Test period no. 7 was started.
- 12-07-83 Test period no. 7 was completed.
- 1-21-84 One section of porcelain on the 1600-kV standard capacitor cracked. It was then replaced with an 800-kV capacitor.
- 2-15-84 Voltage was raised to 1053 kV ( $\emptyset$ - $\emptyset$ ) for the first time and test period no. 8 was started.
- 3-16-84 Test period no. 8 was completed.
- 3-23-84 Test period no. 9 was started.
- 5-01-84 Test period no. 9 was completed.
- 5-07-84 Test period no. 10 was started.
- 9-11-84 Test period no. 10 was completed.
- 9-25-84 Circulating pump was repaired.
- 10-02-84 Test period no. 11 was started.
- 11-01-84 Test period no. 11 was completed.

- 11-09-84 Test period no. 12 was started.
- 1-28-85 Test period no. 12 was completed. Cable was left at a temperature of 20°C on the main runs, with no current or voltage.
- 5-02-88 Extended test program at 800 kV and cyclic temperature to 85°C was started.
- 12-31-91 To this date, the cable had been under voltage and temperature for 120 weeks in the extended programs, which is continuing.



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