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MASTER

EVALUATION, DESIGN, DEVELOPMENT AND
DELIVERY OF A 1200 kV PROTOTYPE TERMINATION

Seventh Technical Progress Report

Covering the Period From
June 1, 1980 to August 31, 1980

October 17, 1980

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Reporting Period: June 1, 1980 to August 31, 1980

Preparation Date: October 17, 1980

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Evaluation, Design, Development and Delivery
of a 1200 kV Prototype Termination

Seventh Technical Progress Report

October 17, 1980

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Evaluation, Design, Development and Delivery
of a 1200 kV Prototype Termination

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1.0 ABSTRACT

Results of wet tests on the small scale resistive grading model are inconclusive. A significant improvement is observed however in the intermediate scale resistive grading models, especially on 60 Hz tests. Photographs of epoxy insulator puncture tests graphically illustrate the improvement due to use of a shatter-resistant reinforcement. Calculated results of expected mechanical forces for several designs are reported. Final design of the full scale prototype termination has commenced and critical considerations are evaluated.

2.0 INTRODUCTION

This is the Seventh Technical Progress Report on the Evaluation, Design, Development and Delivery of a 1200 kV Prototype Termination. The SF₆ gas bushing termination will be integrated into a gas insulated substation. The produced design will be economically attractive and will exhibit improved electrostatic performance, acceptable temperature gradients, and better mechanical integrity when compared with the gas/air termination of typical ratings built with conventional technology.

The project is divided into nine tasks which include the evaluation of innovative and novel concepts and materials uses, thorough paper and model studies of the electrical, thermal and mechanical characteristics of the most promising configurations, designs, production and testing of a full scale prototype and finally delivery of the prototype termination to an appropriate field site.

3.0 TASK 2 - ELECTROSTATIC STUDIES

3.1 Shield Effectiveness Studies

The study of the effectiveness of electrostatic shielding was completed in the sixth quarter. Application of the conclusions of that study is given in Section 6.1 of this report.

3.2 Resistive Grading - Small Model Studies

The design and construction of the small scale model bushings were described in Section 3.2 of the Third and Fourth Technical Progress Reports. Hollow insulators were stress-graded with internal coatings of silicon carbide paint. The results of dry 60 Hz one-minute tests are 218 kV RMS/meter and impulse tests at 395 kV/meter were given in the Fourth Technical Progress Report. Both dry tests were successfully passed by both bushing models.

3.2.1 Tests of Model Bushings in Moist Conditions

In these tests a 60 Hz AC voltage, rising from zero at a rate of about 1 kV RMS/sec., was applied to the bushing while it was subjected to a fine spray of room-temperature tap water.

The intent of this test was to simulate a wet switching surge test. The level specified for that test is 1800 kV peak for the full-sized 5.5-meter bushing; for these 20.3 cm (8-inch) model bushings the equivalent 60 Hz voltage would have been 66.4 peak or 46.9 kV RMS. Under test, the bushing whose stress-grading paint contained 600 grit silicon carbide flashed over externally at voltages of 34 kV and 32 kV RMS,

while the one whose paint contained 400 grit silicon carbide flashed over at 33, 31.5, and 30.5 kV RMS.

It is evident that these values of flash-over voltage are significantly lower than the desired levels, which suggests that this means of stress-grading, with these specific paints, is inadequate for this test configuration. It seems likely that the layer of water on the insulator surface was of a sufficiently low resistance that the dynamic voltage distribution which it produced was not only unfavorable but of a low enough impedance that the internal stress-grading layer was unable to significantly alter it. This indicates that a lower-resistance (i.e. coarser grit) silicon carbide paint would have to be used; however, it may also be that even if an internal stress-grading coating were used which produced a completely uniform voltage distribution on the inner surface, the capacitive coupling to the outer surface may be insufficient (especially in this test of a straight walled insulator with no sheds or skirts, and where the voltage rate of change is relatively slow) to impose significant control over voltage on the outer surfaces.

No further work is contemplated on the small scale resistive grading study.

3.3 Resistive Grading - Intermediate Scale Model Studies

3.3.1 Application of Resistive Coating and Assembly of the Bushings

As described in section 3.2.2 of the Sixth Technical Progress Report a 242 kV oil/paper condenser bushing weathercase was chosen for this study. So that the coating would adhere well to the epoxy weathercase, the inside circumference was first wiped with trichloroethane solvent (51550FA) to remove the silicone mold release. The inside surface was then shotblasted using 46250BA glass frit (30-50 mesh) to remove any remaining shining surface and residual silicone mold release. The loose material was then removed with clean trichloroethane solvent. The epoxy weathercase was then placed horizontally on a series of rollers (see Fig. 3-1) so that it could be rotated during the application of the semi-conductive coating. The coating selected was an air dry Vinyl modified alkyd varnish filled with silicon carbide. (Coronox 54201FK). The paint was applied with a special paint brush (Figure 3-1C) stroking in the axial direction while rotating the weathercase through 360° on the rollers. The coating was brushed until uniform on the inner circumference and the piece was rotated until the varnish was dry. A fan aimed at one end enhanced the drying. The coated piece was air cured for 16 hours at 25°C.

A one inch band of conducting graphite filled epoxy paint (53701NX) was applied on the top and bottom inside circumference of the weathercase and extended over the top and bottom gasket area.

a) Rolling Apparatus

c) Special Brushes

b) Rolling Apparatus

d) Finished Insulator

SiC COATED INSULATOR

Figure 3-1

The weathercase were built up into bushings as shown in Figure 3-2. Seals at each end of the weathercase were accomplished by means of soft, flat inner gaskets whose compression were limited by hard outer gaskets. The hard gaskets were prepared by coating all over with the graphite filled epoxy paint (53701NX) to ensure electrical continuity between the weathercase ends and their respective mating metal surfaces.

FIGURE 3-2 -- RESISTIVE GRADING BUSHING MODEL
(DIMENSIONS IN CENTIMETERS)

3.3.2 Test Results

The bushings were mounted, successively, as described in the Sixth Technical Progress Report, on the test tank, (See Figure 3-3a). No external shielding was used. The test results for the two bushings are compared in Table 3-1. The improvement of the surface stress on the weathercase for elevated voltages is clearly demonstrated by the 60 hertz tests. Although the corona inception voltage (applied voltage at which measurable corona discharges exceed background) appears to be nearly the same for both bushings, a significant difference is noted at higher applied voltage. Figure 3-4 shows how much more quickly the corona level increases for the uncoated weathercase than for the coated weathercase bushing. Figure 3-3 explains the improvement. Corona is visible below the bottom "shed" or skirt of the weathercase in Figure 3-3b. Since there is no resistive grading or throat shield in this bushing the voltage stress is very high along the surface on the bottom end of the weathercase. But when the weathercase has been coated, as in Fig. 3-3c, there is no visible corona anywhere on the surface of the weathercase, even at a much higher voltage. The highest stress has been transferred instead to the spring assembly cap at the top end of the bushing. Whereas the bushing with the uncoated weathercase could just barely withstand 350 kV, RMS, the bushing with the coated weathercase easily withstood 425 kV RMS for one minute.

Since switching surge capability is usually most dependent on the voltage gradient on the positive electrode, the switching surge results tabulated in Table 3-1 are understandable. The uncoated model withstood higher positive switching impulses since the highly

a) Resistive Grading Model

b) 350 kV Without Coating

c) 425 kV With Coating

Figure 3-3 Intermediate Scale
Resistive Grading Model Tests

INTERMEDIATE SCALE
RESISTIVE GRADING MODEL
DIELECTRIC TESTS

<u>TEST DESCRIPTION</u>	<u>WITHOUT GRADING</u>	<u>WITH GRADING</u>
1. 60 Hz Corona Inception Voltage (RMS kV)	125	125
2. Corona Level at 325 kV (QP μ V)	2100-3000	75
3. 60 Hz Withstand, one minute (RMS kV)	350	425
4. Wet Switching Surge Withstand (Peak kV)		
Positive	640	590
Negative	592	640
5. Repeat 60 Hz Corona Inception (RMS kV)		175
6. Corona Level at 325 kV (QP μ V)		300
7. 60 Hz Leakage Current (RMS MA) @		
100 kV		2.19
200 kV		4.56
300 kV		7.33
400 kV		10.35
8. 60 Hz Withstand, 4 Hours @ 275 kV RMS		OK
9. Repeat 60 Hz Corona Inception (RMS kV)		275
10. Corona Level at 325 kV (QP μ V)		135

TABLE 3-1

FIGURE 3-4 -- COMPARISON OF CORONA WITH AND WITHOUT NON-LINEAR RESISTIVE COATING

stressed bottom end is negative for positive impulse. But the negative switching surge capability is better for the coated model because the high stress is at the top end. The bushing model with the coated weathercase was subjected to 275 kV, RMS, 60 hertz for four hours to determine if there was any long term degradation at elevated voltage. The average voltage stress during this test was about 30% greater than the average stress in the 1200 kV design. As shown in Figure 3-5, the leakage current through the coating at 275 kV was 6.6 milliamperes. Since the surface area of the coating was 11400 CM², the average thermal dissipation was then

$$(275 \text{ kV}) \times (6.6 \text{ ma}) / 11400 \text{ cm}^2 = .159 \text{ w/cm}^2$$

This is considerably greater than the 0.015 w/cm² recommended in the Second Technical Progress Report for this project (Section 4.2) for continuous operating dissipation. There was apparently no degradation of the insulator due to this test.

Figure 3-5 also shows that at 133 kV, which would be the normal operating voltage for this size bushing, the dissipation would be

$$(133 \text{ kV}) \times (3 \text{ ma}) / 11400 \text{ cm}^2 = 0.035 \text{ w/cm}^2.$$

This is more than twice the 0.015 w/cm² recommended in the Second Technical Progress Report for operating conditions.

3-12

FIGURE 3-5 -- LEAKAGE CURRENT OF MEDIUM SCALE MODEL BUSHING

3.3.3 Conclusions

The model tests have shown that the dielectric field outside a bushing can be significantly influenced by means of a nonlinear resistive coating on the inside of the weathercase. Silicon carbide filled paints are commercially available which have good field experience in rugged applications such as large motors and generators. Thus they have a very good life expectancy for this use. And the additional cost of applying a resistive coating to a weathercase surface would be relatively insignificant.

Unfortunately, however, when applied end-to-end, as in the models, significant leakage current losses are experienced. In order to reduce the loss in the coating, either a thinner coating or a higher resistance paint would be required. Another alternative would be to coat only the bottom end, or otherwise highest stressed part, of the insulator so that only at very high applied voltage would any significant current flow.

Thus a silicon carbide filled coating is an excellent simply implemented option which may provide a carefully controlled improvement to a gas bushing termination, if such improvement is necessary.

4.0 TASK 4 - MECHANICAL STUDIES

4.1 Shatter-Resistant Weathercase

4.1.1 Puncture Test Results

The results of Tests #4 and #6 (semi hard material 53841MC without and with glass mesh 525CRX reinforcement) were reported in the Sixth Technical Progress Report. Photographs of those tests are shown in Figures 4-1 and 4-2. Note in Figure 4-1 the size and scatter of fragments for the unreinforced insulator. Figure 4-2 shows that reinforcement limits damage to a very small area. This is a very significant improvement.

4.1.2 Epoxy Formulation Characteristics

Missing from the material data in the Sixth Technical Progress Report Table 5-3 was the long term mechanical creep of the three epoxy materials. Some difficulty was encountered in mounting the sample bars on the test machines. The problems have now been overcome and the tests are proceeding. The data will hopefully be published in the Eighth Technical Progress Report.

4.2 Clamping and Fastening Study

4.2.1 Mechanical Analysis

There are six termination design concepts which have been studied from a clamping and fastening standpoint. They are shown skematically in Figure (4-3). Preliminary layout sketches of concepts were shown in Section 5 of the Fourth Technical Progress Report.

a) Before Puncture

b) During Explosion

c) After Explosion

d) Fragment Scatter

Figure 4-1

Test #4 - 53841MC Epoxy Insulator - No Reinforcement

a) Before Puncture

c) After Puncture

b) After Puncture

Figure 4-2 Test #6 - 53841 MC Epoxy Insulator with 525CRX Mesh

Figure 4-3

Type 1 employs an insulating tube, such as glass filament wound epoxy, located adjacent to the inside diameter of the weathercasing. The tube runs the full length of the weathercasing. The springs compensate for the differences in thermal expansion and contraction between the tube and the weathercasing. The lower end of the conductor is supported by a sliding finger assembly.

The Type 2 concept utilizes a CGIT disk spacer at the base of the conductor. The disk spacer is supported on its outside diameter by the lower weathercasing flange. The spring assembly compensates for the difference in thermal expansion and contraction of the conductor, weathercasing and disk spacer.

The Type 3 design is the same as Type 2 except a conical insulator is used in place of the CGIT disk spacer.

Type 4 termination employs a weathercasing with cement-on flanges at both ends. The conductor is supported at its lower end by a sliding finger assembly.

Terminations designated as Types 1, 2, 3 and 4 use porcelain weathercases and flat seal gaskets. A study was also made of the Type 3 concept using a cast epoxy weathercase. Two epoxy weathercase designs were investigated. The Type 3E employs a flat gasket seal and the Type 3EO uses an O-ring.

4.2.2 Analysis Results

Partial results of an axial force analysis were reported in the Fourth Quarterly Report. Additional data have been calculated and the previous values have been updated to report the latest design. Types 3E and 3EO have been added. Table (4-1) list the results of the axial force study.

Termin. Type	Type of Seal	Gasket Compr. %	Force-Newton (Pounds)						Deflection Millimeters (Inches)		
			Gasket	Gas Pressure Total	Gas Pressure Porcelain	Spring Initial	Spring Final	Load On Conductor	Expansion	Contraction	Springs Initial to Final
1	Flat	30	9,900 (44,000)	17,500 (77,900)	10,200 (45,400)	19,400 (86,400)	23,300 (103,600)	--	4.3 (.17)	3.8 (1.5)	8.1 (.32)
2	Flat	30	8,800 (39,300)	14,000 (62,300)	6,700 (29,800)	14,900 (66,100)	17,800 (79,300)	25,100 (111,800)	7.9 (.31)	4.6 (.18)	12.4 (.49)
3	Flat	30	8,800 (39,300)	14,000 (62,300)	6,700 (29,800)	14,900 (66,100)	17,800 (79,300)	25,100 (111,800)	6.6 (.26)	5.1 (.2)	11.7 (.46)
4	Flat	30	(39,700)	(63,500)	(49,200)	--	--	--	10.2 (.4)	6.6 (.26)	--
3E	Flat	30	8,800 (39,300)	14,000 (62,300)	6,700 (29,800)	14,900 (66,100)	20,800 (92,500)	28,100 (125,000)	8.4 (.33)	16.3 (.64)	24.6 (.97)
3E-O	O-Ring	30	1,570 (7,000)	14,000 (62,300)	6,700 (29,800)	7,600 (33,800)	10,600 (47,300)	18,000 (79,800)	8.4 (.33)	16.3 (.64)	26.6 (.97)

TABLE 4-1

Data is listed for the 30% gasket compresssion condition since this is the maximum force condition. It will require 2.76 MPa (400 psi) to compress the flat gasket to 30% and it will take 122 N/cm (70 lb/in) for the O-ring seal. The total pressure force listed in the table is equal to the axial projected area of the termination times the maximum SF₆ gas pressure. The SF₆ gas pressure at 20°C will be about 446 kPa (50 psig), so the maximum SF₆ gas pressure, which is the relief pressure, will be about 660 kPa (81 psig). The gas pressure force acting on the porcelain weathercase is equal to the axial projected area of the weathercase times the maximum SF₆ pressure. The initial spring force required is equal to the gas force plus the porcelain gas force minus the weight of the weathercase. The initial spring force occurs at the maximum compressed length of the spring. The final spring force takes place at the minimum compressed length of the spring. The final spring force is equal to the spring constant times the total depression of the springs. The load on the conductor is equal to the final spring force plus the total gas pressure load minus the gas pressure force on the porcelain.

The expansion deflection is the differential thermal expansion of the weathercasing, conductor, and insulators from room temperature to the termination maximum operating temperature. The contraction deflection is that due to the differential thermal expansion of the weathercasing, conductor and insulators from room temperature to minus 40°C. The final column in the table is the sum of the contraction and expansion deflection and is equal to that required by the springs in service.

4.2.3 Discussion of Results

Technically the Type 1 design is feasible even though the forces are quite high. The axial load on the glass filament tube would be 591KN (133,000#) which would require a tube thickness in the order of 1.27 cm (.5 in). The Type 1 design would be expensive because of the cost of the tube and increased diameter of porcelain required.

The axial forces present in Types 2 and 3 termination designs are high. The resulting stresses on the epoxy cones and the aluminum conductor are above the allowable maximum values. Therefore, Type 2 and 3 are not recommended in their present form.

Even though the forces for termination Type 4 are high, this design is feasible.

As was the case with Types 2 and 3 the axial forces for Type 3E are high resulting in excessively high stresses in the epoxy cone and aluminum conductor. The Type 3E is not recommended.

The use of O-ring seals in Type 3E-O results in a substantial reduction in axial forces. The stresses in the conductor and cone are reduced to more reasonable values. Supports of some type would be needed for the weathercase for shipping.

4.2.4. Work To Be Undertaken In The Next Period

A more detailed design and stress analysis will be run on Type 3E-O and will be reported upon in the section on the Design of a Prototype. Long term creep data at 100°C will be obtained for the epoxy material and for the aluminum. Other design modifications which reduce the axial forces will be investigated for the basic Type 3E-O concept.

5.0 TASK 5 MODEL STUDIES

5.1 Electrostatic Models

Fog chamber tests on the small resistively graded models were performed as described in Section 3.2 of this report. Two intermediate scale models were built and tested as described in Section 3.3 of this report. No further reduced scale model work is expected in the electrostatic studies part of this project. The full scale models will be built as a part of Task 7, Production and the Testing of a Prototype.

5.2 Mechanical Models

Hollow insulators with and without fiberglass fabric reinforcing are being made for hydrostatic burst tests. Reinforced slabs are being prepared for thermocycle testing in the next period.

All other model studies have been completed.

6.0 TASK 6 DESIGN OF A PROTOTYPE

The objectives of this project are to develop a termination of less cost and better performance than existing designs. Cost may be reduced by eliminating components, by simplifying, by substituting less expensive parts, and by reducing sizes of components. All of these methods of reducing cost should be employed in the prototype termination design. Improved electrostatic performance of the termination is the primary performance goal. Earlier attempts at building 1200 kV gas bushings have had difficulty with electrical tests. Earlier reports of studies performed as a part of this project showed that reducing the diameter of the central conductor, particularly in the throat region can improve the wet switching surge capability of a gas bushing.

Several concepts were studied in the areas of weathercase construction, conductor configuration, cooling, axial clamping, lateral support and lower and upper voltage gradient control. Models of many of the most promising concepts were built and tested. Based on our latest calculations, the test results, data from the literature and other sources, each of the promising concepts was compared and the combinations of concepts were evaluated. Table 6-1 summarizes the weighted benefits (or penalties) for each of the considered components toward meeting the project goals. The table demonstrates clearly how severely the cost contribution can penalize the overall "score" for each component. For example, comparing a porcelain weathercase with unreinforced epoxy, despite superior mechanical properties, the high cost of porcelain (negative benefit) results in nearly equal overall benefit.

COMPONENT	GEN'L COST	CHARACTERISTIC			TOTAL
		DIELECTRIC	THERMAL	MECHANICAL	
Porcelain	-76	0	0	32	-44
Unreif. Epoxy	-15	0	0	-34	-49
Reinf. Epoxy	-42	0	0	12	-30
Large Conductor	-23	-3	7	2	-17
Small Conductor	44	-5	-14	2	27
Heat Pipe	-13	0	20	-4	3
No Heat Pipe	61	0	-30	2	33
Flanges	22	-8	-4	-6	4
Fiberglass Tube	-69	-6	-4	30	-49
Tie Rods	-10	-6	0	27	11
Springs & Cond.	25	16	4	34	79
CGIT Insulator	-5	-7	0	-29	-41
Frustum	0	-14	0	2	-12
No Bottom Ins.	71	7	0	-39	39
SF6 Film Cond.	-137	19	-8	-4	-130
Throat Shields	55	-5	34	16	100
Resis. Paint	34	19	18	-11	60

TABLE 6-1

SUMMARY OF RELATIVE BENEFITS OF EACH COMPONENT

The total "scores" for a number of (but not all possible) combinations of components are compiled in Table 6-2. The simpler all-gas internally insulated designs are shown to be much better than the more complicated impregnated film combinations.

Tables 6-3, 6-4, 6-5 and 6-6 are the input and intermediate data which were generated and analyzed as described in the first and second (February 1979 and May 1979) Technical Progress Reports for this project.

Based on this analysis, work has commenced on the design of the full scale 1200 kV prototype termination. Gas will provide the major internal insulation. An appropriately shaped small diameter conductor and a throat shield will grade the voltage in the air outside the bottom end of the weathercase and the vertical cylindrical top end shield will grade the voltage at the top end. A conical frustum insulator will provide lateral support for the bottom end of the conductor as well as support for compression-spring loading of the weathercase. A glass-fiber mesh-reinforced shatter-resistant insulator will be used for the weathercase. The proposed design is shown in Figure 6-1.

6.1 Thermal Limitation on Conductor Sizing

Data is available from a number of sources on the temperature rise of a tubular conductor in an SF₆ gas insulated space. For example, Doepkin's¹ predictions were replotted in Figure 4-7, of the Third Technical Progress Report, September 1979 of

1 "Calculated Heat Transfer Characteristics of Air and SF₆", H. C. Doepkin, Jr., IEEE Paper No. 70TP173-PWR

WEATHERCASE	CONDUCTOR	COOLING	CLAMPING	LOWER INSULATION	BOTTOM GRADING	TOP GRADING	TOTAL BENEFIT
REINF. EPOXY	SMALL CONDUCTOR	NO HEAT PIPE	SPRINGS & COND.	FRUSTUM	THROAT SHIELDS	VERT. CYLINDER	197
PORCELAIN	SMALL CONDUCTOR	NO HEAT PIPE	SPRINGS & COND.	FRUSTUM	THROAT SHIELDS	VERT. CYLINDER	183
REINF. EPOXY	SMALL CONDUCTOR	NO HEAT PIPE	TIE RODS	NO BOTTOM INS.	THROAT SHIELDS	VERT. CYLINDER	180
UNREIF. EPOXY	SMALL CONDUCTOR	NO HEAT PIPE	SPRINGS & COND.	FRUSTUM	THROAT SHIELDS	VERT. CYLINDER	178
REINF. EPOXY	SMALL CONDUCTOR	NO HEAT PIPE	FLANGES	NO BOTTOM INS.	THROAT SHIELDS	VERT. CYLINDER	173
REINF. EPOXY	SMALL CONDUCTOR	NO HEAT PIPE	SPRINGS & COND.	CGIT INSULATOR	THROAT SHIELDS	VERT. CYLINDER	168
PORCELAIN	SMALL CONDUCTOR	NO HEAT PIPE	TIE RODS	NO BOTTOM INS.	THROAT SHIELDS	VERT. CYLINDER	166
REINF. EPOXY	SMALL CONDUCTOR	NO HEAT PIPE	SPRINGS & COND.	FRUSTUM	RESIS. PAINT	VERT. CYLINDER	157
PORCELAIN	SMALL CONDUCTOR	NO HEAT PIPE	SPRINGS & COND.	CGIT INSULATOR	THROAT SHIELDS	VERT. CYLINDER	154
UNREIF. EPOXY	SMALL CONDUCTOR	NO HEAT PIPE	SPRINGS & COND.	CGIT INSULATOR	THROAT SHIELDS	VERT. CYLINDER	149
REINF. EPOXY	SMALL CONDUCTOR	NO HEAT PIPE	TIE RODS	NO BOTTOM INS.	RESIS. PAINT	VERT. CYLINDER	140
UNREIF. EPOXY	SMALL CONDUCTOR	NO HEAT PIPE	SPRINGS & COND.	FRUSTUM	RESIS. PAINT	VERT. CYLINDER	138
REINF. EPOXY	SMALL CONDUCTOR	NO HEAT PIPE	FLANGES	NO BOTTOM INS.	RESIS. PAINT	VERT. CYLINDER	133
REINF. EPOXY	SMALL CONDUCTOR	NO HEAT PIPE	SPRINGS & COND.	CGIT INSULATOR	RESIS. PAINT	VERT. CYLINDER	128
REINF. EPOXY	SMALL CONDUCTOR	NO HEAT PIPE	FIBERGLASS TUBE	NO BOTTOM INS.	THROAT SHIELDS	VERT. CYLINDER	120
REINF. EPOXY	LARGE CONDUCTOR	NO HEAT PIPE	SPRINGS & COND.	FRUSTUM	RESIS. PAINT	VERT. CYLINDER	113
UNREIF. EPOXY	SMALL CONDUCTOR	NO HEAT PIPE	SPRINGS & COND.	CGIT INSULATOR	RESIS. PAINT	VERT. CYLINDER	109
PORCELAIN	SMALL CONDUCTOR	NO HEAT PIPE	FIBERGLASS TUBE	NO BOTTOM INS.	THROAT SHIELDS	VERT. CYLINDER	106
UNREIF. EPOXY	SMALL CONDUCTOR	NO HEAT PIPE	FIBERGLASS TUBE	NO BOTTOM INS.	THROAT SHIELDS	VERT. CYLINDER	101
REINF. EPOXY	LARGE CONDUCTOR	NO HEAT PIPE	TIE RODS	NO BOTTOM INS.	RESIS. PAINT	VERT. CYLINDER	96
UNREIF. EPOXY	LARGE CONDUCTOR	NO HEAT PIPE	SPRINGS & COND.	FRUSTUM	RESIS. PAINT	VERT. CYLINDER	94
REINF. EPOXY	LARGE CONDUCTOR	NO HEAT PIPE	FLANGES	NO BOTTOM INS.	RESIS. PAINT	VERT. CYLINDER	89
REINF. EPOXY	LARGE CONDUCTOR	NO HEAT PIPE	SPRINGS & COND.	CGIT INSULATOR	RESIS. PAINT	VERT. CYLINDER	84
REINF. EPOXY	SMALL CONDUCTOR	NO HEAT PIPE	FIBERGLASS TUBE	NO BOTTOM INS.	RESIS. PAINT	VERT. CYLINDER	80
UNREIF. EPOXY	LARGE CONDUCTOR	NO HEAT PIPE	SPRINGS & COND.	CGIT INSULATOR	RESIS. PAINT	VERT. CYLINDER	65
UNREIF. EPOXY	SMALL CONDUCTOR	NO HEAT PIPE	FIBERGLASS TUBE	NO BOTTOM INS.	RESIS. PAINT	VERT. CYLINDER	61
REINF. EPOXY	LARGE CONDUCTOR	NO HEAT PIPE	FIBERGLASS TUBE	NO BOTTOM INS.	RESIS. PAINT	VERT. CYLINDER	36
UNREIF. EPOXY	LARGE CONDUCTOR	NO HEAT PIPE	FIBERGLASS TUBE	NO BOTTOM INS.	RESIS. PAINT	VERT. CYLINDER	17
							0
REINF. EPOXY	LARGE CONDUCTOR	NO HEAT PIPE	SPRINGS & COND.	FRUSTUM	SF6 FILM COND.	VERT. CYLINDER	-77
PORCELAIN	LARGE CONDUCTOR	NO HEAT PIPE	SPRINGS & COND.	FRUSTUM	SF6 FILM COND.	VERT. CYLINDER	-91
UNREIF. EPOXY	LARGE CONDUCTOR	NO HEAT PIPE	SPRINGS & COND.	FRUSTUM	SF6 FILM COND.	VERT. CYLINDER	-96
REINF. EPOXY	LARGE CONDUCTOR	NO HEAT PIPE	SPRINGS & COND.	CGIT INSULATOR	SF6 FILM COND.	VERT. CYLINDER	-106
REINF. EPOXY	LARGE CONDUCTOR	HEAT PIPE	SPRINGS & COND.	FRUSTUM	SF6 FILM COND.	VERT. CYLINDER	-107
PORCELAIN	LARGE CONDUCTOR	NO HEAT PIPE	SPRINGS & COND.	CGIT INSULATOR	SF6 FILM COND.	VERT. CYLINDER	-120
PORCELAIN	LARGE CONDUCTOR	HEAT PIPE	SPRINGS & COND.	FRUSTUM	SF6 FILM COND.	VERT. CYLINDER	-121
UNREIF. EPOXY	LARGE CONDUCTOR	NO HEAT PIPE	SPRINGS & COND.	CGIT INSULATOR	SF6 FILM COND.	VERT. CYLINDER	-125
UNREIF. EPOXY	LARGE CONDUCTOR	HEAT PIPE	SPRINGS & COND.	FRUSTUM	SF6 FILM COND.	VERT. CYLINDER	-126
REINF. EPOXY	LARGE CONDUCTOR	HEAT PIPE	SPRINGS & COND.	CGIT INSULATOR	SF6 FILM COND.	VERT. CYLINDER	-136
UNREIF. EPOXY	LARGE CONDUCTOR	HEAT PIPE	SPRINGS & COND.	CGIT INSULATOR	SF6 FILM COND.	VERT. CYLINDER	-155

Table 6-2

RELATIVE EVALUATIONS OF COMBINATIONS OF COMPONENTS

<u>Specific Characteristic</u>	<u>General Characteristic</u>	
1. Cost/Piece	General Cost	11
2. New Facilities	"	3
3. Weight	"	4
4. Interface	"	10
5. Difficulty of Manufacture or Assy.	"	8
6. Lead Time	"	2
7. Storage	"	2
8. Internal Diel. Str. at Throat	Dielectric	7
9. Internal Diel. Str. Elsewhere	"	6
10. External Diel. Str. Bottom End	"	7
11. External Diel. Str. Intermediate	"	5
12. External Diel. Str. Top End	"	8
13. RI Limit	"	3
14. I ² R Heating	Thermal	7
15. Diel. Loss Heating (Int. Only)	"	6
16. Flange Heating	"	4
17. Other Heating (Weathercases)	"	8
18. Heat Transport	"	10
19. Life (Established)	Mechanical	2
20. Material Temperature Limit	"	7
21. Clamping Forces Safety Factor	"	8
22. Shipability	"	2
23. Lateral Strength	"	3
24. Wind Load Area	"	5
25. Danger Factor	"	6

RELATIVE WEIGHTINGS OF EACH CHARACTERISTIC

(ADJUSTED TO WEIGHT GENERAL CHARACTERISTIC TOTALS
ACCORDING TO CONTRACT STATED GOALS)

TABLE 6-3

COMPONENT	CHARACTERISTIC NUMBER																								
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
*****	*****																								
PORCELAIN	-4	5	2	0	4	-3	4	0	0	0	0	0	0	0	0	0	0	0	5	5	5	0	0	0	0
UNREIF. EPCXY	0	2	5	0	4	4	4	0	0	0	0	0	0	0	0	0	0	0	3	1	2	1	0	0	-2
REINF. EPOXY	-1	0	5	0	3	3	4	0	0	0	0	0	0	0	0	0	0	0	2	1	2	4	0	0	5
LARGE CONDUCTOR	0	4	2	0	4	3	4	5	0	3	4	0	4	5	0	0	0	0	5	0	0	0	0	0	0
SMALL CONDUCTOR	4	5	5	0	5	3	4	4	0	4	3	0	5	2	0	0	0	0	5	0	0	0	0	0	0
HEAT PIPE	3	1	3	0	2	3	3	0	0	0	0	0	0	0	0	0	0	5	2	0	0	0	0	0	0
NO HEAT PIPE	5	5	5	0	5	5	5	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0
FLANGES	4	3	3	0	4	3	4	0	5	0	0	2	0	0	0	3	0	0	4	5	-1	-1	0	5	-1
FIBERGLASS TUBE	-1	-1	0	0	3	1	4	0	4	0	0	3	0	0	0	3	0	0	3	3	2	5	5	-2	5
TIE RODS	1	4	1	0	5	2	4	0	4	0	0	3	0	0	0	4	0	0	3	3	5	2	2	-2	3
SPRINGS & COND.	4	4	3	0	4	3	4	0	5	0	0	5	0	0	0	5	0	0	5	5	2	2	-2	3	3
CGIT INSULATOR	0	4	4	5	4	3	4	3	0	0	0	0	0	0	0	0	0	0	3	2	-1	-1	0	5	-1
FRUSTUM	3	2	3	3	4	4	4	2	0	0	0	0	0	0	0	0	0	0	3	1	2	2	-2	3	3
NO BOTTOM INS.	5	5	5	5	5	5	5	5	0	0	0	0	0	0	0	0	0	0	5	5	-1	-1	0	-2	-1
SF6 FILM COND.	-2	-4	2	0	-4	4	1	5	0	5	5	0	5	0	3	0	5	2	2	3	0	0	0	0	0
THROAT SHIELDS	5	5	5	0	5	3	4	4	0	4	3	0	5	0	5	0	5	5	5	5	0	0	0	0	0
RESIS. PAINT	5	2	5	0	3	5	4	5	0	5	5	0	5	0	5	0	3	5	2	2	0	0	0	0	0

Table 6-4

INPUT DATA: RELATIVE EVALUATION OF EACH CHARACTERISTIC AS IT APPLIES TO EACH COMPONENT.

COMPONENT	CHARACTERISTIC NUMBER																								
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****
PORCELAIN	-6	2	-1	0	0	-6	0	0	0	0	0	0	0	0	0	0	0	0	1	2	3	-1	0	0	-1
UNREIF. EPOXY	-2	-1	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	-1	-2	0	0	0	0	-3
REINF. EPOXY	-3	-3	2	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	-2	-2	0	3	0	0	4
LARGE CONDUCTOR	-2	1	-1	0	0	0	0	1	0	-1	0	0	-1	1	0	0	0	0	1	0	0	0	0	0	0
SMALL CONDUCTOR	2	2	2	0	1	0	0	0	0	0	-1	0	0	-2	0	0	0	0	1	0	0	0	0	0	0
HEAT PIPE	1	-2	0	0	-2	0	-1	0	0	0	0	0	0	0	0	0	0	2	-2	0	0	0	0	0	0
NO HEAT PIPE	3	2	2	0	1	2	1	0	0	0	0	0	0	0	0	0	0	-3	1	0	0	0	0	0	0
FLANGES	2	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	-1	0	0	0	2	-3	-2	0	4	-2
FIBERGLASS TUBE	-3	-4	-3	0	-1	-2	0	0	-1	0	0	0	0	0	0	-1	0	0	-1	0	0	4	5	-3	4
TIE RODS	-1	1	-2	0	1	-1	0	0	-1	0	0	0	0	0	0	0	0	0	-1	0	3	1	2	-3	2
SPRINGS & COND.	2	1	0	0	0	0	0	0	0	0	0	2	0	0	0	1	0	0	1	2	0	1	-2	2	2
CGIT INSULATOR	-2	1	1	1	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	-1	-1	-3	-2	0	4	-2
FRUSTUM	1	-1	0	-1	0	1	0	-2	0	0	0	0	0	0	0	0	0	0	-1	-2	0	1	-2	2	2
NO BOTTOM INS.	3	2	2	1	1	2	1	1	0	0	0	0	0	0	0	0	0	0	1	2	-3	-2	0	-3	-2
SF6 FILM COND.	-4	-7	-1	0	-8	1	-3	1	0	1	1	0	0	0	-1	0	1	-1	-2	0	0	0	0	0	0
THROAT SHIELDS	3	2	2	0	1	0	0	0	0	0	-1	0	0	0	1	0	1	2	1	2	0	0	0	0	0
RESIS. PAINT	3	-1	2	0	-1	2	0	1	0	1	1	0	0	0	1	0	-1	2	-2	-1	0	0	0	0	0

Table 6-5

INPUT DATA: ADJUSTED FOR ZEROS IN COLUMN TOTALS

COMPONENT	CHARACTERISTIC NUMBER																									TOTAL
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	
*****	*****																									
PORCELAIN	-66	6	-4	0	0	-12	0	0	0	0	0	0	0	0	0	0	0	0	2	14	24	-2	0	0	-6	-44
UNREIF. EPOXY	-22	-3	8	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	-2	-14	0	0	0	0	-18	-49
REINF. EPOXY	-33	-9	8	0	-8	0	0	0	0	0	0	0	0	0	0	0	0	0	-4	-14	0	6	0	0	24	-30
LARGE CONDUCTOR	-22	3	-4	0	0	0	0	7	0	-7	0	0	-3	7	0	0	0	0	2	0	0	0	0	0	0	-17
SMALL CONDUCTOR	22	6	8	0	8	0	0	0	0	0	-5	0	0	-14	0	0	0	0	2	0	0	0	0	0	0	27
HEAT PIPE	11	-6	0	0	-16	0	-2	0	0	0	0	0	0	0	0	0	0	20	-4	0	0	0	0	0	0	3
NO HEAT PIPE	33	6	8	0	8	4	2	0	0	0	0	0	0	0	0	0	0	-30	2	0	0	0	0	0	0	33
FLANGES	22	0	0	0	0	0	0	0	0	0	0	-8	0	0	0	-4	0	0	0	14	-24	-4	0	20	-12	4
FIBERGLASS TUBE	-33	-12	-12	0	-8	-4	0	0	-6	0	0	0	0	0	0	-4	0	0	-2	0	0	8	15	-15	24	-49
TIE RODS	-11	3	-8	0	8	-2	0	0	-6	0	0	0	0	0	0	0	0	0	-2	0	24	2	6	-15	12	11
SPRINGS & COND.	22	3	0	0	0	0	0	0	0	0	0	16	0	0	0	4	0	0	2	14	0	2	-6	10	12	79
CGIT INSULATOR	-22	3	4	10	0	0	0	-7	0	0	0	0	0	0	0	0	0	0	-2	-7	-24	-4	0	20	-12	-41
FRUSTUM	11	-3	0	-10	0	2	0	-14	0	0	0	0	0	0	0	0	0	0	-2	-14	0	2	-6	10	12	-12
NO BOTTOM INS.	33	6	8	10	8	4	2	7	0	0	0	0	0	0	0	0	0	0	2	14	-24	-4	0	-15	-12	39
SF6 FILM COND.	-44	-21	-4	0	-64	2	-6	7	0	7	5	0	0	0	-6	0	8	-10	-4	0	0	0	0	0	0	-130
THROAT SHIELDS	33	6	8	0	8	0	0	0	0	0	-5	0	0	0	6	0	8	20	2	14	0	0	0	0	0	100
RESIS. PAINT	33	-3	8	0	-8	4	0	7	0	7	5	0	0	0	6	0	-8	20	-4	-7	0	0	0	0	0	60

Table 6-6

OUTPUT DATA: RELATIVE VALUE OF EACH CHARACTERISTIC AS IT APPLIES TO EACH COMPONENT

AND TOTAL VALUE OF EACH COMPONENT

of this project. Using this data, and assuming 1.3 cm wall aluminum conductor material 6061-T6 (40% IACS) and a 74 cm inside diameter weathercase, conductor temperature rises were calculated and plotted in Figure 6-2. The limit for inner conductors in gas insulated equipment being proposed in NEMA SG-15 is 85C rise. Westinghouse and other manufacturers have had many years of successful experience with equipment operated to that limit. Thus according to the curve, a conductor as small as 10.7 cm in diameter may be used. Even with the conductor operating at 85C, the maximum temperature on the inside surface of the weathercase will be 15C above ambient or 65C total temperature. This is quite acceptable for the solid insulation being considered. Temperature profiles through two sections of the bushing are shown in Figure 6-3.

If the aluminum conductor should prove inadequate for some unforeseen reason, substitution of a copper tube of the same dimensions will reduce the temperature rise by 30 to 35%. Since copper is typically used for conductors in high voltage equipment, no compatibility problems are expected.

All flanges will be made from aluminum so that induced current heating will be negligible. All joints in the current path will be made according to standard practice and will not contribute significantly to heating.

6.2 Dielectric Limitations

The three critical factors which limit the dielectric withstand capability of a gas bushing are:

1. Voltage gradient in the SF₆ gas.
2. Voltage gradient in the air at the bottom end of the weathercasing
3. Voltage gradient in the air at the top end of the bushing.

FIGURE 6-3 -- TEMPERATURE PROFILES THROUGH BUSHING SECTIONS

Factors 1 and 2 are somewhat interdependent. The gas gradient may be adjusted to optimize the air gradient at the bottom end of the weathercasing. The third factor is less dependent on the other two but is still somewhat interdependent. The 1200 kV design attempts to utilize an optimum combination of these three factors.

6.2.1 Gradient in SF₆

The maximum voltage gradient in a coaxial cylindrical system (of infinite length) is given by

$$\frac{E}{R_1 \ln (R_2/R_1)}$$

Where E is the applied voltage, R_1 is the diameter of the inner electrode, and R_2 is the diameter of the outer electrode. For a given R_2 , the maximum gradient is minimized when $R_2/R_1 = 2.73$. If the equation is plotted for different values of R_2/R_1 and normalized as shown in Figure 6-4 we see that increasing the ratio from the optimum has a small effect on the inner cylinder gradient. But the stress on the outer cylinder decreases quickly.

Studies² of gas insulated coaxial bus have shown that a practical limit for maximum SF₆ gradient at 455 kPa is about 216 kV/cm. For an outer cylinder radius (R_2) of 35.5 cm, the minimum inner conductor (R_1) is then calculated from the equation to be 5.23 cm or a diameter of 10.46 cm.

2 For example see the Seventh Progress Report of DOE Contract E(49-18)-2061, "Prototype UHV Compressed Gas Insulated Transmission System", May 1978.

6.2.2 Gradient at Bottom End of Weathercasing

For the simple gas bushing, the highest voltage gradient in the air just outside the weathercasing tends to be at the bottom end. The most obvious way to reduce the lower end gradient is to increase the diameter of the weather casing. If the gradient is assumed to be inversely proportional to the ratio of the diameter of the weathercase D_E to the diameter of the center conductor D_R , for large diameters, a diminishing benefit results with increasing diameter. Furthermore, the cost of the weathercase increases very quickly for large diameters (greater than the square of the diameter for porcelain). A less obvious but more practical method for increasing the ratio D_E/D_R and consequently decreasing the bottom end gradient which has also been in general use for many years is to reduce the diameter of the conductor D_R .

For a gas bushing with a throat shield extending up into the bottom end of the weathercasing, the maximum axial voltage stress in the air at the bottom end has been found by experience to be approximately proportional to the radial voltage gradient in the gas on the inside of the throat shield. Thus referring again to Figure 6-4, increasing the ratio of R_2/R_1 will decrease the stress at the shield, and consequently, in the air outside the weathercasing.

As a result of this project, the performance versus the ratio of D_E/D_R can be predicted. "Radial Stress Factor" curves were plotted in Figure 6-5. From these curves and using the criteria in Section 2.2.1, Figure 6-6 was drawn. In order to

NORMALIZED STRESS ON CONCENTRIC
CYLINDER CONFIGURATION

Figure 6-4

FIGURE 6-5 --- FAILURE STRESS FACTORS FOR SF₆ BUSINS

meet the severe 1800 kV wet switching surge requirement for this bushing the conductor diameter must be no greater than 14.7 cm for a 71 cm diameter weathercase. A bushing with a 11.4 cm diameter conductor and 74 cm inside diameter weathercase should be capable of withstanding a 2000 kV switching impulse, a reasonable margin.

6.2.3 Gradient at the Top End of the Bushing

Conventional bushings are typically terminated at their top ends with toroidal or roughly spherically shaped shields. Referring to Figure 6-7³, a solid sphere is the best generally spherically shaped electrode for long gaps and wet switching surges. Segmented spheres and toroids do not perform nearly as well. The gap required for the 1800 kV wet switching impulse is less than 5 meters for a 2 meter sphere. But the voltage gradient on a sphere is far more divergent than for a cylinder. Thus, for a 5 meter gap, the cylinder equivalent to a 2 meter diameter sphere can be found to have a diameter of about .5 meter.

6.3 MECHANICAL LIMITATIONS

This bushing design uses the weathercase in axial compression rather than tension as is typical of conventional gas bus terminations. The two most significant reasons for employing a compression configuration are:

3 Redrawn from Proposal for this project.
Original source: Schneider, H., and Turner, F.,
"Switching Surge Flashover Characteristics of
Long Sphere-Plane Gaps for UHV Station Design",
IEEE Trans. PAS-94, 551 (1975).

FIGURE 6-6 -- WET SWITCHING SURGE WITHSTAND BOTTOM-TO-TOP

Figure 6-7

WET SWITCHING SURGE CFOV AS A FUNCTION
OF GAP LENGTH (375 MICROSECONDS TIME TO CREST)

SWITCHING IMPULSE CRITICAL FLASHOVER VOLTAGE (MEGAVOLTS)

1. Rod Plane
2. Segmented 2.5 meter sphere
3. Solid 2 meter sphere

1. The top end flange required for tensile mounting the weathercase makes implementation of the cylindrical shielding discussed in section 6.2.3 very difficult, if not impossible.
2. Since the weathercase materials are much stronger in compression than in tension, compression mounting the insulators improves the safety of pressurized bushings as well as relaxing the mechanical requirements on the insulator materials (pressure and cantilever stresses are not additive for compression mounted weathercases).

In order to further enhance the mechanical safety of the bushing, the shatter-resistant epoxy weathercase developed in this project will be used. An open weave glass fiber reinforcing mesh encapsulated in the epoxy weathercase wall prevents the rigid insulating resin from flying apart in case of puncture. The internal gas pressure is safely relieved through the puncture.

The bottom end of the bushing conductor is supported by a conically shaped insulator. This configuration ties the bushing together into a rigid package which is advantageous for shipping and installation purposes. The support insulator helps isolate the bushing and connected bus compartments from contamination and sudden pressure buildup (often the case in circuit breakers). A filtered orifice will equalize the pressures between the compartments for steady state conditions. The bottom terminal of the bushing will interface with the adjacent bus through the standard plug-in sliding contact.

Springs located at the top end of the bushing will be sized to maintain pressure on the sealing gaskets at all foreseeable pressures and temperatures the bushing will experience, and make up for axial creepage of any of the parts over the lifetime of the bushing. No major departures from the conventional compression spring loading design of gas bushings are expected for this design.

6.4 Work to be Undertaken in the Next Period

Detailed analysis of the 1200 kV Prototype design will continue especially in the mechanical area. Drafting will begin on layout of the prototype to make sure all the pieces will fit together properly. Detailed drawings of all of the parts will be made as the analysis and design is finalized. Procurement of parts and tooling must await evaluation and review by Westinghouse and DOE.

7.0 TASK 9 Reporting

Under this task the following reports were prepared and submitted to DOE during the reporting period:

<u>Quantity</u>	<u>Report Title</u>
3	Project Status Reports
3	Contract Management Summary Reports
3	Cost Management Reports
1	Topical Report

7.1 Program Status

The progress of each individual subtask is shown in the program schedule Figure 7-1. This same schedule is incorporated in each quarterly report as a means of showing clearly the technical progress on the project.

7.2 Manpower Status

With regard to the manpower utilization in the project, the following key personnel have been committed to carrying out this project in an efficient and timely manner.

<u>Key Personnel</u>	<u>Hours Worked During Reporting Period (Seventh Quarter)</u>
J. S. Billings	229 Hours
Z. Neri	148 Hours
C. F. Hofmann	2 Hours
R. W. Crookston	0 Hours

SCHEDULE FOR 1200 kV TERMINATION

TASK 1 - CONCEPTUAL DESIGN AND MATERIAL STUDY

- 1.1 PROBLEM DEFINITION
- 1.2 INNOVATIVE CONCEPTS
- 1.3 MATERIALS INVESTIGATION
- 1.4 FABRICATION TECHNIQUES

TASK 2 - ELECTROSTATIC STUDIES

- 2.1 SHIELD EFFECTIVENESS
 - 2.1.1 CONCEPT STUDY AND MODEL DESIGN
 - 2.1.2 ESTABLISH TEST OBJECTIVES
 - 2.1.3 DATA EVALUATIONS & RECOMMENDATIONS
- 2.2 RESISTIVE GRADING
 - 2.2.1 GRADING OBJECTIVES & CRITERIA
 - 2.2.2 DESIGN MODELS
 - 2.2.3 ESTABLISH TEST OBJECTIVES
 - 2.2.4 DATA EVALUATIONS & RECOMMENDATIONS
- 2.3 FIELD PLOTTING

TASK 3 - THERMAL STUDIES

- 3.1 THERMAL TRANSPORT STUDY
- 3.2 HEAT PIPE STUDY

TASK 4 - MECHANICAL STUDIES

- 4.1 SHATTER-RESISTANT WEATHERCASE
 - 4.1.1 CONCEPT STUDY, MODEL DESIGN, AND TEST CRITERIA
 - 4.1.2 DATA EVALUATIONS & RECOMMENDATIONS
- 4.2 REINFORCING LINERS
 - 4.2.1 CONCEPT STUDY, MODEL DESIGN, AND TEST CRITERIA
 - 4.2.2 DATA EVALUATIONS & RECOMMENDATIONS
- 4.3 CLAMPING AND FASTENING

TASK 5 - MODEL STUDIES

- 5.1 SHIELD EFFECTIVENESS
- 5.2 RESISTIVE GRADING
- 5.3 SHATTER RESISTANT WEATHERCASE
- 5.4 REINFORCING LINER

TASK 6 - DESIGN OF A PROTOTYPE

- 6.1 FINALIZE DESIGN PARAMETERS
- 6.2 MAKE ENGINEERING DRAWINGS
- 6.3 REVIEW AND EVALUATE

TASK 7 - PRODUCTION AND THE TESTING OF A PROTOTYPE

- 7.1 QUALITY ASSURANCE & PREPARATIONS FOR TEST
- 7.2 PROCUREMENT OF SPECIAL TOOLING AND COMPONENT PARTS
- 7.3 FABRICATING THE WEATHERCASE AND ASSEMBLING THE PROTOTYPE
- 7.4 ELECTRICAL DESIGN TESTS
- 7.5 OTHER DESIGN TESTS
- 7.6 REVISE & FINALIZE DRAWINGS
- 7.7 DISASSEMBLY PROTOTYPE
- 7.8 MODIFY PROTOTYPE
- 7.9 REASSEMBLE PROTOTYPE
- 7.10 COMPLETE TESTS

TASK 8 - DELIVERY OF THE PROTOTYPE AND MONITORING PERFORMANCE

TASK 9 - REPORTS & RECOMMENDATIONS

Figure 7-1

) Total manhours worked during the reporting period (including Key Personnel).

TASK 1 - 3 Manhours
TASK 2 - 178 Manhours
TASK 3 - 0 Manhours

TASK 4 - 66 Manhours
TASK 5 - 238 Manhours
TASK 6 - 66 Manhours
TASK 9 - 194 Manhours

8.0 SUMMARY

Wet 60 Hz test on small-scale resistive grading models showed little difference for two paints. Significant improvement in 60 Hz performance were obtained on the intermediate scale resistive grading model. Differences in wet switching surges were also effected. The clamping and fastening study showed that several configurations are mechanically feasible. A spring compressed two-ended bushing with an epoxy weathercase will work best with O-ring rather than flat gaskets.

Thermal, dielectric and mechanical considerations were reviewed for the selection of the center-conductor for the full scale prototype termination. Other details of the prototype are now being finalized. Drawings are expected to be completed during the next period and long lead-time components and tooling will soon after be put on order.